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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

MEMORANDUM REPORT 80-1

ON THE EFFECTS OF EXPOSURE TO INTENSE UNDERWATER SOUND ON NAVY DIVERS

A Report of a Conference on the Bio-Effects of Sound

by

Paul F. Smith

and

William L. Hunter, Jr.

Naval Medical Research and Development Command
Research Work Unit M0099.PN.003-3155

Released by:

R. A. Margulies, CDR, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

20 February 1980

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28 APR 1980

SUMMARY PAGE

THE PROBLEM

To determine potential risks to the health of Navy divers from exposure to intense sound in water.

FINDINGS

There is insufficient experimental evidence to conclude that there is no biological hazard to divers exposed to intense sound under water at levels currently permitted. Decompressing divers may be at risk. Further research is required to establish safe underwater noise dosage levels.

APPLICATIONS

These findings contribute toward the establishment of long-term health standards for exposure of divers to underwater sound.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Naval Medical Research and Development Command Research Work Unit Number M0099.PN. 003-3155 - "The effects of whole body exposure to underwater sound on the health of Navy divers." The present report was submitted for review in January 1980, approved for publication on 20 February 1980 and designated as NavSubMedRschLab Memo Report Number 80-1.

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ABSTRACT

A conference was held to discuss the effects of intense water-borne sound on the health of Navy divers. The participants were personnel from Navy laboratories who have conducted research on various aspects of the problem and persons from various academic institutions who are experts in bio-medical ultrasonics. Mechanisms which might provide harmful effects in divers were identified and research approaches which would be fruitful in establishing safety standards for underwater noise exposure were outlined.

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Introduction

As part of an investigation of the effects of whole-body exposure to underwater sound on the health of Navy divers, a meeting with bio-acousticians was arranged through the auspices of the American Institute of Biological Sciences. The attendees (see Appendix A) included five consultants who are authorities on the biological effects of ultrasound, two representatives of the Naval Ocean Systems Center (NOSC) and the two authors of this report.

The consultants were selected on the basis of their particular experience in research in medical ultrasonics. Of the five consultants selected two have extensive research experience in the lower kilohertz (kHz) frequency range, the range of interest here. Three men are members of the American Institute of Ultrasound in Medicine's panel on safety in diagnostic ultrasound, a group which is attempting to develop exposure guidelines for ultrasonics. One of the consultants has extensive experience in bio-medical telemetry as well as in ultrasonics, and has worked with the Navy through the Naval Studies Group of the National Academy of Sciences - National Research Council on several aspects of diving technology including studies on the exposure of divers to intense underwater sound. One consultant has previously advised on this project and has conducted a study on the relevance of biomedical ultrasonics research to the establishment of safety standards for underwater sound exposure. All of the consultants are internationally recognized leaders in the field of bioacoustics. It was felt that this particular group could provide a fresh look at the problem of underwater sound exposure and could provide guidance for a systematic approach to the problem of establishing safety standards for such exposures.

The two NOSC representatives have conducted research on the effects of intense underwater sound on the lungs of mammals.

While there are many other individuals whose participation in this effort might have been of great value it was decided to keep the number of participants small in order to facilitate communications.

With few exceptions, past Navy efforts to assess the hazards of exposure to intense sound in water have been sporadic. Some efforts have been directed toward the development of acoustic swimmer determent systems. Those were attempts to develop devices which would immediately disable divers and swimmers either physically or psychologically. Long-term health effects were not considered (Hunt, 1978). Some work has been done in connection with the development of diver tracking systems, hand-held sonars, and diver detection systems. These efforts gave no more than slight considerations to health problems. Christian and Gaspin (1974) have recommended safe standoff distances for swimmers from underwater explosions based on extensive previous analytical work by Christian and others and experimental work by Richmond et al. (1970, 1973, Yelverton et al., 1973). This latter area (blast) is beyond the scope of the present investigation. The only systematic approach of the long-term health effects of underwater expsoure to intense sound was work at NSMRL (Smith, 1969; Smith and Linaweaver, 1966; Smith et al., 1970), but it was concerned primarily with establishing hearing conservation standards for specific sonar systems.

This report is based on transcriptions of tape recordings made during the meetings. In most cases discussions are summarized rather than presented verbatim. In some cases statements are attributed to particular participants. However, since the attendees have not been given an opportunity to review the material, the authors of this report are solely responsible for its contents.

FIRST SESSION

The meeting convened at 1:00 P.M., Thursday, 14 September 1978, in the Physics Department of the University of Vermont, Burlington, Vermont. Dr. Nyborg, who graciously consented to host the meeting, made introductions. Then, the ground rules for the meeting were discussed. The agenda was to be informal, and no classified material was to be discussed.

Mr. Smith presented background information on the problem. The Portable Acoustics Tracking System (PATS) was described. The PATS transducer produces a signal at a frequency of 31.25 kilo-Hertz (kHz) at an output power of 100 acoustic watts. The signal consists of a 10 millisecond (msec) pulse emitted once a second. Exposure durations for a single dive or excursion from a habitat may be as long as six hours. The transducer is mounted between the diver's SCUBA bottles and is therefore only a few cm from the divers's body and less than .5 m from the diver's head. Under anticipated normal operating conditions a diver wearing a wet suit may not be exposed to sound intensities capable of producing catastrophic trauma. However, the effect of chronic exposure to such sound fields on the health of divers is not known. There may also be a question of performance interference.

It was pointed out that although PATS was of immediate concern other systems may also be hazardous and discussions should be general in nature. The present concern is with sound in the 1 to 100 kHz region orginating from various large scale sonar systems, special purpose sonars, and diver tracking systems. Attention is restricted to devices producing sinusoidal signals in pulses of a few to a few thousand milliseconds (msec) and to continuous (CW) transmission.

Next, Dr. Rooney presented his findings (see Rooney 1978). In keeping with the informality of the meeting, Dr. Rooney's paper was discussed on-the-run, so to speak.

Dr. Rooney had been contracted by NSMRL to provide the following:

1. Citations and evaluations of the world's literature on the effect of ultrasonics on water-immersed tissues.

2. Derivation of transfer functions so that, if at all possible, the mega-Hertz region can be used in prediction for the kilo-Hertz region. The parameters of interest are: (1) frequency of range of 1 to 100 kHz; (2) pulse lengths of 1 to 5000 msec; (3) duty cycles up to 50 percent.

3. Development of a conservative interim Damage Risk Criterion (DRC) in terms of power in Watts at 31.25 kHz for a duration of 6 hours, which should be innocuous on the basis of current knowledge, however scanty.

4. Development of an animal model or models which should provide a firm base for a final DRC.

5. Comment on the animal experiments which should be successfully undertaken before exposing a Navy diver to the currently-projected PATS output.

6. Comment on the systems of the body of a Navy diver which should be examined when he is exposed to the PATS output at less than full power.

Of particular interest was a calculation by Rooney that, given a pre-existing bubble of 100 microns radius, an intensity of .1 milliwatt per square centimeter ($mWcm^{-2}$) at 31 kHz would be required to drive the bubble with sufficient displacement amplitude to produce shearing stresses capable of damaging cellular systems in aqueous suspensions. This led to a discussion of whether or not bubbles of this size might be found in tissues of divers. Dr. Hunter reviewed current decompression theory and practice citing recent work at Duke University supporting the theory that gas nuclei do in fact exist in divers tissue at all times. Dr. Carstensen cited work of his laboratory in which the absorption coefficient for excised liver was reduced by a factor of 10 on return to surface pressures following compression to 500 psi for 30 minutes. Hunter then also cited Hill's theory that existing decompression practice allows bubbles to form in a decompressing diver. The implication of current decompression theories is that gas bubbles, or at least nuclei (collections of gas molecules) are present all the time, not just during decompression. Although the PATS pulse length (10 msec) is perhaps too short to induce bubbles through rectified diffusion (that taking many cycles) the pre-existence of gas nuclei raises the serious question of whether PATS pulses could cause these bubbles to grow beyond a critical size with ambient pressure remaining unchanged (that is, the diver not ascending).

There was also some discussion concerning thermal effects. When sound passes through any medium acoustical energy is converted to thermal energy. The extent of this conversion is described by the absorption coefficient (α) of the medium. As Rooney points out α theoretically varies as the square of the frequency. At low frequencies α would be much smaller than at higher frequencies. In the frequency range of interest (1 to 100 kHz) Rooney concluded that thermal effects would not be important. Further discussions following Duyker's presentation (see below) led to a modification of this view, at least for long exposures at high intensities.

Rooney also raised the question of the effects of diver's dress on the sound intensity reaching the diver's body. Any suit providing an impedance mismatch between the water and the diver's body would be expected to provide significant protection for the diver.

Montague and Strickland (1961) and Smith (1969) have found that wet suit hoods attenuate sound by 15-35 dB at 1-8 kHz. At higher frequencies the attenuation might be greater but measurements have not been made in this frequency range.

Dr. Nyborg presented a series of films demonstrating the effects of sound on plant cells and blood platelets in the presence of gas bubbles and membranes with holes.

The session adjourned.

SECOND SESSION

The second session convened in the evening of 14 September 1978, at the Sheraton-Burlington Motel.

Work done by Messrs. Percy and Duykers of NOSC on the effects of sound on mammals was presented by Duykers. Measurements of lung resonances were made for dolphin (Tursiops truncatus), domestic swine and human divers. During the tests on one diver at frequencies below 100 Hz, the diver (head above water) reported sensations of vibration in the chest at a Sound Pressure Level of 135 dB re 1 microPascal (μPa) (measured 2 m from the diver). The lung resonance frequency for this diver was found to be at 70 Hz. Subsequent tests on seven Navy divers at depths of 6 m using a variety of breathing apparatus and either wet suited or unsuited, the resonance frequency was found to be between 30-40 Hz which agrees with calculated values.

Initial work with the domestic swine investigated high intensity exposures of 3-7 kHz and 40-80 Hz, the latter region being that in which total lung resonance of domestic swine had been found. The 3-7 kHz exposures at SPLs 191-214 dB above 1 microPascal (μPa) for 30-90 sec, appeared to produce slight but consistent alveolar damage. The low frequency tests (also at lower SPLs) produced no damage.

No control animals were used. That is, there was no sham treatment group. Thus, the possibility that the effects observed were due to the respiratory health of the animals or to respiratory stress imposed by the experimental procedure cannot be ruled out. Duykers feels that the animals run at low frequencies (no damage) might be considered as controls for those run at higher frequencies. However, these two experiments were done approximately one year apart and it is not certain that the animals used in the two tests were truly comparable. It was stated by Duykers that at least some of these animals were survivors of a previous (biochemical) research project.

Assuming that the observed damage was due to insonation, the question arose as to whether the effect was due to resonance or to some other mechanism. This is an important point because unless the mechanism is clearly known it is impossible to predict effects in other mammals, specifically, human divers. For example, Duykers and Percy, concluding that the effect was due to alveolar resonance, predict that, since the average alveoli diameter in human lungs is 250 μ (corresponding to a resonance frequency of 26 kHz), the frequency region from 21 to 31 kHz could be harmful to divers. However, if the damage was due to a thermal effect this particular prediction would be invalid.

Given the very high intensity used (10-50w/cm^2) and the very high attenuation coefficient of lung tissue the possibility that the damage observed by Duykers and Percy was due to a thermal effect cannot be ruled out. That the effect was due to resonance has not been demonstrated. For example, it was pointed out that the "alveoli resonance" was measured with an excised whole lung but that the exposure was for a live, intact swine. Because the surrounding tissue may modify (by damping) the resonance of the lung it is not certain that the resonance observed in the excised lung is that which would occur in the intact lung. There was also a question raised as to whether alveoli would exhibit resonance or whether the lung as a whole would control the motion of the individual alveolar walls. The procedure used to observe alveolar resonance in the excised lung was also questioned. In addition, it was pointed out that in order to demonstrate that the damage was due to resonance one would have to show that the effect occurs only in a particular frequency range and that it occurs to a lesser extent or not at all at other frequencies at the same intensity. There followed some discussion of the absorption coefficient of lung tissue. Attenuation coefficients for swine lung tissue have not been reported. For human lung tissue a value of 30 dB/cm has been reported for 1 MHz (Goss, et al., 1978). Because of the high α for lung tissue it was generally concluded that a thermal mechanism could not be ruled out.

The question was raised as to what implications this work might have for Navy divers. First, considering the PATS system, the lowest exposure duration used by Percy and Duykers at 7.5 min. continuous transmission corresponds to 12.5 hours exposure to PATS (10 msec pulses, 1 per second). Secondly, the interpulse interval may permit dissipation of heat (if the effect is thermal) or recovery of function (circulatory) if the effect is due to resonance. Third, divers using PATS would most likely be wearing wet or dry suits which would offer some protection from the sound. Fourth, the PATS transducer is presumed not to be mounted directly on the diver's body as was the case with the swine. Thus, it would seem that the PATS system would produce lesser damage than the conditions used by Duykers and Percy. However, there is no basis in the NOSC data for estimating what exposure to PATS would produce no damage what-so-ever.

It was also generally agreed that the NOSC research raises serious questions concerning the safety of exposure to PATS and similar systems.

It was agreed further that the work should be extended to explore other exposure parameters and other tissues with due consideration for the points of criticism raised above.

THIRD SESSION

The third session convened at 0800 Friday, 15 October 1978, in the Department of Physics, University of Vermont.

There was some discussion as to the maximum exposure levels a diver might encounter. In a free field (that is, sound source not in contact with the diver) the maximum exposure intensity would be limited by cavitation phenomena occurring in the water. Near the surface in sea water, cavitation occurs at intensities of about 1/3 watt/cm^2. However, the intensity at which cavitation will occur increases with depth. Thus, at a depth of 200 m divers could be exposed to some 10s of watt/cm^2 if sufficiently powerful transducers were employed.

Normally, divers will be wearing either wet or dry suits which would provide considerable protection from the waterborne sound but the attenuation provided by such suits is not known.

It was suggested that the problem of cavitation be considered in three cases:

1. The case of pre-existing bubbles or gas nuclei in tissue. Effects may be expected at very low levels.

2. The case of sonically induced cavitation in tissue. Large powers and pulse lengths are required to generate bubbles.

3. The case of cavitation occurring in the medium. Rupture of the water may have certain surface effects on divers but may also serve a protective function since such cavitation limits the sound intensity possible.

Consideration was next given to proposed hearing conservation standards for exposure to sonar in the 3-5 kHz range. It is known that in this frequency region the hearing threshold sound pressure level in water is approximately 60 dB greater than in air. And it has been shown that the sound pressure levels required to induce comparable amounts of temporary threshold shift differ by about 68 dB in the two media. Hearing conservation standards currently in effect permit exposure to 85 dB(A) (referred to 20 μPa) for eight hours a day and to 110 dB(A) re 20 μPa for 15 minutes a day. Comparable permissible exposure levels in water may be obtained by adding 60 dB to these values. This (and a change of reference level) yields permissible underwater exposure levels of 171 dB re 1 μPa (8 hours/day) and 196 dB re 1 μPa for 15 minutes a day. Divers' hoods act as fairly effective underwater ear defenders and based on measured attenuation of divers' hoods at these levels an allowance of 20 dB is made. Hence for a hooded diver 15 minutes exposure per day to a sound pressure level of 211 dB re 1 μPa would be permitted. These limits would be for exposure to continuous transmissions. For discontinuous operation the exposure duration may be extended as a function of duty cycle. For a 3% duty cycle a diver could be exposed up to 8 hours.

Such a standard would be proposed on the basis of what is known about underwater hearing. Apart from unpublished NSMRL data on extra-auditory perceptions which might affect divers' ability to work in such intense sound fields no other information is considered. The question was asked of the consultants as to whether or not it was likely that significant biologic effects (other than effects on hearing) might occur at such levels. If so, ought these be considered as long-term health hazards to the divers. The consensus was that insufficient information is available to make a judgment. The possibility was discussed that if hearing is not affected perhaps no other organ systems would be affected on the assumption that the ear, being specialized for sound reception, is the most sensitive body system. But there is no evidence that in water the ear is the most sensitive organ. On the contrary, it is known that, on an intensity basis, the ear is 30-35 dB less sensitive to sound in water than to sound in air. It has also been observed (unpublished NSMRL data) that, contrary to the situation in air, underwater exposure to shock waves produces reddening of eardrums and other symptoms in the absence of any reportable or measurable auditory effect (tinnitus and/or temporary threshold shift).

Noting again that the intensities at which bubbles may be driven to sufficient amplitude to damage cells is .1 μ w/cm^2 the proposed standard would permit exposure of a diver to this level (approximately 182 dB re 1 μPa) for almost two hours. Thus, the standard would permit exposures which are in the area of concern. For decompressing divers it was felt the exposure levels may indeed constitute a health hazard. However, on the basis of some years of experience with an existing Navy exposure standard, it is known that exposure at these levels is not disturbing to wet suited divers.

In order to establish safety standards for such exposure it is first necessary to determine certain basic parameters. For example, the measurement of absorption in various tissues in this frequency range is necessary in order to predict what thermal effects might occur with these exposure levels. Whole body exposure studies using either divers or animal models are not appropriate at this point. The most economical approach to the problem is on the basis of mechanisms involved. Mechanisms of interest must be identified on a theoretical basis. To attempt to identify bio-effects using whole body animal exposures would take enormous amounts of time and money. Of the mechanisms discussed, thermal effects perhaps ought to be investigated initially, it being the easiest to do, and perhaps the most important. It is probable that the tissue most affected by thermal effects are lungs and bones.

On the other hand, bubble activity (cavitation phenomena) based on pre-existing bubbles might be most important for a diver for whom pressure is decreasing (coming up toward the surface). In this case effects may occur in the circulatory system at rather low intensities. The so-called STASIS phenomenon occurs in short times (in millisecs) at intensities of 1 watt/cm^2. This may be of little consequence considering the wave lengths involved.

Another phenomenon, perhaps the most critical one, which has been observed is of the aggregation of blood platelets at quite low intensities. There is also some indication that in a decompressing diver platelets appear to aggregate on bubbles and that these aggregates persist after the bubbles disappear. The possibility exists then of a synergistic action of sound at relatively low intensities and pressure changes on the formation of such aggregates.

Dr. Nyborg presented a short film on the clumping of platelets in ultrasonic fields. A brief tour of Dr. Nyborg's laboratory followed.

It having been established by this point that it is possible that some long-term health hazard exists it is necessary to formulate an approach to the problem.

The consultants were asked to present in summary fashion their thoughts regarding what needs to be done in order to establish health standards for exposure to underwater sound.

Dr. Rooney's recommendations are incorporated in his report (Rooney 1978).

Dr. Carstensen feels it is necessary to follow a mechanistic approach in order to reach reasonable conclusions in a reasonable amount of time. It is useful to look at the problem in two separate categories. One of these is the kind of process that will occur when bubbles pre-exist at a size that will resonate with the sound to which the subject is exposed. In that particular case it may turn out that extremely low sound levels will produce biological effects. That category of problems will have to be solved in terms of determining what is the probability that you will find a bubble of the right size and that, statistically, there is the chance that there will be an important effect. It is a very difficult class of problems. First of all, because these effects are very subtle and the very thing that one has to find out first (what is the distribution of bubbles?) is a wide open subject at the moment. The second category will be relatively easier to solve and this would be the category in which acoustic cavitation occurs inside the body. The approach there is to find out what the maximum sound levels are that will be anticipated in a diver. On the basis of physical principles, you can estimate the maximum sound levels that will be found in a diver's body. This will be determined by the maximum level possible in the water - which is limited by the onset of cavitation, and by how much sound gets into the body from the water.

This will depend to some extent on what kind of protection is afforded by the diver's suit. It is quite likely that you will be able to demonstrate that this kind of cavitation phenomenon can be ruled out on theoretical grounds particularly if a protective device (suit) is specified.

The mechanisms which must be dealt with are thermal and cavitation. Cavitation is more apt to be of interest, but on the basis of the discussion of the NOSC work, one cannot rule out thermal effects at very high intensities in the 10s of kHz frequency range.

Dr. Mackay suggested that divers must be considered separately from swimmers. In divers it is certain that bubbles will often be present. In any real case the nature of the diver's suit will determine what exposure levels are tolerable.

The technology for building a swallowable radio transmitter of sounds exists and such transmitters have been described in detail and tested in humans. Their absolute calibration has also been given in detail. (Mackay 1970).

It is of interest to look more methodically at the limiting tissues (lens of eye, lungs, bone, etc.) to estimate what system may be most affected by underwater sound. Obviously, in determining how much sound gets into the body you could use a sound-sensing radio transmitter which a diver could swallow. However, if you wish to make precise estimates there is some missing information. There may be some more fundamental biological experiments you may wish to encourage but which would be much more demanding to do.

Concerning the PATS system specifically, questions arise as to the need for such large output powers and for **emitting** pulses once every second. If the need for large power output arises from shielding effects of the diver's body perhaps this problem could be overcome by a different placement of the transducer or by using two transducers driven at lower powers with one being mounted on the diver's back and one on his chest. Concerning the pulse rate, one might ask how far a diver can move in one second. Is there a need for the location precision derived by using the one-second rate? Reducing the power level and the pulse repetition rate could significantly reduce the dosage to the diver.

We have demonstrated that even in dives that are safe according to U.S. Navy diving tables there will often be bubbles that are without symptoms present in the bodies of human divers. (These are the long-ago hypothesized "silent bubbles" which we have demonstrated to exist using ultrasonic images.) This is quite separate from the fact that a sound wave can release gas or cause "cavitation" at a lower intensity when traversing a supersaturated tissue than in an ordinary one (a diver vs. a swimmer), you might more easily "bend" a diver exposed to both sound and pressure changes simultaneously. Thus limits for the two groups should be different, even within 30 feet of the surface unless an oxygen rebreather was in use (Mackay, 1963, 1978).

Dr. Neppiras felt that bubble effects - resonance - perhaps should be considered more than anything else. One needs to know what sort of damping there is on radial motion of bubbles. Nobody really knows what sort of Q values will be found in the blood as compared to inside of a cell or membrane, etc. This is vitally important, of course. In water at the frequencies of concern here, Q values on the order of 15 or 20 will be found so that even at low levels of sound big effects of streaming and shear, shear gradients particularly so, will occur. One must know something about damping and resonant motion in bubbles.

Then, there is also the question of bubbles growing to resonant size. The lack of data needed for the rectified diffusion formula makes it impossible to see how it applies in this case. This should be looked into.

More important than that, of course, is the whole attenuation problem. How much sound gets into the body in the first place? As has already been pointed out, one would imagine the attenuation from water into the tissues is enormous. Once you can estimate the levels in tissue then laboratory experiments on damping of resonances, rectified diffusion, and so on, would be very valuable. Most of the effects do occur in the blood and are due to resonance. The damping there is going to be a good deal less than inside cells. Blood being a watery sort of liquid, the Q value will be comparable to that of an air bubble in water.

Dr. Nyborg pointed out that the thermal mechanism has to be recognized and that there should be measurements of temperature elevation in the body under conditions to which the divers are likely to be subjected. Assuming that the intensities to which divers are subjected are known, obtain information on what temperature elevations are to be expected in the body. This may be done by measuring attenuations and absorption coefficients of various tissues and making predictions.

The organs which would be most critical are the lungs and the bone. These are the ones found to be most cirtical in the megaHertz range and they might also be at the lower frequencies.

Secondly, it is important to determine bubble distributions in the bodies of divers under conditions to which they are subjected. The most critical condition would presumably be the case of decreasing pressure. Techniques for doing that exist and are not difficult. If one spends the time, money and effort, results can be obtained. Finally, information ought to be obtained on what the consequences are to the diver of having bubble distributions of various kinds which exist in the presence of sound fields. In pursuing that, in vitro experiments are very useful. The technology is developed and such experiments are much easier to do than in vivo ones. But it can be very important to try very hard to do in vivo experiments of one kind or another. There might be ways to view parts of the circulatory system if they are separated in the body so parts can be viewed in the microscope or examined in some other way. Then, bubbles may be introduced or somehow controlled or the bubble distributions under the conditions of the experiment may be determined. Then, see what happens to the animal in that part of the tissue or in other parts of the body as a result of those bubbles and as a result of the ultrasound.

There followed some discussion of the kinds of experiments that might be pursued. Should animal experiments (in vivo) be pursued and, if so, what animal model or models would provide a basis for predicting biological effects in divers? Carstensen pointed out that none of the consultants except Nyborg had mentioned in vivo experiments. Unless preliminary investigations have suggested what to look for and under what conditions, animal experiments should be avoided. It would be counter-productive to do them without knowing precisely what to look for. Such experiments might produce "effects" which on replication may turn out not to be real effects at all. Until in vitro experiments have been done, in vivo experiments should not be done. In vivo experiments will be extremely difficult to do.

It was generally agreed, however, that since the NOSC work had raised the possibility of lung damage, that sufficient additional work clarifying those results is desirable. Whether the work should continue using the same animal or not was discussed without resolution. In order to run all of the control conditions required to demonstrate that the observed lung damage was in fact due to insonation and if due to insonation, whether the effect was due to resonance, absorption, or some other mechanism will require using large numbers of animals. But using smaller animals may preclude understanding the results previously obtained with swine.

REFERENCES

Christian, E. A. and Gaspin, J. B. Swimmer safe standoffs from underwater explosions. Naval Ordance Laboratory, White Oak, Report NOLX80, 1 July 1970.

Duykers, L. R. B. and Percy, J. L. Lung resonance characteristics of submerged mammals. J. Acoust. Soc. Am., 64, 1978, S 97.

Goss, S. A., Johnston, R. L. and Dunn, F. Comprehensive compilation of empirical ultrasonic properties of mammalian tissues. J. Acoust. Soc. Am. 64, 1978, 432-457.

Hills, B. A. Biophysical aspects of decompression. In P. B. Bennett and D. A. Elliott (Eds.), The Physiology and Medicine of Diving, 2nd Ed. Williams and Wilkins (Baltimore), 1975.

Hunt, F. L. Private communication, 1978.

IEEE BME-25, 538-544, 1978.

Mackay, R. S. Bio-Medical Telemetry, 2nd Edition, pages 200-225. Publisher: John Wiley, Inc. (New York), 1970.

Montague, W. E. and Strickland, J. F. Sensitivity of water-immersed ear to high- and low-level tones. J. Acoust. Soc. Am., 33, 1961, 1376-1381.

Proc. Second Symp. Underwater Physiol. NAS/NRC 1181, pg 41, 1963.

Richmond, D. R., Yelverton, J. T., Gaylord, C. S. and Fletcher, R. E. Underwater blast studies with animals (U). Defense Atomic Support Agency Report DASA 2463, Feb 1970 (CONF).

Richmond, D. R., Yelverton, J. T. and Fletcher, R. E. Far-field underwater blast injuries produced by small charges. Defense Nuclear Agency Report DNA 3091T, 1 July 1973.

Rooney, J. A. Biological effects of ultrasound and their relevance to the establishment of safety standards for the exposure of divers to intense ultrasound. NSMRL Rept. No. 893, 9 May 1979.

Smith, P. F. and Linaweaver, P. G. Effects of sonar transmissions on underwater divers: An attempt to establish auditory damage risk criteria for exposure to AN/SQS-26 (U). NSMC Memo Report 66-1, 14 Jan 1966 (CONF).

Smith, P. F. Underwater hearing in man: I. Sensitivity. NSMC Report No. 569, 28 Feb 1969.

Smith, P. F., et al. Underwater hearing in Man: II. A comparison of temporary threshold shifts induced by 3500 Hertz tones in air and under water. NSMRL Report No. 608, 15 Jan 1970.

Vann, R. V. Development of decompression sickness-evidence for the presence of pre-existing gas nuclei. Presented at Annual Scientific Session of the Undersea Medical Society (Seattle, WA), 30 April 1978.

Yelverton, J. T., Richmond, D. R., Fletcher, E. R. and Jones, R. K. Safe distances from underwater explosions for mammals and birds. Defense Nuclear Agency Report DNA 3114T, 1973.

APPENDIX A

Meeting at University of Vermont, Burlington, Vermont, on the effects of exposure of divers to intense underwater sound, 14 and 15 September 1978.

List of Attendees

Dr. Wesley Nyborg
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Mr. Joseph L. Percy
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Dr. William L. Hunter
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A conference was held to discuss the effects of intense water-borne sound on the health of Navy divers. The participants were personnel from Navy laboratories who have conducted research on various aspects of the problem and persons from various academic institutions who are experts in bio-medical ultrasonics. Mechanisms which might provide harmful effects in divers were identified and research approaches which would be fruitful in establishing safety standards for underwater noise exposure were outlined.

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