Peer Review Report:

Technical Section from: NOAA Guidance for Assessing the Effects of Anthropogenic Noise on Marine Mammal Hearing: Underwater Acoustic Threshold Levels for Permanent and Temporary Threshold Shifts

Peer Reviewers[1]

Robert Burkard, Ph.D., University at Buffalo
Peter Dahl, Ph.D., Applied Physics Laboratory University of Washington
Colleen Reichmuth, Ph.D., University of California, Santa Cruz
Kevin Williams, Ph.D., Applied Physics Laboratory University of Washington

NOAA did not request the peer reviewers evaluate the entire Acoustic Guidance document but instead a particular, brief (15 page) technical section relating to the Acoustic Guidance's proposed application of impulsive and non-impulsive PTS acoustic threshold levels based on physical characteristics at the source and how those characteristics change with range. This technical section appears within the main Acoustic Guidance, as well as within an associated appendix.

General Comments[2]

REVIEWER 1

Comment 1: I understand that the aim of this technical section of the draft guidance is to explain and justify the Guidance's proposed application of impulsive and non-impulsive PTS acoustic threshold levels based on physical characteristics at the sound source, and how those characteristics change from impulsive to non-impulsive with transmission range.

This section describes the propagation of impulsive sounds from sources such as high explosives, airguns, and pile driving, and the transition zone where these initially impulsive sounds can be considered to become non-impulsive with respect to hearing damage criteria for marine mammals. As an invited reviewer, I must emphasize that my expertise is mainly in biology and hearing, and not

[1] Note: Peer Reviewers' comments are presented as provided to NOAA. Generally, NOAA did not make any alterations (i.e., there may be spelling, grammatical, or other minor errors). If alterations were made, they were done for clarity and are indicated by brackets.

[2] Reviewer identification numbers do not correspond to the order of reviewers above.

physical acoustics. I defer to the other specialty reviewers on the appropriate interpretation of sound source characteristics and peak pressure/pulse duration ratios. Nevertheless, I have summarized my comments on this section of the Guidance below and hope these will be of some use to the authors.

Response: NOAA thanks the Reviewer for their comments.

Comment 2: I have read this technical section very carefully from the standpoint of clarity to a non-expert, and with a biological perspective. As far as I can tell, NOAA has made several important points here, including the necessary use of a peak pressure metric to evaluate impulsive sounds, and the understanding that these sounds transition from impulsive to non-impulsive with increasing distance from the source. There are not a great deal of source or receiver data to inform this criteria. However, it seems that NOAA has evaluated the data that are available to reasonably bracket a transition range from one sound source type to the other that would be appropriate for pulsed sounds associated airguns and pile driving (but not high explosives). Overall, the main criticism I have is a lack of consideration for frequency range of the TTS data presented, which could alter the interpretation of whether or not an auditory threshold shift actually occurred. (that is, in cases where no TTS was documented, was it possible for a shift to occur at frequencies lower than the ones tested?). At least a footnote to this portion of the analysis would be helpful.

Response: NOAA thanks the Reviewer for the evaluation. As for the main criticism of not considering the importance of frequency in assessing TTS studies, NOAA has added more information to the Table summarizing available marine mammal TTS studies, including frequencies where hearing was measured and which frequencies where TTS occurred (See Table 1; <u>Note</u>: This Table also reflects changes made in response to Comments 58 and 59 regarding depicting peak pressure in terms of Pascals (Pa) rather than decibels).

NOAA agrees that frequency is an important consideration and has added information about the importance of frequency content associated with impulsive sounds to the text (i.e., to identify it as a source for consideration for future studies). Upon evaluation of frequencies where TTS occurred associated with impulsive sounds, NOAA believes most available studies tested an adequate range of frequencies where TTS was expected to occur, especially those more recent studies.

Table 1: Summary of marine mammal TTS studies using impulsive sounds.

Source	Species (n)	Measured TTS Frequencies^Δ	Peak Pressure	Pulse Duration	Ratio* (Pa/s)	Reference
Explosion simulator (500 kg charge)	Beluga (1); Bottlenose dolphin (2)	1.2, 1.8, and 2.4 kHz	69183 Pa (216.8 dB)	0.0095 s	7,282,421	Finneran et al. 2000
Water gun (80 in^3)	Beluga (1)	**0.4**, 4, and **30** kHz	158489 Pa (224 dB)	0.0063 s	**25,156,984**	Finneran et al. 2002
Water gun (80 in^3)	Bottlenose dolphin (1)	0.4, 4, and 30 kHz	218776 Pa (226.8 dB)	0.01 s	21,877,600	Finneran et al. 2002
Arc-gap transducer	California sea lion (2)	1 and 10 kHz	13963 Pa (202.9 dB)	0.0142	983,310	Finneran et al. 2003
Airgun (20 in^3)	Harbor porpoise	**4**, 32, and 100 kHz	5623 Pa (195 dB)	0.05 s$^+$	**112,460**	Lucke et al. 2009
Impact pile driver (4.2 m pile at 800 m)	Harbor porpoise	0.5, 1, 2, 4, 8, 16, 32, 63, and 125 kHz	1000 Pa (180 dB)	0.124 s	1452	Kastelein et al. 2015
Airgun (40-150 in^3)	Bottlenose dolphin (3)	0.25, 0.5, 1, 2, 4, 8, 16, 32, 40, 45, 50, and 64 kHz	31622 Pa (210 dB)	0.3 s	105,407	Finneran et al. 2015

^Δ Frequencies in bold indicate those where measurable TTS occurred.

* Ratios in bold text indicate exposure scenarios where measurable TTS occurred.

$^+$ Lucke et al. 2009 did not provide the exact pulse duration in their experiment and only indicated it was less than 0.05 s. NOAA conservatively chose to use 0.05 s for calculating the ratio (i.e., the use of a shorter duration would only result in a higher ratio).

Comment 3: Without having reviewed the sections describing the acoustic threshold levels themselves, I found the language about these in the present sections sometimes inconsistent or confusing. The authors may want to take another look at this and attempt to clarify where possible.

Finally, while the emphasis of this section was on the transition range used to apply acoustic threshold levels, I did not find a lot of information about how this would be done (e.g., by hearing group, by distance, etc.). I assume this information exists elsewhere in the larger document, it may be necessary to cross-reference this material.

> ***Response***: NOAA addresses the Reviewer's remark about inconsistent descriptions of acoustic threshold levels in a subsequent comment (See Response to Comment 21).
>
> NOAA intends the transition range to be assessed on a per functional hearing group basis (i.e., PTS onset thresholds are established by functional hearing groups). This was probably

unclear for the Reviewer reading the technical section in isolation from the rest of the Acoustic Guidance but will be more transparent when this section is read in context of the entire document.

Comment 4: In summary, given the decision to use PTS as the injury criteria for marine mammals (which is debatable) I have no major objections with this section.

I have made a lot of minor suggestions for edits to clarify or improve the text, and a few significant comments that request clarity on the material presented. These are listed below.

Response: NOAA thanks the Reviewer for their evaluation and addresses specific comments in the appropriate sections below.

REVIEWER 2

Comment 5: My overall comment is that the logic behind the Peak Pressure/Pulse duration calculations used to set the 3 km range seems subject to criticism. The idea, as I understand it, is that as sound propagates in a waveguide the increase in pulse duration can be used as a surrogate for decrease in rise time of the impulse. I believe this mixes to pieces of physics in a debatable manner.

Response: The Reviewer's understanding that NOAA is using the increase in pulse duration with propagation, as a surrogate for decrease in rise time, is correct. NOAA acknowledges that the proposed methodology is extremely simplistic, which it the intent, in order to encompass the vast array of impulsive sources we analyze and the variety of environmental conditions where they may be used. NOAA recognizes that the distance from the source where this transition (i.e., impulsive sounds transitioning to having less injurious physical characteristics) occurs depends on a multitude of factors (e.g., source characteristics, including frequency, bathymetry, water depth, bottom sediment composition), which may subject this methodology to criticism. However, NOAA believes it has chosen a conservative transition zone based on the available data. Additionally, we will add this topic as Appendix on Research Recommendations to encourage further measurements that will help substantiate our transition zone or offer an alternative methodology. Additionally, NOAA has made further refinements to the methodology, including more appropriately depicting and using pressure expressed as Pascals, rather than decibels (see Response to Comments 58 and 59).

REVIEWER 3

Comment 6: This review of the DRAFT NOAA Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals Hearing was undertaken at the request NOAA as documented in email received on 1 April 2015. As specified in the request, the review is limited to 15 pages of the DRAFT Guidance commencing with Section 2.3.2.

Summary of DRAFT Guidance

Section 2.3.2 relates to acoustic thresholds associated with the onset of TTS (temporary threshold shift) and PTS (permanent threshold shift) on marine mammal species. Essential to establishing these acoustics thresholds is a determination of the impulsive versus non-impulsive property of the anthropogenic underwater sound signal.

In the DRAFT Guidance this property is quantified by the ratio of peak pressure, expressed in decibels, to the time scale T, representing 90% of the acoustic energy. For example, in Table A2.1, first row, peak pressure is 204 dB re 1 μPa and T is 0.0087 sec, therefore the ratio is 204/.0087 = 23448, with evidently units of dB/sec.

Fast *rise time* is considered to be the feature of the signal that most likely is the cause of TTS and PTS auditory injury. NOAA acknowledges that rise time is not a reliably measurable quantity, and thus the time scale T is considered a surrogate for rise time. The ratio of peak pressure to time scale T comes into play because there must also be a relatively high acoustic pressure in effect, for the signal to be of biological significance.

Three kinds of representative anthropogenic impulsive signals are discussed in the context of this ratio: (1) explosive, (2) air gun, and (3) impact pile driving. The ratio metric is central to the Section 2.3.2, and a sound signal with ratio less than 2500 is considered to be less likely to result in auditory injury.

> ***Response***: NOAA agrees that the Reviewer's summary is mostly correct. However, peak pressure is also considered an important factor of a sound contributing to noise-induced hearing loss (i.e., peak pressure was not considered a means for a signal to be of biological significance as stated by the Reviewer).

REVIEWER 4

Comment 7: I have completed my review of 2.3.2 Impulsive and Non-Impulsive Acoustic Threshold Levels, and Appendix A.2: Analysis to Support Recommended Transition from Impulsive to Non-Impulsive Acoustic Threshold levels. Overall, I consider this to be an important issue, and worthy of discussion, argument and ultimately consensus. In preparing for this review, I read the proposal several times, read through at least of Executive Summaries of the supporting materials[3] emailed along with the proposal, and read through other materials concerning noise-induced hearing loss.

I of course have some comments.

> ***Response***: NOAA appreciates your time and efforts on this review and will address individual comments by specific section.

[3] In addition to the Technical Section, NOAA provided Reviewers with unpublished report associated with our analysis (See Appendix B of Draft Guidance, July 2015 version, for all unpublished reports used).

<u>**Main Document: Specific Comments (by Section)**</u>

2.3.2 Impulsive and Non-Impulsive Acoustic Threshold Levels

<u>REVIEWER 1</u>

Comment 8: Re: "Within the Guidance, sources are divided into impulsive and non-impulsive based on physical characteristics at the source, with impulsive sounds having physical characteristics that make them more injurious (e.g., high peak pressure and rapid rise time) than non-impulsive sounds sources."

"impulsive sounds sources" (typo) – "impulsive sound sources"

> ***Response***: The typo has been corrected.

Comment 9: Re: "<u>Non-impulsive</u>: produce sounds that can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak pressure with rapid rise time that impulsive sounds do."

Wording suggests that non-impulsive sounds do not have high peak pressure.

> ***Response***: NOAA's definition of non-impulsive sounds indicates that these sources *typically* do not have high peak pressures. However, both impulsive and non-impulsive sounds are subject to dual criteria, meaning that the peak pressure acoustic threshold level must be considered for impulsive sounds, as well as non-impulsive sounds. This is an added protective measure, even though for most non-impulsive sounds, the cumulative sound exposure level acoustic threshold is expected to be the conservative threshold of the dual criteria (i.e., result in the larger isopleth).

Comment 10: Re (footnote): "Exposure to impulsive sounds more often lead to mechanical damage of the inner ear, as well as more complex patterns of recovery (e.g., Henderson and Hamernik 1986; Hamernik and Hsueh 1991)."

Suggest stating "hearing recovery" rather than "recovery"

> ***Response***: NOAA has made the Reviewer's suggested edit.

Comment 11: Re: "At close ranges, these sounds typically have primary pulse durations of 50 ms or less,…"

Wording shifts from considering these as sources to sounds, suggest, "at close ranges, the sounds associated with these sources" to clarify

> ***Response***: NOAA has made the Reviewer's suggested edit to better clarify.

Comment 12: Re (heading): "Recommended Transition from Impulsive to Non-Impulsive Acoustic Threshold Levels"

The header seems a bit confusing. Would it be appropriate to change "Recommended transition from impulsive to non-impulsive acoustic threshold levels" to something like "Recommended transition range from impulsive to non-impulsive sound type" (unless the "acoustic threshold levels" are referenced to something earlier in the report, this is not clear, and it does not fit clearly in reference to the next header, "application of transition range")

> ***Response***: NOAA's intent for this section is to provide action proponents guidance on when it might be appropriate to transition from using impulsive to non-impulsive acoustic threshold levels, which is based on when the actual characteristics of the sounds transition. Thus, NOAA believes the original header best reflects our intent.

Comment 13: Re: "However, based on previously collected measurements at various distances from the source,…"

Suggest changing "at various distances to the source" to "at various distances to a particular source"

> ***Response***: NOAA has made the Reviewer's suggested edit.

Comment 14: "NOAA has approximated that 3 km is conservative estimate of range" – this should be clarified. Suggest "NOAA has determined that 3 km conservatively estimates the range"

> ***Response***: NOAA has made the Reviewer's suggested edit to better clarify.

Comment 15: Application of transition range section. This seems to be lacking an initial statement to review the non-controversial use of this range prior to getting into exceptions. Unless this is covered elsewhere, this section should note, for example, if the number of animals within a 3 km range should be handled one way, and the number of animals beyond that range should be handled another way. And then get into the exceptions to the rule.

> ***Response***: NOAA agrees that the section as written was unclear in providing guidance to action proponents on what to do if exposure modeling predicts that an impulsive sound produces PTS onset less than 3 km from the source (i.e., the action proponent must use the predictions from this range). This has now been clarified in the text.

Comment 16: Re: "If the exposure modeling predicts that an impulsive sound produces a PTS onset of greater than 3 km from the source, then the action proponent may wish to explore substituting the non-impulsive PTS onset threshold for the impulsive threshold…"

If there are two options here for the action proponent, both should be stated (that is, either use X or else use Y).

> ***Response***: NOAA has clarified the text to indicate that the action proponent may explore substituting the non-impulsive PTS onset threshold for the impulsive threshold or the action

proponent may instead decide to continue to use the impulsive threshold. The decision is left to the action proponent.

Comment 17: Re: "If upon substitution, the non-impulsive PTS onset acoustic threshold level results in a predicted auditor injury isopleth greater than 3 km, then the action proponent may calculate PTS onset based on this new isopleth rather than the previous isopleth…"

Should this be *may* or *should*?

> ***Response***: The decision is left to the action proponent, so "may" is the appropriate here (i.e., the acoustic thresholds levels are presented within a guidance document and not regulations).

Comment 18: Re: "NOAA acknowledges that based on available data (Table A.2.1), a 3 km transition range may not be appropriate for sounds such as high explosives, due to their extremely short pulse duration and high peak pressures."

Consider noting "relative to other impulsive sources"

> ***Response***: NOAA has made the Reviewer's suggested edit.

Comment 19: Re: "Note: This proposed methodology does not suggest PTS onset beyond 3 km is entirely unlikely…"

PTS as a result of what? Exposure to impulse noise? Or just as a result of noise exposure that could comprise either noise type? Clarify if possible.

> ***Response***: NOAA has provided additional clarification to indicate this Note applies to potential exposure to all sound sources.

Comment 20: Overall, this section left me wondering if any action is required for these impulsive sources as their sound extend past 3 km and are assumed to become non-impulsive. This perhaps could be more clearly stated.

> ***Response***: Again, the decision is left to the action proponent as to whether they want to pursue using this transition range or not. There is no requirement to do so. Additional clarification has been added to the text to indicate this.

Comment 21: Re (footnote): "Note: There are additional non-auditory thresholds for high explosives (i.e., lung and gastrointestinal tract injury) and a peak pressure PTS onset threshold, which is part of this Guidance's dual thresholds, is most likely to be the dominant threshold (i.e., threshold exceeded first with the largest isopleth) for these sounds."

This footnote is hard to read and interpret, consider breaking into two sentences, and fixing the grammar. What is meant by "is more likely to be the dominant threshold"? This needs clarification so that read knows if it is the more conservative of these two thresholds (non-auditor threshold vs.

PTS onset threshold). Or perhaps it is the threshold that is reached at a lower received sound level. Incidentally, am not always clear on the use of the terms acoustic threshold, peak pressure PTS onset threshold, impulsive PTS onset threshold, and the other terms referring to acoustic thresholds throughout the document. I realize these terms are covered in other sections of the Guidance, but it would be helpful to go through the document and carefully review how these thresholds are identified/labeled to ensure consistency throughout.

> ***Response***: NOAA has reworded this footnote and provided additional clarification on what is meant by the term "dominant threshold" (i.e., threshold resulting in the largest isopleth).
>
> NOAA has re-evaluated within this technical section, as well as the entire Acoustic Guidance, the use of terms relating to acoustic threshold levels to ensure consistency (i.e., has used acoustic threshold level to represent the term "acoustic threshold" mentioned by the Reviewer).

REVIEWER 3

Comment 22: Re: "Within the Guidance, sources are divided into impulsive and non-impulsive based on physical characteristics at the source, with impulsive sound having physical characteristics that make them more injurious (e.g., high peak pressures and rapid rise times) than non-impulsive sounds sources (terrestrial mammal data: Buck et al. 1984; Dunn et al. 1991; Hamernik et al. 1993; Clifford and Rogers 2009; marine mammal data: reviewed in Southall et al. 2007)."

Why this reference at this point? Why not something related to injury such as by Popper?

> ***Response***: The references provided in this technical section reflect the potential for impulsive sounds to be more injurious to mammalian ears than non-impulsive sounds. NOAA did not include reference to publications by Art Popper, since his research relates primarily to noise-induced hearing loss in fishes. However, Popper et al. (2014) use similar characteristics to make distinctions between impulsive and non-impulsive sounds.

Comment 23: Re: "Impulsive: produce sounds that are transient, brief (less than 1 second), broadband, and typically consist of high peak pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). These sounds also have pressure amplitudes that vary with time (i.e., from one cycle to the next), making it necessary to specify an averaging time window in order to define root-mean-square pressure levels (Madsen 2005; Ainslie 2010)."

Less than 1 sec? This duration is an eternity in some contexts.

This seems extremely vague. What is a cycle? Effectively any signal propagated underwater would satisfy this. Delete.

This is very vague. What is many cycles? What is small fluctuations? Non-impulsive sounds can become highly randomized with "saturated" statistics indicating fluctuations are of same amplitude as the mean.

Response: NOAA has re-evaluated its definitions for both impulsive and non-impulsive sounds based on the Reviewer's comments. Based on the Reviewer's suggestion, we have removed the sections referring to "cycles" and "fluctuations" in pressure amplitudes.

Furthermore, NOAA agrees that many impulsive sounds can be much shorter than 1 second (i.e., on order of milliseconds). However, defining impulsive sounds using the duration of less than 1 second is consistent with how these sounds have previously been defined (e.g., NIOSH 1998; ANSI 2005).

Comment 24: Re: "The characteristics that make impulsive sounds particularly injurious are their high peak pressures and rapid rise times (e.g., Ketten 1995; Richardson et al. 1995). Thus, it is necessary for NOAA to provide some quantitative means to determine when impulsive sounds are less likely to possess those physical characteristics that most likely result in auditory injury."

This is the key right here. But the approach above does not achieve this.

Response: NOAA agrees with the reviewer that the "key" is to to provide some quantitative means to determine when impulsive sounds are less likely to possess those physical characteristics that most likely result in auditory injury and that was the intent of our proposed methodology. NOAA addresses specific criticisms of this approach in subsequent comments made by this Reviewer.

Comment 25: Re (footnote): "High explosives are those that produce detonations with shock waves (e.g., TNT), versus those that burn rather than detonate (e.g., black powder) (Urick 1983)."

This footnote is completely unnecessarily, unclear, and very likely highly inaccurate. It should be deleted.

Response: NOAA was using this footnote to distinguish between high explosives and other types of explosives. However, based on the Reviewer's recommendation, NOAA has decided to delete it.

REVIEWER 4

Comment 26: P. 1, l. 9; p. 1, l.42; p. 6, l. 38; p. 7, l. 4: In these sentences, the authors state that impulsive sounds are particularly injurious due to the high peak pressure and their rapid risetimes. I know of absolutely no empirical evidence that has manipulated risetime of impulsive sounds and demonstrated that this has a substantial effects of temporary threshold shift, permanent threshold shift, hair cell loss, otoacoustic emission amplitude, or any other measure of hearing. I am much more familiar with noise-induced hearing loss data in humans and other terrestrial animals, but considering the overall paucity of data concerning permanent noise-induced hearing loss in marine mammals, it is unlikely that specific risetime data relevant to the present proposal arises directly from marine-mammal studies.

Response: NOAA agrees with the reviewer. We are unaware of any empirical studies specifically manipulating rise time of impulsive sounds and evaluating this effect on noise-induced hearing loss for terrestrial or marine mammals. However, Walker and Behar (1971) found that playbacks of tape-recorded impulsive sounds resulted in less TTS than from being exposed to the actual source. The authors attributed this to tape recorders not being able to accurately reproduce either rise time and/or high-frequency content of the sound (NOAA has added more information on the importance of frequency content within impulses; See Response to Comment 44). Rise time is often used as a characteristic to distinguish impulsive sounds from non-impulsive sounds and as possibly contributing to noise-induced hearing loss (Dunn et al. 1991; Southall et al. 2007), which is why we specifically pursued this approach. We have identified this as an area where further study is needed (i.e., characteristics that make impulsive sounds more injurious) in our Appendix on Research Recommendations.

Appendix: Specific Comments (by Section)

III. INTRODUCTION

REVIEWER 1

Comment 27: Re: "This Appendix provided analysis (field measurements and marine mammal TTS data) used to support the Guidance's recommendation that action proponents be able to transition…"

This introduction is clearly stated but again, the phrase "*be able to transition*" makes it unclear to me whether as to whether this is a may or should statement, and how one might decide. Are there conditions under which one would NOT use a non-impulse TTS onset criterion after 3 km? That doesn't seem to make sense given the rationale provided. If so, the guidance should perhaps give an example, if not they should just use should instead of may to clarify. I suspect the Guidance authors have already given this a good deal of thought in section of the term "may," but it is not clear as to why.

Response: As mentioned in previous responses, it is ultimately the action proponent's decision as whether or not to explore this transition methodology. Since this document is guidance, it does not create or confer any rights for or on any person, or operate to bind the public. Thus, the term "may" is appropriate, as opposed to "should." However, NOAA believes our approach for transitioning from impulsive to non-impulsive acoustic thresholds levels is supported by the best available science and recommends action proponent's take it into consideration as to whether it is appropriate for their specific action.

1.1 Peak Pressure Levels

REVIEWER 1

Comment 28: Re: "Typically, most sound source measurements (i.e., sound source verifications) area done to examine [at] what distance various isopleths occur based on specific acoustic threshold levels…"

Consider adding "regulatory" here, that is: "based on regulatory acoustic threshold levels"

> ***Response***: NOAA finds this additional clarification unnecessary (i.e., already stated earlier in Acoustic Guidance how these thresholds comport with NOAA's various statutes in Section III).

Comment 29: This section should make reference to impulsive sound sources somewhere, and perhaps should end with "these studies are reviewed below for high explosives, seismic airguns, and impact pile drivers." This would provide some scope for the subsequent sections.

> ***Response***: NOAA agrees and has made the Reviewer's suggested edits.

1.1.1 Underwater High Explosives

REVIEWER 1

Comment 30: Re: "Furthermore, the peak pressure PTS onset threshold, which is part of the Guidance's dual thresholds, is most likely to be the dominant threshold (i.e., threshold exceeded first with the largest isopleth) for a source, like high explosives."

The discussion of dominant threshold is tricky – "i.e., threshold exceeded first with the largest isopleth". The largest isopleth makes sense to me, the exceeded first part is somewhat unclear to me, I would read this as the criteria that is more conservative, or met at a lower received level of sound exposure.

> ***Response***: NOAA has clarified its terminology to indicate that the dominant threshold is the one that produces the largest isopleth.

Comment 31: Re: "Compared to high explosives, airguns and impact pile drivers have a lower peak pressures…"

Typo – "a lower peak pressures", suggest here "lower peak pressures and longer rise times"

> ***Response***: NOAA has corrected the typo and made the Reviewer's suggested edit.

1.1.2 Seismic Airguns

<u>REVIEWER 1</u>

Comment 32: I don't know if this report is available to cite but I think it would be helpful here (I have found this to be a very helpful resource on sound propagation from operational seismic arrays.). The main advantage is that rather than a stationary source with microphones placed at various distances, the recording array was stationary and the airgun array drove towards and past the recorders with measurements made at various distances out to 30 km.

> Patterson, H., S.B. Blackwell, B. Haley, A. Hunter, M. Jankowski, R. Rodrigues, D. Ireland and D.W. Funk. 2007. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July-September 2006. 90-day report. LGL Draft Rep. P891-1. Rep. from LGL Alaska Research Associates Inc., Anchorage, AK, LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Goleta, CA for Shell Offshore Inc., Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 199 p.
>
> ***Response***: NOAA agrees this is a valuable report and has used it in constructing Table A.2.1.

Comment 33: Re: "Greene and Richardson 1988: Measurements of various marine seismic survey sounds (i.e., sleeve exploders, open bottom gas guns, single airguns, and airgun arrays) in the Beaufort Sea (water depth 9 to 130 m, but mostly less than 50 m), from various distances, were provided. In general, they concluded that "Pulses received at ranges greater than 3-4 km were usually 0.25-0.75 s long.""

The main conclusion here is that "pulses received at ranges greater than 3-4 km were usually 0.25-0.75 s long"- this would be more compelling if the duration near the source were provided. Also seems a bit inconsistent with the definition on page 1 of impulsive sounds being brief (less than 1 second). Need to discuss here if these sounds were impulsive or not at the 3-4 km distance noted.

> ***Response***: NOAA's definition of impulsive sounds indicates that these are transient (less than 1 second). However, NOAA's definition of non-impulsive sounds indicated that these can also be brief (i.e., there is nothing inherent in NOAA's definitions tying whether a sound is impulsive or non-impulsive to a duration of less than 1 second). Based on other characteristics associated with impulsive sounds, such as high peak pressures and rapid rise times, NOAA would consider the sounds at ranges 3 to 4 presented in the Greene and Richardson 1988 paper to be non-impulsive.

Comment 34: Re: "…Duncan and McCauley (2008) provides comparisons of a single airgun shots measured…"

Typos – should be "Duncan and McCauley provide" (not provides)…" comparisons of singe airgun shots" (not a single airgun shot).

Response: This typo is no longer relevant, since reference to Duncan and McCauley (2008) has been removed (See Response to Comment 35).

Comment 35: Why is the Duncan and McCauley reference not shown with the rest? Is it because of the use of a single gun? This is not clear, and should be set up better. At least the Duncan and McCauley airgun should be described in cubic inches as are the other sources.

Response: NOAA is aware of the inconsistent presentation of the Duncan and McCauley data compared to other data sources in this section. This is because this paper does not supply as detailed information as other papers/reports (i.e., information is not provided). Nevertheless, NOAA wanted to include all available information. However, upon further evaluation, NOAA has decided to remove reference to this paper (i.e., paper does not provide any benefit and may only cause confusion).

Comment 36: Re (footnote): "Many of the available examples included are from sound source verification studies in the Arctic from 2006 to 2012."

Looks like only three of the examples are from the Artic, consider just noting in the footnote which studies are from the Arctic during that time period, if it is important to do so.

Response: After further consideration, NOAA has decided to delete this footnote (i.e., does not provide any further clarity and may only add confusion).

1.1.3 Impact Pile Drivers

<u>REVIEWER 1</u>

Comment 37: Re: "There have been fewer measurements for impact pile drivers:"

Suggest: There have been fewer measurements for impact pile drivers *than seismic airguns*.

Response: NOAA has made the Reviewer's suggested edit.

Comment 38: On all four examples, suggest stating *water* depth rather than depth to avoid confusion with pile depth (if that is the correct interpretation).

Response: The Reviewer's interpretation is correct, NOAA intended depth to indicate water depth and has now clarified this in the text.

<u>REVIEWER 3</u>

Comment 39: Re: "There have been fewer measurements for impact pile drivers"

Many new references have become available in recent [years]. See works by Dahl, Lippert and others in JASA.

> ***Response***: NOAA's original sentence reflects those studies that have provided measurements of impulsive sounds at various distances from the source, including information on pulse duration. Based on the Reviewer's comment, NOAA has re-evaluated available data with emphasis on recent publications on impact pile drivers (i.e., Stockham et al. 2010; Reinhall and Dahl 2010; Reinhall and Dahl 2011a, b; Dahl et al. 2013; Dahl and Reinhall 2013; Lippert et al. 2013; Lippert and von Estorff 2014). Upon evaluation of these publications, NOAA determined that these papers do provide useful information on a variety of topics, including the complexities associated with propagation (in water and in sediment) during impact pile driving, including how the pressure field is depth dependent and appropriate modeling techniques, but they do not provide the specific information NOAA needed to evaluate its proposed ratio (i.e., most measurements were made fairly close to the source).
>
> However, based on NOAA's re-evaluation, some additional sources were found to provide information on how peak pressure varies with distance from the source and were included in the updated section (i.e., Caltrans 2012; Zampolli et al. 2013).

Comment 40: Re: "Blackwell et al. 2004: Measurements associated with the installation of 51-cm well conductor 11 and 107-cm well insulator pipes, associated with the construction of the Northstar Island 12 facility in Prudhoe Bay, Alaska (depth 6 m), were reported at distances 63 to 1000 m from 13 the source. From Figure 4 of their publication, for the 51-cm pipe at 1000 m from the 14 source, the peak pressure had dropped by over 30 dB (i.e., at 63 m peak pressure is 157 dB, 15 while at 1000 m it is less than 130 dB). For the 107-cm pipe, at 200 m from the source, the 16 peak pressure was ~155 dB, while at 1000 m from the source; it had dropped to ~140 dB. 17 Pulse durations for these measurements varied from 0.11 to 0.6 s. "

This is a 107 cm diameter pile (or radius?)

> ***Response***: They were 107-cm diameter pipes. NOAA has clarified this in the text.

1.2 Pulse Duration

REVIEWER 1

Comment 41: On page 6 and throughout this entire technical section, suggest using either ms or s to describe pulse duration, the mixture of these units is confusing (e.g., on page 6 pulse duration is described as 0.6 s in one example and 84 ms in the next).

> ***Response***: NOAA has corrected this inconsistency (i.e., used seconds instead of milliseconds).

Comment 42: The increase in pulse duration described for airguns and pile driving is challenging to interpret. This is because the decrease in pulse duration still exceeds the definition for impulsive sound on the first page. Some clarification on the decay pulsatile characteristics might be needed. For example, is the increase in duration in Illington and Rodkin (2014) also associated with more stable/less impulsive amplitude fluctuations….?

> ***Response***: See Response to Comment 33.

Comment 43: Re: "Guidance uses total pulse duration as a surrogate for rise time duration because as a sound propagate[s] through the environment, pulse duration is expected to increase resulting in a subsequent decrease in rise time (i.e., slower rise times)."

Needs a comma here.

> ***Response***: NOAA has made the Reviewer's edit.

<u>REVIEWER 2</u>

Comment 44: Decrease in the rise time of an impulsive signal is related to the frequency content of that signal and is [affected] by attenuation, dispersion etc. I believe the article by Chapman (J. Acoust. Soc. Am Vol. 78, pp. 673, 1985) is an excellent introduction into the time decay and pressure peak levels in the case of explosive sources. I also believe the recent experimental test by Soloway and Dahl (J. Acoust. Soc. Am. Vol. 136, pp. EL222, 2014) points to a more traditional way forward that uses the Chapman results as one starting point.

> ***Response***: Thank you for directing NOAA to the Chapman (1985) and Soloway and Dahl (2014) publications, which support shock wave predictions and provide actual measurements indicating that for explosives, peak pressure scales with range and charge weight (i.e., $R/w^{1/3}$). These publications also provide information on time decay, which could be used to better support an alternative transition range for explosives. Reference to the Soloway and Dahl (2014) has been included in the updated technical write-up with the Acoustic Guidance.
>
> NOAA has further investigated the how the frequency content of impulsive sounds change with propagation (i.e., high frequencies attenuate faster than low frequencies) and agrees this is an important consideration that was neglected in the technical section that underwent peer review. NOAA has added this information to the updated technical section (i.e., as indicated by Southall et al. 2007 "The rapid rise-time characteristic of these sounds ensures that they are also broadband in nature, with the higher-frequency components being related to the rapidity of the rise-time").

Comment 45: The Chapman article treats explosive charge signal evolution for essentially an infinite medium since the geometry is such that the boundaries do not come into play. In the simplest sense in a waveguide (the reality of most experiments including the one of Soloway and Dahl as well the ones used in the section reviewed) the pressure resulting at any range due to the multiple interactions with the surface and bottom can be replaced by a series of image sources in an infinite medium. Though there are many complexities to this, the picture helps one understand that the increase in pulse duration is due to the existence of multiple replicas of the same signal that show up after the direct path. As such these multipath[s] do little to [affect] the rise time characteristics of the first arrival that, again with some simplicity, can be viewed as that examined by Chapman. This fact is evident in fig. 8 of Breitzke et al, 2008 (shown below) where the initial rise time of the earliest signal remains very short at the longer range while the pulse duration (as measured by their evaluation of SEL as a function of time window length) is much longer.

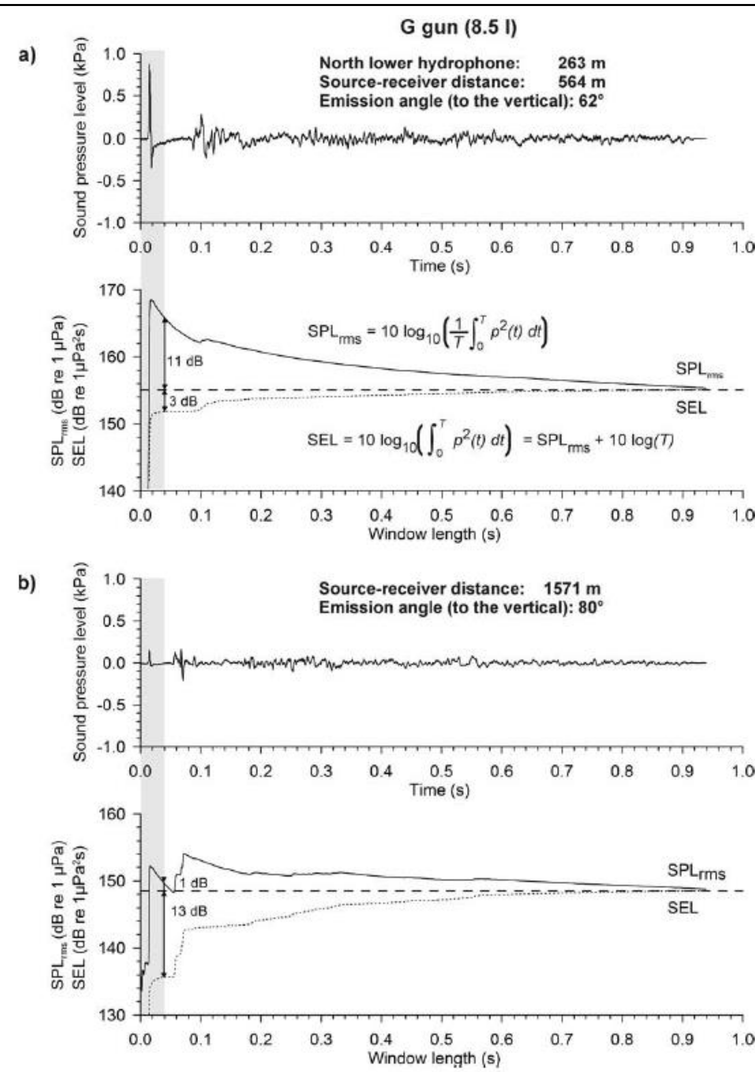

Figure 8. G-gun traces recorded at the lower northern hydrophone at (a) 564 m and (b) 1571 m source–receiver distance. Below each trace the rms sound pressure (SPL_{rms}, solid line) and sound exposure level (SEL, dotted line) are displayed as functions of window length. The formulae for the rms sound pressure and sound exposure levels are given in (a), with T = window length in s, $p(t)$ = sound pressure in µPa as function of time t. The dashed line marks the rms sound pressure and sound exposure level for a 1 s window. The grey-shaded area indicates the 40 ms window used for the computation of the rms sound pressure and sound exposure levels displayed in Figs 5 and 6.

With this in mind, it seems to me that simply retaining the peak level and SEL as metrics, as done in Soloway and Dahl, is appropriate for impulsive sound sources and a simple way forward.

Response: NOAA appreciates the Reviewer's expertise related to multipath propagation and its effects on pulse duration and rise time. The Reviewer's example from Breitzke et al. 2008 illustrates these relationships, and NOAA understands that using pulse duration as a surrogate for reflecting rise time is not entirely ideal. Nevertheless, by using both peak pressure and pulse duration in our proposed ratio, NOAA believes this ratio captures characteristics the reflect the injurious nature of impulsive sounds and how this changes with increasing distance from the source (i.e., despite the Breitzke et al. 2008 example illustrating that rise time may be similar between recordings at 564 and 1571 m from the source, the peak sound pressure level has already dropped by more than 10 dB [180 dB_{peak} at 564 m versus <170 dB_{peak} at 1571 m]).

The Reviewer has misunderstood the intent of using a ratio to evaluate when impulsive sounds start losing their more injurious characteristics. NOAA has no intent to replace the peak pressure and SEL_{cum} metric being used to assess PTS/TTS onset. Instead, the transition ratio is meant to reflect when impulsive sounds begin to develop physical characteristics making them less injurious.

Comment 46: Having said this, there still remains the question as to whether there is a correlation between the reduction in rise time of the earliest arrival and the overall pulse duration in the waveguide even though there may be little physical connection. In a general sense one can believe there is since the further the initial, direct arrival propagates the more dispersion and attenuation [affects] it and at the same time the image source time structure of the multipath changes. It is important in this regard to note that as the sound continues to propagate in the waveguide the sound structure can actually get simpler (i.e., shorter) as mode stripping occurs (or in the image source picture, sources associated with steeper grazing angles become attenuated due to multiple interactions with the bottom). This is just one indication that the details of how one may relate the phenomena will certainly be a function of many things, one of the most important probably being the range-to-depth ratio since it is important in understanding the multipath structure as a function of range in any waveguide problem.

Response: NOAA agrees that range-to-depth ratio is an important factor in understanding multipath propagation (see Response to Comment 64) and believes dispersion and attenuation effects associated with propagation contribute to impulsive sounds losing those characteristics that make them more injurious.

Comment 47: This is my, perhaps long-winded way, to say that there undoubtedly merit in the criterion being proposed by NOAA but it could be subject to a large amount of criticism since validating this merit could be difficult and is certainly a function of the details of any situation. The guidance recognizes this by using what is believed to be a very conservative range (based on data) in transitioning from impulsive to non-impulsive source calculations. However, it is difficult for me to see the need (from a purely physics standpoint, I can believe there is regulatory need) for this extra complexity (and the risk of criticism) when peak pressure and SEL would seem to suffice regardless of the nature of the source. I say this while being fully aware of my lack of understanding of the nuances in play in formulating a realistic, enforceable, set of guidelines.

I hope this viewpoint is useful. I am certainly willing to discuss this further if there is a feeling that I have misunderstood the rational and evidence presented for development and use of the guidance[4].

> ***Response***: NOAA thanks the Reviewer for this evaluation and agrees that there are multitudes of factors that would affect the ratio we are proposing. Additionally, NOAA is not advocating that the metrics of peak pressure and SEL_{cum} no longer be used. We believe these are both important metrics in determining the onset of PTS, which is why they are included in our Acoustic Guidance. Instead, the intent of the proposed transition range was to reflect better, when impulsive sounds begin to lose those characteristics that make them more injurious.

1.2.1 Ratio of Peak Pressure to Pulse Duration

<u>REVIEWER 1</u>

Comment 48: Re (footnote): "Many of the available examples included are from sound source verification studies in the Arctic from 2006 to 2012."

Not sure why this is relevant here, as the Arctic locations described are quite different from one another.

> ***Response***: NOAA agrees with the Reviewer and has removed this footnote from the text.

Comment 49: Since larger and smaller are relative terms, is it possible here to note the ratios, as in < X or > X, that help to define these terms?

> ***Response***: NOAA has provided more information to clarify the meaning of "larger" and "smaller."

Comment 50: Re: "…resulting in progressively smaller and smaller ratios."

Should just be "*progressively smaller*."

> ***Response***: NOAA has made the Reviewer's suggested edit.

Comment 51: Reisner et al. 2010 reference: Is the duration term for the 0.3 km condition correct? (showing no difference in duration between 0.3 and 1 km).

> ***Response***: NOAA has reviewed Reisner et al. 2010 to confirm that the pulse duration between measurements at 0.3 and 1 km at the Honeyguide site are correct and identical (i.e., 0.1 seconds). Upon evaluation, NOAA has confirmed that these approximations are correct. Often there is a lot of variation in pulse duration closer to the source. This is particularly the

[4] NOAA had a follow-up discussion with Reviewer 2 to clarify the intentions of the proposed ratio and that NOAA was not advocating that the metrics of peak pressure and SEL_{cum} no longer be used.

case with this study. Reisner et al. 2010 specifically noted, "The pulse duration showed much more variability at the Honeyguide site than at the Burger site."

Comment 52: Re (header): "How Ratio Relates to Marine Mammal TTS Data."

In header, I would note expand the term "ratio" for clarification, e.g., *Peak pressure/pulse duration ratio*.

Response: NOAA has made the Reviewer's suggested edit.

Comment 53: Re: "There are limited TTS studies for marine mammals exposed to impulsive sounds, and of those studies only two induced TTS…"

Suggest: "*only two induced measurable TTS*"

Response: NOAA has made the Reviewer's suggested edit.

Comment 54: Re: "…the harbor porpoise (HF cetacean), which is known to have a lower TTS onset threshold compared to most other cetaceans measured…"

A lower TTS onset for what type of noise, please clarify.

Response: NOAA has clarified the text to indicate that harbor porpoise (HF cetaceans) have lower TTS onset threshold levels for both impulsive and non-impulsive sound.

Comment 55: Since you use HF cetacean for harbor porpoise, should probably label the bottlenose dolphin and beluga as MF cetaceans for clarity..suggest "most other mid-frequency (MF) cetaceans measured…"

Response: NOAA agrees and has made the Reviewer's suggested edit.

Comment 56: Re: "…PTS onset (i.e., considered non-recoverable and would have a much higher ratio than TTS onset)."

Suggest:…"(i.e., considered non-recoverable; the equivalent ratio expressing PTS onset would have a higher value than the ratio expressing TTS onset."

Response: NOAA has made the Reviewer's suggested edit.

Comment 57: Table A.2.2. I don't know if this information on TTS is represented elsewhere in the criteria. If not, it really needs to be noted at what frequencies TTS was measured. Were they all measured at comparable frequencies (covering spectra of impulsive noise) and were they measured using similar methods? Especially for the studies failing to show evidence of TTS, it should be clear they looked at appropriate frequency bandwidth for the effect.

Response: See Response to Comment 2

REVIEWER 3

Comment 58: Concerning of peak pressure (in dB) to time scale T
Let me state upfront that while I appreciate the challenge to NOAA to provide a means to classify impulsive versus non-impulsive underwater sounds, I strongly disagree with the approach taken in the DRAFT Guidance to achieve this based on the ratio as defined in Section 2.3.2. If the ratio is formally adopted by NOAA it will invariably lead to contradictions and confusion in future policy decisions regarding noise exposure levels that can be used to predict the onset of TTS and PTS from all sound sources.

The primary reason for this conclusion is that the ratio is entirely non-physical, as it is defined by taking a logarithmic measure (peak pressure in decibels) and dividing it by a non-logarithmic measure (the time scale, T). This point can be made clear by taking a peak pressure of 210 dB, representing twice the pressure amplitude of the example of 204 dB given in the above summary. We might plausibly associate the same T = 0.087 sec to this peak pressure, for which the new ratio becomes 24138, compared with 23448. Thus, an increase in peak pressure by a factor of two only gives rise to an increase by a factor of 0.03, or 3%, change in the DRAFT ratio. Similarly, we might take a peak pressure of 198 dB, or a factor two less than 204 dB and associate the same T; here the NOAA ratio is reduced by just 3%.

> ***Response***: NOAA appreciates the Reviewer's comment and agrees that in expressing the ratio of peak pressure to pulse duration, it is more appropriate to provide peak pressure in terms of a non-logarithmic measure, such as Pascals. NOAA has made this adjustment and re-explored our proposed ratio (See Response to Comment 2, specifically modification to Table 1, where the pressure has now been expressed in Pascals). NOAA will also make this change in the technical section where a summary of impulsive sound datasets is provided.

Comment 59: Rise time ought to be more closely associated with the mathematical derivative: dP/dt, or change in pressure over change in time. An approximation for this derivative would be the ratio of change-in pressure over change-in-time, or $\Delta P/\Delta T$, where it would be reasonable to associate T (as defined above) with ΔT, and take some non-decibel measure of pressure for P in units of Pa or kPa. Therefore, in the example in going from 204 to 210 dB, where the pressure increased by a factor of two, we ought to expect a 200% change in the ratio $\Delta P/\Delta T$.

The basic problem then with the DRAFT Guidance ratio, is that this ratio is completely distorted by expressing peak pressure in dB, as shown by the example above. To see more how this distortion happens let us look at 8 arbitrary entries from Table A.2.1 of the DRAFT, and two additional values supplied by this reviewer. These entries are peak pressures in dB re 1 µP, and 90% energy duration T in sec., as given below in the first and second row, respectively. The first 6 entries are from air guns and other 2 are associated with impact pile driving. An additional 2 entries (last in the rows) are also from impact pile driving measurements computed by this reviewer [Dahl et al. 2015].

Peak Pressure (dB)	181	203	193	205	208	195	205	185	185	175
T (Sec)	0.200	0.005	0.040	0.070	0.050	0.030	0.100	0.060	0.055	0.077
Case	1	2	3	4	5	6	7	8	9	10

Figure 1 shows the ratio used in this DRAFT guidance obtained by dividing the top row of the above data by the bottom row (red squares), and another a, true ratio ΔP/ΔT, computed by first converting the decibel quantities to pressure in Pascal then dividing by T (black squares). The data are plotted in terms of test case, 1 to 10, representing the column number, from left to right, of the above data.

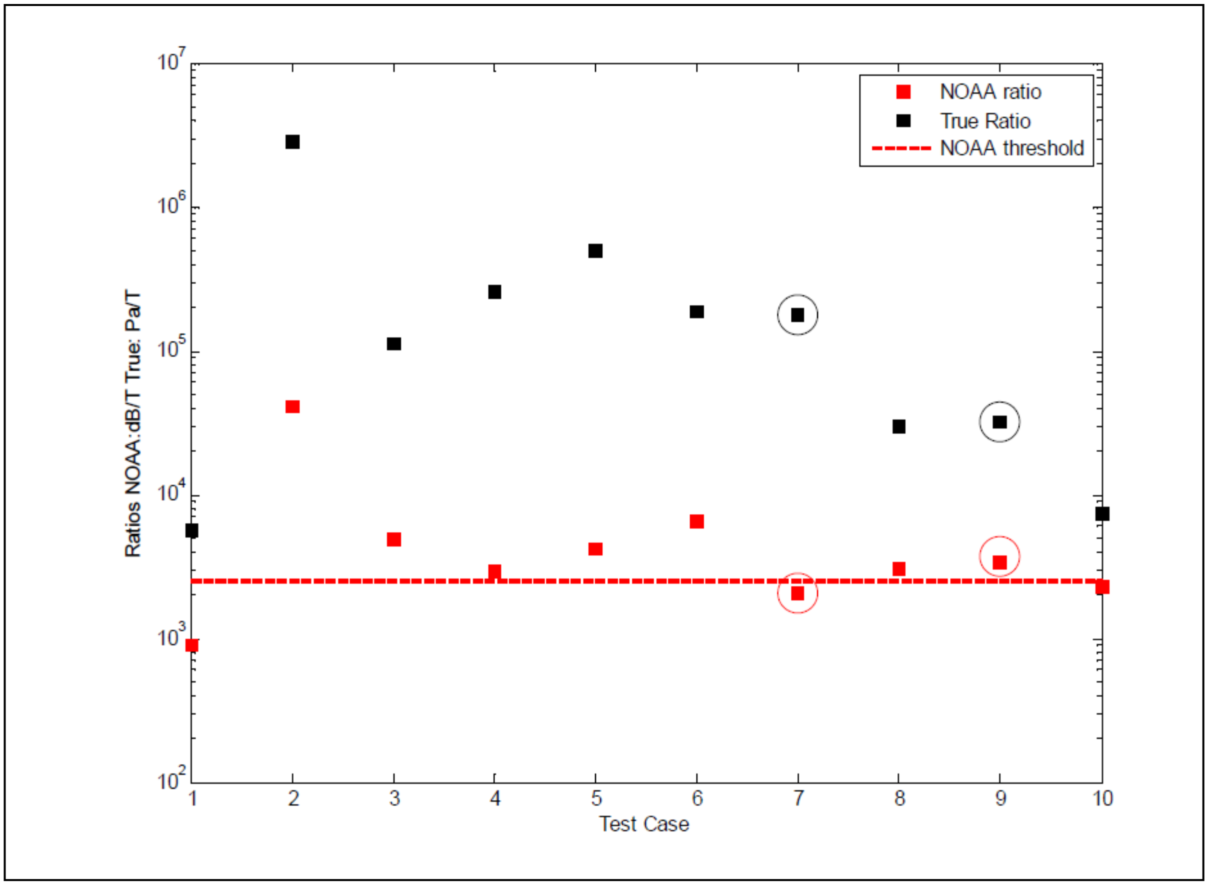

Fig. 1: Plot of data from Table A.2.1 (cases 1-8) plus data supplied by reviewer (cases 9,10). Data are plotted in terms of ratio of peak pressure in decibels over characteristic time T (NOAA ratio, red squares), and peak pressure in Pascals over characteristic time T (True ratio, black squares).

The two examples (case 7 and 9) outlined in circles correspond to peak pressure of 205 dB and 185 dB, respectively. The corresponding DRAFT ratios are 2050 and 3363-- or case 7 is below the NOAA threshold of 2500, and case 9 is above the threshold. Notice, however, in terms of the true ratio (ΔP/ΔT), it can be seen that case 7 has a significantly higher true ratio than case 9, meaning it has a much shorter rise time. It is easy find other examples from the sample of data from Table A.2.2, where the black symbols (true relation to rise time) show the opposite trend as the red symbols (DRAFT ratios), such as for cases 3 & 4, and cases 5 & 6.

> ***Response***: NOAA appreciates the Reviewer's analysis and has made the suggested change. It should be noted that the all the test cases the Reviewer used as an example for this comment were not used to establish NOAA proposed transition ratio (i.e., all the provided test cases occurred at ranges closer than the 3 km transition range, with most being much closer (0.06 to 0.35 km).

Comment 60: Re: "Nevertheless, NOAA explored using a simple ratio of peak pressure to pulse duration to gauge how these characteristics changed with range by compiling currently available datasets for high explosives, seismic airguns, and impact pile drivers (Table A.2.1)."

Non-physical analysis involving dB over time dimension.

> ***Response***: See Responses to Comments 58 and 59.

REVIEWER 4

Comment 61: In the appendix (A.2), Section/Table 1.2.1 suggest that using the ratio of peak pressure to pulse duration might be a good way to document the decrease in peak pressure and increase in impulse duration with increasing distance from the source. The report used duration as a surrogate measure of risetime, as risetime may at times be difficult to measure, and (for the most part) is not mentioned in various noise-exposure reports.

My argument against such normalization is: i) Assuming one is not in the acoustic nearfield, and assuming the environment is not highly reverberant, then with increasing distance from the source, there will be a decrease in pSPL with increasing distance from the source. Thus, adjusting for duration might not really be required. ii) I know of no data manipulating pulse duration (at least for reasonably brief duration exposures), and hence, to the best of my knowledge, using the same argument as i) above, then I see no reason to propose some sort of consideration for the duration of the impulsive sound. iii) i and ii are really in response to the human and other terrestrial mammal literature about the two types of noise-induced hearing loss.

In the first type, long-term exposure (in the case of human population studies, this is exposure over a 5-day, 40 hour work week, for 10 years, which leads to no more than a modest hearing loss in a small subset of the population so exposed. Generally, this is based on an 85 dBA exposure level). This sort of exposure is thought to result from what has bene termed historically as metabolic exhaustion, and more recently been considered to arise from the limited capabilities of free-radical scavenging in the inner ear. There is a time/intensity trade to this risk (e.g., you must halve the duration exposure for a 3- or 5- dB increase in level). In the second type, the sound level is so high that the pressure wave causes mechanical damage to the inner ear, which leads to direct damage to the sensitive transducers in the organ of Corti, and/or the mixing of endolymph with perilymph leads to damage to the epithelium.

In this scenario, only the peak level of the sound is the critical variable. Thus, to my way of viewing this literature, for longer-duration sounds the sound energy matters (and hence the duration and the level are both important. For high-intensity sounds (in the human literature sounds with peak levels above 130-140 dB pSPL), the peak level matters, as a single exposure might lead to permanent hearing loss. I believe that the metric for consideration of whether a sound is impulsive or nonimpulsive should be the crest factor (in decibels, dB pSPL- dB SPL). This is related to the measure of kurtosis as described by Hamernik and colleagues. I would think crest factors greater than perhaps 20 dB might be consider 'impulse', while those less than 20 dB are 'non-impulsive'

Response: NOAA thanks the Reviewer for the detailed comment. NOAA agrees that there will be decreasing peak pressure levels with increasing distance from the source. Within the Acoustic Guidance, has provided PTS onset acoustic thresholds levels in both the peak pressure and cumulative sound exposure level metric (dual metrics) to address both of the types of noise-induced hearing loss mentioned (i.e., metabolic exhaustion and mechanical damage).

Regarding the Reviewer's comment about the need to consider duration, as mentioned above, NOAA agrees peak pressure is a critical metric for assessing noise-induced hearing loss. NOAA also agrees with the Reviewer and is unaware of studies specifically manipulating pulse duration. However, NOAA believes relying strictly on peak pressure alone does not provide a practical means of determining when an impulsive sound begins transition to having more non-injurious characteristics. Furthermore, NOAA has established peak pressure acoustic thresholds levels (dual metrics) for both impulsive and non-impulsive sources that are identical and have been based on marine mammal TTS studies using impulsive sources (i.e., NOAA's peak pressure acoustic threshold levels do not distinguish between impulsive and non-impulsive sounds). It is for these reasons that NOAA explored using another characteristic (i.e., pulse duration) to provide information as to when impulsive sounds begin to transition to being less injurious (i.e., ratio of peak pressure to pulse duration is not intended to determine PTS onset, which will continue to rely on the peak pressure and cumulative sound exposure level metric).

NOAA initially considered using the metric of crest factor (difference in decibels between peak sound pressure amplitude and means-square pressure amplitude between; ANSI 2008) to when impulsive sounds began to develop characteristics making them less injurious. Based on the Reviewer's comment, NOAA further explored crest factor. Based on available datasets, crest factor did not prove to be a consistent or reliable metric indicating when impulsive sounds began transitioning to having less injurious characteristics (i.e., crest factor remained relatively unchanged close to source and up to distances 10+ km from the source). It should be noted that crest factor is typically used to distinguish impulsive sounds from non-impulsive sounds close to the source (i.e., not typically used to distinguish the transition to having less injurious characteristics and accommodate the changes associated with the characteristics of sounds as they propagate through the environment).

1.3 Recommended Transition from Impulsive to Non-Impulsive Acoustic Threshold Levels

REVIEWER 1

Comment 62: This might be worded more clearly, e.g.:

"*Based on previously reported characteristics of impulsive sound sources propagating through marine environments – including decrease in peak pressure, increase in pulse duration, and ratio of peak pressure to pulse duration – and available marine mammal TTS onset data for impulsive sounds, NOAA has approximated that a ratio of 2500 is…*"
It is not clear how NOAA got to 2500 as the ratio to use. I realize that this is a rough and conservative approximation, but perhaps some specific reference points can be provided (for example, 2500 is lower than the ratio reported in table A.2.2 for harbor porpoises and bottlenose dolphins showing TTS, but its higher than the ratios reported for these and other species that did not show TTS). Is this the way the number was chosen? Or else explain some other way. Also, it seems like this section should refer back to acoustic threshold levels in some way (given the section header and goals of this section) but it doesn't.

> ***Response***: NOAA has included more explanation in how it chose the ratio we are using to inform the distance where impulsive sounds begin to lose those characteristics that make them more injurious. Note: Since peak sound pressure levels, associated with the Acoustic Guidance's ratio, have now been expressed in Pascals (opposed to decibels), this ratio is no longer 2500. Nevertheless, the Reviewer's comment is still valid.

Comment 63: Re (header): Recommended Transition from Impulsive to Non-Impulsive Acoustic Threshold Levels."

Suggest that this should include "based on peak pressure to duration ratio"

> ***Response***: NOAA has made the Reviewer's suggested edit.

REVIEWER 3

Comment 64: Concerning of threshold range of 3000 m
Impulses spread out in time due to multiple reflections from the sea surface and seabed. The DRAFT Guidance states a single value for range, 3000 m, as a point beyond which the signal has spread out in time and is less likely to be of biological significance.

However, the degree to which this happens is much more reliably predicted by a threshold number that includes both range, R, and characteristic depth, H, such as R/H which gives number of characteristic depth scales, rather than an arbitrary range value of 3000 m. The ratio R/H will be a much better predictor of the multi-path time spreading of an impulsive signal due to interaction with the sea surface and seabed. For example, if depth H is very shallow, say 10 m, then time spreading will be very different at given range than were the depth to be 1000 m.

> ***Response***: NOAA agrees that impulses spread in time due to multipath propagation and chose 3 km as a conservative point as to where an impulsive sound would be less injurious. NOAA agrees that sound propagation is highly dependent on the range (R) and depth (H) and that this ratio can be useful in predicting multipath time spreading (i.e., more multipath arrivals in shallower water and with higher R/H ratios). NOAA will suggest that this ratio be considered by action proponents in the application of the transition range. Furthermore, NOAA has provided additional justification in its selection of the appropriate transition range.

Comment 65: Re: "Based on previously measured characteristics of impulsive sounds in a variety of environments (decrease in peak pressure and increase in pulse duration; ratio of peak pressure to pulse duration; previous marine mammal TTS onset data for impulsive sounds), NOAA has approximated that a ratio of 2500 is representative as to where most impulsive sound sources begin to transition to having physical characteristics less likely to result in auditory injury. Based on this ratio, NOAA is recommending 3 km from the source be considered a conservative estimate of transition range. For most sounds, where data are available, a ratio of 2500 typically occurs much closer to the source than our recommended 3 km transition range (i.e., <2 km)."

This is completely flawed, non-physical and ad hoc ratio.

> ***Response***: NOAA has provided additional justification in this technical section to support its selection of a 3-kilometer transition range.

Comment 66: Recommendations

1. The ratio defined in the DRAFT Guidance equal to peak pressure expressed in dB divided by time T, should be revised because the logarithmic measure (dB) distorts the ratio. This ratio is fundamental to this segment of the DRAFT Guidance and should be re-assessed.

> ***Response***: NOAA agrees and has revised its ratio to reflect peak pressure in terms of Pascals, instead of decibels (See Responses to Comments 58 and 59).

Comment 67:

2. In any revision, dual criteria should be incorporated, combining: (1) peak threshold in decibels, e.g., a threshold > 190 dB, plus (2) a true (non-decibel) time ratio $\Delta P/\Delta T$. The dual criteria will define more appropriately the parameter space of interest, and lead to a more robust criterion for establishing TTS and PTS

> ***Response***: NOAA's Acoustic Guidance provides PTS onset acoustic thresholds levels using the peak sound pressure level metric, as well as a cumulative sound exposure level metric. NOAA's intent with the technical section that underwent peer review was to establish a

simple methodology to determine when impulsive sounds begin to transition to being less injurious at further distances from the source and have incorporated the Reviewer's recommendation of using a "true (non-decibel) time ratio."

Comment 68:

3. A limited, focused study should be undertaken where the performer in study works with NOAA and is supplied the PTS and TTS observational data base. Goal of study is to identify a more appropriate linear-based ratio derived from the true ratio ($\Delta P/\Delta T$) and corresponding threshold. This linear-based ratio will more clearly identify biologically significant rise time. The performer should also be familiar with the technical literature associated with multi-path time spreading of an impulsive signal due to interaction with the sea surface and seabed.

Response: NOAA has identified data gaps and added research recommendations to the Acoustic Guidance based on comments received during this peer review, including those mentioned by the Reviewer in this comment.

Comment 69:

4. Many references are out of date. A recent one [Soloway and Dahl 2014] on explosive sources in shallow water can be brought to bear on both issue of peak pressure and time scale T. Additionally, there are at least five, fully-refereed, works on impact pile driving published in the J. Acoust. Soc. of Am., since 2011, none of which are utilized here.

Response: The Soloway and Dahl (2014) publication has been consulted (See Response to Comment 44). In regards to including updated publications on pile driving, see Response to Comment 39.

REVIEWER 4

Comment 70: I believe this guideline regarding impulsive versus non-impulse sounds should consider relevant weighting functions. At the very least, using underwater average threshold curves for classes of marine mammals for those that are low-frequency, mid-frequency, moderately high frequency, and high frequency animals could be used to create relevant weighting functions. I believe the (rms) SPL should be appropriately weighted by hearing ability, but arguments can be made to either use the same weighting function for the measure of pSPL, or to use Z-weighting (linear) for the pSPL estimate.

Response: NOAA's Acoustic Guidance does incorporate marine mammal auditory weighting functions for the SEL_{cum} metric acoustic threshold levels and divides marine mammals into five functional hearing groups (low-, mid-, and high-frequency cetaceans and underwater phocid and otariid pinnipeds). The Acoustic Guidance's peak pressure acoustic threshold levels are unweighted because direct mechanical damage associated with sounds having high peak pressures typically does not strictly reflect the frequencies an individual species hears best (Ward 1962; Saunders et al. 1985; ANSI 1986; DOD 2004; OSHA 29 CFR 1910.95).

Comment 71: Guidelines for impulsive noise exposure is challenging because it is based on very little data, not only in marine mammals, but also in terrestrial mammals. Much more anatomical, physiological and behavioral data regarding exposure to impulse noise is needed in terrestrial mammals, which could likely be generalized to marine mammals with similar audiograms. As stated above, we need evidence about the dependence of permanent threshold shift/anatomical changes on impulse duration and/or risetime.

> ***Response***: NOAA agrees with the Reviewer's assessment that establishing marine mammal acoustic threshold levels for impulsive source is challenging and that there are limited data available. The Reviewer's suggestion that more data are needed regarding the anatomical, physiological and behavioral impacts of impulsive sounds on marine mammals has been added to the Acoustic Guidance's Appendix on Research Recommendations, which identifies critical data gaps.

Comment 72: [In] humans, 80-90 dB SPL might be considered to be the noise level where one is at risk, long term, for permanent threshold shift for continuous noise, where pSPL at 130-140 dB and above put the patient at risk for permanent threshold shift. Perhaps this 50 dB difference should be considered the difference between the impulsive/non-impulsive sounds for marine mammals, at least until better empirical data in marine mammals is available. If we accept 180-190 dB SPL for non-impulse noise is marine mammals as the upper limit, then for impulsive noise, this limit would then be on the order of 220-230 dB pSPL.

> ***Response***: It was unclear in the Technical Section that was peer-reviewed that NOAA's Acoustic Guidance has established PTS onset acoustic threshold levels for both impulsive and non-impulsive sounds based on available marine mammal studies. Furthermore, the Acoustic Guidance's threshold level for PTS onset expressed in the peak pressure metric is 230 dB for all functional hearing groups based on data from a beluga exposed to a watergun (Finneran et al. 2002), except high-frequency cetaceans where a lower threshold is presented (Lucke et al. 2009).

Literature Cited (as referenced within Peer Review Report)

ANSI (American National Standards Institute). 1986. Methods of Measurement for Impulse Noise (ANSI S12.7-1986). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2005. Measurement of Sound Pressure Levels in Air (ANSI S1.13-2005). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2008. Bioacoustical Terminology (ANSI S3.20-1995).New York: Acoustical Society of America.

Blackwell, S.B., J.W. Lawson, and M.T. Williams. 2004. Tolerance by ringed seals (*Phoca hispida*) to 24 impact pipe-driving and construction sounds at an oil production island. Journal of the 25 Acoustical Society of America 115:2346–2357.

Breitzke, M., O. Boebel, S. El Naggar, W. Jokat, and B. Werner. 2008 Broad-band calibration of marine seismic sources used by R/V *Polarstern* for academic research in polar regions. Geophysical Journal International 174:505-524.

Caltrans (California Department of Transportation). 2012. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. Appendix I: Updated Compendium of Pile Driving Sounds. Sacramento, California: California Department of Transportation.

Chapman, N.R. 1985. Measurement of the waveform parameters of shallow explosive charges. Journal of the Acoustical Society of America.

Dahl, P.H., and P.G. Reinhall. 2013. Beam forming of the underwater sound field from impact pile driving. Journal of the Acoustical Society of America 134:EL1-EL6.

Dahl, P.H., P.G. Reinhall, and D.M. Farrell. 2013. Transmission loss and range, depth scales associated with impact pile driving. Edinburgh, Scotland: Proceedings of the 11th European Conference on Underwater Acoustics.

Dahl, P.H., C.A.F de Jong, and A.N. Popper. 2015. The underwater sound field from impact pile driving and its potential effects on marine life. Acoustics Today, Spring issue 2015, *in press.*

DOD (Department of Defense). 2004. Department of Defense Instruction: DOD Hearing Conservation Program (HCP). Washington, D.C.: Department of Defense.

Duncan, A.J., and R.D. McCauley. 2008. Environmental Impact Assessment of underwater sound: Progress and pitfalls. Proceedings of Acoustics 2008, 24-26 November, Geelong, Australia. Kensington, Australia: Australian Acoustical Society. 6 pp.

Dunn, D.E., R.R. Davis, C.J. Merry, and J.R. Franks. 1991. Hearing loss in the chinchilla from impact and continuous noise exposure. Journal of the Acoustical Society of America 90:1979-1985.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. Journal of the Acoustical Society of America 111:2929-2940.

Greene, R., and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. Journal of the Acoustical Society of America 83:2246-2254.

Lippert, T., and O. von Estorff. 2014. The significance of parameter uncertainties for the prediction of offshore pile driving noise. Journal of the Acoustical Society of America 136:2463-2471.

Lippert, S., T. Lippert, K. Heitmann, and O. von Estorff. 2013. 2pUWa7. Prediction of underwater noise and far field propagation due to pile driving for offshore wind farms. Proceedings of Meetings on Acoustics 19:1-9.

Lucke, K., U. Siebert, P.A. Lepper, and M-A.Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America 125:4060-4070.

NIOSH (National Institute for Occupational Safety and Health). 1998. Criteria for a recommended standard: Occupational noise exposure. Cincinnati, Ohio: United States Department of Health and Human Services.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, M.B. Halvorsen, S. Løkkeborg, P.H. Rogers, B.L. Southall, D.G. Zeddies, and W.N. Tavolga. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1. New York: Springer.

Reinhall, P.G., and P.H. Dahl. 2010. Acoustic radiation form submerged pile driving during pile driving. Seattle, Washington: Proceedings of the 2010 IEEE/MTS Oceans Conference.

Reinhall, P.G., and P.H. Dahl. 2011a. Underwater Mach wave radiation form impact pile driving: Theory and observation. Journal of the Acoustical Society of America 130:1209-1216.

Reinhall, P.G., and P.H. Dahl. 2011b. An investigation of underwater sound propagation from pile driving. WSDOT Research Report WA-RD 781.1. Seattle, Washington: Washington State Department of Transportation.

Reiser, C. M, D. W. Funk, R. Rodrigues, and D. Hannay. 2010. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore, Inc. in the Alaskan Chukchi Sea, July–October 2009: 90-day report. LGL Rep. P1112-1. Rep. from LGL Alaska Research Associates Inc. and JASCO Research Ltd. for Shell Offshore Inc., Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 104 pp, plus appendices.

Saunders, J.C., S.P. Dear, and M.E. Schneider. 1985. The anatomical consequences of acoustic injury: A review and tutorial. Journal of the Acoustical Society of America 78:833-860.

Soloway, A.G., and P.H. Dahl. 2014. Peak sound pressure and sound exposure level from underwater explosions in shallow water. Journal of the Acoustical Society of America.136: EL218-EL223.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33:411-521.

Stockham, M.L., P.H. Dahl, and P.G. Reinhall. 2010. Characterizing underwater noise form industrial pile driving at close range. . Seattle, Washington: Proceedings of the 2010 IEEE/MTS Oceans Conference.

Walker, J.G., and A. Behar. 1971. Problems associated with the reproduction of impulse noise for TTS studies and impulse noise measurements. Journal of Sound and Vibration 19:349-354.

Ward, W.D. 1962. Damage-risk criteria for line spectra. Journal of the Acoustical Society of America 341610-1619.

Zampolli, M., M. J.J. Nijhof, C.AF. de Jong, M.A. Ainslie, E.H.W. Jansen, and B.A.J. Quesson. 2013. Validation of finite element computations for the quantitative prediction of underwater noise from impact pile driving. Journal of the Acoustical Society of America 133:72-81.