

NSWC TR 82-188

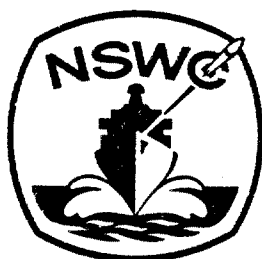
PREDICTION OF UNDERWATER EXPLOSION SAFE RANGES FOR SEA MAMMALS

BY JOHN F. GOERTNER

RESEARCH AND TECHNOLOGY DEPARTMENT

16 AUGUST 1982

Approved for public release, distribution unlimited



NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

NSWC TR 82-188

FOREWORD

The Navy is required to assess the environmental consequences of all its activities and to take appropriate measures to avoid or mitigate adverse effects. In the case of underwater explosion testing, the effect on marine life of most concern is the possible killing of fish. Marine mammals are rarely encountered at test sites, but the effects on these animals are given special attention because of legislation such as the Endangered Species Act and the Marine Mammal Protection Act. Although a low level of fish-kill can be tolerated in most cases, harmful effects on marine mammals are not acceptable.

This study was conducted to determine the ranges within which sea mammals could be injured. Its purpose is to provide guidance to personnel engaged in underwater explosion testing, but the method is also useful for planning underwater blasting for channel clearance or construction.

This work was funded by the Naval Sea Systems Command (SEA-62R) under Program Element 63721N, Work Unit: Environmental Effects of Explosive Testing. This report is one of a series published under this sponsorship during a period of about ten years.

The assistance of George A. Young in reviewing this report is gratefully acknowledged.

APPROVED BY:



J. F. PROCTOR

Energetic Materials Division

NSWC TR 82-188

CONTENTS

	<u>Page</u>
1. INTRODUCTION AND SUMMARY	1
2. METHOD OF SOLUTION	2
3. SAMPLE PROBLEMS	8
3-1. WHALES - KEY WEST	8
3-2. WHALES - NORTH ATLANTIC	12
3-3. PORPOISES	17
3-4. MANATEES	21
REFERENCES	25

NSWC TR 82-188

ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
3.1.1	CONTOURS FOR SLIGHT INJURY TO WHALES: 1200-LB CHARGE AT 125-FT DEPTH	9
3.1.2	CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 200-FT DEPTH	10
3.1.3	CONTOURS FOR SLIGHT INJURY TO WHALES: 40,000-LB CHARGE AT 200-FT DEPTH	11
3.2.1	CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 1,312 FEET	13
3.2.2	CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 4,265 FEET: SURFACE DISK	14
3.2.3	CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 4,265 FEET: DEEP SPHERE	15
3.3.1	CONTOURS FOR SLIGHT INJURY TO PORPOISES: 1200-LB CHARGE AT 125 FEET	18
3.3.2	CONTOURS FOR SLIGHT INJURY TO PORPOISES: 10,000-LB CHARGE AT 200 FEET	19
3.3.3	CONTOURS FOR SLIGHT INJURY TO PORPOISES: 40,000-LB CHARGE AT 200 FEET	20
3.4.1	CONTOURS FOR SLIGHT INJURY TO MANATEES: 12-LB CHARGE AT 5-FT DEPTH	22
3.4.2	CONTOURS FOR SLIGHT INJURY TO MANATEES: 12-LB CHARGE AT 40-FT DEPTH	23

TABLES

<u>Table</u>		<u>Page</u>
3.2.1	HORIZONTAL EXTENT OF REGIONS OF SLIGHT INJURY TO WHALES BY 10,000-POUND EXPLOSIONS	16
3.4.1	MAXIMUM HORIZONTAL EXTENT OF SLIGHT INJURIES TO MANATEES BY 12-POUND EXPLOSIONS	24

NSWC TR 82-188

1. INTRODUCTION AND SUMMARY

The problem is to determine the region of injury to sea mammals such as whales, porpoises and manatees for explosion tests and blasting operations. Our starting point is the body of experimental data which has been obtained by the Lovelace Foundation from underwater explosion tests using dogs, sheep and monkeys.^{1,2} The solution consists of scaling these results using plausible physical models to large sea mammals and to different charge sizes and explosion geometries.

The method has been used at this Center in the planning and in the environmental assessments for Navy underwater explosion tests. It has been implemented by a computer program (MAMDAM) which outputs the predicted contour (locations) corresponding to slight injury for a given weight mammal. This is a level of injury from which the animals would recover on their own.

The purpose of this report is to describe both this computer program (Section 2) and typical results (Section 3). This information can be used to avoid injuries to animals by postponing explosive operations if the animals are within the zone of possible injury.

1. Richmond, Donald R., Yelverton, John T., and Fletcher, E. Royce, "Far-Field Underwater-Blast Injuries Produced by Small Charges," Lovelace Foundation, DNA 3081T, 1973.
2. Yelverton, John T., et al, "Safe Distances from Underwater Explosions for Mammals and Birds," Lovelace Foundation, DNA 3114T, 1973.

NSWC TR 82-188

2. METHOD OF SOLUTION

The Lovelace Foundation studies^{1,2} indicate that hemorrhaging in and around the lungs is the primary source of injury to submerged mammals. These studies also indicate that another significant source of injury to submerged mammals is excitation of radial oscillations in the small gas bubbles which are normally present in the small and large intestines. These are two distinct mechanisms for injury. We will scale them separately for each location in the explosion pressure field and then use the more severe of these two mechanisms to define our injury region.

Lung Hemorrhaging. The severity of lung hemorrhaging appears to be related to the amplitude of the excitation of the lung cavity by the explosion. For our purposes this motion can be approximated by the radial oscillation response of an equal volume spherical air bubble in water subjected to the same pressure wave.

We will assume that the explosion loading is impulsive. We will get around the difficulty that this is not true for long duration positive pressures by using a modification of the concept of partial positive impulse used by Bowen et al to describe air-blast mammal mortality test results.³

For this purpose we compute the small amplitude oscillation period \bar{T} for the substitute air bubble,

$$\bar{T} = 2\pi A_0 \sqrt{\rho / 3\gamma p_0} \quad (2.1a)$$

where A_0 is the at-rest bubble radius, ρ is the water density ($= 1.940$ slugs/ft³), γ is the adiabatic exponent for air ($= 1.40$), and p_0 is the hydrostatic pressure.⁴

3. Bowen, I. G., et al., "Biophysical Mechanisms and Scaling Procedures Applicable in Assessing Responses of the Thorax Energized by Air-Blast Overpressures or by Non-Penetrating Missiles," Lovelace Foundation, DASA 1857, 1966.
4. Kennard, E. H., "Radial Motion of Water Surrounding a Sphere of Gas in Relation to Pressure Waves," 1943, published in Vol. II of Underwater Explosion Research, Office of Naval Research, 1950.

Inserting the values for the water density and adiabatic exponent, equation 2.1a becomes

$$\bar{T} = 29.7 \frac{A_0}{\sqrt{p_0}} \text{ milliseconds} \quad (2.1b)$$

where A_0 is in inches and p_0 is in pounds per square inch.

The at-rest bubble radius A_0 is calculated from the estimated lung volume V_0 at hydrostatic pressure p_0 using

$$A_0 = [V_0 / (4/3)\pi]^{1/3} \quad (2.2)$$

V_0 in turn is estimated from the estimated lung volume V_1 at atmospheric pressure assuming isothermal compression to hydrostatic pressure p_0 , i.e.,

$$V_0 = V_1 \times (p_1/p_0) \quad (2.3)$$

where p_1 is the atmospheric pressure (generally taken equal to 14.7 psi). V_1 in turn is estimated from the body mass of the sea mammal under the assumption that like large land mammals - dogs, sheep and monkeys of the experimental data set - the lung volume in liters is approximately 3% of the body mass in kilograms. Thus,

$$V_1 = 1.83 M \quad (2.4)$$

where V_1 is the lung volume in cubic inches and M is the body mass in kilograms.

Next we compute the positive pressure duration, TP0S, from the difference in travel times for the direct and surface-reflected pressure waves, using a constant velocity of sound.

NSWC TR 82-188

In order to compute the impulse, I , to be used for calculating the lung cavity response, we define a parameter, τ , which we take as the lesser of the times, $TPOS$ and $0.2 \bar{T}$. We use the parameter, τ , as the integration limit for computing the impulse, I , to be used in this analysis. Thus,

$$I \equiv \int_0^{\tau} p(t) dt \quad (2.5)$$

where

$$p(t) = \begin{cases} P_{MAX} \cdot \exp(t/\theta) & (t \leq 1.8\theta) \\ P_{MAX} \cdot \exp(-1.8) \cdot \exp\left(-\frac{t-1.8\theta}{4.3\theta}\right) & (t > 1.8\theta) \end{cases} \quad (2.6a)$$

$$(2.6b)$$

and P_{MAX} and θ are the peak pressure and decay constant for the incident explosion pressure wave. Through the introduction of the parameter, τ , we are attempting to define an effective (or partial) impulse for the excitation due to long duration pressures.

The peak pressure P_{MAX} in psi and the decay constant θ in milliseconds can be calculated from the similitude relations for pentolite developed at this Center.

$$P_{MAX} = 2.46 \times 10^4 (R/W^{1/3})^{-1.19} \quad (2.7)$$

$$\theta = 0.052 W^{1/3} (R/W^{1/3})^{0.26} \quad (2.8)$$

NSWC TR 82-188

where W is the explosive mass in pounds and R is the slant range from the charge in feet. For these environmental studies we have not accounted for differences in explosive output among detonating explosives.

Assuming that the lung hemorrhaging is related to the amplitude of the induced oscillation, described for example by $AMAX/AMIN$, where $AMAX$ and $AMIN$ are the maximum and minimum radii of the oscillations, we are led to a damage parameter for scaling lung injuries in the form of the product,

$$I/(A_0 \rho^{1/2} p_0^{1/2}) \quad (2.9)$$

where ρ is the water density, since under impulsive loading, $AMAX/AMIN$ can be computed as a function of this dimensionless product⁵.

For a diving mammal the equivalent lung radius A_0 at ambient pressure is related to A_1 the radius at atmospheric pressure by

$$A_0 = A_1 (p_1/p_0)^{1/3} \quad (2.10)$$

where p_1 is the atmospheric pressure. Substituting (2.10) into (2.9) our damage parameter becomes

$$I/(A_1 p_1^{1/3} \rho^{1/2} p_0^{1/6}) \quad (2.11)$$

5. Goertner, John F., Fish Killing Potential of a Cylindrical Charge Exploded Above the Water Surface, NSWC/WOL TR 77-90, 1978. See Section 3.4 and Equation 3.4.5.

Since the lung volume is assumed proportional to the body mass of the mammal, for the equivalent lung radius A_1 we have

$$A_1 \propto M^{1/3} \quad (2.12)$$

where M is the body mass of the mammal. Substituting (2.12) into (2.11) and dropping the constant water density ρ , the damage parameter for scaling lung injuries becomes

$$I/(M^{1/3} p_1^{1/3} p_0^{1/6}) \quad (2.13)$$

Note that this scaling parameter is no longer dimensionless. (Using the equations developed in this section, I found it convenient to express the impulse I in psi-milliseconds, the body mass M in kilograms, the atmospheric pressure p_1 in psi, and the hydrostatic pressure p_0 in psi.)

The critical values used for the damage parameters in this study are those values at which the animals sustained only slight injuries. These values were taken from the Lovelace Foundation sheep-dog-monkey data.² For lung related injuries slight injury occurred at an impulse of 20 psi-milliseconds for a 40 kilogram animal. Atmospheric pressure p_1 was about 12 psi and the hydrostatic pressure p_0 was about 12.9 psi (corresponding to 2-foot immersion depth).*

Intestinal Injuries. Since we do not know the sizes of air bubbles in the intestines we will make the conservative assumption that their oscillation periods are short relative to the duration of the incident pressure wave. This leads to a

* For most of these tests the animals were held vertically in the water with their lungs 1, 2, or 10 feet below the surface. For the tests at 2 and 10 feet, sheep were supplied air thru a face mask tied to their heads. The average atmospheric pressure at the Lovelace Foundation is about 12 psi.

damage parameter for injuries due to the excitation of these bubbles of the form

$$P_{MAX}/p_0 \quad (2.14)$$

where P_{MAX} is the maximum or peak incident overpressure. From the Lovelace Foundation sheep-dog-monkey data we estimate slight injuries to occur by this mechanism at about 600 psi at an ambient pressure of about 12.9 psi.

What we do now is compute two injury regions - one by the lung injury mechanism, the other by the intestinal injury mechanism. We then take the outer boundary of these two regions as the contour for incurring slight injury to the mammal.

Contouring Parameters. We accomplish our task by computing two contouring parameters - one for lung injuries, the other for intestinal injuries. These contouring parameters have the mathematical form of an injury probability as a function of the appropriate damage parameter, i.e.,

$$P = 1 / \{ 1 + \text{EXP}[-\lambda(\mu - \bar{\mu})] \} \quad (2.15)$$

where P is the contouring parameter, λ is a constant assigned some arbitrary value based on the computation mesh size, $\mu = \text{LOG}_{10} [\text{DAMAGE PARAMETER}]$, and $\bar{\mu}$ is the value of μ computed from the damage parameter value corresponding to the desired contour. Note that regardless of the value assigned to λ , P -values greater than 0.5 lie inside the contour corresponding to $\bar{\mu}$ and P -values less than 0.5 lie outside. Thus if at each mesh point of the region surrounding the explosion we compute both the contouring parameter for lung injury and the contouring parameter for intestinal injury, we can obtain the contouring parameter for injury by either of the two mechanisms by simply selecting at each

NSWC TR 82-188

mesh point the greater of the two computed values. The corresponding contour for injury by either of the two mechanisms is then obtained by interpolating for a value of 0.5 over the entire grid.

3. SAMPLE PROBLEMS

3-1. WHALES - KEY WEST

These computations were done as part of a Preliminary Environmental Assessment for an ongoing program of routine shock testing of Naval targets, including ships, with large conventional explosive charges placed under water. The current site is in the Atlantic Ocean about 19 nautical miles SSE of Key West, Florida. The average water depth is 900 feet. The explosive is HBX-1, a standard Navy explosive, placed in steel cases. There are three typical explosion test geometries: a 1,200 pound charge at a depth of 125 feet, a 10,000 pound charge at a depth of 200 feet, and a 40,000 pound charge at a depth of 200 feet.

The results are shown in Figures 3.1.1, 3.1.2, and 3.1.3 for the three explosion configurations employed at the test site and for 20-foot and 55-foot whales. For these computations it was assumed that the body mass versus length for whales is given by⁶

$$M = 6.23 L^3 \quad (3.1.1)$$

where M is the body mass in kilograms and L is the length in meters. For 20-foot and 55-foot whales this gives:

6. Ommanney, F.D., Lost Leviathan, Dodd, Mead and Co., New York, 1971.

NSWC TR 82-188

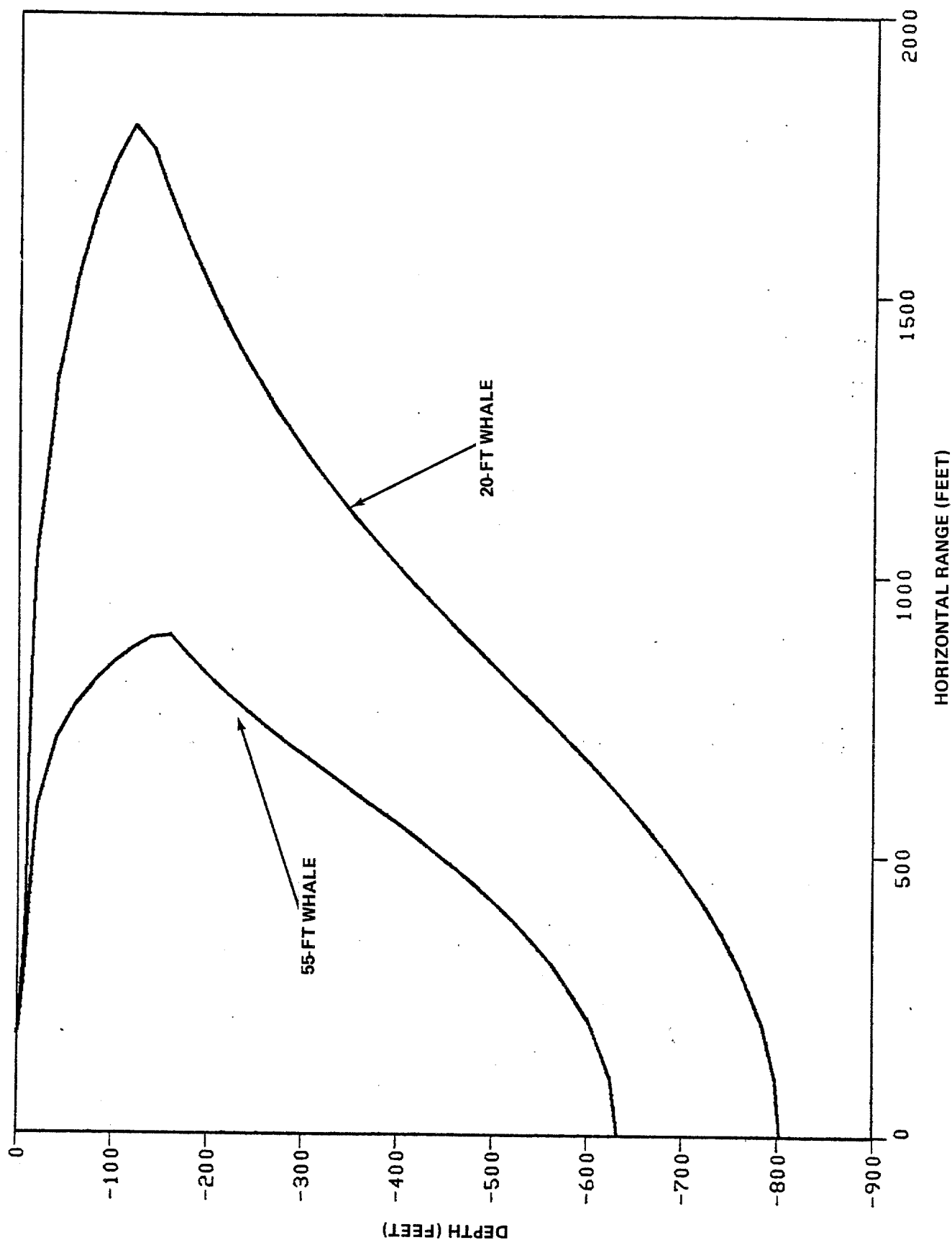


FIGURE 3.1.1. CONTOURS FOR SLIGHT INJURY TO WHALES: 1200-LB CHARGE
AT 125-FT DEPTH

NSWC TR 82-188

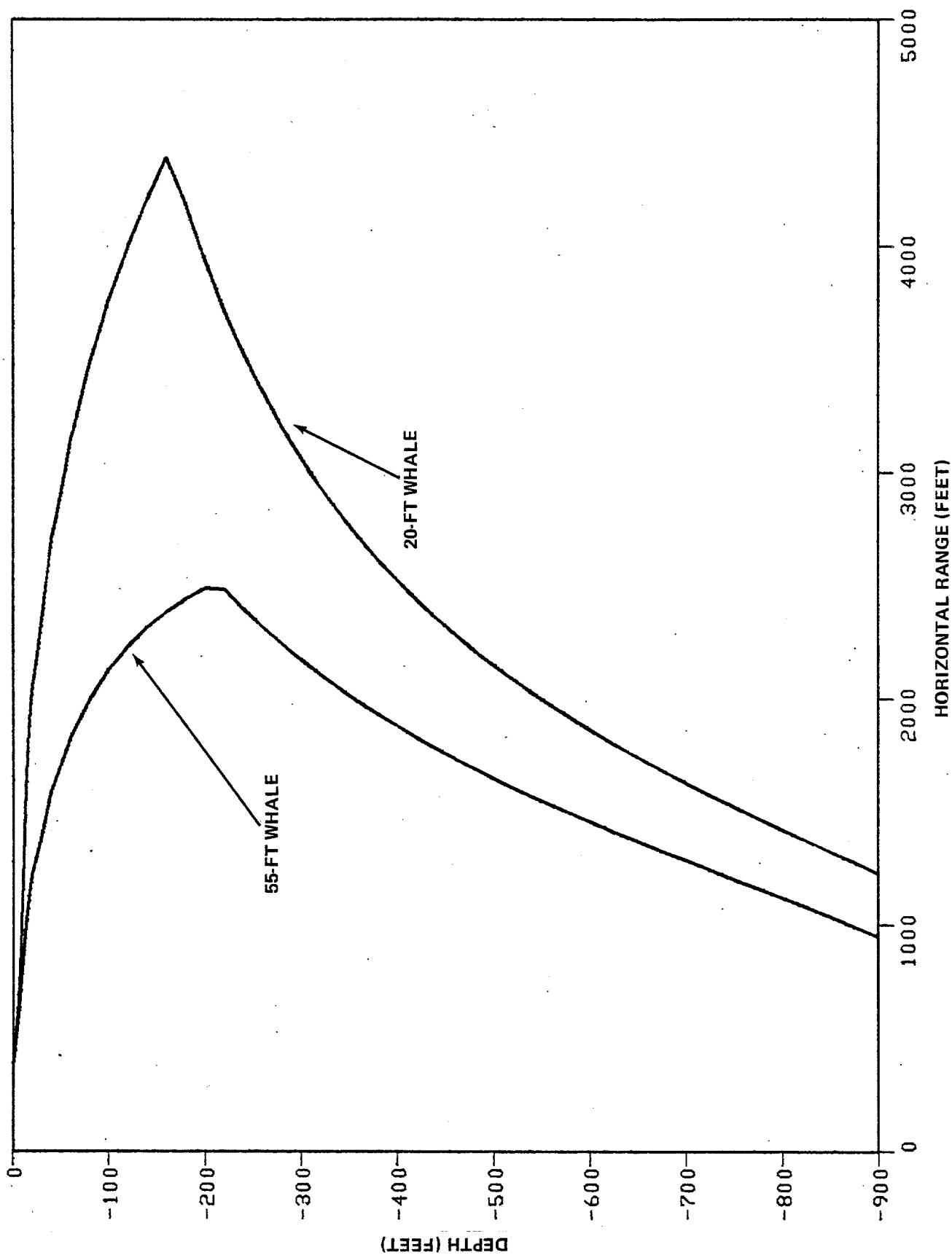


FIGURE 3.1.2 CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 200-FT DEPTH

NSWC TR 82-188

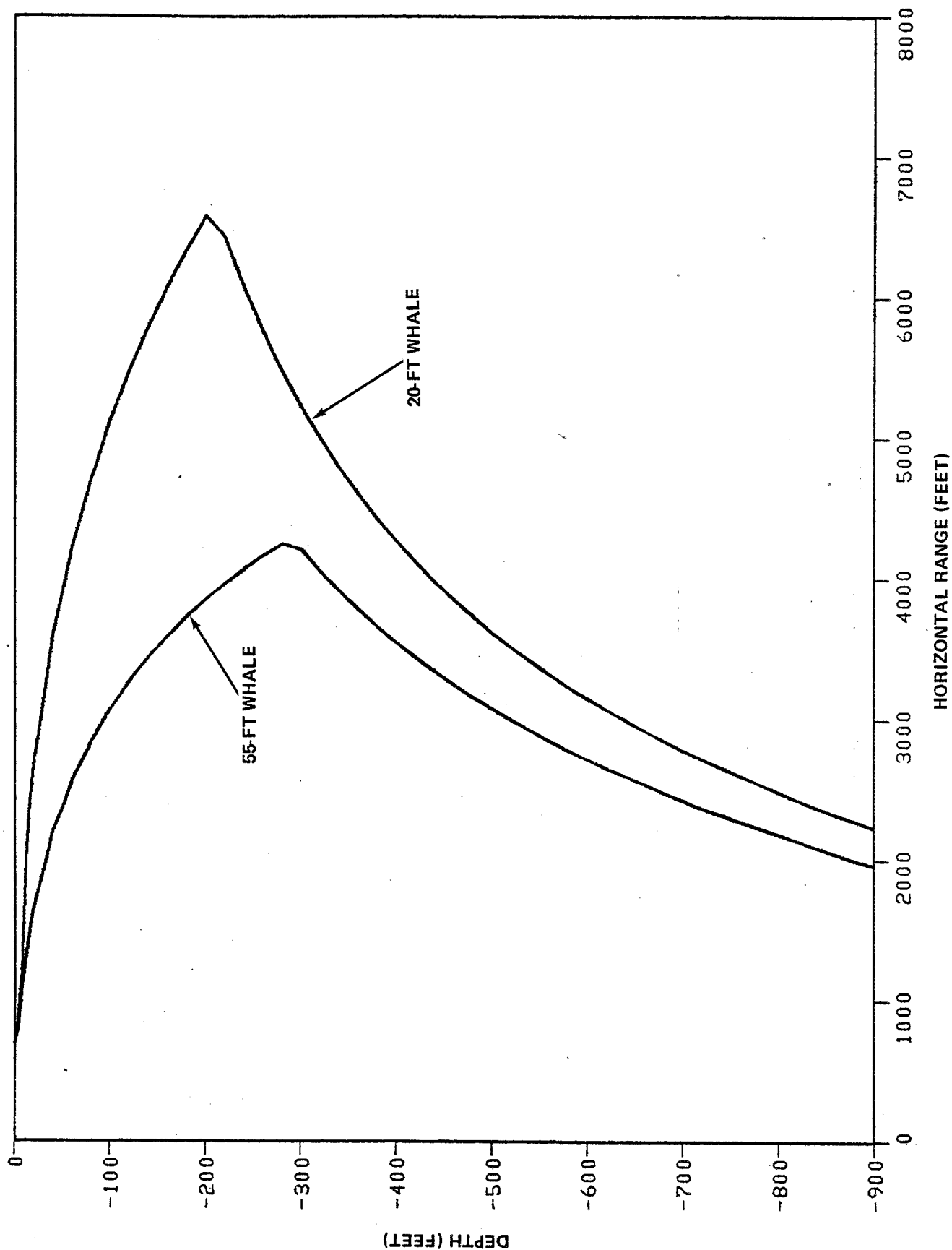


FIGURE 3.1.3. CONTOURS FOR SLIGHT INJURY TO WHALES: 40,000-LB CHARGE AT 200-FT DEPTH

NSWC TR 82-188

<u>Length</u>		<u>Body Mass</u>	
(Feet)	(Meters)	(Kilograms)	(English Tons)
20	6.1	1.41×10^3	1.6
55	16.8	29.4×10^3	32

Note that the extent of the predicted regions for incurring injuries are larger for the smaller whales.

3-2. WHALES - NORTH ATLANTIC

These computations were done as part of a Preliminary Environmental Assessment for explosion tests employing 10,000 pound HBX-1 charges fired under water in the North Atlantic. The water depth was about 15,000 feet. The charge depths were 400 meters (1312 feet) and 1300 meters (4265 feet).

The results for 20-foot and 55-foot whales are shown in Figures 3.2.1, 3.2.2 and 3.2.3 for the two charge depths. For explosive charges fired at such great depths, two separate injury regions will often occur - a deep roughly spherical region enclosing the charge, and a shallow disk directly over the charge near the water surface. Two such regions occur with the 4,265-foot depth explosion. Figure 3.2.2 shows the shallow disk regions for the two whale sizes. Figure 3.2.3 shows the deeper spherical regions surrounding the charge.

The rough overall dimensions from these 10,000-pound explosion computations are summarized in Table 3.2.1. In Table 3.2.1 the small (insignificant) shallow disk region for the 55-foot whale (shown in Figure 3.2.2) has been omitted.

NSWC TR 82-188

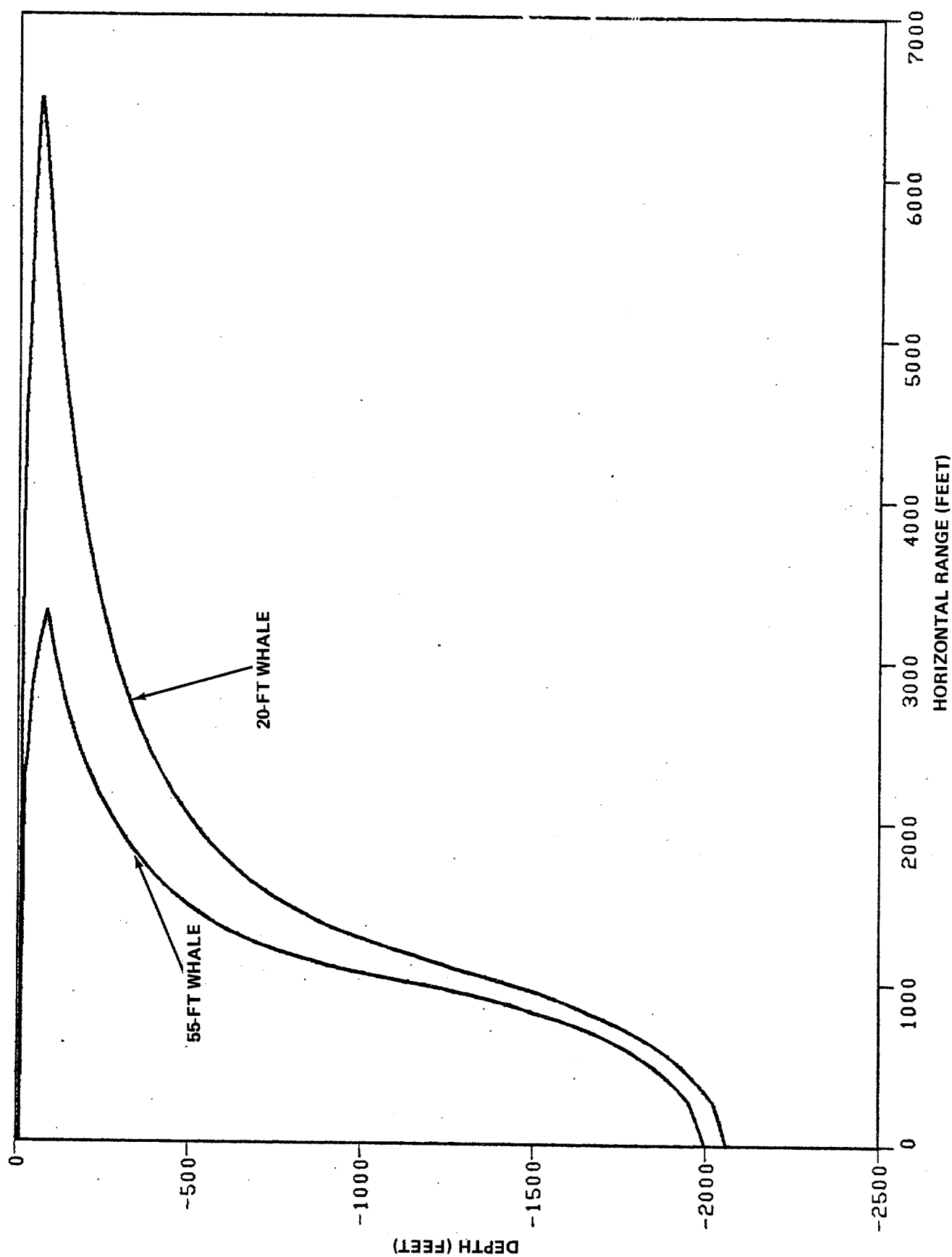


FIGURE 3.2.1. CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE
AT 1,312 FEET

NSWC TR 82-188

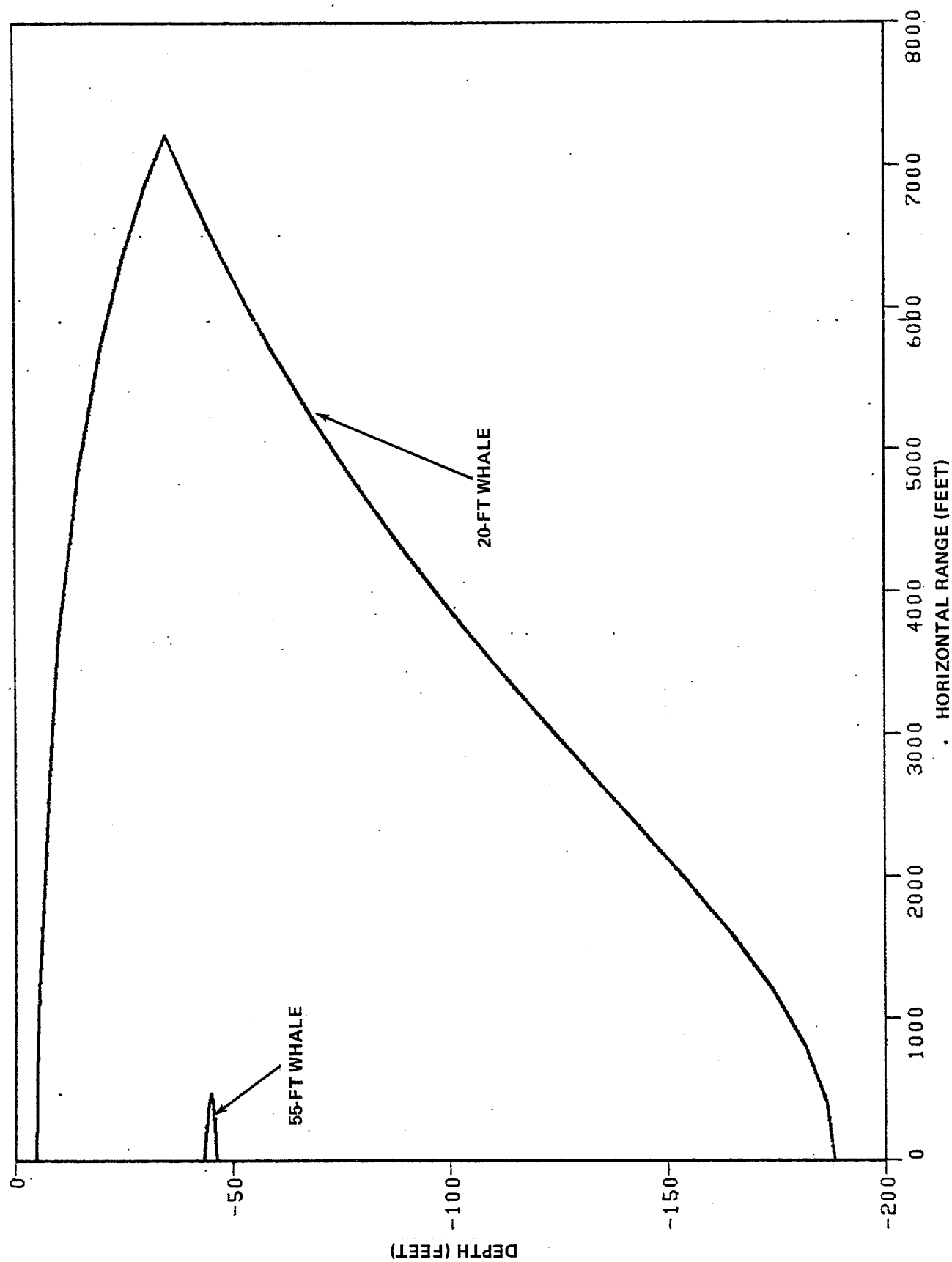


FIGURE 3.2.2. CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE
AT 4,265 FEET: SURFACE DISK

NSWC TR 82-188

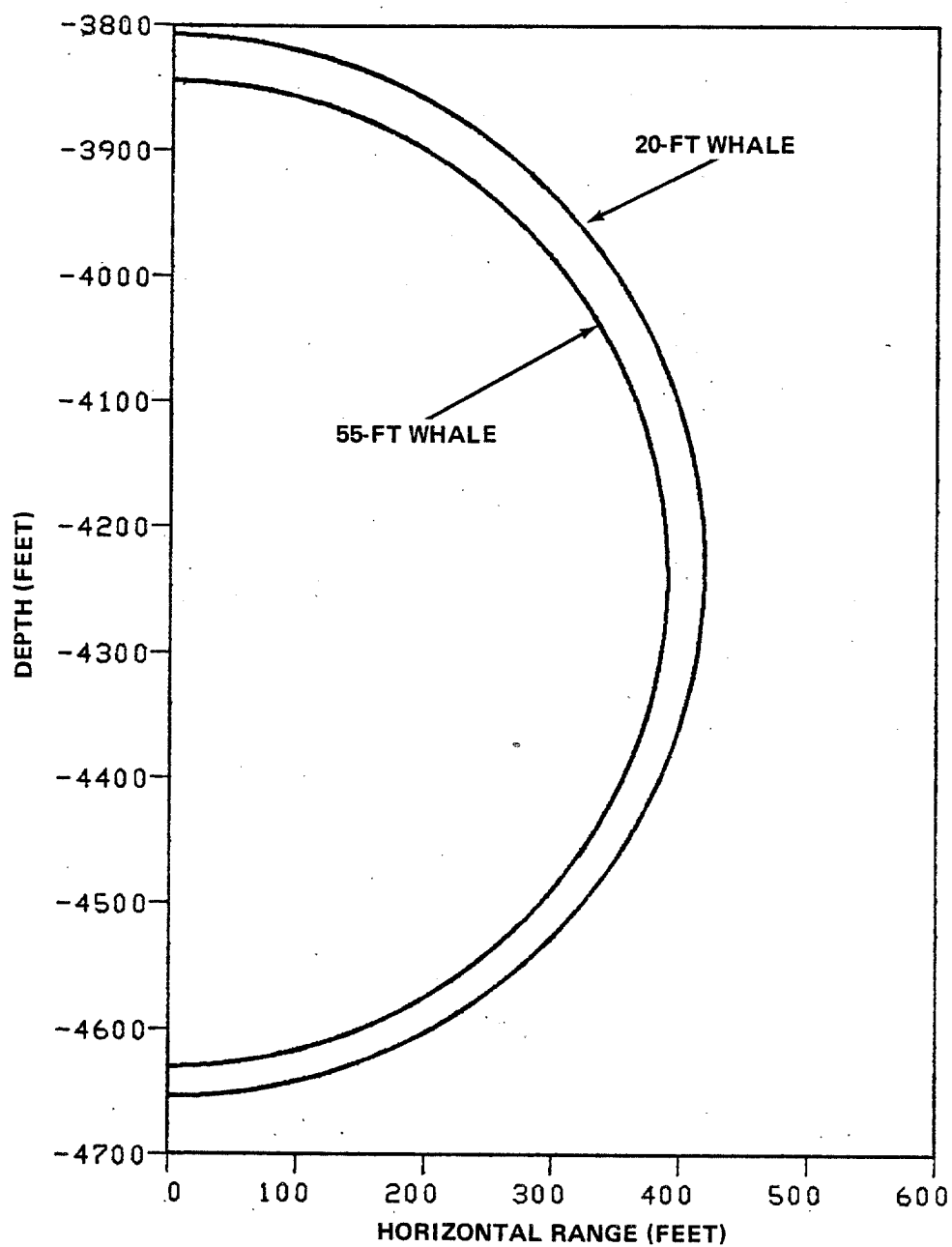


FIGURE 3.2.3. CONTOURS FOR SLIGHT INJURY TO WHALES: 10,000-LB CHARGE AT 4,265 FEET; DEEP SPHERE

NSWC TR 82-188

TABLE 3.2.1.- HORIZONTAL EXTENT OF REGIONS OF SLIGHT
INJURY TO WHALES BY 10,000-POUND EXPLOSIONS

<u>Depth of Explosion</u> (feet)	<u>Length of Whale</u> (feet)	<u>Maximum Horizontal Radius</u>	
		<u>Near Water Surface</u> (feet)	<u>At Explosion Depth</u> (feet)
1,312	20	6500	1060
1,312	55	3300	930
4,265	20	7200	420
4,265	55	None	390

NSWC TR 82-188

3-3. PORPOISES

These computations are new for this report and were done for the Navy shock testing conditions at the Key West, Florida test site (see Section 3-1). The computations were done for the two sizes of Atlantic Bottlenose Dolphin (*Tursiops Truncatus*) - 8-foot long adults and 3.3-foot long newborn calves. For the body mass we assumed that the body mass versus length is given by

$$M = 12 L^3 \quad (3.3.1)$$

where M is in kilograms and L is in meters.

For a 3.3-foot long and an 8-foot long Bottlenose Dolphin this gives:

	Length		Body Mass	
	(feet)	(meters)	(kilograms)	(pounds)
Calf	3.3	1.01	12.2	27
Adult	8.0	2.44	174	384

The computed results - locations (contours) where slight injuries to the porpoise are predicted - are shown in Figures 3.3.1, 3.3.2 and 3.3.3.

These computations can also be used for other similar size dolphins or porpoises, such as the variety of Bottlenose Dolphin found in the Western Atlantic which are a bit larger, and the Common Dolphin (*Delphinus delphi*) which are a bit smaller. Note that this section and Figures 3.3.1 through 3.3.3 have been labelled "porpoises" rather than "dolphins" in order to avoid confusion with the dolphin fish which is not related to these deep diving mammals.

NSWC TR 82-188

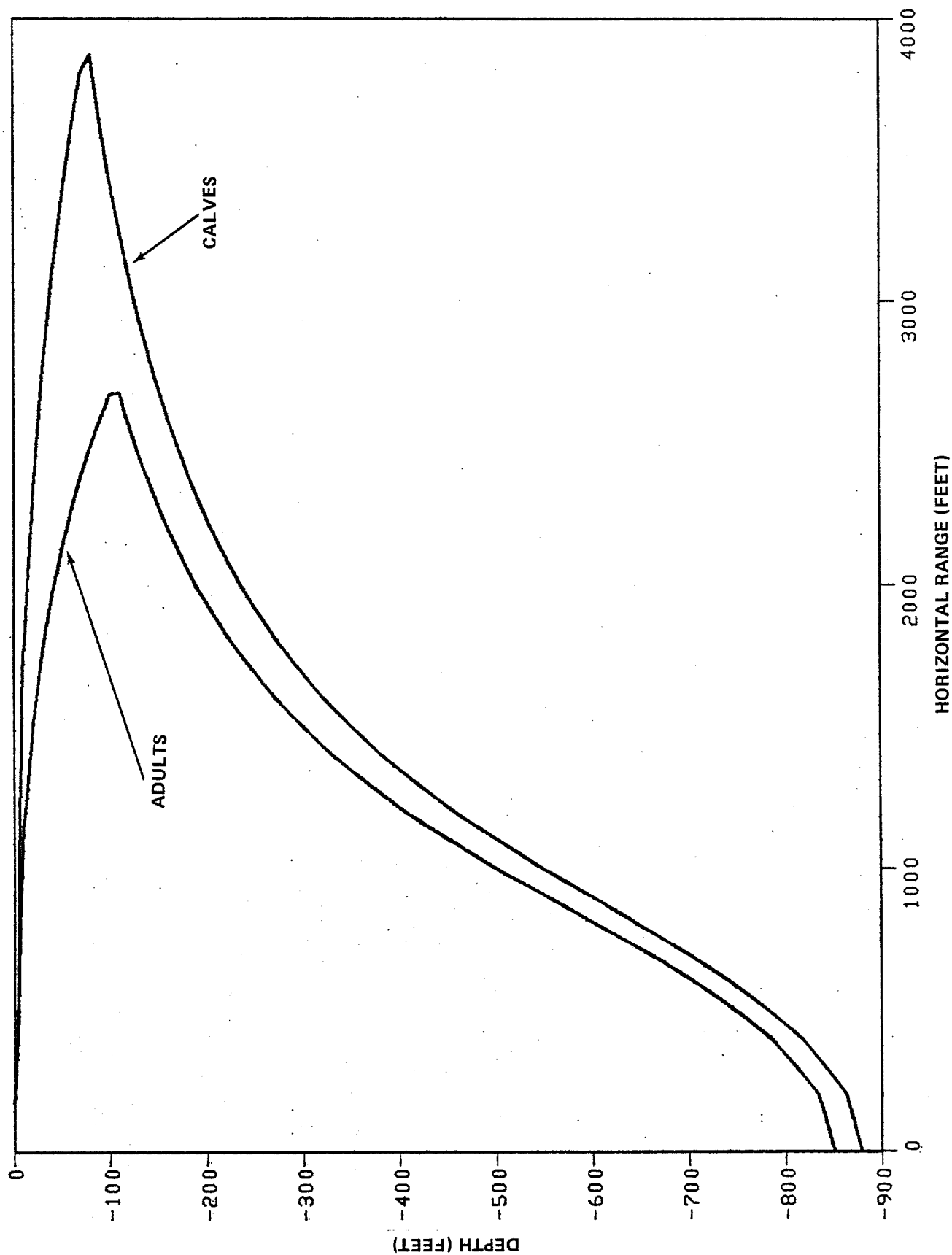


FIGURE 3.3.1. CONTOURS FOR SLIGHT INJURY TO PORPOISES : 1200-LB
CHARGE AT 125 FEET

NSWC TR 82-188

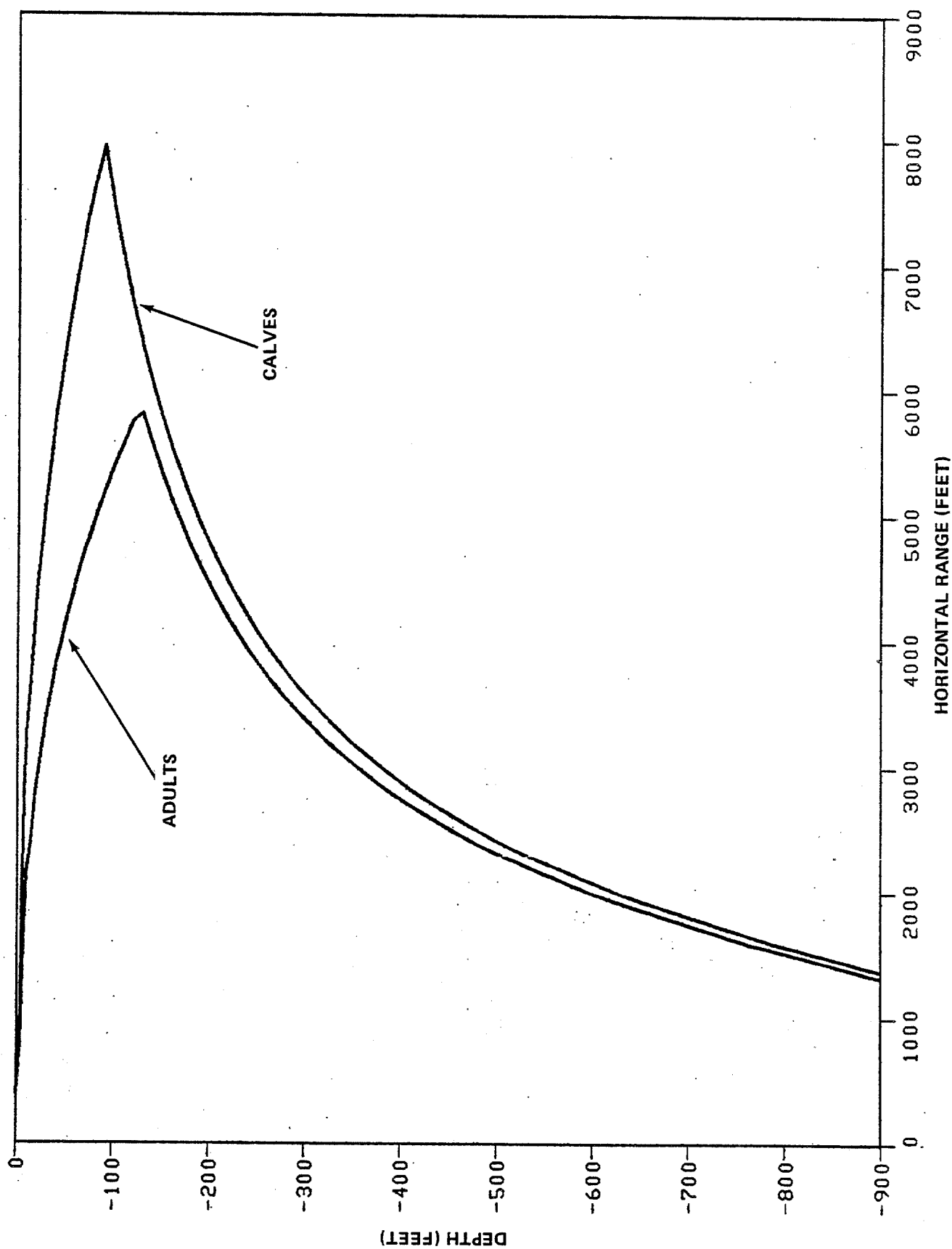


FIGURE 3.3.2. CONTOURS FOR SLIGHT INJURY TO PORPOISES: 10,000-LB CHARGE AT 200 FEET

NSWC TR 82-188

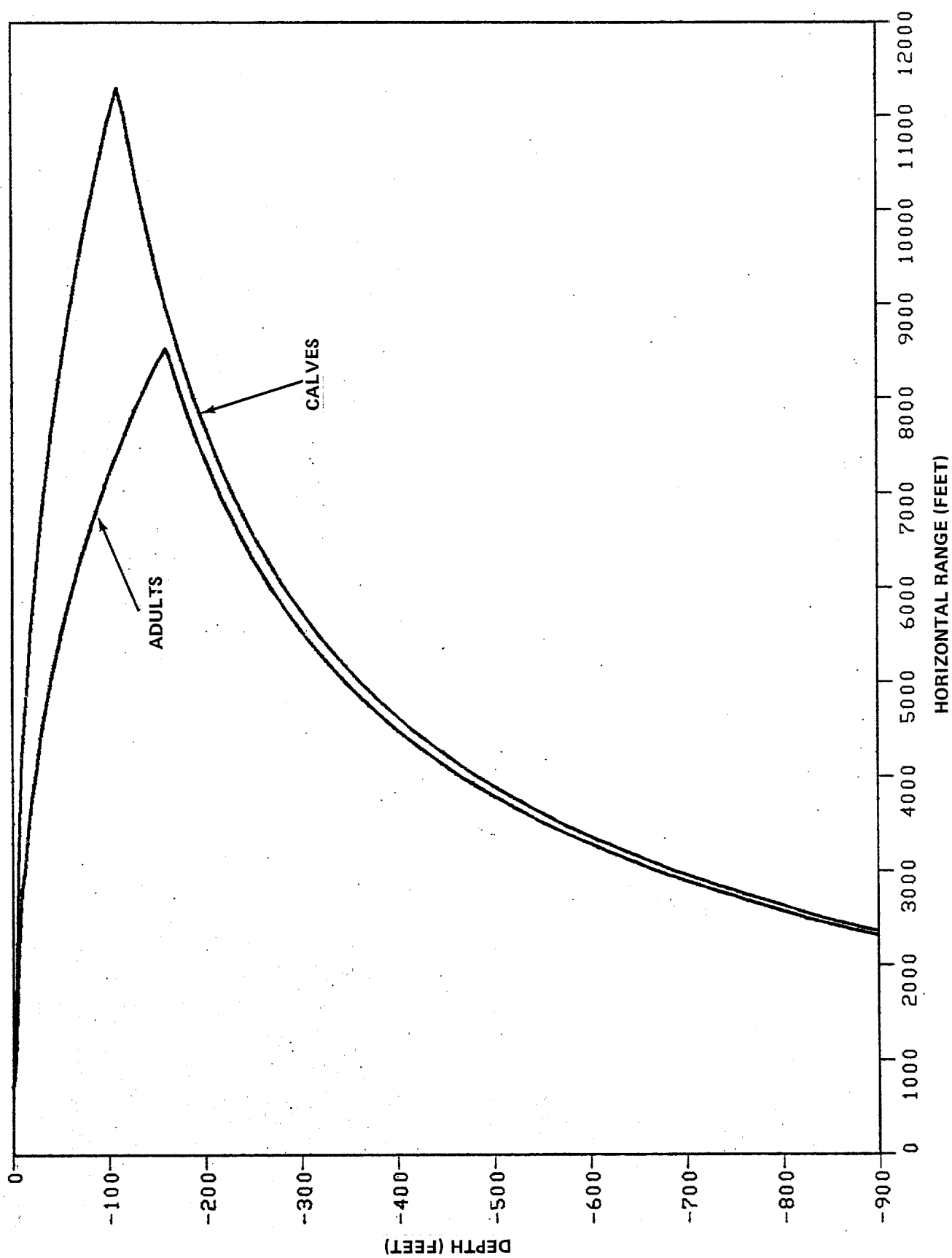


FIGURE 3.3.3. CONTOURS FOR SLIGHT INJURY TO PORPOISES: 40,000-LB CHARGE AT 200 FEET

3-4. MANATEES

These computations were done in response to a request from the Army Corps of Engineers for information on the effects of underwater blasting on manatees. A 12-pound explosive charge was used to represent the effect of charges weighing from 6 to 24 pounds. Computations were done for two charge depths, 5-feet and 40-feet, in order to bracket the situations ordinarily encountered by the Corps of Engineers; and for two mammal weights, 70-pounds (to represent calves), 1200-pounds (for juveniles and adults).

While the effects of the water surface are a major component of the computations, effects of bottom proximity are ignored. Bottom effects are considered to be of secondary importance, and, as yet, have not been considered in any of our environmental studies.

The results of these computations are presented in Figures 3.4.1 and 3.4.2, and are summarized in Table 3.4.1.

NSWC TR 82-188

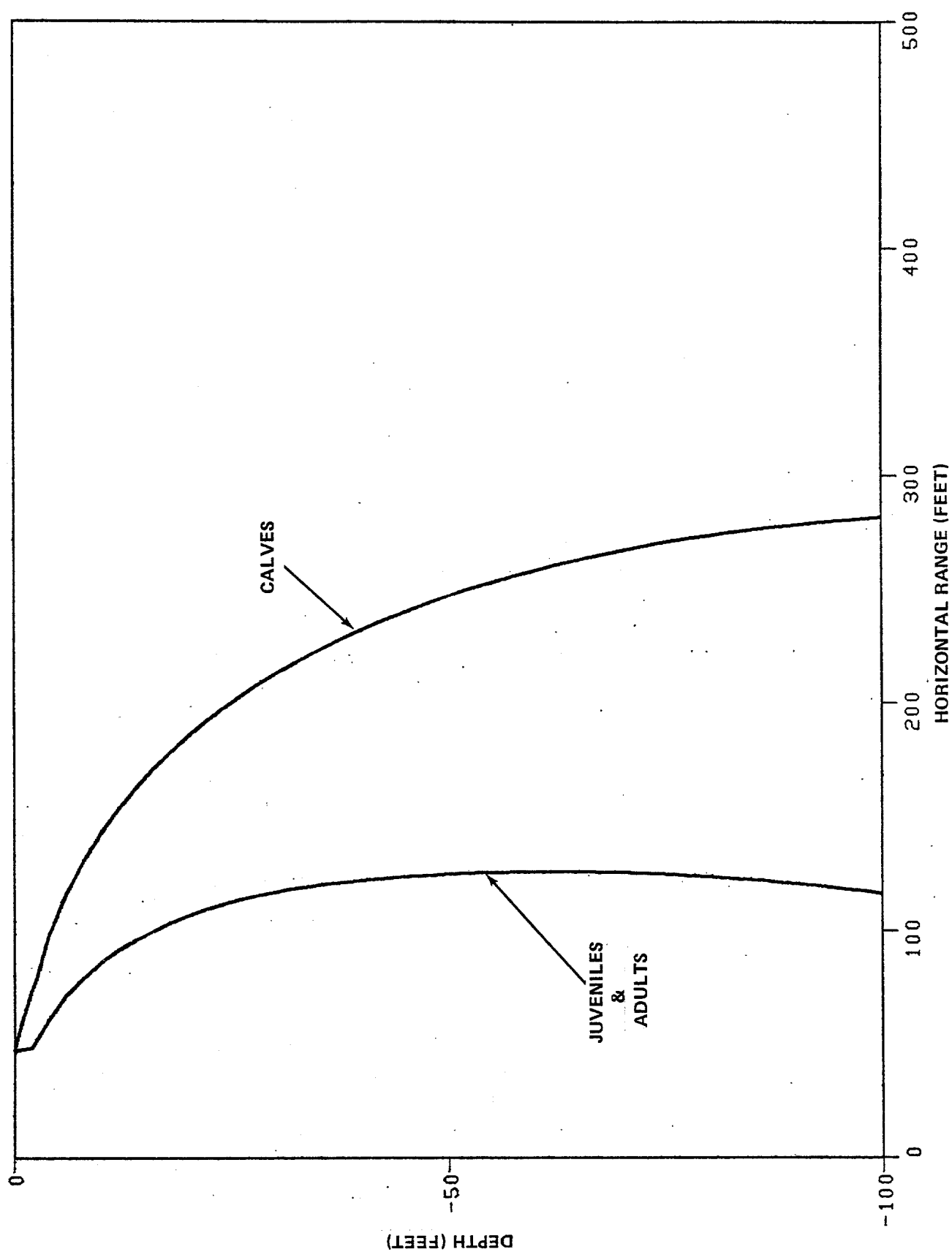


FIGURE 3.4.1. CONTOURS FOR SLIGHT INJURY TO MANATEES: 12-LB CHARGE AT 5-FT DEPTH

NSWC TR 82-188

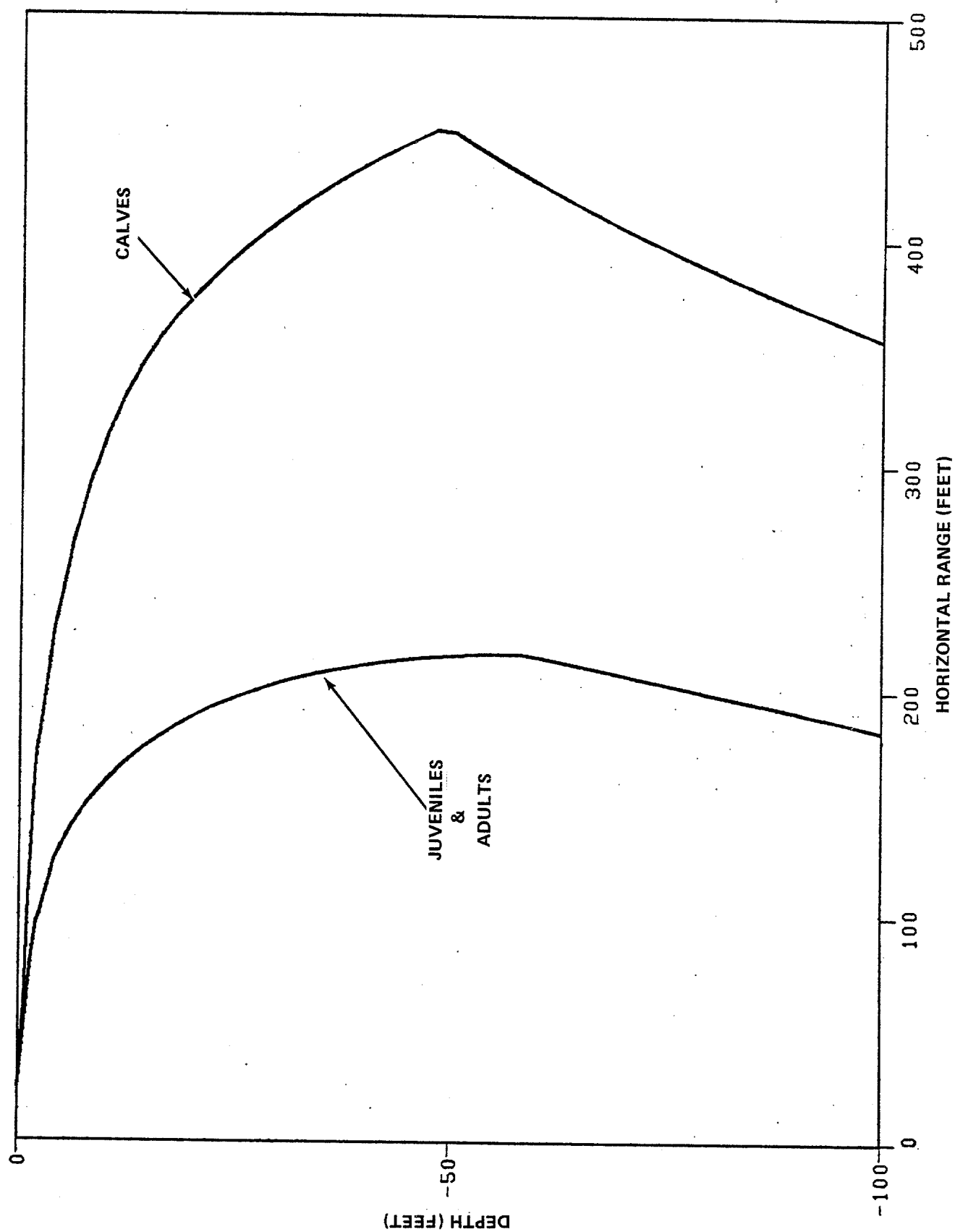


FIGURE 3.4.2. CONTOURS FOR SLIGHT INJURY TO MANATEES: 12-LB CHARGE AT 40-FT DEPTH

NSWC TR 82-188

TABLE 3.4.1. - MAXIMUM HORIZONTAL EXTENT OF SLIGHT INJURIES TO MANATEES
BY 12-POUND EXPLOSIONS¹

<u>Depth of Explosion</u> (feet)	<u>Predicted Horizontal Range</u>	
	<u>Juveniles and Adults²</u> (feet)	<u>Calves³</u> (feet)
5	130	280
40	220	450

1 For multiple blasts from submerged boreholes (simultaneous and/or time-delay), with 6 to 24 pounds explosive per hole, measure horizontal range to manatee from nearest borehole.

2 Range for juveniles and adults computed using 1200-pound animal weight.

3 Range for calves computed using 70-pound animal weight.

NSWC TR 82-188

REFERENCES

1. Richmond, Donald R., Yelverton, John T., and Fletcher, E. Royce, "Far-Field Underwater-Blast Injuries Produced by Small Charges," Lovelace Foundation, DNA 3081T, 1973.
2. Yelverton, John T., et al, "Safe Distances from Underwater Explosions for Mammals and Birds," Lovelace Foundation, DNA 3114T, 1973.
3. Bowen, I.G., et al, "Biophysical Mechanisms and Scaling Procedures Applicable in Assessing Responses of the Thorax Energized by Air-Blast Overpressures or by Non-Penetrating Missiles," Lovelace Foundation, DASA 1857, 1966.
4. Kennard, E. H., "Radial Motion of Water Surrounding a Sphere of Gas in Relation to Pressure Waves," 1943, published in Vol. II of Underwater Explosion Research Office of Naval Research, 1950.
5. Goertner, John F., Fish Killing Potential of a Cylindrical Charge Exploded Above the Water Surface NSWC/WOL TR 77-90, 1978.
6. Ommanney, F. D., Lost Leviathan, Dodd, Mead and Co., New York, 1971.

NSWC TR 82-188

DISTRIBUTION

	<u>Copies</u>		<u>Copies</u>
Commander		Defense Technical Information	
Naval Sea Systems Command		Center	
Attn: SEA-55X1 (J. Sullivan)	1	Cameron Station	
SEA-55X11 (D. M. Hurt)	1	Alexandria, VA 22314	12
SEA-55X13R. E. Fuss)	1		
SEA-55X1 (W. Forehand)	1	Office of Naval Research	
SEA-62R32 (G. D. Edwards)	1	Attn: Code 480	2
SEA-62R (W. W. Blaine)	1	Code 441	1
Washington, D.C. 20362		800 North Quincy Street	
		Arlington, VA 22217	
Commander		Library of Congress	
David Taylor Naval Ship Research		Attn: Gift and Exchange Division	4
& Development Center		Washington, D.C. 20540	
Attn: Code 17	1		
Code 1740	1	Commander	
Code 1740.1	1	Naval Coastal Systems Center	
Code 1750	1	Attn: Code 734 (H. Loftin)	1
Code 1720	1	Library	1
Code 1720.3	1	Panama City, FL 32407	
Code 042	1		
Bethesda, MD 20084		Chief of Naval Material	
Underwater Explosions Research Division		Office of Naval Technology	
David Taylor Naval Ship Research		Attn: MAT-07 (J. W. Enig)	1
& Development Center		Washington, D.C. 20360	
Attn: Technical Reference Center	1		
R. Oliver	1	Director	
Portsmouth, VA 23709		Waterways Experiment Station	
		Attn: Technical Library	1
Director		Kim Davis	1
Naval Research Laboratory		P.O. Box 631	
Attn: Code 2027	1	Vicksburg, MS 39180	
Code 8400	1		
Code 8406	1	Commanding Officer	
Washington, D.C. 20375		Naval Biosciences Laboratory	
Commanding Officer		Attn: Dr. Harold E. Guard	1
Naval Underwater Systems Center		LCDR Andre B. Cobet	1
Attn: Technical Library	1	Bldg. 844, Naval Supply Center	
Newport, RI 02840		Oakland, CA 94625	

NSWC TR 82-188

DISTRIBUTION (Cont.)

	<u>Copies</u>		<u>Copies</u>
Commanding Officer		Officer in Charge	
Naval Underwater Systems Center		Civil Engineering Laboratory	
Attn: Code EA 11 (Roy R. Manstan)	1	Attn: Code L70	1
Newport, RI 02840		Code L71	1
		Code L43	1
		Code L65	1
Commander		Naval Construction Battalion	
Naval Ocean Systems Center		Center	
Attn: Code 406 (S. Yamamoto)	1	Port Hueneme, CA 93043	
D. A. Wilson	1		
Code 5104 (F. G. Wood)	1	Commanding Officer	
Code 6565	1	Naval Air Station	
Michael H. Salazar	1	Attn: A. L. Clark, Environmental	
Code 311 (C. L. Brown)	1	Protection Coordinator	
Code 311 (A. L. Brooks)	1	Public Works Department	1
San Diego, CA 92152		Patuxent River, MD 20670	
Commander			
Naval Ocean Systems Center		U.S. Army Engineer District	
Attn: Jack W. Hoyt	1	Attn: Tom Crews, III, Environmental	
Code 2531 (J. D. Warner)	1	Branch	1
Code 4013 (W. C. Cummings)	1	100 McAllister Street	
Technical Library	1	San Francisco, CA 94102	
San Diego, CA 92152			
		U.S. Army Engineer Division,	
Naval Ocean Systems Center		Pacific Ocean	
Hawaii Laboratory		Attn: Michael T. Lee, Biologist	1
Attn: William Friedl	1	Environmental Section	
Evan C. Evans, III	1	Bldg. 230, Ft. Shafter	
Head Marine Environmental		APO San Francisco 96558	
Management Office	1		
P.O. Box 997, Kailua, Oahu		ADTC/DLV	
Hawaii 96734		Attn: J. C. Cornette	1
		Eglin AFB, FL 32542	
Officer in Charge			
New London Laboratory		National Marine Fisheries Service	
Naval Underwater Systems Center		Auke Bay Biological Laboratory	
Attn: Albert B. Brooks	1	Attn: Theodore Merrell	1
Code TA13 (C. L. Brown, Jr.)	1	P.O. Box 155	
New London, CT 06329		Auke Bay, AK 99821	
Commanding Officer			
Naval Explosive Ordnance Disposal		National Marine Fisheries Service	
Facility		Water Resources Division	
Attn: Library Division	1	Attn: Dale R. Evans, Chief	1
Code 5D (L. A. Dickinson)	1	P.O. Box 1668	
Richard Burdette	1	Juneau, AK 99801	
Lyle Malotky	1		
Indian Head, MD 20640			

NSWC TR 82-188

DISTRIBUTION (Cont.)

	<u>Copies</u>		<u>Copies</u>
National Marine Fisheries Services Southwest Fisheries Center P.O. Box 271 La Jolla, CA 92037	1	South Carolina Marine Resources Division Attn: Michael D. McKenzie 2024 Maybank Highway Charleston, SC 29412	1
Department of Commerce Biological Laboratory Midford, CT 06460	1	Trust Territory Environmental Protection Board Attn: M. Falanruw, Staff Ecologist P.O. Box 215 Yap, W.C.I. 96943	1
Department of the Interior Attn: Karen Bachman Mark L. Holmes 1107 NE 45th Street Suite 110 Seattle, WA 98105	1 1	State of Alaska Department of Fish and Game Attn: L. L. Trasky, Fisheries Research Biologist 333 Raspberry Road Anchorage, AK 99502	1
Department of the Interior Bureau of Sports Fisheries and Wildlife Attn: J. S. Gottschalk, Director Interior Building Washington, D.C. 20240	1	Deputy Commissioner Alaska Department of Fish and Game Attn: Joseph R. Blum Support Building Juneau, AK 99801	1
Bureau of Commercial Fisheries Attn: Philip M. Roedel, Director Interior Building Washington, D.C. 20240	1	State of Alaska Department of Fish and Game Habitat Section 333 Raspberry Road Anchorage, AK 99502	1
State of Maryland Fish and Wildlife Administration Attn: Charles Frisbie Barbara Holden Howard J. King Annapolis, MD 21404	1 1 1	Department of Fish and Game Wildlife Protection Branch 1416 Ninth Street Sacramento, CA 95814	1
State of North Carolina Department of Natural and Economic Resources Attn: Willard Lane, Artificial Reef Program Jim Tyler, Artificial Reef Program Division of Marine Fisheries Box 769 Morehead City, NC 28557	1 1	State of California Marine Resources Division Attn: D. Gates, Regional Manager 350 Golden Shore Long Beach, CA 90802	1
		State of Florida Department of Natural Resources Larson Building Tallahassee, FL 32304	1

NSWC TR 82-188

DISTRIBUTION (Cont.)

<u>Copies</u>	<u>Copies</u>
State of Louisiana Wildlife and Fisheries Commission Attn: Fred Dunham 1 P.O. Box 44095, Capital Station Baton Rouge, LA 70804	University of Hawaii at Manoa Hawaii Institute of Marine Biology Attn: G. H. Balazs, Jr., Marine Biologist 1 P.O. Box 1346, Coconut Island Kaneohe, HI 96744
Virginia Institute of Marine Science Attn: William J. Hargis, Director 1 Gloucester Point, VA 23062	Department of Biology Juniata College Attn: Robert L. Fisher 1 Huntington, PA 16652
Director Woods Hole Oceanographic Institution Attn: Earl E. Hays 1 Lincoln Baxter, II 1 Library 1 Woods Hole, MA 02543	Marine Resources Division California State Fisheries Lab Attn: Robert Kanlen 1 350 South Magnolia Long Beach, CA 30802
Director Scripps Institution of Oceanography Attn: Fred Spiess 1 La Jolla, CA 92037	Robert E. Eckels & Associates Consulting Engineers 2102 Youngfield Golden, CO 80401 1
School of Oceanography Oregon State University Attn: A. G. Carey, Jr. 1 Librarian 1 Corvallis, OR 97331	Woodward Clyde Consultant Attn: Jack Kiker 1 Box 1149 Orange, CA 92668
Chesapeake Bay Institute The Johns Hopkins University Baltimore, MD 21218 1	Lovelace Biomedical & Environmental Research Institute, Inc. Attn: Donald R. Richmond 1 E. Royce Fletcher 1 Robert K. Jones 1 John T. Yelverton 1 P.O. Box 5890 Albuquerque, NM 87115
Chesapeake Biological Laboratory Attn: T. S. Y. Koo 1 Joseph A. Mihursky 1 Martin L. Wiley 1 John S. Wilson 1 P.O. Box 38 Solomons, MD 20688	Tetra Tech, Inc. Attn: Li-San Hwang 1 630 North Rosemead Blvd. Pasadena, CA 91107
Marine Physical Laboratory, SIO/UCSD Attn: Charles B. Bishop 1 Bldg. 106, Naval Undersea Center San Diego, CA 92106	Explo Precision Engineering Corporation Attn: John J. Ridgeway 1 Manager of Technical Services Gretna, LA 70053

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSWC TR 82-188	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PREDICTION OF UNDERWATER EXPLOSION SAFE RANGES FOR SEA MAMMALS		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John F. Goertner		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center (CODE R14) White Oak, Silver Spring, Md 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6372IN;S0400SL;S0400SL:R14CA
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 16 August 1982
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Underwater Explosions Whales Underwater Blast Porpoises Injuries Dolphins Mammals Manatees		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes a method for the prediction of the water regions in the vicinity of an underwater explosion where significant injuries to sea mammals can occur. The method is based on an approximate scaling of underwater explosion test data obtained by the Lovelace Foundation using live sheep, dogs, and monkeys. The scaling is based on the calculated radial oscillation responses of the lung cavity and of small bubbles of intestinal gas. At each point in the water the more significant of the two effects is used to define the predicted injury region. (Continued)		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The method has been used in preparing Preliminary Environmental Assessments for explosion test programs. Results from several such computations done for sea mammals (whales, dolphins and manatees) are presented.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

