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Title: Underwater Nuclear Weapons Effects

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Underwater Nuclear Weapons Effects

For Actinide Lecture Series 2020

Jeremy Best
NSIS


Crossroads Baker: 1946 23kT 90ft underwater


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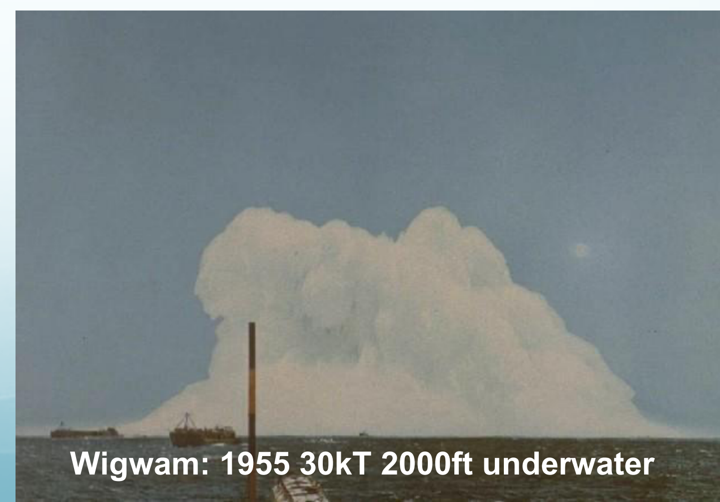
Swordfish, May 11, 1962 “LOW yield”
Anti-submarine rocket system proof test


Wigwam: 1955 30kT 2000ft underwater

Overview of Underwater Nuclear Detonations

Operation	Test	Date	Location	Yield (kT)	Depth (ft)
Crossroads	Baker	7/24/1946	Bikini Atoll	21	90
Wigwam	Wigwam	5/14/1955	Pacific	30	2000
Hardtack I	Wahoo	5/16/1958	Enewetak Atoll	9	500
Hardtack I	Umbrella	6/9/1958	Enewetak Atoll	8	150
Nougat	Swordfish	5/11/1962	Pacific	Low	0

DOE/NV

Zones of Underwater

- On the surface of water – Ivy Mike – 10.4 Mt
  - This is at or near the surface of the water so that the initial fireball touches the water at or before hydrodynamic separation (similar to regular surface bursts)
- Shallow under water – Crossroads Baker 21 kt, Hardtack 1 Umbrella 8 kt, Wahoo 9 kt
  - Defined as a depth of burst such that the fireball breaches the water – air interface within the initial expansion phase
  - SDOB < 35 ft / $W^{(1/3)}$
- Deep underwater – Wigwam 30 kt
  - Below a depth of burst where the initial gas bubble created by the energy release of the weapon begins a negative phase before "venting" or breaching the water – air interface.
  - SDOB > 150 ft / $W^{(1/3)}$

Baker Shot

- https://youtu.be/gy6-ZKWCoH0?t=53

Properties of Water

- Water is mostly incompressible. We generally treat it that way for calculations (except high fidelity).
- Water is 784 times more dense than air. ~1000 kg/m^3
- Sound travels about 343.6 m/s in dry air, while it travels 1484 m/s in normal water (20^o C). About 4.3 times faster.
- For a shockwave impacting the air - water interface, the direction is very important as to how much energy is transferred.

Shockwave in Water

- A shockwave in water is similar to air, but the details are very different
  - Sharp rise in overpressure
  - Overpressure duration is much shorter
  - The radial overpressure decrease is much slower
    - Eg: 100 kt burst in deep water at 3000 ft still has peak overpressures of ~2700 psi, while the same radial distance for an airburst would be in the single digits of psi.

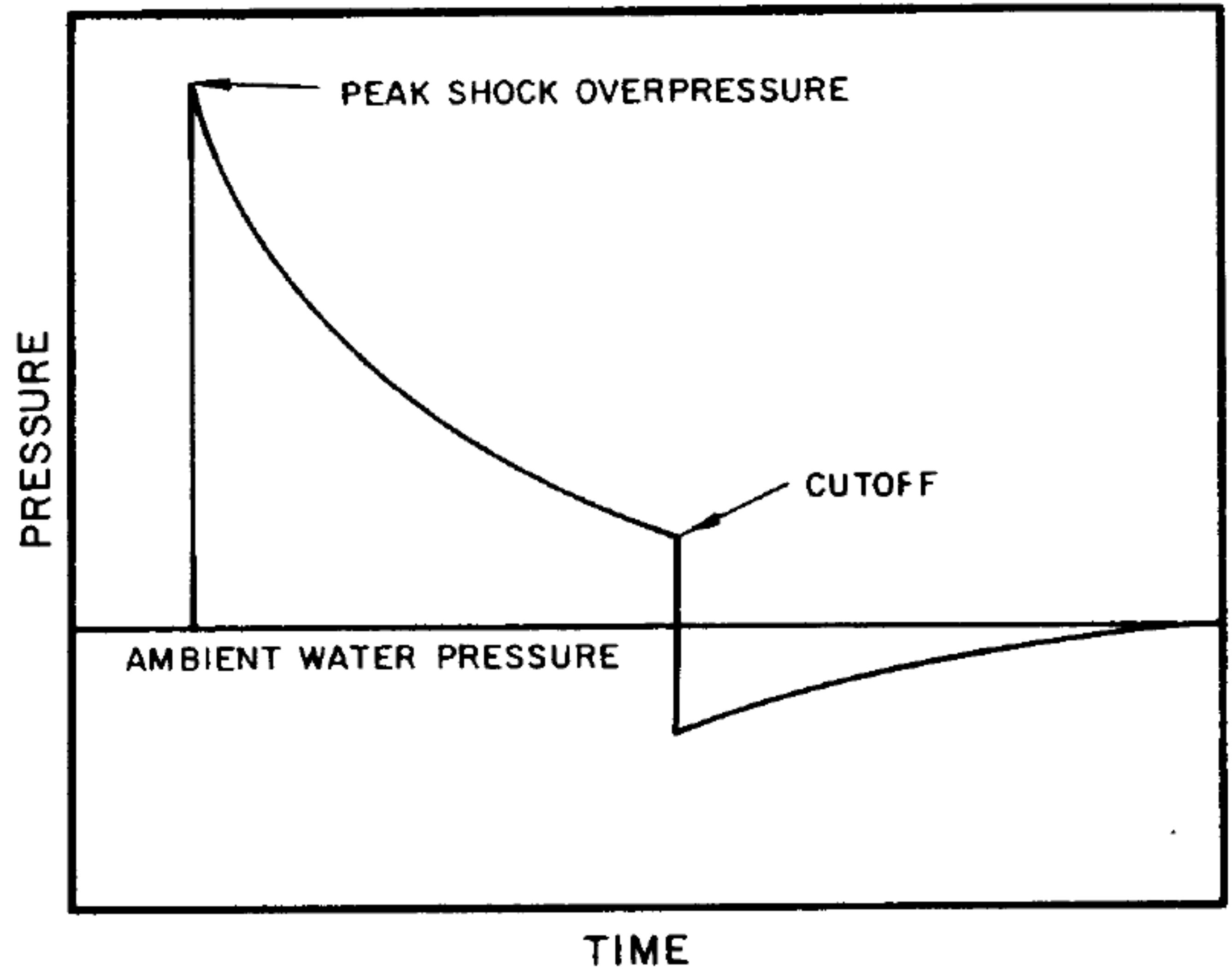


Figure 6.44. Idealized (acoustic approximation) variation of water pressure with time in an underwater explosion at a point near the air surface in the absence of bottom reflections.

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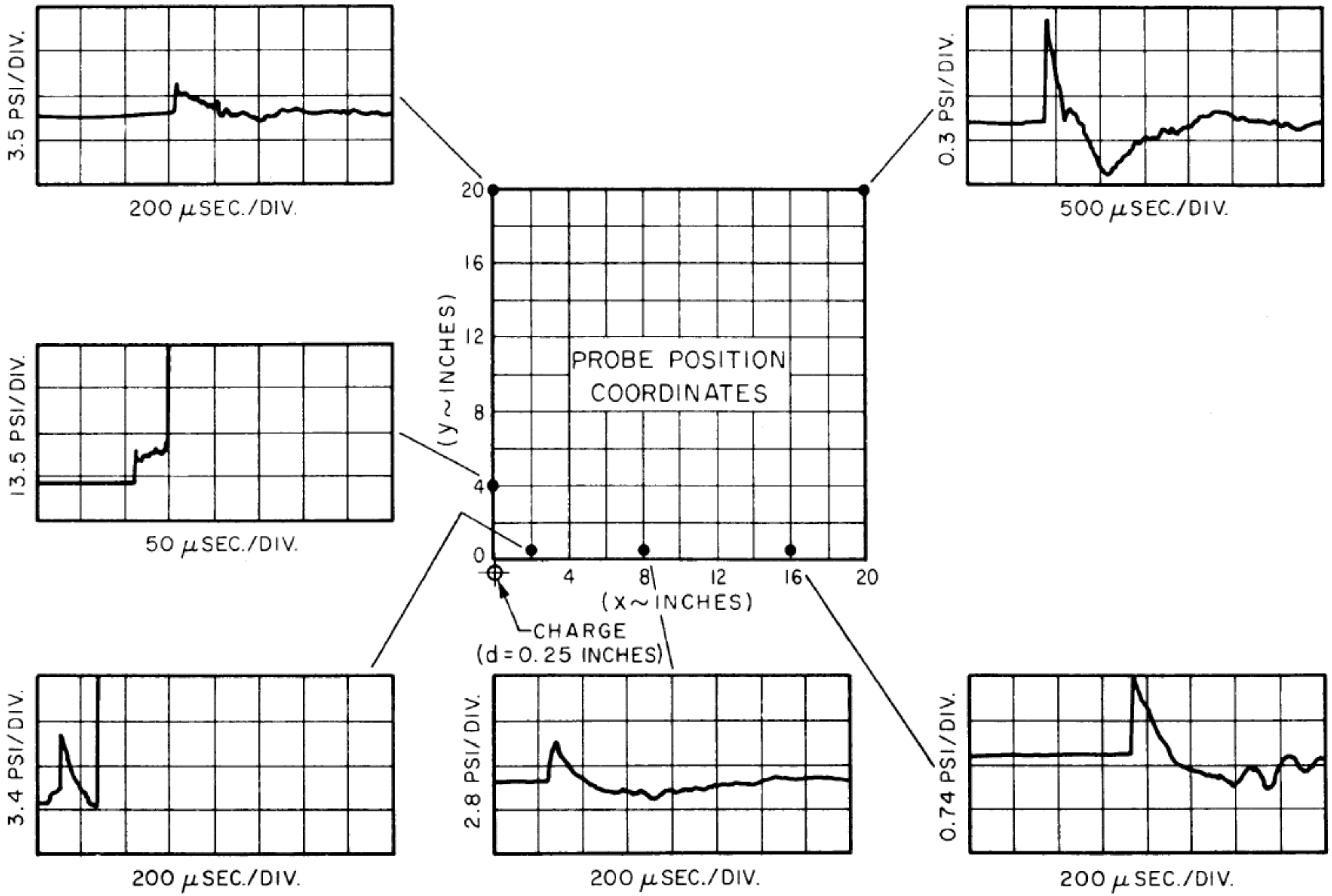

FIG. 9 AIRBLAST WAVEFORMS FROM SHALLOW EXPLOSIONS ($\lambda_d \cong 0.3$)

Reflections

- Similar to surface bursts, the shockwave in water can reflect off of the air – water boundary, sometimes known as “air slap”.
  - This can be understood with standard wave theory with a semi-rigid boundary, where some of the energy is transmitted into the air, and some reflected back into the water.
  - This reflection from the air creates a rarefaction which tends to attenuate some of the shock energy and creates an acoustic “anomalous” zone.
- The shockwave also reflects off of the bottom of the ocean. The properties of the reflected wave are highly dependent on the bottom properties: Mud, silt, coral, rock.
  - Generally this bottom slap creates a compression wave similar to surface burst interactions.

Reflections

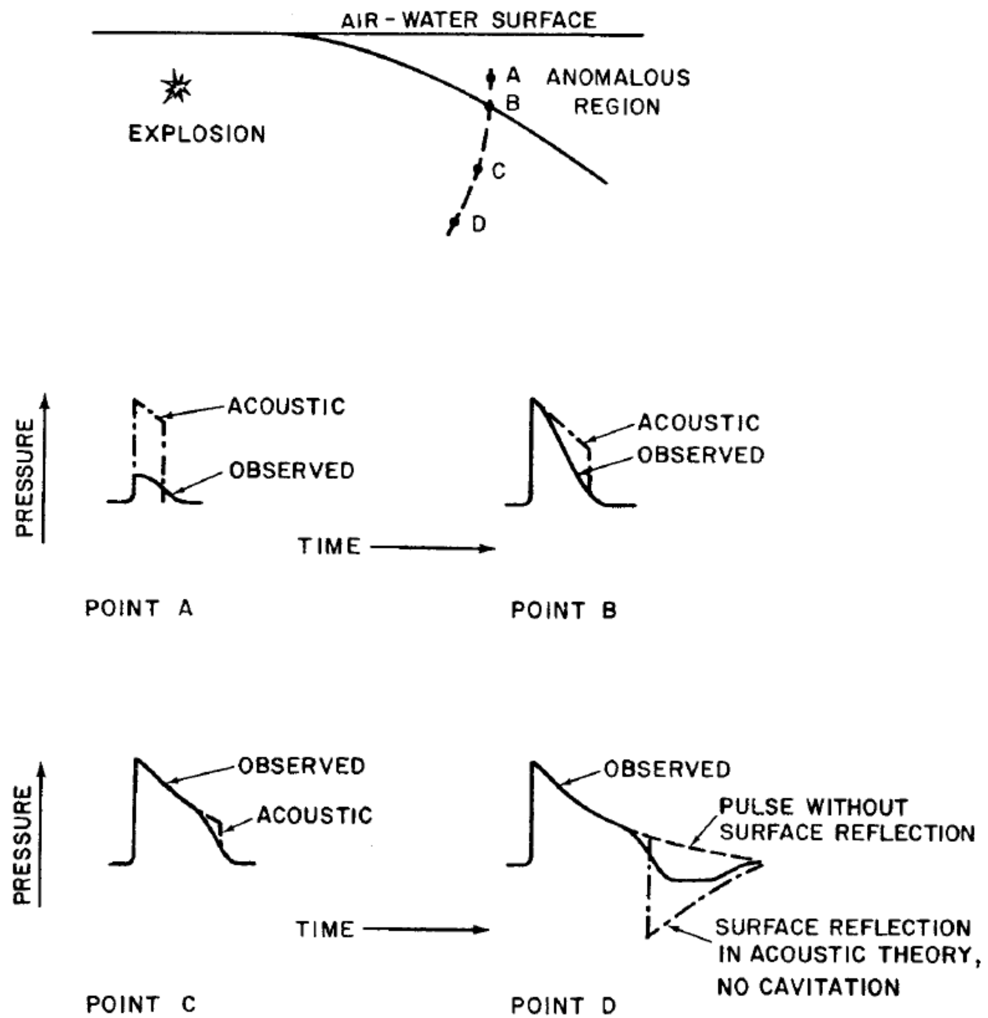

Figure 6.46. Typical pressure pulses affected by air–water surface reflection in the absence of bottom reflections.

GD

Surface Waves

- Depending on the depth of burst, resulting surface waves can be quite severe.
- For shallow bursts, there is a lone solitary initial wave with a very sharp crest that is higher in intensity than any of the following waves due to the initial fireball venting.
  - $H \sim = 150\ d_w\ W^{(.25)}/R$ where W (kt), and H, R, d_w (ft)
- For deep underwater bursts, the waves generally group together to form a wave train where the wavelength decreases as the wave train moves radially away from surface zero.
  - $H \sim = 40{,}500\ W^{(.54)}/R$ where W (kt), and H, R are (ft)

Wave Train

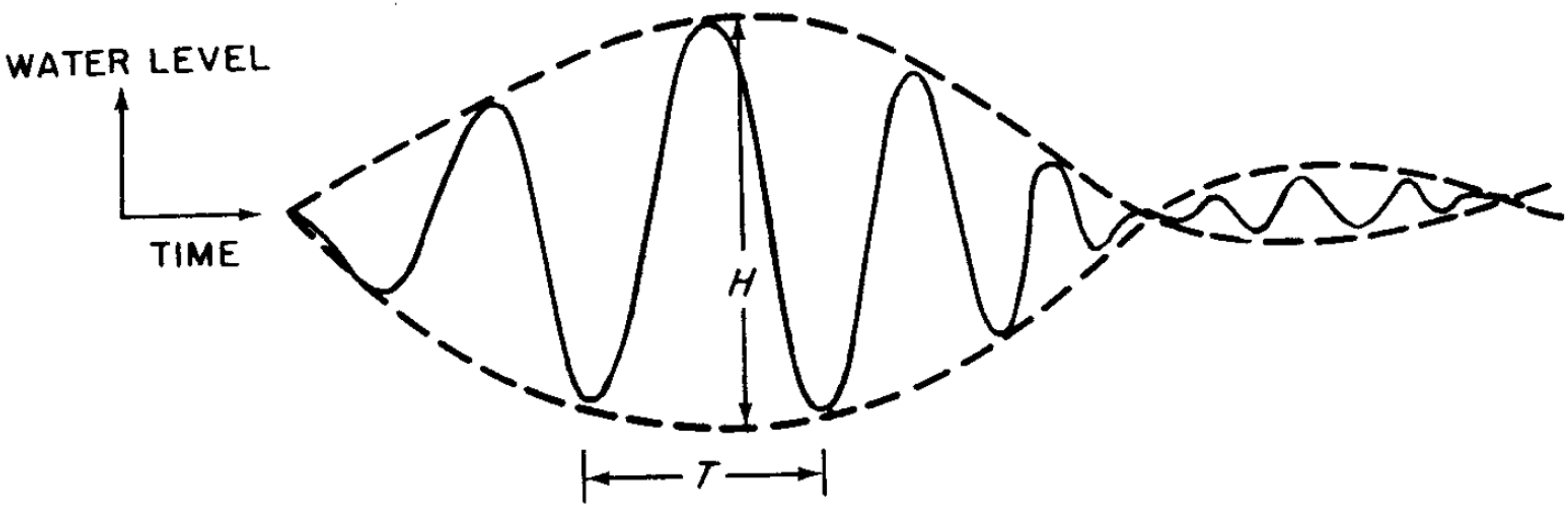

Figure 6.119 An explosion-generated wave train as observed at a given distance from surface zero.

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Deep Underwater Burst

- Gas bubble expansion/contraction → secondary shock waves
- Refraction leads to non-spherical divergence
- Explosively generated water waves
- No shear waves (p-body waves only)
- http://mit.tv/yoHmiu

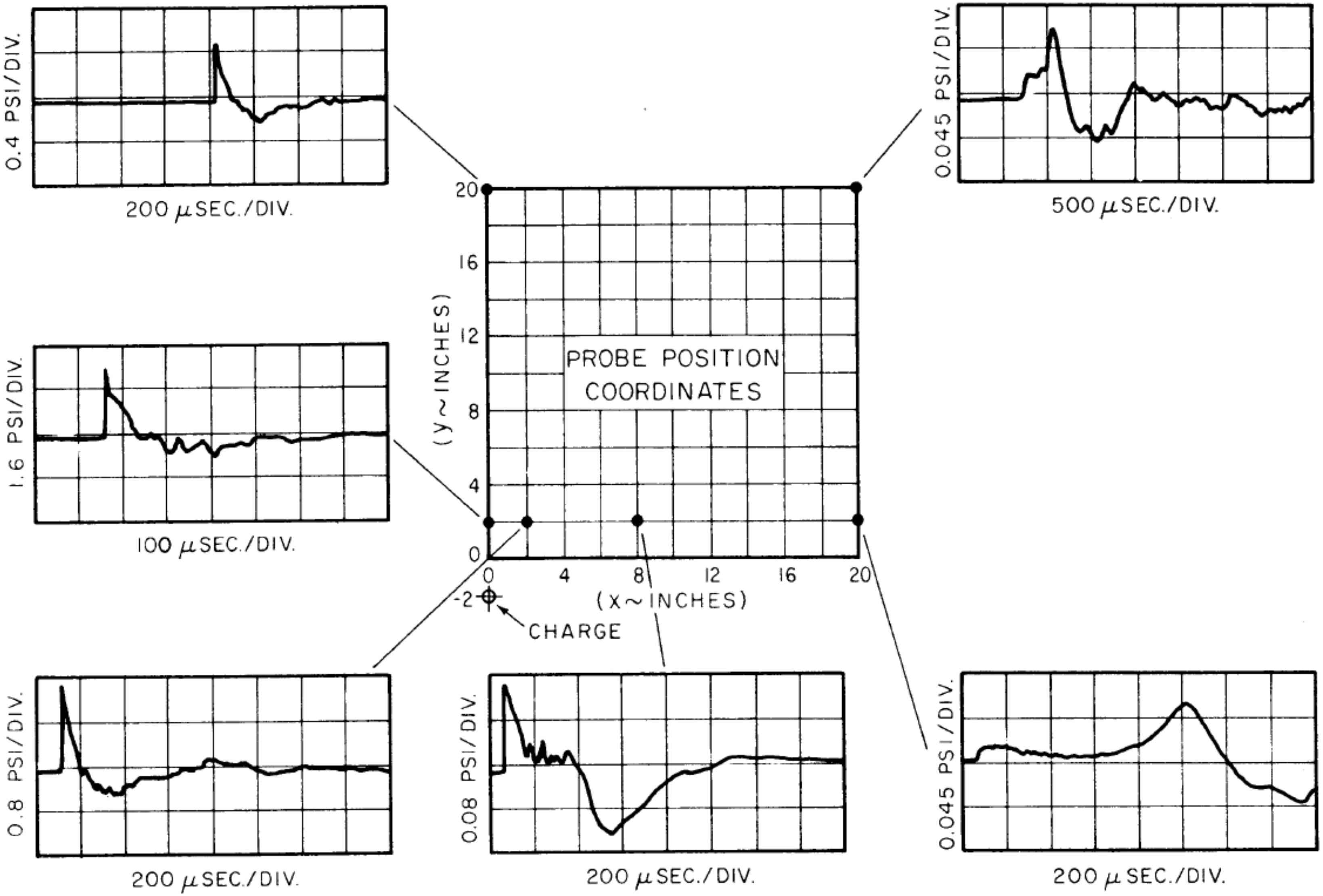

FIG.4 AIRBLAST WAVEFORMS FROM DEEP EXPLOSIONS ($\lambda_d \cong 2.3$)

Empirical Functions for Effects

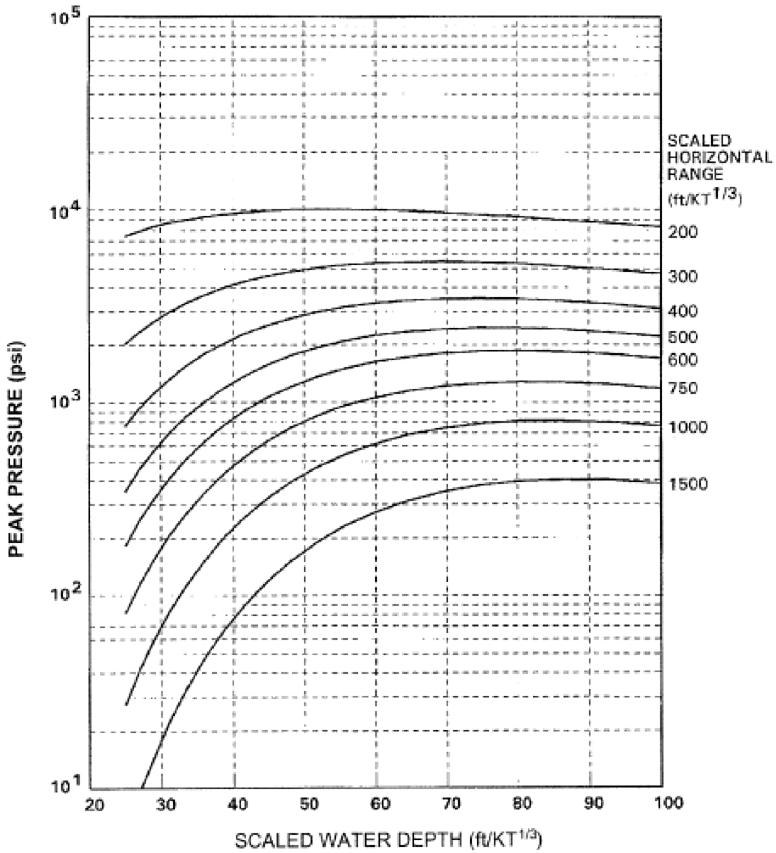

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Figure 5II-57. (U) Peak Pressure as a Function of Scaled Water Depth and Scaled Horizontal Range for an Explosion on a Mud Bottom and Targets at Middepth (Source: Niffenegger and Heathcote, 1958; EM-1 Date: May 1996)

Table 5VIII-2. (U) Largest Possible Maximum Wave Response from Upper-Critical-Depth Burst ($Z = 0.05\ W^{1/3}$) (EM-1 Date: March 1990)

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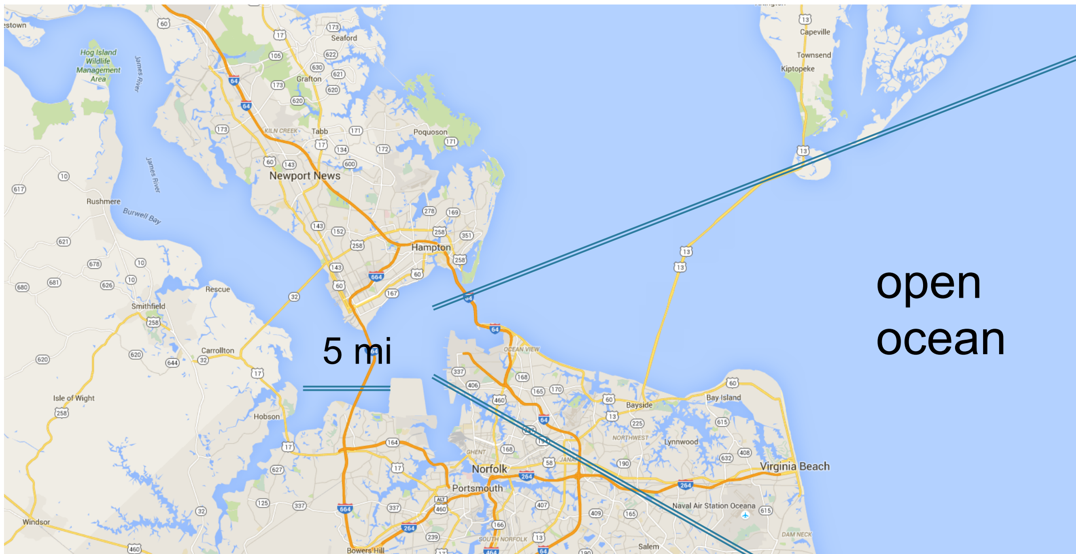
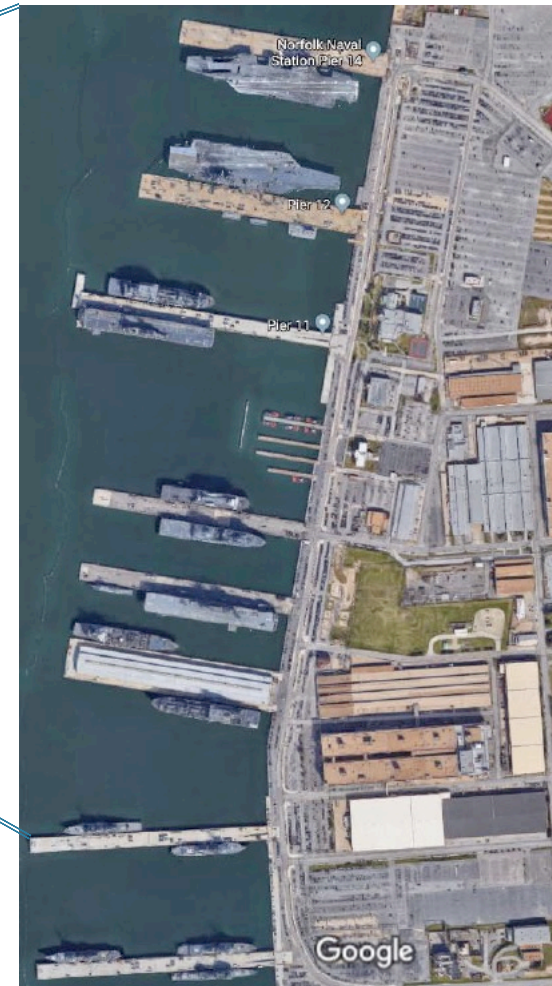
Yield, W (KT)	Depth/Yield Ratio, $D/W^{1/3}$	Water Depth, D (feet)	Wave Amplitude (feet) at Distance r (nmi)			
			r = 5	r = 10	r = 50	r = 100
1	1	126	0.57	0.32	0.08	0.05
	2	252	0.87	0.47	0.12	0.06
	5	630	1.48	0.78	0.17	0.09
	10	1,260	2.19	1.11	0.23	0.12
10	1	271	1.92	1.08	0.28	0.16
	2	543	3.01	1.64	0.40	0.22
	5	1,357	5.37	2.82	0.63	0.33
	10	2,714	8.23	4.19	0.87	0.44
100	1	585	6.45	3.63	0.95	0.54
	2	1,170	10.44	5.71	1.40	0.77
	5	2,924	19.48	10.23	2.29	1.21
	10	5,848	30.93	15.73	3.27	1.67
1,000	1	1,260	21.68	12.20	3.21	1.80
	2	2,520	36.23	19.80	4.87	2.66
	5	6,300	70.68	37.13	8.32	4.37
	10	12,599	116.26	59.14	12.31	6.26

Both from EM-1

Understanding Underwater Effects today



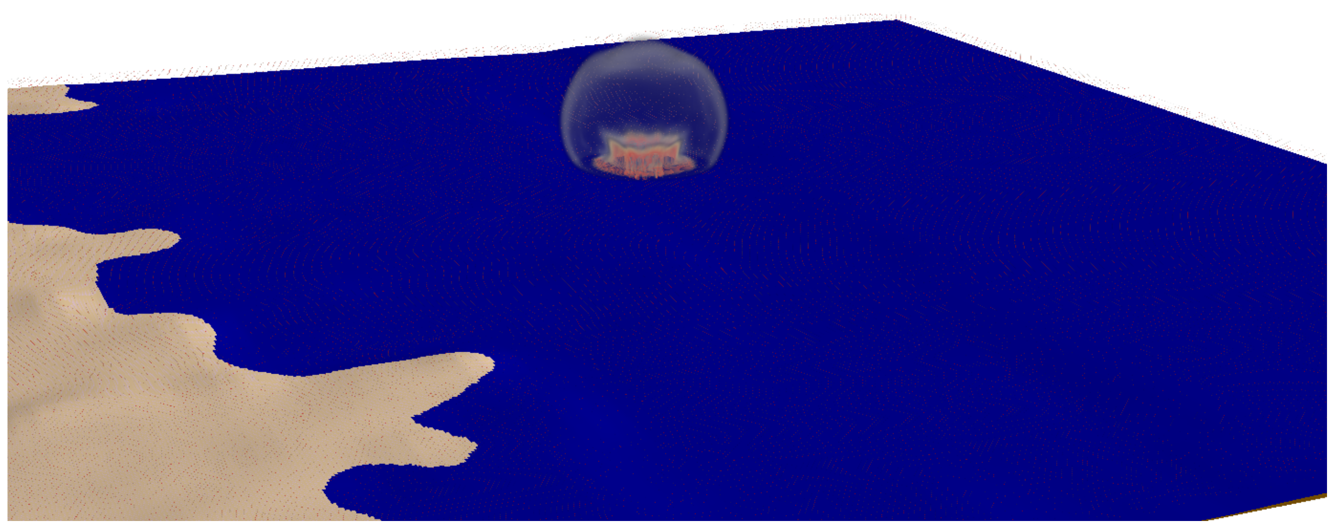


Underwater and Infrastructure
Norfolk, VA

A few Trillion $ of Navy assets in shallow (10-20 meter deep) waters near public waterway

Underwater Detonation Code Capabilities

- Modern Advanced Simulation and Computing (ASC) codes
  - xRage
  - HIGRAD
  - Other coders
- Capabilities:
  - Initialize energy (weapon)
  - Couple to water and air
  - Codes that are validated on test data
  - Produce useful data for modern analysis



Hardtack Umbrella Shot

- https://youtu.be/sGk8V8MBok4?t=20

Questions?

Videos

- Hardtack Umbrella: https://www.youtube.com/watch?v=_RvOnAMdr_s
- Wigwam: https://youtu.be/ku7R1TSBfjI

Bibliography

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- (EM-1) "Handbook of Nuclear Weapon Effects", John Northrop 1996
- (NOL) "Mechanisms in the Generation of Airblasts by Underwater Explosions", C. Malme, J. Carbonell, I. Dyer, NOLTR 66-88, 1966
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