Center for Independent Experts (CIE) Independent Peer Review Report of Underwater Calculator for Shocks, or UWCv2 (Vers 2.0)

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Executive Summary

This document constitutes a technical review of the Underwater Calculator for Shocks version 2.0 (UWCv2). The primary purpose of the UWCv2 is to provide estimates of certain metrics of underwater sound field resulting from the explosive removal of offshore structures (EROS). The metrics are used for comparison with criteria that establish Level B impacts and Level A impacts on marine mammals and sea turtles, as a result of EROS activities. The technical review was initiated by the Center for Independent Experts (CIE) on behalf of NOAA's Office of Protected Resources.

The UWCv2 is based on evaluation of a database of processed metrics consisting of (1) peak pressure, (2) pressure impulse and (3) energy flux density (EFD). This data base originates from *in-situ* measurements of the underwater sound field associated with a diverse set of EROS activities, representing different explosive charge weights, detonation depths within the sediment, slant ranges to measurement location, and offshore structures. Linear regression is used to develop predictive, empirical equations for the observed quantities (1-3).

Finally, the review relates to the four *Terms of Reference for the Peer Review* (TOR) as provided by CIE. Thus, TOR 1-4 will be identified in parenthesis whenever applicable to associate with conclusions.

Key points from our review are as follows:

- The regression analysis involves scaled range, or $R/W^{1/3}$, where R is measurement range and W is the explosive weight, as the independent variable. Additionally, the two quantities pressure impulse and EFD are each scaled, or divided by $W^{1/3}$, prior to regression analysis. This is a correct approach. (*TOR-1*)

- There is no account taken, however, in the UWCv2 for the inherent uncertainty in dependent variables (1-3). For example, there are no upper and lower 90% confidence interval bands associated with a given prediction. (*TOR-2*)

- Our review included a re-analysis of three sets of raw pressure time series originating from the *in-situ* measurements from which the database of processed metrics originates. In this analysis the same values for peak pressure listed in the database of processed metrics were recovered. However, slightly different values were found to be associated with pressure impulse and EFD, than those listed in the database.

- Sound Exposure Level (SEL) is a key metric used by NMFS for assessment of marine mammal and sea turtles. Though closely related SEL is not the same quantity as energy flux density (ESD). Although the UWCv2 properly converts ESD predicted from empirical equations into values of SEL in dB re μPa^2-sec, the casual labeling of one with the other in the panels of UWCv2 is apt to lead to a high degree of confusion.

- The UWCv2 incorporates English units into the mix, and also in the graphical displays of data plotted as function of scaled range (i.e., with *R* in ft. and *W* in lb.), which makes comparison with other studies involving MKS units difficult if not impossible. We recognize that this is neither a quantitative issue nor an issue involving model accuracy. However, the potential for confusion is high as result of this unnecessary feature.

- The quantity called "dB 1/3-Octave Band Energy Flux Density" **is** an important input variable for the UWCv2. We learn this term is supposed to represent the maximum value in a 1/3-octave spectrum of SEL, and therefore the term has the same problem with units and nomenclature as mentioned above in the context of ESD and SEL. That said, this quantity is not estimated by the UWCv2 in the same manner that pressure impulse and EFD are estimated, i.e., involving linear regression analysis of the database of processed metrics. Instead, "dB 1/3-Octave Band Energy Flux Density" **is** obtained from an empirical relation between synthetic values of SEL and equivalent synthetic values of the maximum value of 1/3-octave spectrum of SEL.

  Our review also involved a frequency analysis of the aforementioned raw pressure time series, processing the data into 1/3-octave bands to estimate this same quantity. Results from our analysis differed by 3 dB from that predicted by this empirical relation involving synthetic data. *(TOR-1)*

- It was shown that notionally when the UWCv2 is applied at large scaled ranges (> 100) the ability to predict a Level A take was diminished. Specifically, the UWCv2 could not be validated with NMFS PROP data relating to Level A takes on sea turtles, corresponding to scaled ranges > 100. (*TOR-1, and TOR-3*)

- The above taken together constitutes a noteworthy degree of shortcoming insofar as satisfying EPA Council for Regulatory Monitoring (CREM) guidelines for model development (*relates to TOR-4*)

I. Introduction and Background

The Underwater Calculator for Shocks, or UWCv2 (Vers 2.0) [1] is an excel-based calculator for computing three acoustic metrics descriptive of the underwater sound field resulting from the explosive removal of offshore structures (EROS). The acoustics metrics are: (1) peak acoustic pressure, (2) pressure impulse, and (3) energy flux density or EFD.

This report constitutes my formal review of UWCv2, as requested by the Center for Independent Experts (CIE). The report is organized as follows: Sec. II cover our review and associated analysis including a detailed analysis of some examples of the original pressure time series; Sec. III provides a summary of findings; Sec. IV provides a brief description of my role as a reviewer, with references given in Sec. V. Finally, the review relates to the four *Terms of Reference for the Peer Review* (TOR) as provided by CIE. Thus, TOR 1-4 will be identified in parenthesis whenever applicable to associate with conclusions.

The primary use of UWCv2 is to provide realistic predictions of acoustic metrics (1-3) for comparison with criteria that establish Level B impacts, such as temporary hearing threshold shift (TTS), and Level A impacts, such permanent hearing threshold shift (PTS), injury, or mortality, on marine mammals and sea turtles as a result of EROS activities. These criteria are set by the National Marine Fisheries Service, and Level B and Level A impacts are collectively called *take*, with predictions made by the UWCv2 used to establish safety zones to reduce or avoid take.

The most common offshore structures destined for removal in EROS activities in the Gulf of Mexico Region are conventionally piled platforms. For example, as described by Barkaszi, Frankel, Martin, and Poe in Ref. [2]:

> "….these structures are secured to the seafloor by steel piles called piles (or pilings) ... Piles have varying diameters and wall thickness and their number can vary from three to eight or more, depending the platform's configuration and location…"

Additionally the EROS process is described in terms of the following, [2]:

> "Decommissioning of an offshore platform generally entails plugging all wells supported by the platform, severing the well casing 15 feet below the mudline (BML)…"

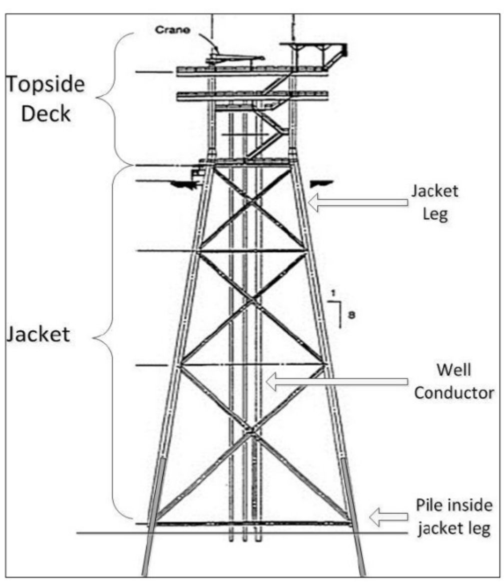

Fig. 1 Typical platform found in the Gulf of Mexico Outer Continental Shelf Region. Figure reproduced from: Barkaski,M.J., A. Frankel, J.S. Martin, and W. Poe, "Pressure Wave and Acoustic Properties Generated by the Explosive Removal of Offshore Structures in the Gulf of Mexico". OCS Study, BOEM 2016-019

The severing of well casings, piles and other structures is achieved by placement of explosive severance charges at various BML depths. A generic platform showing well casing pile structure is illustrated in Fig. 1.

With the above in mind, the EROS scenarios that are addressed in UWCv2 are: main pile, well conductors, open caisson, and skirt piles. In addition there is an "open water" scenario where both explosive charge and acoustic receiving locations are considered to be in the water column. With exception of the latter, each of these EROS scenarios, as can be imagined, involves a very complex acoustic environment that depends on, in addition to the complexity of the structure to be decommissioned, explosive charge weight, charge BML depth, slant range to a receiver in the water column, and sediment properties.

Predicting high-pressure acoustic fields from explosive sources under such conditions necessarily involves the analysis of field measurements from which empirical relations can be derived and used for predictions. The UWCv2 is based in large part on analysis of the data in the Technical Assessment and Research (TAR) project entitled: "Effect of Depth Below Mudline of Charge Placement During Explosive Removal of Offshore Structures (EROS)", TAR Project 570 [3], henceforth referred to in this report as TAR570.

Units and dimensions are both subtle and important in the context of the UWCv2. The unit of acoustic pressure used in the UWCv2 is psi, with a metric equivalent being kPa (0.145 psi = 1 kPa). The unit of pressure impulse, being a time-integrated measure of pressure, is thus psi-sec, or kPa-sec. The unit of energy flux density (EFD) being a time-integrated measure of squared pressure divided by $\rho\, c$, the acoustic impedance of water where ρ is water density and c is water sound speed, is expressed in the UWCv2 in both in English units, as psi-in, and metric units as kPa-m. (The particular issue of how values of EFD in units of psi-in, or kPa-m, are translated to sound exposure level, or SEL in dB re 1 μPa^2 - sec, is discussed further below).

II. Review and Analysis of UWCv2

a. Scaled Range

As result of experimental measurements emerging from World War II, a semi-empirical equation for predicting the peak underwater sound pressure from underwater explosions was developed as function of range from the source R divided by charge weight W to the one-third power, $R/W^{1/3}$, referred to as scaled range. Scaled range relations are based on the principle of similarity [4], and although not a physical theory *per se*, have been shown to be highly accurate in predicting acoustic properties of underwater explosive sources, particularly peak pressure [5].

The peak pressure from an explosive source in open water, i.e., neither the explosive charge nor acoustic receiver are within the sediment or BML, is as follows:

$$P_{peak} = 52.4\ 10^6 \left(\frac{R}{W^{\frac{1}{3}}}\right)^{-1.13} \tag{1}$$

Where P_{peak} is peak (absolute value) acoustic pressure in Pa, R is range in m, and W is charge weight in kg TNT. Eq. (1) is essentially that used in the UWCv2 to predict the open water scenario, upon accounting for difference in units employed.

The pressure magnitudes for which we can expect scaled range relations such as Eq. (1) to apply are illustrated in Fig. 2 from ref. [5]. This range clearly encompasses the range of peak pressures expected in any EROS activity. For example, the maximum pressure listed in TAR570 (Table D-4) is 250 dB re 1 μPa.

At this point it is important note that W is TNT-equivalent weight, which equals the mass of the particular explosive compound times the TNT-equivalent coefficient, which permits comparison of the effectiveness of various explosive compounds. For example, the TNT-equivalent coefficient for C-4 explosive equals 1.34, Composition B equals 1.35, HMX equals 1.5, and for TNT the coefficient is identically 1. All explosives used for BML tests in TAR570 were Composition B; however, it is not clear how UWCv2 can handle different TNT-equivalent coefficients.

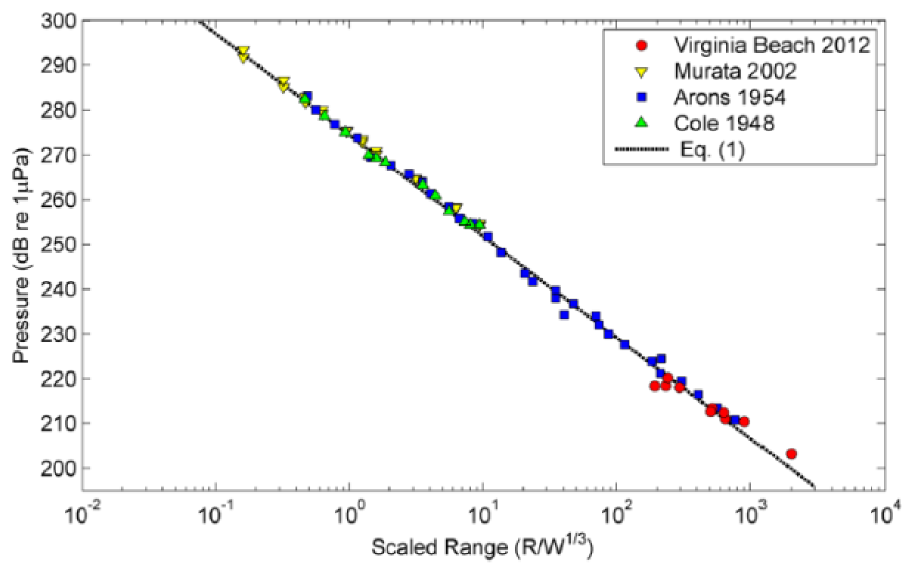

Fig. 2 Measurements of peak pressure plotted against levels predicted by scaled range and Eq. (1). See Ref. [6] for further explanation on origins of data shown here.

b. Concerning the empirical fits of peak pressure, impulse and energy flux density (EFD) using data from TAR570 to generate the predictive models in UWCv2

As noted previously construction of UWCv2 is based in large part on processed *in-situ* measurement data tabulated in Appendix D TAR570 [3]. By processed data we mean values of metrics corresponding to peak pressure, impulse and EFD.

These measurements cover various classes of piles, well conductors and open caissons, including different BML values ranging from 15-30 ft. Additional EROS scenarios are derived from another report by Conner [6], for example, covering well conductors and skirt piles. Our evaluation however will focus on the TAR570 data since it constitutes the majority of the measurements going into the empirical curve fitting for UWCv2.

From the above discussion, scaled range, or $R/W^{1/3}$, is the key independent variable, with which to compare metrics against. For example, the data base of peak pressure values from TAR570 were subject to linear regression in log-log space to obtain estimates of coefficients K and a such as in the following equation analogous to Eq. (1).

$$P_{peak} = K \left(\frac{R}{W^{\frac{1}{3}}}\right)^{-a} \tag{2}$$

Given the additional dampening effects of the structures, combined the sediment attenuation which increases with increasing BML detonation, we anticipate that the magnitude of coefficient a determined for any EROS scenario will be greater than that for the open water scenario (a = 1.13), which is in fact the case in UWCv2.

To derive similar empirical data fits for the impulse and EFD databases, these values are first scaled, or divided, by $W^{1/3}$, as originally suggested Slifko [7] as well as others.

Given that it is the database of *processed metrics* from TAR570 that was studied for the purposes of building UWCv2, and not the original pressure data, it is worthwhile examining the latter to assess how these metrics were generated. For peak pressure there is no issue as this value is relatively straightforward to extract from the original data, but for pressure impulse, and EFD, both of which depend on a time integration over integration time T, there can be multiple definitions for T.

For example, the report by Barkaski *et al*. [2] is explicit as to how they compute pressure impulse and EFD. First, a time constant θ is estimated from the data by finding the time needed for the peak pressure to decay to Pm/e, where e = 2.718, or one e-folding scale (Fig. 3). The integration time [8] is then taken as $T = 5\ \theta$.

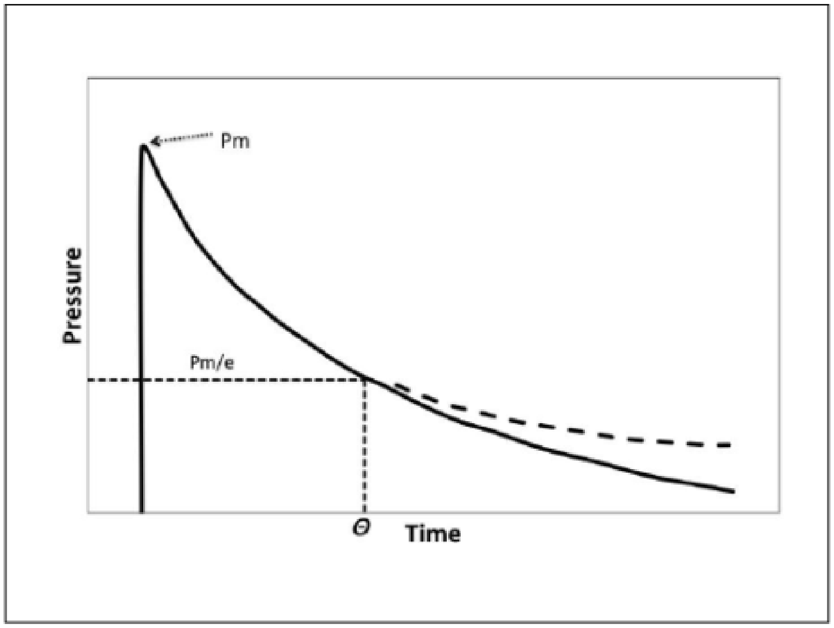

Fig. 3 Illustrating the determination of the e-folding time scale, q. Figure from Ref. [2].

Upon obtaining a reasonable estimate of *T*, the pressure data, $P(t)$, can be integrated over this interval to obtain an estimate of pressure impulse, *I*, via

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

which is expressed in , for example, in units of kPa-sec. Similarly, the energy flux density is computed via

$$\mathrm{EFD} = 1/\rho c \int_0^T P^2(t)dt \tag{4}$$

which is expressed in , for example, in units of kPa-m. This approach is reasonably robust, however there can be instances, as discussed in [2], where multiple peaks in the pressure data make it difficult to estimate the original e-folding scale, θ.

The above algorithms, however, are *not* used to derive the processed metrics from TAR570 (according to email correspondence with Peter Dzwilewski, July 2016). Instead, $P(t)$ and its squared counterpart are integrated over the entire time series with increasing end time, τ . The maximum value of the corresponding cumulative integral is taken as the final estimate of pressure impulse *I.* For EFD, however, the maximum value is simply the end point of the integration since the square of $P(t)$ is being integrated. Therefore, we assume that the algorithms for computing *I* and EFD from the TAR570 data are as follows:

$$I = \max\left[\int_0^\tau P(t)dt\right] \tag{5}$$

and

$$\text{EFD} = 1/\rho c \int_0^{\tau\_max} P^2(t)dt \qquad (6)$$

where τ_max in Eq.(6) is taken to represent the entire duration of the time series.

Next three examples of original pressure time series data subject to analysis in TAR570, and from which processed metrics were subsequently used to build the UWCv2, are re-examined in the context of Eqs. (3-6). Processed metrics from these data are listed in TAR570 Appendix D, Table D-4, and the time series data were uploaded by Peter Dzwilewski to a Dropbox site arranged by this reviewer.

The first set (Fig. 4) are measurements of an 80 lb charge detonated at 15 ft BML, made at a slant range 56.5 ft. Peak pressure for the time series is 282 psi, with location of peak in the time series identified by the asterisk; this peak value is the same as that given in Table D-4. The pressure time series displays a clear exponential-like decay over the first 10 ms, followed by a negative phase associated with the bubble pulse (e.g, see Fig. 1 in ref. [4]).

The top set of listed values in the figure are pressure impulse and EFD as given in Table D-4. The center set of values are corresponding estimates of impulse and EFD computed using Eq. (3) and Eq. (4), respectively. The lower set of values are corresponding estimates of impulse and EFD computed using Eq. (5) and Eq. (6), respectively. This is the approach presumably used to compute pressure impulse and EFD from the raw data associated with the TAR570 report. The lower set of values are close to, but do not recover exactly the corresponding values in Table D-4 values for pressure impulse and EFD. The reason for this is unknown; it is possible that there are additional nuances in the estimation procedure applied by the authors of TAR570 that are not fully conveyed in Eqs. (5) and (6).

The second set (Fig. 5) are measurements of an 80 lb charge detonated at 15 ft BML, made at a slant range 125.3 ft. Peak pressure for the time series is 94 psi, which is also consistent with that given in Table D-4. However, we are again not able to recover exactly the listed values for pressure impulse and EFD using Eqs. (5) and (6). That said, all estimates, the Table D-4 and those re-estimated here are within the same magnitude, and our estimate of EFD would translate to a difference in sound exposure level (SEL) in dB re 1 μPa^2-sec from that listed in Table D-4, of less than 2 dB.

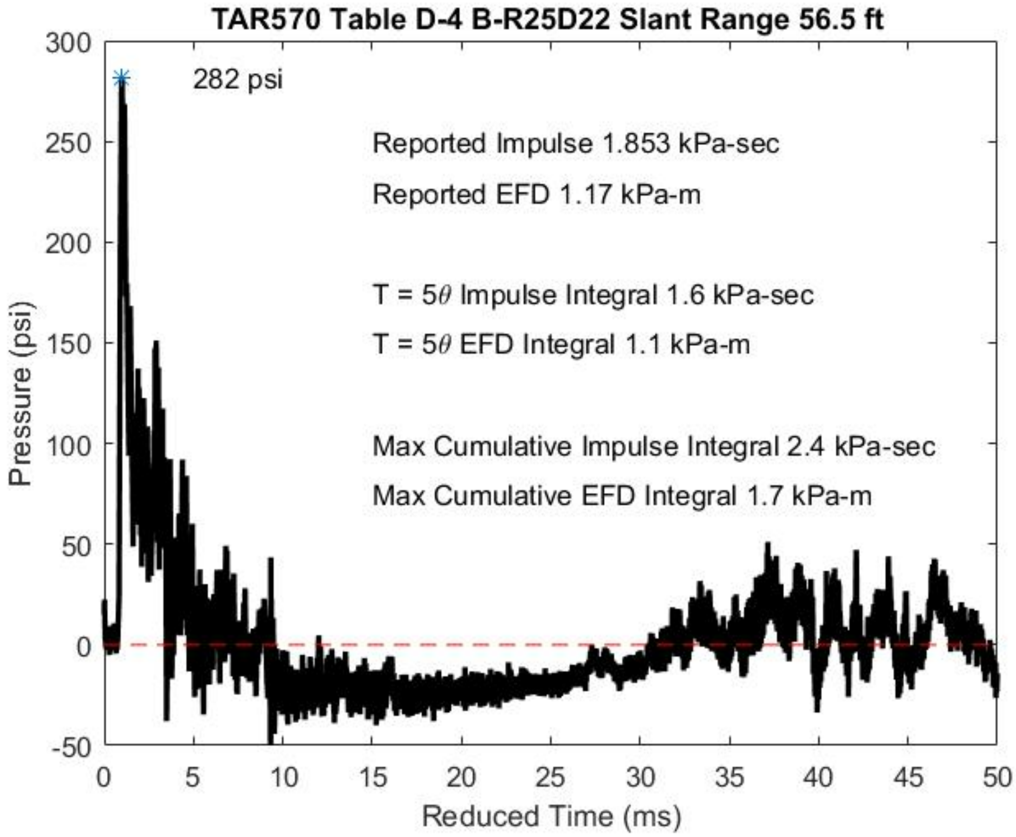

Fig. 4 Original pressure time series data used in TAR570 [3], corresponding to 80 lbs charge detonate15 ft BML and measured at a slant range of 56.5 ft. Reported impulse and EFD values from Table D-4 [top set] are listed along with corresponding estimates based integration to 5 times the e-folding scale or 5 θ, using Eqs. (3) and (4) [middle set], and based on the maximum value of the cumulative integral using Eqs. (5) and (6) [bottom set]. Exponential decay behavior is seen between about 0 and 10 ms, after which a negative phase exists between about 10 and 30 ms.

Finally, the third set (Fig. 6) are measurements of an 80 lb charge detonated at 15 ft BML, made at a slant range 84.5 ft. Peak pressure for the time series is 204 psi, also consistent with that given in Table D-4. With this example, it is not possible to identify an e-folding scale in a simple manner because the time series is considerably more complex, displaying multiple peaks as shown in an expanded scale (Fig. 7). However the maximum cumulative integral algorithm in Eqs. (5) and (6) still can recover estimates, which again does not re-produce values given in Table D-4 but are reasonably close.

A key point emerging from this analysis is that estimates of pressure impulse and *EFD* extracted from the *in-situ* measurements described in TAR570 are likely to be encumbered with higher variance (more so with pressure impulse.) This fact is acknowledged somewhat on page 8 of the UWCv2 report [1]. The algorithm, Eqs. (5-6), assumed to have been used to compute these metrics seems reasonable enough, given the complexity of the time series involved. That we cannot recover precisely the same values for pressure impulse and EFD as shown in Table D-4 using this algorithm does not imply we are advocating a complete re-analysis of the raw data. Instead, the take home point from Figs 4-6 is the reality of higher uncertainty in these processed metrics. We note here that there has been no attempt to describe this uncertainty in UWCv2.

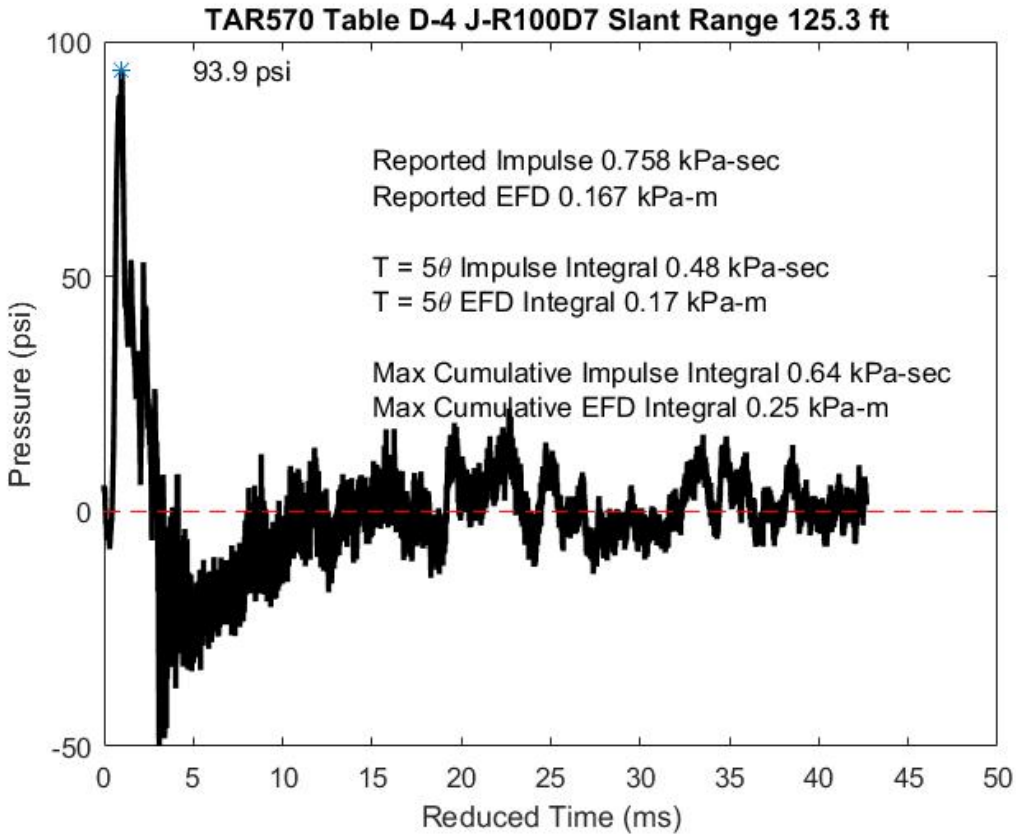

Fig. 5 Original pressure time series data used in TAR570 [3], corresponding to 80 lbs charge detonate15 ft BML and measured at a slant range of 125 ft. Reported impulse and EFD values from Table D-4 [top set] are listed along with corresponding estimates based integration to 5 times the e-folding scale or 5 θ, using Eqs. (3) and (4) [middle set], and based on the maximum value of the cumulative integral using Eqs. (5) and (6) [bottom set]. Exponential decay behavior is seen between about 0 and 2 ms, after which a negative phase exists between about 2 and 10 ms.

For example, the processed metrics (peak pressure, pressure impulse and EFD) associated with the three pressure data sets re-analyzed here are shown (Fig. 8) in relation to other values from the TAR570 database. From the greater spread in the dependent variable we anticipate that inferences relating to linear regression analysis, i.e., UWCv2 predictions, are likely to be less accurate for pressure impulse and EFD than for peak pressure. It is relatively straightforward to deal with this spread in regression by, for example, computing confidence bands [9] to quantify the uncertainty in prediction.

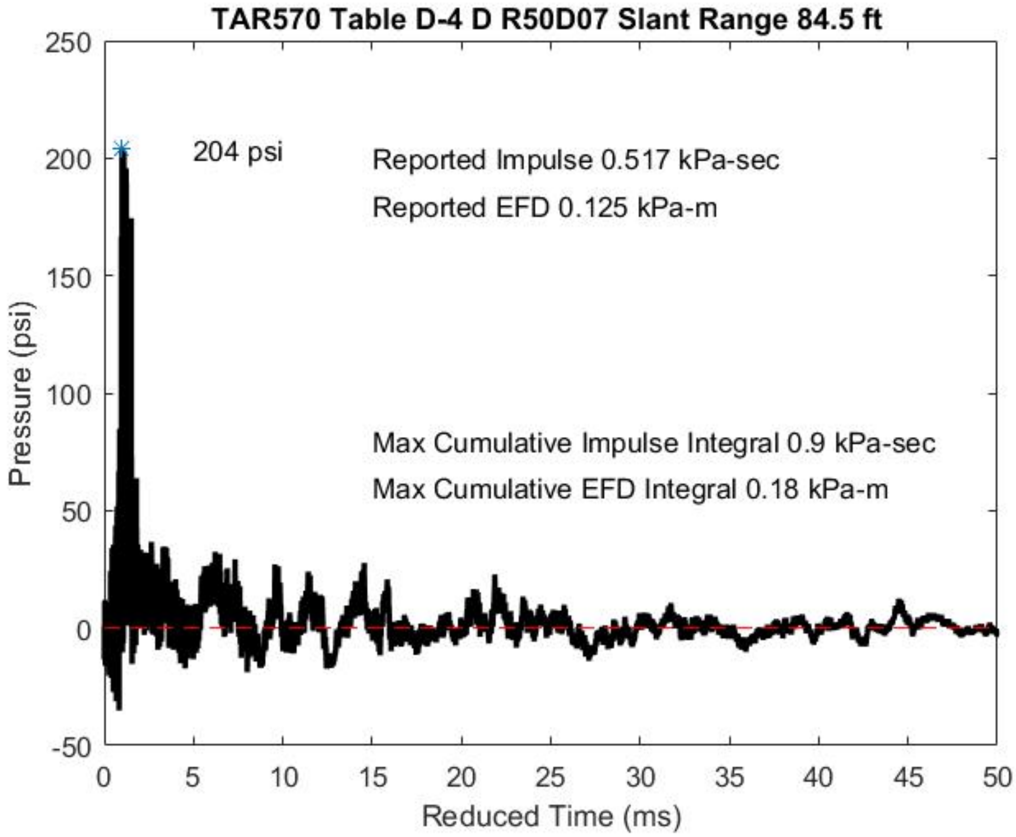

Fig. 6 Original pressure time series data used in TAR570 [3], corresponding to 80 lbs charge detonate15 ft BML and measured at a slant range of 84.5 ft. Reported impulse and EFD values from Table D-4 [top set] are listed along with corresponding estimates based on the maximum value of the cumulative integral using Eqs. (5) and (6) [bottom set]. A typical e-folding scale cannot be identified with this data.

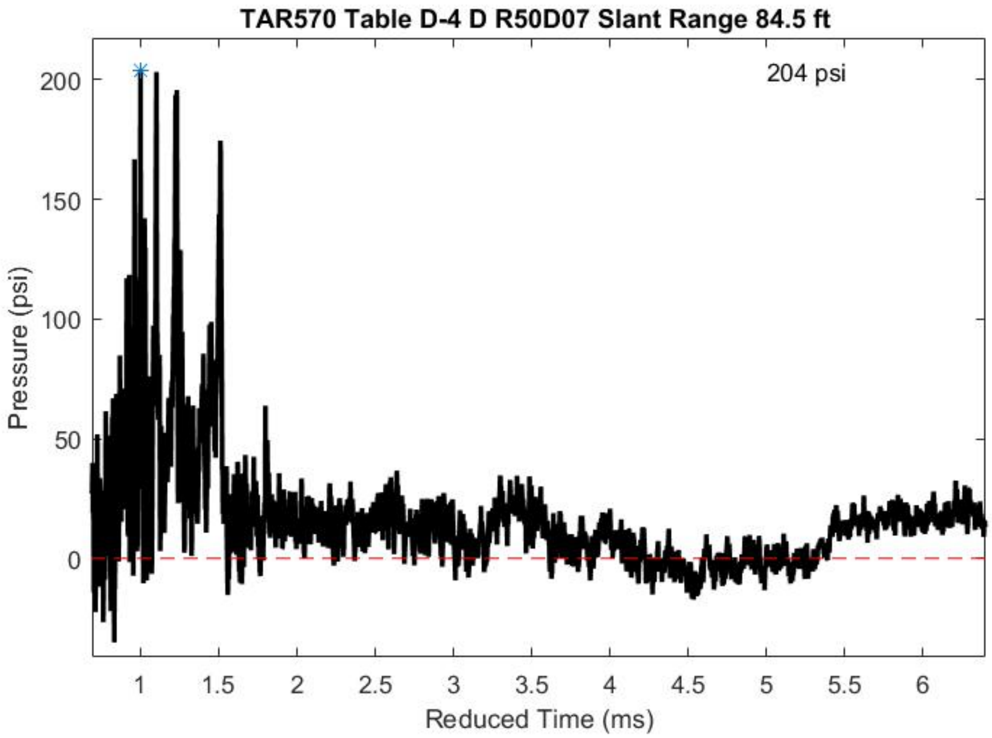

Fig. 7 Expanded time scale for the data in Fig. 6, showing an example of multiple peaks that make it difficult to identify an e-folding scale.

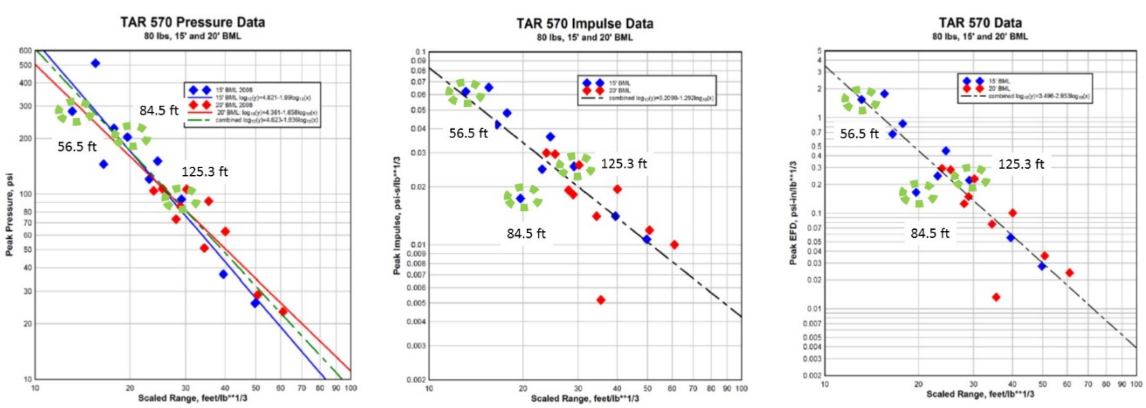

Fig. 8 Original Fig. 3 (left), Fig. 5 (center) and Fig. 6 (right) from UWC Vers. 2.0 report [1] annotated here to show the three peak pressure, pressure impulse and EFD data points (green circles) that correspond to data listed in Table D-4 of the TAR 570 Report, with analysis of the corresponding raw pressure time series presented here.

c. Concerning the value called “dB 1/3-Octave Band Energy Flux Density”

The UWCv2 refers to values of “dB 1/3-Octave Band Energy Flux Density”, for example, as identified by the 182 dB value in the yellow highlighted region of Figs. 22 and 23 in the UWCv2 report [1], which is a user-defined input. Admittedly, the UWCv2 report is unclear as to what this quantity means. However the report by Dzwilewski and Fenton [10], which is referenced in UWCv2, clarifies the definition, and " dB 1/3-Octave Band Energy Flux Density" corresponds to the *maximum* 1/3-octave band energy flux density. As it applies to the UWCv2, the value "dB 1/3-Octave Band Energy Flux Density" pertains to Level B (TTS) impacts, and the companion value of sound exposure level or SEL (the relation between these values is explained below) pertains to Level A (injury) impacts.

At this stage we first return to the original remark made in the background section on how values of energy flux density (EFD) in units of psi-in, or kPa-m, are translated to sound exposure level, or SEL in dB re 1 μPa^2-sec. The quantities EFD and SEL are closely related but not the same. As reminder, SEL stands for "Sound Exposure Level" and it is a metric that NMFS and the other services considers important for evaluating impacts. For example, the criterion for Level A injury to marine mammals is 205 dB re 1 μPa^2-sec. Computation of SEL involves integration of the square of pressure over the duration of the pulse, and therefore the computation could involve an algorithm like Eq. (6) used for EFD, but with $P(t)$ expressed in μPa, and there must be no division by acoustic impedance of water, or $\rho\, c$. Upon completing the integral $10\log_{10}$ of the result is taken to express the value in decibels.

Thus, there is high risk for confusion by an uninformed user when the UWCv2 displays "Energy Flux Density", as in the lower left corner of Fig. 22 from [1], together with an engineering unit value of EFD, such as 7.91E-02 kPa-m, along with English units psi-in, and then also displays SEL expressed in dB (200.8). Getting from kPa-m to 200.8 dB re 1 μPa^2-sec requires a simple, but multi-step, conversion: undo the $\rho\, c$ division, convert from kPa to μPa, and then convert to decibels. The UWCv2 of course gets this conversion right, but what is purpose of mixing these quantities?

Returning to the quantity "dB 1/3-Octave Band Energy Flux Density", we now understand this is supposed to represent the maximum value in a 1/3-octave band spectrum of SEL for a particular EROS scenario. Additionally, since only the *processed metrics* from TAR570 were examined and not the time series data itself, the required spectral analysis to determine the maximum 1/3-octave band SEL was not done. Instead, an empirical relation [10] is used which relates the total SEL to the SEL corresponding to the maximum 1/3-octave band which is

$$\text{Maximum Band SEL} = \text{Total SEL} * .8345 + 21.419 \text{ dB} \qquad (7)$$

For example, take the192.4 dB total SEL as shown in the *Back Calculation* window of Fig. 22 in [1]; this value yields a maximum band SEL of 182 dB according to Eq. (7) which is labeled "dB 1/3-Octave Band Energy Flux Density" in Fig. 22.

Apart from the fact that this approach does not tell us *which 1/3-octave frequency band* is maximum, there may be additional uncertainties associated with using the formula expressed by Eq. (7).

This is demonstrated by our computing the 1/3-octave band spectrum for the time series data shown in Figs. 4 and 5, with results shown in Fig. 9. For the BR25D22 data (Fig. 9, left side), the maximum of the 1/3-octave spectrum occurs at the band centered at 31.5 Hz and equals 203 dB or 10 dB less than total SEL. For the JR100D7 data (Fig. 9, right side), the maximum of the 1/3-octave band spectrum occurs at the band centered at 100 Hz and equals 195 dB or about 9 dB less than total SEL. Predictions using Eq. (7) would have these maximum band levels be 199 dB and 192 dB, respectively. This difference is not that far off (about 3 dB in each case) but if the difference between UWCv2 estimates and those such as shown in Fig 9 are *systematic*, then such differences can have a real influence on the ranges associated zones of influence which can differ by a factor of 2.

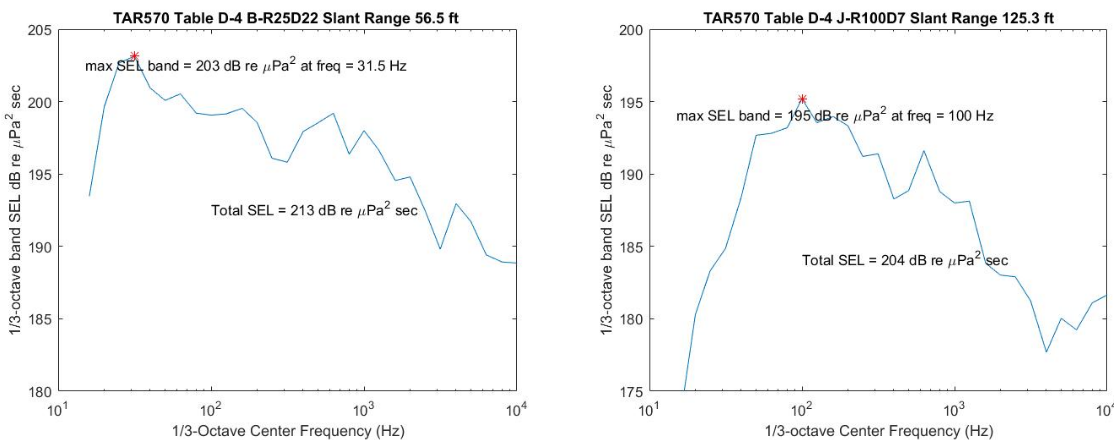

Fig. 9 The sound exposure level partitioned into 1/3-octave bands computed from the pressure time series data from TAR570, corresponding to 80 lbs charge detonate15 ft BML and measured at a slant range of 56.5 ft (left plot) and slant range 125.3 ft (right plot). The maximum 1/3-octave band sound exposure level (SEL) is identified for each case by the red asterisk.

According to discussion in Ref. [10], the empirical relation in Eq. (7) was generated using synthetic data derived from navy's REFMS sound propagation model for explosive sources. The REFMS model was developed to study sound propagation from underwater explosive sources for naval applications. To this reviewer's knowledge, REFMS has never been validated in the context of the complex sound propagation conditions associated with EROS activities and explosive detonations at various BML depths. Therefore, although there is no debate about the clear linear relationship between the synthetic (REFMS) total SEL and synthetic maximum 1/3-octave band SEL as shown in Fig. 13 of Ref. [10], it is not clear how the relationship in Eq. (7) applies to the immediate problem involving EROS activities.

To see the importance of Eq. (7) in the UWCv2 we run the first panel entitled: **Press-Imp-EFD Calculator** that computes: (1) peak pressure, (2) pressure impulse and (3) EFD as a function of slant range and explosive weight for one of 7 EROS user-selected scenarios. Figure 10 is a screen shot of this panel based on inputs of slant range = 400 ft, and explosive weight = 50 lb, for Well Conductor EROS scenario. The three key predictions are shown in the lower left of the panel along with conversion of EFD to SEL equal to 177.2 dB (re 1 μPa^2-sec)—although these correct SEL units are not shown.

Next, we experiment with the back calculation (right side of panel) where the input is "dB 1/3-Octave Band Energy Flux Density" as we now understand it from the above discussion. We can vary with this input to find a value that maps back to the same total SEL of 177.2 and this value is 169.2 dB, a value found via the inverse application of Eq. (7). Back calculation also recovers the approximate original slant range of 400 ft.

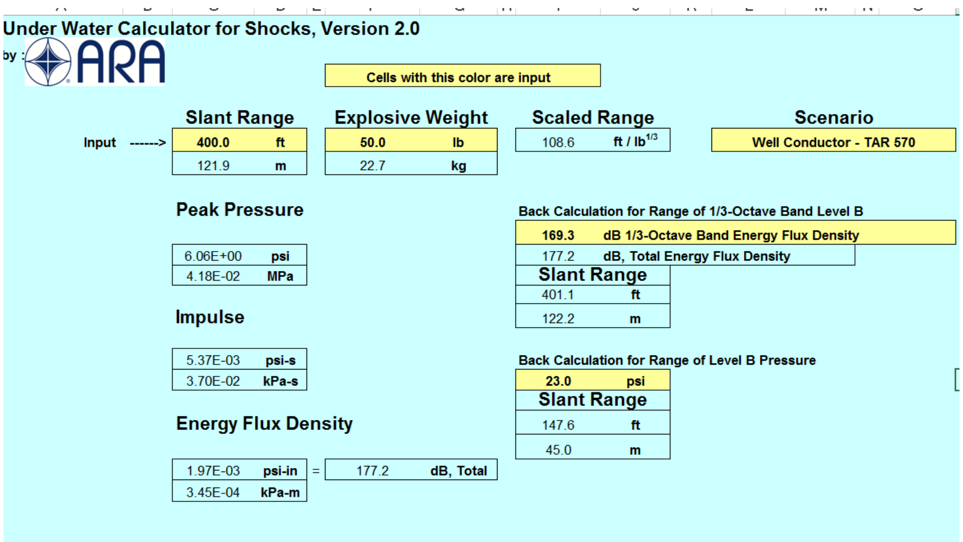

Fig. 10 The Press-Imp-EFD Calculator panel of the UWCv2 showing results of inputs as discussed in text.

d. Concerning NMFS PROP data

The spreadsheet from the PROP data (excel spread sheet received from CIE, "PROP takes 2010-2015") is reproduced below (Fig. 11) with three news columns (G, H, I) added as result of our analysis. From the descriptions in the spreadsheet, it is assumed that these data all represent Level A takes. Thus, UWCv2 is run to assess whether or not a Level A would have occurred based on the listed charge weight (W) and listed range to the animal converted to feet (R). Since there are no EROS scenarios specified we test all scenarios, with result YES = Level A predicted, NO = Level A not predicted, listed in column G. If a Level A take is predicted, then the basis for it (either psi, SEL or both) is listed in column I. (I confess to being not 100% certain of the Level A criteria for sea turtles, as I understand these are also undergoing changes. Hence this should be viewed only as a *notional* analysis of the UWCv2 with respect to the PROP data.)

Column H is the scaled range to the animal for each assumed Level A take incident. It is noteworthy that predictions on acoustic exposure associated with higher scaled range values (> 100, yellow highlight) are less accurate with respect to take prediction than those with lower scaled range.

We note that when UWCv2 is operated in the *Open Water* scenario, which is a more conservative prediction scenario, the model does predict Level A take for NMFS report numbers 2012-125, and 2011-118 on the basis of peak pressure (again assuming I have the correct interpretation of the current NMFS criteria).

Date	NMFS Report #	Weight of Charge (	BML depth ft	Water depth ft	distance to turtle		SCALED RANGE	Level A basis
8/8/2010	2010-78	180/80	18/25	77	10 yards (DEAD)	YES	5	psi, SEL
8/20/2010	2010-86	200/80	16	241	50 yards (DEAD)	YES	26	psi
8/15/2011	2011-118	60	15	52	506 yards (STUNNED - not recovered)	NO	388	
8/27/2011	2011-133	80/160	20/30	136	266-300 yards (STUNNED - not recovered)	NO	157	
3/29/2012	2012-06	160	20	98	66 yards (STUNNED - not recovered)	YES	36	psi
10/23/2012	2012-125	80	20/30	165	465 yards (STUNNED - not recovered)	NO	324	
7/18/2013	2013-39	80	15/25/35	18	10 yards - (DEAD)	YES	7	psi, SEL
3/3/2015	2015-01	200	16	130	25 yards - (cracked carapace/bleeding -	YES	13	psi, SEL
11/11/2015	2015-41	80	20/35	130	648 yds - stunned - not recovered)	NO	451	

Fig. 11 Screen shot of NMFS spreadsheet PROP takes 2010-2015, with columns G-H-I added by the review and discussed in text. Yellow highlight applied to cases with large scaled range.

III. Summary of Findings including Editorial Remarks on Units

In this section we summarize findings of our review of UWCv2 including additional comments on the units and notation.

The UWCv2 is based on evaluation of a database of processed metrics consisting of (1) peak pressure, (2) pressure impulse and (3) energy flux density (EFD) originating from TAR570 report [3]. Linear regression is used to develop predictive, empirical equations for these quantities. A set of 7 equations are derived for each quantity to accommodate multiple EROS scenarios such as main pile demolition, well conductor demolition, etc. (The 7th set applies to open water conditions; additionally data from the report by Conner [6] is utilized for some EROS scenarios.)

In the following, a series of numbered summary observations are given in bold font, followed by additional comments given in regular font. Many of these observations already relate to the Terms of Reference (TOR) for this review but in slightly different language or context. As noted above, TOR 1-4 will be identified in parenthesis whenever applicable to associate with conclusions, and observations numbered 9 and 10 refer to specific language in the TOR.

1. **All linear regressions involve scaled range, or $R/W^{1/3}$, where R is range and W is the explosive weight, as the independent variable. Furthermore, the dependent variables of pressure impulse and EFD are scaled by $W^{1/3}$, which is an operation that helps to collapse the data prior to regression analysis.** We concur with this approach. (*TOR-1*)

2. **The linear regression analysis is applied separately to processed metrics obtained from the differing EROS scenarios such as well Conductor, main pile, etc.** We concur with this approach, which tends to reduce the spread of data that would exist in a database that combines differing EROS scenarios. (*TOR-1*)

3. **Regression analysis of this kind can easily be accompanied by an analysis that provides an uncertainty bound for subsequent predictions (e.g., 90% or 95% confidence interval).** This analysis has not been included in UWCv2. Such an analysis requires some knowledge of variance/uncertainties of the database subject to regression. It is understood that this unknown, however a practical sense of this variability could readily have been found out by revisiting subsets of the original pressure time series data. Alternatively, techniques known as bootstrapping [11] (e.g. involving analysis of randomized subsets of the database) could have been applied. (*TOR-2*)

4. **Relating to the overall TAR570 data base on pressure impulse and EFD presented in Table D-4 of the TAR570 report and used to build empirical models in UWCv2.** We examined three cases involving the original pressure time series data from TAR570 Table D-4, and, although our estimates for pressure impulse and EFD were of similar magnitude we could not recover the same values for these quantities as those listed in Table D-4. The peak pressures from these time series data were, however, precisely those given in Table D-4. Reasons for difference in pressure impulse and EFD estimates are unclear, but this ought to be resolved. (*TOR-1*)

5. **It is understood that the primary database in TAR570 involved Composition B explosives, for which the TNT equivalence is 1.35.** It would have been preferred to incorporate this TNT equivalence into the empirical modeling such that different explosive compounds with different TNT equivalences could be addressed. However it is understood that this is a non-issue if EROS activities *always* involve Composition B or similar explosives such as C-4 (equivalence = 1.34). That said, we note that Pentolite (TNT equivalence = 1.26) was used in the Conner study [6], results from which are utilized in UWCv2. (*TOR-1*)

6. **Customary English units are incorporated for input, and also used to express outputs.** It is not understood why this was done. The proliferation of units can potentially lead to confusion by an uninformed user. It is understood that such units are useful in referring to the TAR570 database, such as 80 lbs and 15 ft BML, but if the regression analysis involving scaled range and related dependent variables had utilized MKS units the results could have been more readily compared with published open water results. That said, it is understood that this is an issue only of graphical display and is not a quantitative issue.

7. **The display panel "Press-Imp-EFD Calculator" of the UWCv2 shows both customary English units and metric units, and refers to Energy Flux Density (EFD).** This is related to the above comment, but is a more serious drawback. Specifically, Energy Flux Density is not the same as sound exposure level (SEL). The NMFS utilizes the latter quantity, with impact criteria expressed in dB re μPa^2-sec. To be clear, there is no issue with the UWCv2 in converting EFD to SEL (the calculator will always get it right) but the labeling in UWCv2, for example, "dB 1/3-Octave Band Energy Flux Density" will invariably lead to confusion, along with the juxtaposition of the label "Energy Flux Density" with the decibel expression of SEL (see lower left of this panel). Additionally, "Total Energy Flux Density" is not the same as SEL.

8. **Relating to the value "dB 1/3-Octave Band Energy Flux Density".**
   In addition to the issue concerning what this quantity should be called (suggest that it be called "maximum 1/3-octave band level for SEL") we comment further here on how it is estimated.

   First, NMFS needs specify whether the frequency at which this maximum occurs is an important quantity, or not. If the frequency is important then the UWCv2 is not providing that information.

   Second, if frequency is not important, and the Level B criterion requires only an estimate of the "maximum 1/3-octave band level", then it is the opinion of this reviewer that the UWCv2 is providing only very crude approximation of the maximum 1/3-octave band level. The approximation technique, not discussed in UWCv2 but outlined in report [10] is based a linear correlation involving synthetic results, and predictions using it differ from our detailed spectral analysis of two cases (Fig. 9). The synthetic results are in turn based on the navy's REFMS propagation model which has not be validated in the context of EROS activities. (*TOR-1*)

   Given the importance of the quantity referred to as "dB 1/3-Octave Band Energy Flux Density" in UWCv2 for back calculations, and its relevance to Level B take, it seems warranted that estimation of this quantity be revisited. (*TOR-1*)

9. **Observations concerning "whether or not the UWC meets the Environmental protection Agency's Council for Regulatory Monitoring (CREM) guidelines for model development."**

   Two elements in the CREM guidelines are marginally satisfied at best with UWCv2. The first relates to "how closely does the model approximate the real system of interest?" As mentioned above the use of Eq. (7), an expression not necessarily called out but embedded in UWCv2, is unlikely to be a good approximation to the real system. In particular the "real system" is an EROS scenario and the model used to recover an estimate of the maximum 1/3-octave spectrum is a relation developed from synthetic data.

The second relates to uncertainty analysis and potential sources error in the model. No uncertainty analysis was undertaken in UWCv2. (*TOR-2, TOR-4*)

10. **Observations concerning "model validity in relation to field data collected by the PROP program for sea turtles and relevant scientific literature"**

    It was shown notionally that when the UWCv2 is applied at high scaled ranges (> 100) the ability to predict a Level A take was diminished. Specifically, the UWCv2 could not be validated with NMFS PROP data relating to Level A takes on sea turtles, corresponding to scaled ranges > 100. (*TOR-3*)

IV. Description of reviewer's role

My reviewing role is that of underwater acoustician and mathematical modeling reviewer. I have expertise and working experience in the physics of underwater sound propagation, the measurement and modeling of underwater sound fields, including the sound fields from underwater explosive sources.

As such, I have reviewed in detail three key technical reports [1-3], and [10] along with testing the excel spreadsheet associated with UWCv2, and placing technical references [4-9] in context of this review. Additionally I have extracted three cases of original pressure time series data from which the database of peak pressure, pressure impulse, and energy flux density (EFD) was extracted. It is this database that is subject to regression analysis and subsequent generation of the empirical formulas used in UWCv2.

In the context of this review I have not evaluated impact thresholds or otherwise any NMFS criteria for impacts on marine mammals or sea turtles, as this is outside the scope of the review.

V. References

[1] Dzwilewski, P.T., ARA Final Report-Water Shock Prediction for Explosive Removal of Offshore Structures: Underwater Calculator (UWC) Version 2.0 Update based on field data, Applied Research Associates, Inc. (Contract GS23F0278M), January 2014.

[2] Barkaski, M.J., A. Frankel, J.S. Martin, and W. Poe, "Pressure Wave and Acoustic Properties Generated by the Explosive Removal of Offshore Structures in the Gulf of Mexico". OCS Study, BOEM 2016-019

[3] Poe, W.T., C.F. Adams, R. Janda and D. Kirklewski, "Effect of Depth Below Mudline of Charge Placement During Explosive Removal of Offshore Structures (EROS)," Minerals Management Service, TAR Project #570, July 2009

[4] Chapman, N.R. "Measurement of the waveform parameters of shallow explosive charges," J. Acoust. Soc. Am. 78, pp 672-681, 1985.

[5] Soloway, A. G., and P. H. Dahl, "Peak sound pressure and sound exposure level from underwater explosions in shallow water ," J. Acoust. Soc. Am. Express Letters, 136, pp EL218-223, 2014.

[6] Connor, J.G. "Underwater Blast Effects from Explosive Severance of Offshore Platform Legs and Well Conductors," Naval Surface Warfare Center, 1988,1990.

[7] J. P. Slifko, "Pressure-pulse characteristics of deep explosions as function of depth and range," Naval Ordnance Laboratory, NOLTR 67-87, 1967.

[8] M. M. Swisdak, Jr., "Explosion Effects and Properties: Part II – Explosion Effects in Water," Naval Surface Weapons Center, 1978.

[9] D. G. Kleinbaum and L.L. Kupper, Applied Regression Analysis and Other Multivariable Methods, p.55-58, Duxbury Press, North Scituate, MA, 1978.

[10] Dzwilewski, P.T. and G. Fenton, "Shock Wave/Sound Propagation Modeling Results for Calculating Marine Protected Species Impact Zones During Explosive Removal of Offshore Structures." OCS Study MMS 2003-059, 2003.

[11] B. Efron and R. Tibshirani, An introduction to the bootstrap, reprinted by CRC Press, Boca Raton, FL, 1998.

Appendix 1: Statement of Work

Underwater Calculator (UWC) version 2.0.

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards. (http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf).

Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The Bureau of Safety and Environmental Enforcement have developed a tool based on a model to predict the effects of underwater explosions used for the removal of oil and gas structures. The modeling tool is called the Underwater Calculator Version 2.0 (UWC). The UWC was developed through a federally-sponsored environmental study to measure sound pressures during explosive use and develop a mathematical model. The development of the UWC was sponsored by the Bureau of Safety and Environmental Enforcement (MMS Contract 0302P057572) which resulted in the report titled "*Shock Wave/Sound Propagation Modeling Results for Calculating Marine Protected Species Impact Zones During Explosive Removal of Offshore Structures*" (OCS Study 2003-059).

The study used field measurements to conduct numerical simulations of various explosive, target, sediment, and marine environments determining the level of energy coupled into the water. In addition, a separate federal-sponsored study calculated the exposures of marine mammals to explosives used for decommissioning in the Gulf of Mexico which are found in the report "*Explosive Removal Scenario Simulation Results – Final Report*" (MMS OCS study 2004-064).

The purpose of the UWC is to conduct assessments of projects using explosives to remove oil and gas structures and to predict the effects and mitigation needs for protected marine species, primarily marine mammals and sea turtles. The UWC needs to be based on sound scientific principals necessary to conduct environmental assessments under federal requirements (e.g., the Endangered Species Act, Marine Mammal Protection Act, and National Environmental Policy Act). The NMFS requires an independent peer review of the UWC to ensure that the data collection methods, analysis, principals of acoustics, and necessary physical and biological factors have been considered to provide a sound scientific model. The Terms of Reference (TORs) are below.

Requirements

NMFS requires three reviewers to conduct an impartial and independent peer review in accordance with the SOW, OMB Guidelines, and TORs below. The reviewers shall have the combined working knowledge and recent experience in the application of underwater acoustics (especially explosives), acoustic modeling, and sea turtle biology.

The underwater acoustician or physicist reviewer(s):

- shall have expertise and working experience with the physics and principals of the modeling of underwater explosives
- shall have relevant experience in the calculation and relationships of peak pressure, impulse, and energy flux density (EFD) as it relates to underwater shock waves caused by explosive use

The mathematical modeling reviewer(s):

- shall have expertise with underwater propagation of acoustic waves and modeling acoustic exposures of animals
- Experience with relevant acoustic modeling efforts dealing with impacts to marine protected species and NMFS acoustic criteria is desirable.

The sea turtle biologist and marine mammal reviewer(s):

- shall have experience with sea turtles (primarily) and marine mammal (secondarily) physiology and the effects of shock wave injury in marine animals
- shall have experience in sea turtle (primarily) and marine mammal (secondarily) habitat usage and behavioral ecology

Tasks for reviewers

- Review the following background materials and reports prior to conducting the review:

Primary Review Document Titles
1. ARA Final report – Water Shock Prediction for Explosive removal of Offshore Structures: Underwater Calculator (UWC) Version 2.0 Update based on Field Data
2. Underwater Calculator Version 2
3. Effect of Depth Below Mudline of Charge Placement During Explosive Removal of Offshore Structures (EROS)
4. Shock Wave/Sound Propagation Modeling Results for Calculating Marine Protected Species Impact Zones During Explosive Removal of Offshore Structures (OCS Study 2003-059)
5. Pressure Wave and Acoustic Properties Generated by the Explosive Removal of Offshore Structures in the Gulf of Mexico
Secondary Background Document Titles
5. Impacts of the Explosive Removal of Offshore Petroleum Platforms on Sea Turtles and Dolphins
6. Underwater Blast Effects from Explosive Severance of Offshore Platform Legs and Well Conductors
7. Underwater Blast Pressures from a Confined Rock Removal during the Miami Harbor Deepening Project
8. Determination of Acoustic Effects on Marine Mammals and Sea Turtles for the Atlantic Fleet Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement
9. The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts
10. NMFS PROP Reports and Necropsy Reports

Document	**Document Type**	**Number of Pages**
1. ARA Final report – Water Shock Prediction for Explosive removal of Offshore Structures: Underwater Calculator (UWC) Version 2.0 Update based on Field Data	PDF	35 pp
2. Underwater Calculator Version 2.0	Excel Spreadsheet	1 spreadsheet
3. Effect of Depth Below Mudline of Charge Placement During Explosive Removal of Offshore Structures (EROS)	PDF	71 pp
4. Shock Wave/Sound Propagation Modeling Results for Calculating Marine Protected Species Impact Zones During Explosive Removal of Offshore Structures (OCS Study 2003-059)	PDF	41 pp

Document	Document Type	Number of Pages
5. Pressure Wave and Acoustic Properties Generated by the Explosive Removal of Offshore Structures in the Gulf of Mexico	PDF	72 pp
6. Impacts of the Explosive Removal of Offshore Petroleum Platforms on Sea Turtles and Dolphins	PDF	10 pp
7. Underwater Blast Effects from Explosive Severance of Offshore Platform Legs and Well Conductors	PDF	147 pp
8. Underwater Blast Pressures from a Confinded Rock Removal during the Miami Harbor Deepening Project	PDF	12 pp
9. Determination of Acoustic Effects on Marine Mammals and Sea Turtles for the Atlantic Fleet Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement	PDF	109 pp
10. The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts	PDF	54 pp
11. NMFS PROP Reports and Necropsy Reports (7 incidents)	Excel Spreadsheets (7), Word (2), and PDF (2)	10 pp + 7 spreadsheets

- Participate in two, half-day webinars with NOAA, BSEE, and other personnel to discuss the technical aspects of the UWC, terms of reference, and related questions

- Conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines

Place of Performance
The place of performance shall be at the contractor's facilities.

Period of Performance
The period of performance shall be from the time of award through August 31, 2016. Each reviewer's duties shall not exceed 12 days to complete all required tasks.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables in accordance with the following schedule.

6/10/2016	Contractor selects and confirms reviewers
No later than 6/17/2016	Contractor provides the review documents to the reviewers
6/24 – 9/12/16	Each reviewer conducts an independent peer review as a desk review, including participating in two, half-day seminars
9/12/16	Contractor receives draft reports
9/14/16	Contractor submits final reports to the Government

Applicable Performance Standards
The acceptance of the contract deliverables shall be based on three performance standards:
(1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each TOR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel
Since this is a desk review travel is neither required nor authorized for this contract. ODCs are not to exceed $500.00.

Restricted or Limited Use of Data
The contractors may be required to sign and adhere to a non-disclosure agreement.

Terms of Reference for the Peer Review

Underwater Calculator (UWC) version 2.0.

1. Assess whether or not the UWC model sufficiently considers all relevant biological (e.g., animal distribution and movement) and physical variables (e.g., factors affecting sounds propagation) for decommissioning activities.

2. Assess the underlying assumptions resulting from scientific uncertainty in estimating acoustic exposure for animals (with an emphasis on sea turtles, but also odontocetes) within the UWC model.

3. Assess the model validity in relation to field data collected by the PROP program for sea turtles and relevant scientific literature.

4. Assess whether or not the UWC meets the Environmental protection Agency's Council for Regulatory Monitoring (CREM) guidelines for model development.

1. <u>UWC Model Implementation</u>

- Does the UWC model sufficiently consider all relevant physical variables in estimating acoustic exposure? Specifically, does the model:
  - i. Integrate the new in situ data correctly?
  - ii. Accurately represent the acoustic impact zones from explosive use?
- Does (or can) the UWC model correctly consider the necessary parameters to estimate effects on sea turtles (and marine mammals) from exposure to explosives based on current scientific knowledge, such as:
  - i. Water, depth, size of target, size of explosives, location of charge (AML/BML)
  - ii. Habitat use and movement of species (e.g. on surface versus in water column)
- How do the UWC model results compare to both field observations and the scientific literature in terms of zones of influence?
- Does the UWC model consider the appropriate acoustic exposure metrics? How do the predictive outputs of the UWC model compare with the noise exposure guidelines developed by NMFS?
- Comment on the strengths and weaknesses of the UWC modeling approach, and suggest possible improvements (both those that can be accomplished by implementing the current model differently and those that necessitate changes in the model)
- Comment on whether any weaknesses in the UWC model would likely result in over/underestimates of take (and the degree, if possible)

2. CREM Guidelines

The reviewers shall assess whether or not the UWC model meets the Environmental Protection Agency's CREM guidelines for model evaluation, which are summarized below. Some of the points listed below will have been addressed by the reviewers as part of their comments on Terms of Reference 1 and 2 above. Each reviewer shall ensure that clear answers are provided for the CREM guidelines, though extensive repetition of technical comments is not required.

- Have the principles of credible science been addressed during model development?
- Is the choice of model supported given the quantity and quality of available data?
- How closely does the model simulate the system (e.g., ecosystem and sound field) of interest?
- How well does the model perform?
- Is the model capable of being updated with new data as it becomes available?

Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether or not the science reviewed is the best scientific information available.

2. The report must contain a background section, description of the individual reviewers' roles in the review activities, summary of findings for each TOR in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the TORs.

3. The report shall include the following appendices:

Appendix 1: Bibliography of materials provided for review
Appendix 2: A copy of this Statement of Work