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OCCUPATIONAL NOISE EXPOSURE ON FF 1052 (KNOX) AND DD 963 (SPRUA--ETC(U)

JAN 77 B A KUGLER, M E HALE, P E RENTZ

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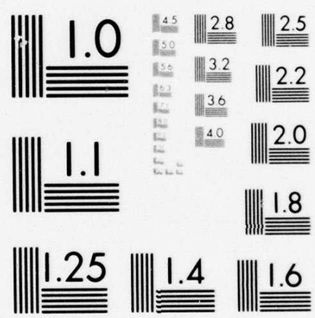

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BBN Report 3410

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B. Andrew Kugler
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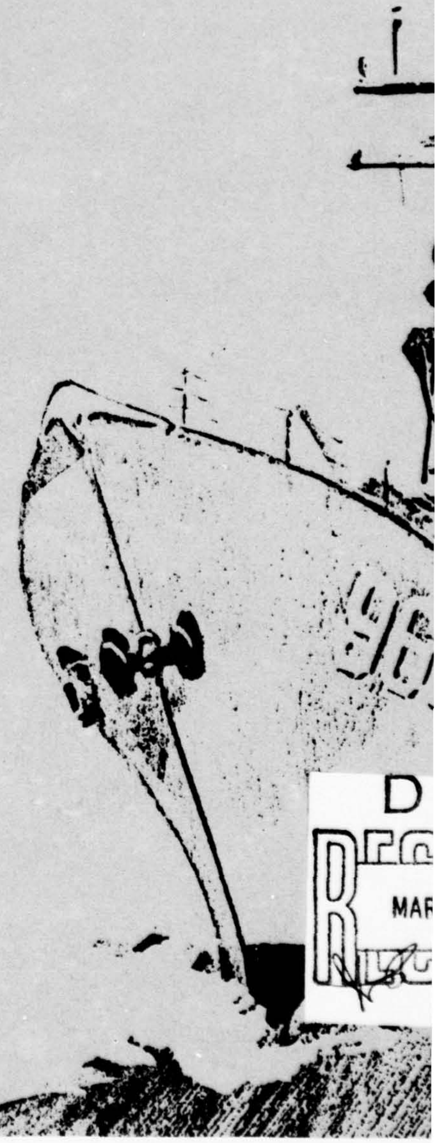

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EXECUTIVE SUMMARY

This study investigates the shipboard personnel noise exposure problem by analyzing the available noise level data on two surface ship classes currently operational in the fleet. These are the FF 1052 (KNOX) class and the DD 963 (SPRUANCE) class. The final objective of the study is a first order estimate of the costs of engineering noise controls necessary to comply with current/proposed personnel noise exposure standards. The standards evaluated are the Navy Compartment Category D, BUMED Instruction 6260.6B, the present OSHA noise standard and the proposed OSHA noise standard. Although the present evaluation is restricted to engineering spaces (i.e., engine rooms, fire rooms, auxiliary rooms, etc.), the model for personnel noise exposure evaluation and noise control assessment developed in this study is meant to be *general* and is *applicable* to other spaces aboard these ships and to other classes in the fleet.

The operational and acoustic data collected represents a summary of all *currently available* information within the Navy on the subject problem. In this sense, the report contains a catalog of existing noise level and noise source diagnostic data available from various Navy departments for the above two ship classes. Analysis of the data shows that noise level information required for the computation of personnel noise exposure is adequate for one class (FF 1052) and only marginal for the other (DD 963). The available personnel work assignment data, necessary for the computation of noise exposure, was found to be insufficient for the purpose of this study and did not reflect the actual duty assignments found on these ships. To that end, a short survey was conducted and first order estimates of this parameter were acquired. The available noise source diagnostic data, vital

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to the proper understanding and solution of the problem, was found to be limited in extent and quantity. The existing information however, was found to be appropriate for this type of analysis.

Due to the emphasis assigned to the data base acquisition, the objectives of the program were not completed in full. The data base collected was evaluated only through the computation of personnel noise exposure; although the steps necessary to complete the source analysis, noise control evaluation and the cost of noise control analysis are provided in full.

The study results show that, at medium to high ship speeds, most crew members in engineering spaces are exposed to excessive noise. This is true regardless of the standard used for the evaluation. Moreover, *excess exposure* to noise is shown to vary from compliance up to 1000% over the OSHA/BUMED limit; overexposure being worst at the higher speeds. Individual noise exposures vary up to 600% between low speeds (8 knots) and high speeds (27 knots). A comparison of the different standards shows that they have the greatest divergent effects at low speeds and in-port.

The parametric framework established for the data base shows the benefits of standardized noise measurement techniques that may be used by various Navy units. The recommendations regarding computarization of the data base, the noise exposure computations, the assessment of the overexposure magnitude and noise reduction requirements, suggest a method by which future assessments of this kind may be made quickly and accurately. To that end, improved data acquisition procedures are also recommended.

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I. INTRODUCTION

High noise exposure in the work place has been fully recognized as a potential occupational hearing loss hazard in the last few years. The federal government, through the Occupational Safety and Health Act (OSHA) of 1970 has established maximum permissible noise limits to which industrial personnel may be exposed. Presently, the Department of Labor, which administrates and enforces OSHA, is in the process of reviewing the noise regulation and various proposals to further restrict personnel noise exposure are being considered.

Similarly, the U. S. Navy has been, for many years, concerned with the noise environment to which its personnel are exposed in shipboard situations. To that effect, space category D, which sets design standards and BUMED Instruction 6260.6B which specifies noise levels similar to the present OSHA regulation, have been adopted for situations where hearing protection is the prime consideration.

The purpose of this program is to investigate the occupational noise exposure problem and the noise control alternatives on board two Navy ship classes. The final objective is to develop a first order estimate of the potential costs associated with compliance with the standard(s) through implementation of engineering noise controls. The standards investigated are: a) the U.S. Navy category D; b) the present OSHA/BUMED standard and; c) the proposed OSHA noise standard.

The estimation of costs associated with the control of the shipboard noise environments requires a number of steps geared to the understanding of the magnitude of the problem, the evaluation of the noise reduction requirements for machinery to meet a specific standard, the assessment of the applicable noise control technology and finally, the estimation of the costs associated with the production and implementation of the controls. Each one of these steps requires careful consideration and evaluation if the final product is to have an acceptable degree of accuracy.

The problem of monitoring noise levels and noise exposure on-board ships and detecting excessive noise level situations has been the responsibility of the Navy's Bureau of Medicine and Surgery (BUMED). The Bureau, through the Environmental Preventative Medicine Units (EPMU), conducts periodic inspections on-board ships and provides a first estimate of the noise exposure problem. The task of on-board retrofit noise control treatments for existing vessels or noise control inputs into new ship designs has been the subject of numerous studies sponsored by the Navy. These data, together with the BUMED information, constitute the data base on which the evaluation undertaken under this program is based.

The data acquisition portion of this study is limited to two ship classes. These are the FF 1052 (KNOX) class and the DD 963 (SPRUANCE) class. Furthermore, the evaluation of personnel noise exposure and subsequent tasks are limited to the engineering spaces in each class, that is; the engine rooms, fire rooms, auxiliary spaces, and after steering rooms, depending on the ship class considered.

The study was limited to the above two classes because: a) they will represent a substantial proportion of the modern destroyer class vessels in the fleet in a few years when all SPRUANCE class ships are operational; b) on first inspection, considerable airborne noise data was believed available within the Navy on their operations. Implicit in the program objectives is a critical evaluation of the existing data base. Although the collection of the data base would be limited to the above two classes, procedures used for the data acquisition and interpretation phase are intended to be *general* and *applicable* to other ship classes in the fleet.

Due to the difficulties encountered in the data base acquisition portion of this program, the final results of the study reflect only a partial fulfillment of the overall objectives. In that sense, the evaluation of the data base is taken only through the definition of the personnel noise exposure problem. However, the step-wise procedure necessary to assess the problem, the equipment noise reduction requirements, the noise control techniques and implementation costs as well as the description of the data base requirements for each one of the above elements is provided in full through a model for occupational noise exposure and noise control. The model is discussed in detail in Chapter Two.

Chapter Three of this report presents the data base used to evaluate the noise exposure problem. This entails both the summary of the compartment noise levels under various ship operating conditions and the personnel assignment description for these same conditions.

Chapter Four presents the results of the personnel noise exposure evaluation for the two ship classes being investigated.

Chapter Five contains the conclusions of this project. The conclusions present the major findings of this study. Finally, Chapter Six presents the recommendations for improved data base acquisition procedures and recommendations for future investigation.

The report contains five appendices in which most of the support noise level and personnel assignment data are contained. Appendix A contains the Personnel Work Assignment Questionnaire. Appendix B contains a summary and a pictorial description of the standard acoustic measurement locations used in engineering compartments. Appendix C is a list of reference reports containing airborne acoustic data in shipboard engineering compartments. This list represents the raw operational and noise level data base, available within the Navy, and used in this study. Appendix D presents a summary of the shipboard compartment "A-weighted" sound level data. The summary is presented as a function of standard locations and ship operating modes. Finally, Appendix E contains a summary of the machinery noise source diagnostic data. Here the contribution of individual noise sources to different locations in the engineering spaces are quantified based on existing Navy information.

II. OCCUPATIONAL NOISE EXPOSURE AND ITS CONTROL --- AN ASSESSMENT MODEL

This chapter presents a discussion of the data base requirements and the sequential steps necessary to evaluate and quantify the noise exposure problem on board surface vessels. The assessment model also explores the acoustic data base and steps necessary to evaluate the noise reduction requirements for equipment in order to meet a specific criterion goal. Finally, the model describes a suggested procedure that may be used to evaluate the state-of-the-art in noise control technology on board ships and the costs associated with the implementation of this technology.

The intent is to develop a model, general enough to evaluate the noise exposure problem of the two ship classes considered as well as other ship classes within the U. S. Navy, and to provide a sequential procedure for the assessment of the noise control alternatives and costs. The parametric organization of the data base allows for a quick evaluation of personnel noise exposure problem in the face of present as well as any future standard. The data base also has the flexibility to be easily expanded by the addition of more information as it becomes available to the Navy, thus providing for a more accurate assessment.

2.1 Existing Occupational Noise Regulations

Before we enter into the discussion of the noise assessment model it is necessary first to review briefly the noise regulations in question. Four standards are discussed; the Navy's space category D, BUMED Instruction 6260.6B, the present

Department of Labor's noise exposure standard and the proposed DOL noise standard.

2.1.1 Navy Shipboard Spaces Noise Criteria

The Navy's shipboard noise criteria is described by compartment noise specifications. This standard, revised on February 2, 1970, specifies a number of shipboard space descriptions and the associated maximum noise limit applicable to each space. Of interest to this study is Category D, which is defined as follows:

> Category D - High noise level areas where voice communication is not important, where ear protection is not provided, and prevention of hearing loss is the primary consideration.

The objective of this standard is to guide ship designers in the the development of specifications for shipboard spaces designed as Category D. In that sense, Category D does not address the problem of personnel noise exposure but is intended to limit the noise levels in designated compartments. Compliance with Category D is generally ascertained by two measurements in each compartment while the vessel is at maximum speed. The standard is written in both a dBA scale and octave band of frequency as follows:

Noise Category	dBA	Octave Bands of Frequency								
		32	63	125	250	500	1000	2000	4000	8000
D	90	105	100	95	90	90	85	85	85	85

The octave bands of frequency, when added, do not sum to 90 decibels but to 93.2 dBA. The intent of the standard is not to exceed any single octave band in the spectrum. The Navy's regulation does not specify allowable time of exposure or how exposure is to be computed when noise levels are in excess of 90 dBA. Reference [1]* contains a description of the criteria derivation for this category as well as the other categories for shipboard spaces.

2.1.2 Occupational Safety and Health Act -- Noise Standard -- and BUMED INSTRUCTION 6262.6B

This section describes the present OSHA noise standard and BUMED Instruction 6260.6B [2]. Due to the similarities of these standards, especially in their application, they are discussed together.

The original noise standard promulgated by the Federal Government was the Walsh Healey Public Contracts Act under Section 50-204.10. The Walsh Healey regulation applied to a very specific type of industrial operation engaged in inter-state commerce and doing over $10,000.00 of business with government agencies. The noise standard contained under section 1910.95 of the Williams-Steiger Occupational Safety and Health Act of 1970 (OSHA) sets essentially the same noise exposure limits proposed by the Walsh Healey regulation, however, their applicability is extended to all industrial operations.

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* Numbers in [ ] indicate references listed at the end of this report.

The Act calls for maximum permissible noise exposure limits as shown in Table 2.1. The regulation also specifies that if these levels are exceeded, corrective action must be taken. The standard is unique in that it limits noise exposure through a number of variables which should be understood. First of all, since this is a standard written for an industrial environment, it specifies a maximum exposure of eight hours during a working day. No allowance is made for exposures in excess of that time limit.

TABLE 2.1
PERMISSIBLE NOISE EXPOSURES

Duration per day, hours	Sound level slow response dBA
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

Secondly, the standard recognizes different types of noise environments and specifies the evaluation of noise exposure based on three types of noise characteristics:

(1) Steady state noise
(2) Time varying noise
(3) Impact noise

By *steady state noise* the regulation defines the signal as follows:

"If the variation in the noise levels involve maxima at intervals of one second or less, it is to be considered continuous."

Here the only requirement, according to Table 2.1, is the measurement of the sound level with a "A-weighted" meter set on the slow response and the determination of the appropriate noise levels to be compared with exposure limits.

Where the operator is exposed to different levels of noise for different, definable periods of time over the course of an eight hour work day, the Act provides a means whereby an equivalent continuous noise exposure rating can be determined. This is the case of the *time varying noise* signal. The time spent at each noise level is noted and the fraction of the permissible time of exposure at that level (according to Table 2.1) is determined. The fractions obtained for each noise level are then summed. If the total is less than or equal to unity, the noise exposure is considered acceptable. If the total is greater than unity, the noise exposure is deemed unacceptable in terms of the requirements of the act. The summation calculated according to this rule is called the *daily noise dose, (d)* and is given by:

$$\text{Daily Noise Dose (d)} = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \cdot \cdot \cdot + \frac{C_N}{T_N} \quad (1)$$

where: C_N is the actual exposure time at a given noise level,
T_N is the total exposure time permitted at that given level, and
$\frac{C_N}{T_N}$ is the fractional noise dose for the Nth time interval.

The BUMED Instruction 6260.6B calls for the computation of noise exposure for steady state and time varying noise in the identical manner to the present OSHA standard. Therefore, future references to these standards will be made under the descriptor of present OSHA/BUMED.

Finally, the last type of noise called *impact noise* is specified in the OSHA standard (not BUMED) as a maximum exposure to impulsive or impact noise not to exceed 140 dB peak sound pressure level. The apparent higher allowable exposure level for impact noise results from the fact that the short burst of noise, such as hammer blows, occur faster than the ear can fully react. Intervals between impact must not be less than one second. Otherwise, it would become steady state noise and the levels applicable under Table 2.1 would control. This type of noise can be properly measured only with an impact type sound level meter or using an oscilloscope with image holding provisions.

2.1.3 Proposed Occupational Safety and Health Act Noise Standard

The major revision to the present OSHA noise standard, proposed by the U. S. Department of Labor[3], is the extension of the permissible exposure time from 8 hours to 16 hours in a workday. Under the new standard the 90 dBA exposure limit for eight hours is retained, but exposures to noise levels down to 85 dBA must also be included in the daily noise dose calculation. Another important change in the regulation is that annual monitoring of exposure would be required for employees exposed to noise levels of 85 dBA and above and for employees with a daily noise dose greater than or equal to 0.5.

Table 2.2 shows the maximum exposure levels and durations as extended to 85 dBA for 16 hours of exposure and under the 5 dBA doubling rate. Except for the extension of noise exposure levels to 85 dBA and to sixteen hours per day, the proposed noise regulation is identical to the present one and the calculation of time-varying noise exposure or daily noise dose is identical as discussed previously.

TABLE 2.2

PROPOSED OSHA PERMISSIBLE NOISE EXPOSURES

Sound Level (dBA)	Time Permitted (Hours-Minutes)	Sound Level (dBA)	Time Permitted (hours-Minutes)
85	16-0	101	1-44
86	13-56	102	1-31
87	12-8	103	1-19
88	10-34	104	1-9
89	9-11	105	1-0
90	8-0	106	0-52
91	6-56	107	0-46
92	6-4	108	0-40
93	5-17	109	0-34
94	4-36	110	0-30
95	4-0	111	0-26
96	3-29	112	0-23
97	3-2	113	0-20
98	2-50	114	0-17
99	2-15	115	0-15
100	2-0		

Where Table 2.2 does not reflect actual exposure times and levels, the permissible exposure to continuous noise at a single level must not exceed time "T" (in hours) as computed by the following formula.

$$T = \frac{16}{2^{[.2(L-85)]}}$$

where "L" is the workplace sound level measured in dBA.

The proposed regulation does contain significant changes in terms of impact noise. As with the current standard, the proposed upper limit for impact noise is 140 dB peak sound pressure level, however, the proposed standard defines impact noise as a sound having a rise time of not more than 35 milliseconds in duration or not more than 500 milliseconds to the 20 dB down point. Intervals between impact must not be longer than .5 seconds according to the proposal. In addition, the proposed standard limits the number of allowable impulses per day by the following:

> *"Exposures to impulses of 140 dB shall not exceed 100 such impulses per day. For each decrease of 10 dB in the peak sound pressure level of the impulse, the number of impulses that the employees are exposed to may be increased by a factor of 10."*

2.1.4 Discussion of Standards

The three standards discussed above have many similarities, however, they also differ on many key points. Some of the most relevant differences are as follows:

1. The Navy space noise standard specifies a 90 dBA limit without mention of the total length of exposure to that level.
2. Both the present OSHA/BUMED and the proposed OSHA standards impose a specific time limit to the 90 dBA level. In the case of the present OSHA/BUMED standard, this exposure limit is applicable to an eight-hour day. This is also the case for the proposed OSHA standard except that the proposed standard starts counting exposure at a level of 85 dBA and therefore is more restrictive.

(3) The Navy space noise standard does not provide for the calculation of personnel noise exposure based on time spent exposed to different noise levels. Non-exceedance of 90 dBA is the only criterion.

(4) The Navy space standard and the BUMED Instruction 6260.6B do not specify a criterion for impact noise as do the present and proposed OSHA regulations.

The significance of the differences among these four sets of noise criterion will be evident in the personnel noise assessment discussion.

2.2 A Model for Noise Exposure Evaluation

This section presents an overview of the general model that will be used to compute the noise exposure problem in shipboard spaces and will discuss the data base requirements necessary to utilize the model.

The need for a model stems from the fact that personnel noise exposure is a complex quantity which requires the understanding of a number of variables; not all of which are noise oriented. For example, since noise exposure is a time weighted quantity (according to OSHA/BUMED), it is necessary to know not only the given noise level at a given location but also how that level changes as a function of the ship's operational characteristics. Furthermore, since personnel noise exposure is time and location dependent, it is necessary to obtain a relationship between crew time and location assignments and the noise levels generated by the different ship conditions.

The data base requirements for a personnel noise exposure evaluation are as follows:

(1) Ship operational characteristics
(2) Personnel work assignments
(3) Airborne noise data

The following discussion explores these parameters in terms of the model and shows they interact for the computation of noise exposure.

2.2.1 Ship Operational Characteristics

Occupational noise criteria are based on the assumption that exposure levels are repetitive, day in and day out, over long periods of times; for example, a number of years. This condition, of course, does not hold true in the Navy since each ship goes through a number of operational characteristics from cruising conditions to at-dock conditions in the course of a year.

Each one of these operational conditions is characterized by different noise levels, especially in the engineering spaces since the number of on-line pieces of equipment needed under the different conditions varies.

The objective of the ship class operational characteristic parameter is the definition of operational modes which can be considered contant. This will allow the computation of personnel noise exposures which are unique to a specific ship operational mode. For the purposes of this program we will define an *operational mode* as a ship condition for which the machinery line-ups in each engineering space and the personnel assignments of the crew can be considered constant. In other words, an operational mode means that the noise level at a specific location is closely related to a specific machinery line-up and can be considered.

constant at that location. Furthermore, it means that the personnel working in the engineering spaces go through typical routines that may be considered nearly constant for that operational mode.

The manner in which naval ships operate varies depending on their mission. In that sense, each vessel proceeds through a number of assignments in the course of a year from at-dock conditions, where the vessel is stationary and only a limited number of equipment is operational, to underway conditions which require it to steam under a variety of speeds. Each speed or range of speeds may be associated, in principle, with the operation of a specific machinery line-up, especially in the propulsion system area. It should be recognized, however, that within a ship's class, the operational characteristics and machinery line-up may vary to some degree.

Since, as was pointed out, noise levels within the engineering spaces vary as a function of machinery line-up (equipment operating for a specific condition), it is necessary to describe the ship operational history as a function of time. Moreover, it is desirable to associate a specific machine line-up with each operational mode. Finally, in order to describe a ship class, it is necessary to evaluate how the operational history and machinery line-up vary within the class. This will permit an assessment of the variability within the class and, in fact, will allow to determine if a typical operational history can be chosen to describe the class. The preceding discussion leads to the following data base requirements necessary to describe the ship class operational characteristics:

(1) Ship operational history where the amount of time spent at-dock and underway is specified for at least a one-year period.

(2) A definition of the machinery line-up (on the average) when the ship is operating in each of the above two modes. It is expected that more than one machinery line-up may exist within each mode (i.e., cold iron and auxiliary steaming at-dock). This will necessitate the definition of a number of sub-modes, which may be characterized by a specific machinery line-up. For example, when underway, it is conceivable that machinery line-up will have a relationship with speed ranges of the ship.

(3) In order to develop an understanding of the mode or sub-mode variability within a ship class the above parameters are required for more than one ship within the class. The number of vessels required for the class evaluation will depend largely on the variability found from ship to ship so that a statistically valid sample may be examined.

The above data will be used to develop a quantitative description of a ship class operational characteristics. The following relationships will be evaluated and computed:

(1) The definition of a ship's "typical time history year" where the percentage of time spent within each mode or sub-mode is quantified (i.e., 20% of the time at cold iron, 10% of the time steaming between 10 and 15 knots, etc.).

(2) The definition of the "typical time history year" variability within the class. This will allow to assess the probability of sub-mode occurrence and confidence limits associated with the assumptions for typical operations. Ideally, it is desirable to introduce statistics into the evaluation by computing the mean and the standard deviation for each mode or sub-mode of operation (i.e., the mean time spent at cold iron sub-mode is 20% with a standard deviation of 5%). This approach will allow to judge if "typical ship class operational history" is indeed quantifiable and define the limits associated with the description.

(3) The definition of "typical ship class machinery line-up within a mode or sub-mode and the variability found in the class. The machinery line-up must be specified separately for each engineering space considered. It is expected that certain variability in this parameter will be found from ship to ship. The definition of the "typical ship class machinery line-up will be obtained similarly to the "typical time history year" by evaluating the statistics associated with the ship's class operation.

In summary, the operational modes and sub-modes will define the ship operating conditions for which the noise levels in different engineering spaces and the operator assignments in those spaces can be considered *constant* or are predictable on a twenty-four hour basis. Furthermore, the variability of these operational modes for a specific ship and across the ship class will also result from this evaluation.

2.2.2 Noise Exposure Model

A "hazard" can be defined as a physical effect which has an adverse impact on the health or safety of individuals in the work environment. In the case of shipboard environments two typical potential hazards are noise and heat stress. Each one of these hazards will have an adverse effect on the health or safety of personnel if they are exposed to the hazard for extended periods of time or the magnitude of the hazard is excessive.

It might be generalized that many health standards ,developed to judge the acceptability of a hazard are written in terms of two parameters: time and magnitude. In other words, an operator may safely withstand a certain level of a hazard for a specified amount of time without adverse effects. In general,the magnitude of the hazard is related to the exposure time to the hazard. The longer the exposure time, the lower the allowable magnitude of the hazard. Time and magnitude, therefore, are the two parameters which specify the permissible exposure to a hazard which, in the judgement of a health standard,is considered permissible.

Let us now address the problem of the data base required to evaluate the magnitude of a hazard on man. In the present case the hazard is *excessive noise*. As specified in the data base requirements of Section 2.2, in addition to ship operational characteristics,the two inputs necessary for the computation of noise exposure are *personnel work assignments* and *airborne noise data*. Airborne noise is given by the physical phenomena which can be readily measured in terms of sound pressure level. Associated with the acoustical measurement is the location at which the measurement is acquired. Therefore, the description of the noise hazard can be accomplished by describing two variables: The *magnitude** of the noise and the *location* at which the noise was measured. The description of the hazard does not require any additional parameters to the magnitude and location and can be considered constant for the same operational mode or sub-mode.

The second requirement of the data base is the description of the personnel work assignments. Since by definition, the word "exposure" implies that an *individual* is exposed to the hazard, it is necessary to quantify where and for how long this exposure takes place. Therefore, the duty or personnel work assignment input has two variables: *time* and *location*.

Figure 2.1 depicts the general arrangement of the noise exposure model. The two basic inputs to the calculation of personnel noise exposure; the personnel work assignment or duty in terms of time and location and the noise level, in terms of location and magnitude are identified for each operational mode or sub-mode. The dependent variable in the data base is "location". The magnitude of noise at a specific *location* and the amount of time the individual spends at the *location*. The independent variables are of course time and magnitude, which are the same variables that we have discussed in our noise standard presentation.

The knowledge of these two data base inputs allows us to develop the relationship between the duty of the operator and the hazard;

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* Since most noise standards are written in terms of the A-weighted sound pressure levels (dBA), the magnitude of the noise is the only necessary physical descriptor of the phenomena. Implied in the descriptor is a frequency weighting of the noise spectrum which allows to describe the entire audio frequency range with a single number.

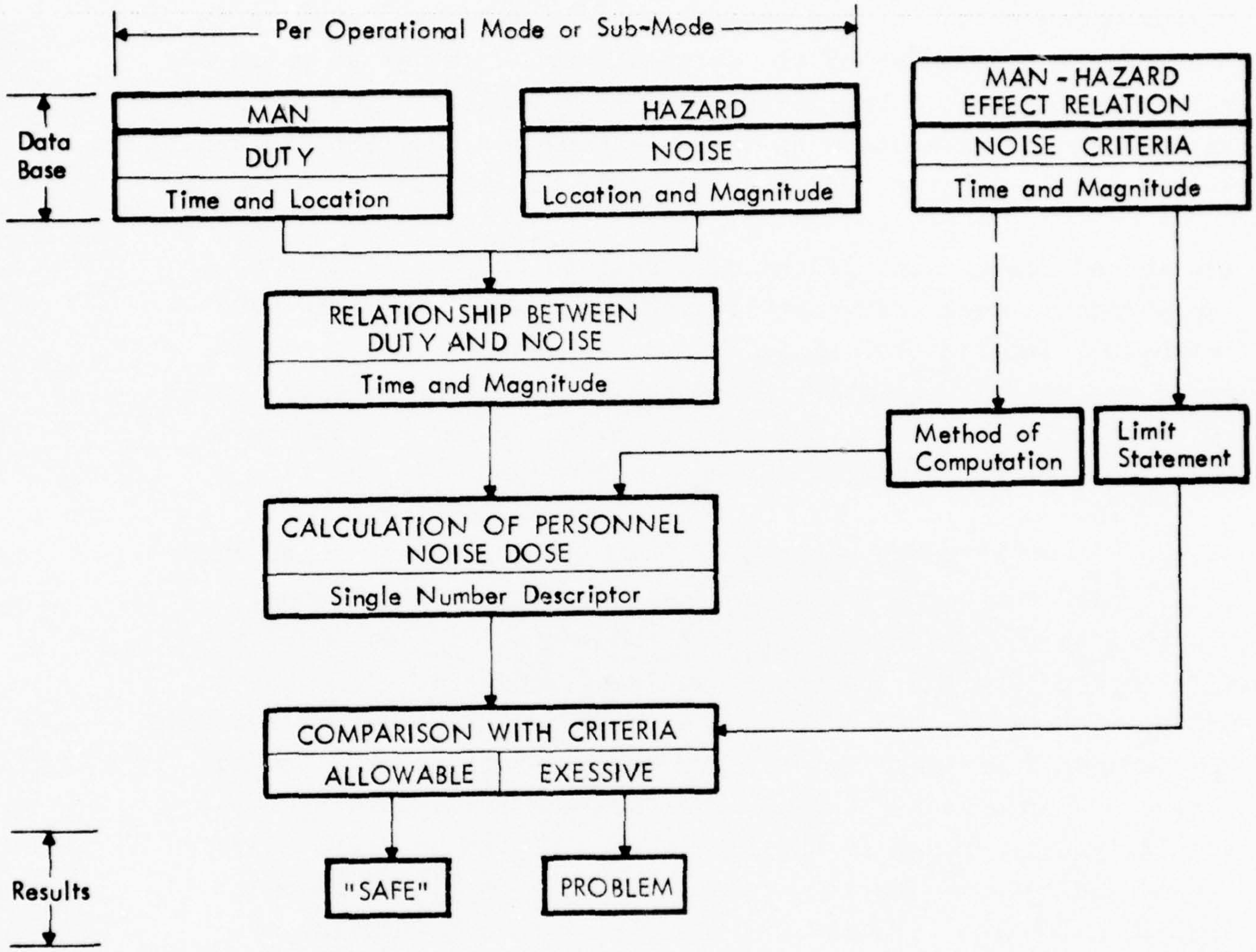

FIGURE 2.1 DEFINITION OF NOISE EXPOSURE PROBLEM

this relationship being a function of time and magnitude as follows:

$$I_{ij} = I_{ij} f(L_j, C_{ij}) \tag{2}$$

where I_{ij} is the i th individual at the j th location, L_j is the level in dBA at location j and C_{ij} is the time spent (in hours) by the i th individual at location j. The subscript j refers to the number of spatial locations considered from 1 to m and the subscript i refers to the number of individuals being evaluated from 1 to n.

The development of the relationship between duty and noise is the *most important* and *difficult step* in the noise exposure problem. Once this relationship has been established, any man-hazard affect standard can be quickly evaluated and computed.

A few notes of interest. In principle, the noise level data base should be given on a point by point basis. Similarly, the data base for the duty or personnel work assignment should be done on an individual by individual basis. In practice, this is not only impossible but under most conditions, not necessary. For example, the spatial description of noise can be associated with an area; the size of the area will depend on the fluctuations in the noise levels and the accuracy required. In some cases, this may mean a quarter of the space in question or even the entire space may be described by a single noise level. In the case of personnel assignment, it is possible to associate duty with a job description or rank which is common to a number of individuals. These groupings will depend on the variability of job assignments, accuracy required and the ability to predict personnel movements over the long term. In deciding on the above groupings and generalizations, it is important to remember that the model is intended to describe and analyze the noise exposure problem of an entire ship class. In that sense, averaging techniques in the spatial description of noise level and grouping techniques in the description of personnel assignment are not only valid but desirable. This will simplify the extent of the data base requirements provided that statistical techniques are used to describe the mean and variability of each descriptor so that, in the end; a meaningful assessment of the accuracy and confidence limits for the personnel exposure predictions can be made.

Furthermore, it should be noted that once the relationship between duty and noise has been established, the information can be updated and refined by any future new information available about one of the above two descriptors. For example, the personnel work assignment data base for a fireman may be described in terms of the number of hours spent at each different location within the engine room based on the information acquired for the group on two ships. The statistics of the data base will provide the confidence limits for that descriptor. If information on the duty assignment for that group is available later for three or more other ships, the confidence limits for the descriptor will be obviously improved. The same reasoning applies to the description of the spatial noise levels.

The relationship between duty and noise may now be used to calculate the personnel noise exposure dose as outlined in Figure 2.1. In the case of the OSHA standard, the relationship formulated in Eq. (1) may be used to define the fractional noise dose (f) as follows:

$$f_{ij} = \frac{C_{ij}}{T_{ij}} \tag{3}$$

where T_{ij} is the maximum allowable time (in hours) permissible by the standard at the noise level L_j. The fractional noise dose is constant for the same operational mode.

The computation of the Daily Noise Dose (d_i) follows directly from the fractional noise dose equations by using the relationship described in the Section 2.1.2:

$$d_i = \frac{C_{i1}}{T_{i1}} + \frac{C_{i2}}{T_{i2}} + \cdot \cdot \cdot + \frac{C_{im}}{T_{im}} = \sum_{j=1}^{m} f_{ij} \tag{4}$$

This calculation results in a single number descriptor which can be compared to the limit statement in the standard to ascertain exceedance or non-exceedance of allowable limits.

The major results that can be drawn from the computation of the daily noise dose are:

(1) *Identification of the number of engineering space personnel exposed to excessive noise levels:* this is done on a space by space basis. For example, if we assume that there are eight operators assigned to the engine room, the results will show that for the cruising mode, between 10 and 20 knots, six of these individuals will have exposures in excess of the present OSHA noise regulation and two are in compliance with the standard.

(2) *Definition of the magnitude of exceedance and the ability to rank order personnel by noise exposure:* An example of this is the same six individuals found over exposed above but now the noise exposure levels for each individual can be rank ordered according to magnitude.

(3) *Ability to evaluate, on a comparative basis, the effect of two or more noise standards:* An example of this is comparing the BUMED regulation versus the proposed OSHA noise regulation. In this case, using the example of the engine room we might find that according to the BUMED standard only six individuals have excessive noise exposures and in the case of the proposed OSHA standard, all eight individuals have a problem.

(4) *Ability to evaluate the noise problem on an operational mode by mode basis:* For example, when in port, under auxiliary steaming, only three individuals may have exposures in excess of the Navy standard. On the other hand, when underway, at 25 knots, seven out of the eight individuals may have an excessive noise exposure. This information, together with the knowledge of percent of time that the ship class spends in each operational mode,may be used to judge the importance of each mode on the overall noise exposure problem of the class.

In summary, the procedure suggested in Figure 2.1 allows for not only the computation of the daily noise exposure for a given operating mode but also for the assessment of the differences in noise exposure among various standards and operational modes.

2.3 A Model for Noise Reduction Evaluation

This section describes the analysis necessary to define the overall noise reduction requirements in each engineering space based on the personnel noise exposure results. Furthermore, it describes the sequential steps and data base necessary to establish the contribution of individual noise sources (equipment) to the overall noise at a given location and the definition of individual source noise reduction requirements.

The analysis of the noise exposure problem is done through the use of fractional noise dose data developed as a result of the relationship between duty and noise discussed in the previous section. The objective of this procedure is to identify the minimum noise reduction requirements (ΔL_j) at each location as a function of the *total noise exposure problem* (not simply noise levels) in an optimum manner. The sequential analysis is shown in Figure 2.2. The analysis is limited to individuals who have been identified as having an excessive daily noise exposure dose, d_k. This operation is defined by the first entry in Figure 2.2 where the individuals with excessive noise exposures are classified as follows:

$$I_k = I_k\ (d_k > 1.0) \qquad (5)$$

where k is a sub-set of i from 1 to ℓ.

First of all, the fractional noise doses, (f_k) are organized in array form together with the daily noise dose (d_k) as follows:

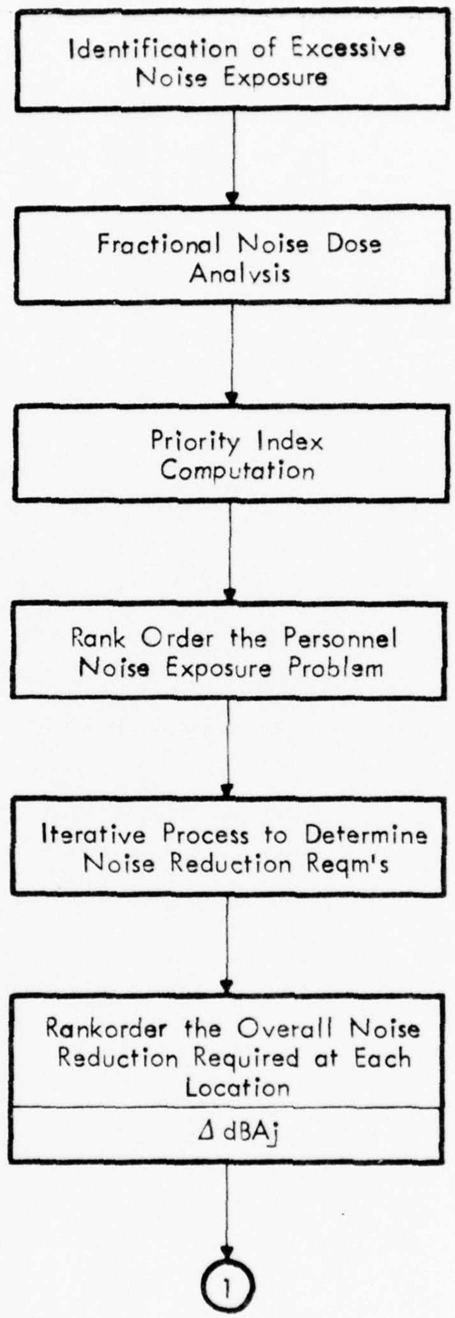

FIGURE 2.2 ANALYSIS OF NOISE EXPOSURE

k \ j	Locations					d_k
	1	2	3	. . .	m	
1	f_{11}	f_{12}	f_{13}	. . .	f_{1m}	d_1
2	f_{21}	f_{22}	f_{23}	. . .	f_{2m}	d_2
⋮	⋮	⋮	⋮	. . .	⋮	⋮
ℓ	$f_{\ell 1}$	$f_{\ell 2}$	$f_{\ell 3}$	. . .	$f_{\ell m}$	d_ℓ

This presentation summarizes all of the daily noise dose information and shows the contribution of each location to the daily noise dose. It is desirable to classify these locations accordint to their contribution to the noise exposure problem. This is accomplished through the calculation of the Priority Index (PI) as shown in Figure 2.2 First of all, we define the Partial Priority (PP) as:

$$(PP)_{kj} \begin{cases} = \dfrac{f_{kj}}{(d_k - 1)} & \text{when} \quad f_{kj} \le (d_k - 1) \\ = 1 & \text{when} \quad f_{kj} > (d_k - 1) \end{cases} \tag{6}$$

As described by the equation, the Partial Priority is the ratio of the fractional noise dose to the excess daily noise dose. The ratio indicates the *fraction of overexposure* that would be eliminated from the individuals daily noise dose if the noise level at location j was reduced to the compliance level for the exposure time.

Using Equation (6), the fractional noise dose array may be converted into a Partial Priority array as shown below:

man k \ j	Locations					d_k
	1	2	3	. . .	m	
1	PP_{11}	PP_{12}	PP_{13}	. . .	PP_{1m}	d_1
2	PP_{21}	PP_{22}	PP_{23}	. . .	PP_{2m}	d_2
:	:	:	:		:	:
ℓ	$PP_{\ell 1}$	$PP_{\ell 2}$	$PP_{\ell 3}$	. . .	$PP_{\ell m}$	d_ℓ
$\sum_{k=1}^{\ell} (PP)_{kj}$	PI_1	PI_2	PI_3	. . .	PI_m	

The sum of all individual partial priorities at a given location is defined as the Priority Index (PI) as follows:

$$(PI)_j = \sum_{k=1}^{\ell} (PP)_{kj} \quad (7)$$

The $(PI)_j$ indicator provides a ranking of each area according to where the most reduction in *excess noise exposure* (not simply noise exposure) could be achieved for the *most people*. The distribution of $(PI)_j$ also provides a quick assessment of the relative importance of one location versus another and in that sense serves as a gauge in identifying the "hot spots" which contribute most to overexposure.

Two factors of note about the $(PI)_j$ indicator. Firstly, the maximum value of $(PI)_j$ is one times the number of overexposed individuals considered ($1 \times \ell$). For example, if 5 individuals are considered, the maximum value of PI = 5. The significance of obtaining the maximum rating at a given location is that by reducing the noise level at that location to the standard, all individuals considered would be in compliance. In other words, the reduction of the noise level from the measured to the standard (90 dBA for OSHA) at that location will bring the exposure of *all individuals* to the maximum permissible or below without any controls at other locations regardless of level. Secondly, if more than one individual is considered in each category k (the individual was defined previously as one person or a group of people performing the same work routine), the $(PI)_j$ indicator may be very simply modified to include a weighting factor that will reflect this case. The required modification includes the addition of a factor N to equation (6) as follows:

$$(PP)_{kj} \begin{cases} = N_k \cdot \dfrac{f_{kj}}{(d_k - 1)} & \text{when } f_{kj} \leq (d_k - 1) \\ = N_k & \text{when } f_{kj} > (d_k - 1) \end{cases} \qquad (8)$$

where N_k is the number of individuals in category k. This change will also modify the maximum value of $(PI)_j$ from ($1 \times \ell$) to:

$$\text{Maximum } (PI) = \sum_{k=1}^{\ell} N_k \qquad (9)$$

In practical cases, the PI indicator is seldom equal to the maximum. In this case, the distribution of PI values allows to rank order the problem areas by location as was pointed out previously. However, the final objective is to evaluate the magnitude of noise reduction that is required at each location to meet a standard. The optimum method to compute the magnitude of noise reduction required is by an iterative process using the PI ranking indicator.

The method calls for reducing the noise level of the highest PI indicator in 1 dB steps until the PI indicator is reduced in magnitude to below the second highest. The operation is repeated until no daily noise dose(s) in excess of the standard are left (i.e., $d_k \le 1.0$). Each iteration involves the following steps:

(1) Reduce the noise level, (L) by 1 dB at the location with the highest PI_{max}.

(2) Compute the new allowable exposure time, (C) for the new level (L - 1) dBA.

(3) Compute the new fractional noise dose, (f) for all individuals affected by this location.

(4) Compute the reduced daily noise dose, (d_k) for all individuals effected by this location.

(5) Re-compute the PI for all locations. Note that by changing the magnitude of d_k, the values of all $(PP)_{kj}$ are modified. The resulting effect is the reduction of the PI indicator at the location with (L-1) dBA and the increase of the PI indicator at all other locations.

(6) Repeat the operation until all d_k values are equal less than 1. Note as *individual* values of d_k become unity or less, the corresponding values of f_k in the array become zero and are excluded from further computation.

The result of this operation will provide the *minimum amount of noise reduction* required at each location that will result in compliance with a standard. This method also optimizes the procedure of assigning noise reduction requirements at each location from the individuals *excess noise exposure* point of view. The magnitude of noise reduction at each location (expressed in dBA) may now be rank ordered as shown in Figure 2.2.

The analysis of the noise exposure problem resulted in the development of noise reduction requirements, ΔdB_j, for each area or location without specifying which *sources* of noise would require noise reduction. The sequential procedure designed to evaluate the individual equipment noise reduction is shown in Figure 2.3*.

Before we enter into the discussion of equipment noise reduction requirements it must be noted that no simplistic procedure for this step is possible since, for the case where two or more sources

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* Note that in addition to the magnitude, the noise reduction requirement retains the statistics associated with the original noise level. For example, a reduction requirement of 10 dB is computed for a location whose mean noise level was described as 95.0 dBA with a standard deviation (σ) of $\pm$ 2.0 dB. Therefore, a noise reduction requirement of 14.0 dB (10 + 2σ) would assure that 95% of the ships within the class would meet the standard at that location.

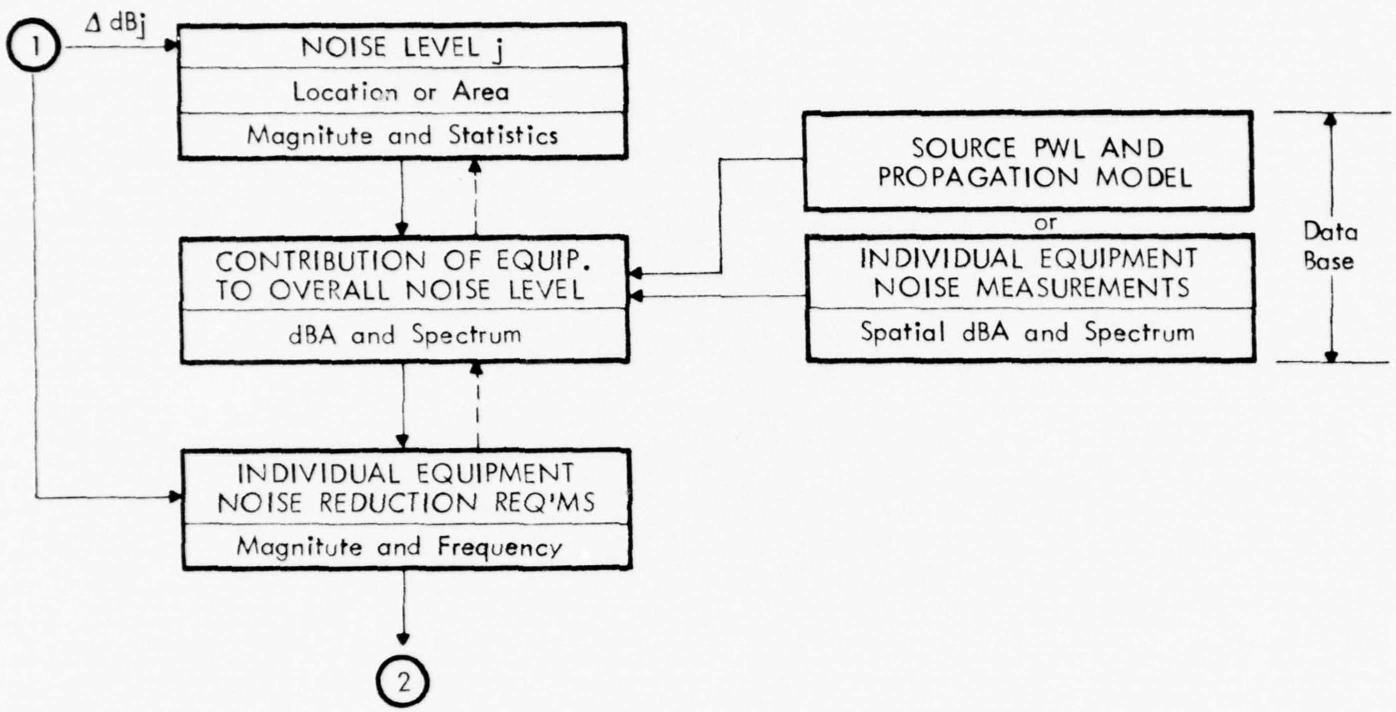

FIGURE 2.3 ANALYSIS OF NOISE PROBLEM

contribute excessively to the noise level at a location, an infinite number of source noise reduction combinations is possible. Furthermore, the assignment of noise reduction to a specific equipment item generally must be weighted with some engineering judgment as to the feasibility and practicality of achieving the desired reduction. Finally, we must recognize the economic trade-off value by weighting the reduction of one machine versus another. For example, often it is more expedient and cost-effective to require a substantially higher reduction of one item over another although the noise level contribution of both may be the same. With these facts in mind, the following procedure is presented as a *guide* rather than a *strict methodology*.

First of all, it is necessary to know, which equipment items or equipment components contribute to the noise level at the location of interest. In other words, what is the noise level, in terms of magnitude and frequency, that may be associated with each equipment item. This requirement defines the need for a second type of *acoustic data base*. The objectives for developing the data base are to describe the noise environment in terms of the individual components and their paths of propagation.

The analysis of the noise environment is very often a complicated problem, especially in a shipboard situation due to the number of sources that must be considered and the complexity of the space within which the noise is propagated. Two approaches are possible:

(1) *Diagnostic Noise Data:* This method relies on a systematic data base accumulation in which individual pieces of equipment are operated, one by one, and their contribution at different locations within the engineering space is measured simultaneously. The

procedure requires not only sophisticated measurement techniques, but many repetitive measurements before confidence limits to different locations across the class can be established. Information typically is presented in dBA and in octave bands or third octave bands of frequency. Narrow band data and equipment noise radiation characteristics are sometimes also available. In addition to the acoustic data the operational characteristics of the ship and machinery under which the test was performed must also be well documented. This type of data are becoming more and more prevalent in the Navy, especially due to work performed by Bolt Beranek and Newman [4, 5, and 6] and by NSRDC [7 and 8].

(2) *Analytic Approach:* This approach relies on a measurement or estimation of Sound Power Level (PWL) for each source and a propagation model that will allow the *prediction* of the sound pressure level (SPL) of the source as a function of frequency at *any specific location* in the compartment. Due to the very complex reflection and the diffraction environment common to machinery dense engineering spaces, this methodology may only have a limited application to the Navy noise problem under the present state-of-the-art.

Using the diagnostic noise data, the noise levels at location j are reconstructed in terms of the individual contributors as shown in Figure 2.3. Based on the overall noise reduction requirements, the individual equipment noise reductions are computed in terms of magnitude and frequency.

Note that the knowledge of the contribution of individual equipment items to the overall noise environment at a location may be used to compute the effect of an individual control on the personnel noise exposure problem. That is, if we assume that a 15 dBA control is available for the gear train, then this information may be used to recompute the *noise levels* at all locations affected by this item. Then the procedure indicated in Figure 2.1 is repeated. This action allows for a quick "cause - effect" assessment of controlling this equipment item on *all personnel* affected and provides a tool for individual equipment noise control trade-off analysis.

2.4 A Model for Cost Estimation of Noise Control

In the previous sections the assessment of personnel noise exposure and individual noise reduction requirements for equipment responsible for excessive noise levels was discussed. This section will dwell on the aspect of *noise control alternatives* that can be introduced to mitigate the noise problem and with the evaluation of *noise control costs*. Figure 2.4 shows the sequential steps suggested to arrive at the estimate of noise control costs.

First of all, the figure shows the individual source noise reduction requirements that were developed in the previous analysis. These requirements are given for each piece of equipment in terms of magnitude and frequency.

The noise reduction requirements can now be addressed in terms of noise control technology which can be applied to the Navy environment. The *noise control technology* represents the third type of data base required in the model.

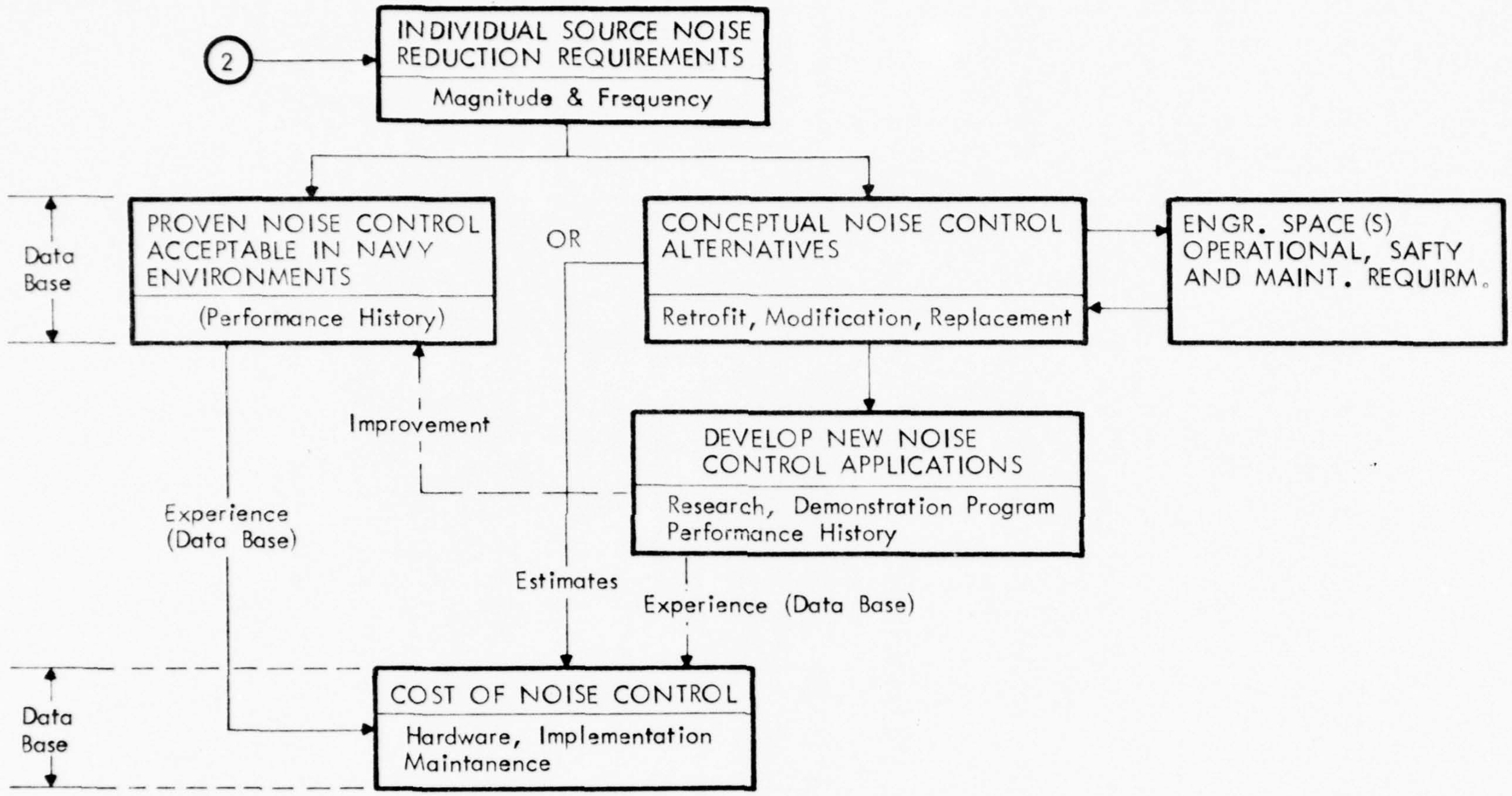

FIGURE 2.4 NOISE CONTROL ALTERNATIVES AND COSTS

The purpose of the noise control data base is to identify the type and quantify the performance of noise reduction systems that may be applied to existing sources of excessive noise. This includes a description of the physical characteristics of the control measure, its mode of application and installation, and the expected or measured noise reduction performance. The noise control techniques fall naturally into two groups:

(1) *Proven Noise Controls:* This group includes successful noise control treatments that are documented by their performance history from Navy applications. The objective here is to list all of the noise control measures that have been successfully developed and implemented in shipboard environments. Data such as the type of treatment, configuration, description of its application, and the amount of the noise reduction achieved through the application are required in this portion of the data base.

(2) *Conceptual Noise Controls:* This group includes noise control treatments used in other than Navy applications or noise control concepts which *have not* yet been proven successful in shipboard enviroments: These measures may take the form of:

a) *Retrofit Controls:* This generally refers to systems that contain the noise near the source, i.e. enclosures, partial barriers, damping, etc.

b) *Modifications:* This generally refers to replacement of machine parts with quieter ones or the addition of noise control components.

c) *Replacement of Sources:* This generally means replacing noisy equipment units with quieter versions.

d) *Space Treatment:* This generally means acoustic absorbtive treatment of the space boundaries with the objective to reduce the reverberant noise level contribution.

The assessment of these conceptual noise control alternatives must be made in line with the operational, safety and maintenance requirements of the engineering spaces in which the installation must be made. In that sense, some of the shipboard operational constraints are taken into account at this stage, even though, no performance history is available for the controls.

The final design of the conceptual noise control alternatives into proven noise controls acceptable in shipboard environments must, in many cases, go through a developmental phase which may be construed as new noise control applications. The new noise control applications may take the form of a demonstration program where potential noise controls are implemented on a vessel and the performance history of the design is monitored.

Both proven noise controls and conceptual noise control alternatives are now the subject of cost estimates. The *cost of noise control* represents the fourth and last type of data base required in the model. The purpose of the cost data base is to identify the cost of hardware, implementation and maintenance of each noise control measure.

The cost data base for the proven noise control techniques are acquired from the experience gained in the installations. Here variability due to the method of installation (using Navy personnel, civilian Navy shipyard personnel or outside contractors) may be evaluated and be the subject of statistical treatment if appropriate. No such experience exists for the conceptual noise controls since these have not been implemented on Navy vessels and the cost of hardware, implementation and maintenance must necessarily be only a first order estimate. It is recommended that shipyard estimators be used for that purpose and an average value from three or more sources used.

The cost of noise control data base may now be used to arrive at the total cost of noise control for each vessel and the class based on the noise reduction requirements of a specific standard. The procedure allows for the development of a number of cost trade-off analyses; the two most prominent being:

(1) The determination of the absolute and relative costs of compliance between two or more noise standards. For example, the cost of compliance with present OSHA standard and the incremental cost of achieving the proposed OSHA standard for a given ship class.

(2) The cost-benefit analysis of individual noise controls where the number of individuals in compliance as a result of the implementation of a control may be assessed on its own merits or versus another control.

The above analysis may be used to develop budgetary estimates for appropriation requests and to assist in defining those noise sources which are most critical from the standpoint of potential hearing damage.

III. THE NOISE DATA BASE

This chapter presents a summary of the FF 1052 and DD 963 data base, collected from Navy sources and required for the computation of personnel noise exposure. The chapter also includes an assessment of the data base completeness and accuracy.

3.1 Present Navy Practice for Noise Exposure Evaluation

The results of on-going Navy efforts in evaluating noise levels aboard ships are obvious potential sources of noise exposure data. Under the direction of the Navy Bureau of Medicine and Surgery, the various Environmental Preventive Medicine Units, (EPMU) measure and compare shipboard noise levels with the 90 dBA, eight hour criteria of BUMEDINST.6260.6B [2]. These measurement programs result in the specification of limitations on daily time any one person may spend at a measurement location before receiving an equivalent permissible noise dose limit. However, the individual ship inspections do not assess personnel exposure, since no effort is made to quantify the time each person is assigned to a noise hazardous location. The measurement acquired by EPMU are useful in quantifying the noise levels associated with different space locations under various ship operating conditions but are not sufficient to establish the noise exposure of the individual seaman.

One study did employ dosimeters to evaluate noise dosage[9]. The results of that study, and others which will hopefully be conducted in the near future, will serve to "calibrate" or validate the calculated exposure values resulting from the methodology of the effort reported herein.

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3.2 Ships Operational Modes

The operation of the two classes of ships studied was divided into periods of time which were both acoustically different and definable from the ships log. The major division of time which satisfies both criterion is simply in-port and underway. These modes are further divided into sub-modes based on the ship's machinery line-up and readiness condition as indicated in Figure 3.1.

3.2.1 In-Port Operating Sub-Modes

The ships readiness Condition V is synonomous with the in-port ship's operating mode. The in-port mode is sub-divided between cold-iron and auxiliary steaming. This sub-division is as much a noise related difference as it is a well defined machinery line-up difference. For the FF 1052 class, the boilers with the required forced draft blowers in the fire room and the turbo-generators in the auxiliary machinery room are operating for auxiliary power. For the DD 963 class, one or more gas turbine generators are on line for auxiliary power, but are not necessary if shore power is available.

The cold-iron sub-mode is further divided into periods of time when the emergency diesel generator is on or off, or undergoing air-start. The diesel-generator-on is listed only with in-port operation, even though it also occurs underway. This is done for convenience and has no effect on the results of this study. Finally, the DD 963 emergency diesels are small and are seldom used. Therefore, the cold iron sub-mode is not subdivided for that class.

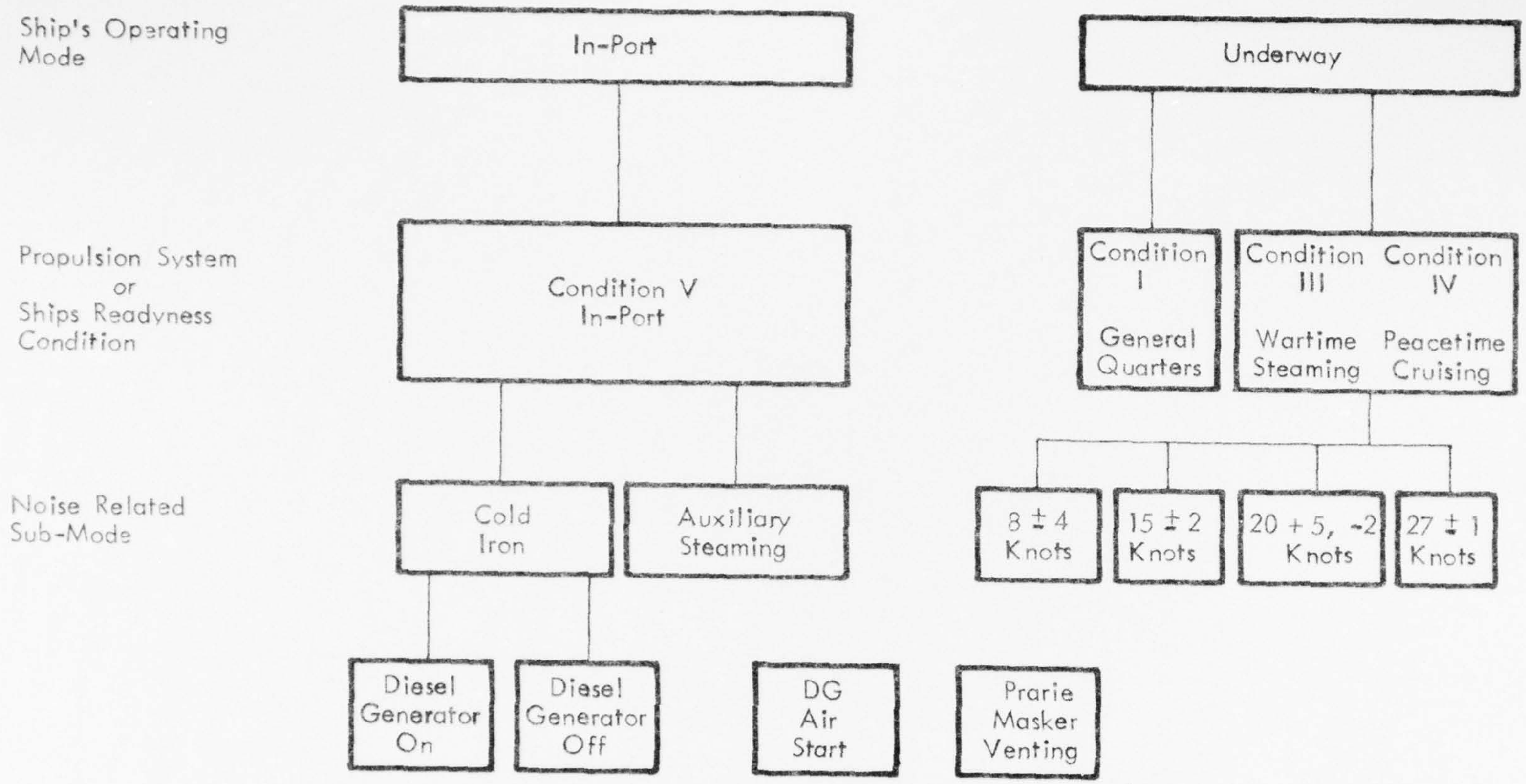

FIGURE 3.1 SHIPS OPERATING MODES AND NOISE RELATED SUB-MODES

3.2.2 Underway Sub-Modes

For the underway sub-modes, no differentiation is made between peacetime cruising (Condition IV) and wartime steaming (Condition III) because the duty assignments are essentially the same for engineering personnel. For the purpose of hearing damage risk evaluation, Condition I, general quarters, is disregarded because the small fraction of time operated under that mode.

The noise related sub-modes for cruising are based only on ships forward speed for the following reasons:

1. Propulsion machinery line-ups and resulting noise are speed dependent.
2. The auxiliary machinery line-ups are not definably different for any other descriptor.
3. The available data are in terms of forward speed.

In order to decide upon the number of different speed ranges to define as sub-modes, it is necessary to know the dependence of noise on speed. Two references [10, 11] give FF 1052 engine room and fire room noise levels in increments of 2.4 and 2.0 knots, respectively. These data are presented in Figures 3.2 and 3.3. For the purposes of this study and from the available data, aggregate noise levels at chosen sub-mode speeds of 8, 15, 20 and 27 knots were computed. In the same spirit, Figure 3.4, shows the speed dependence for auxiliary machinery room 1 and the aft steering room, again for the more extensively documented FF 1052 class.

These figures show that there is a definite speed dependence in the engine room, fire room and aft steering room, with a slight speed dependence in auxiliary machinery room 1. The differences in level between the chosen speeds of 8 knots and

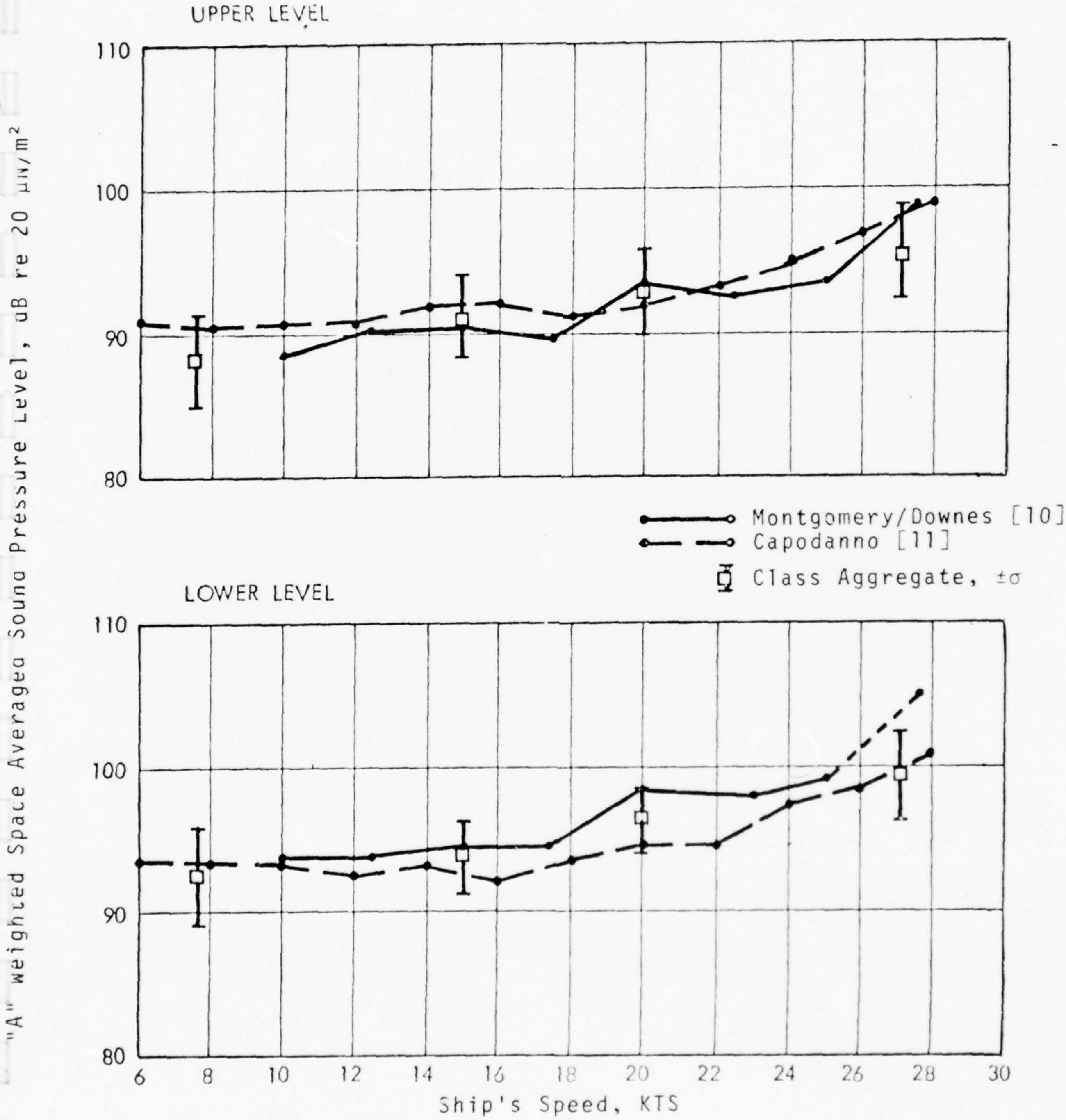

Figure 3.2 - ENGINE ROOM NOISE LEVEL AS A FUNCTION OF SHIP'S SPEED (FF 1052)

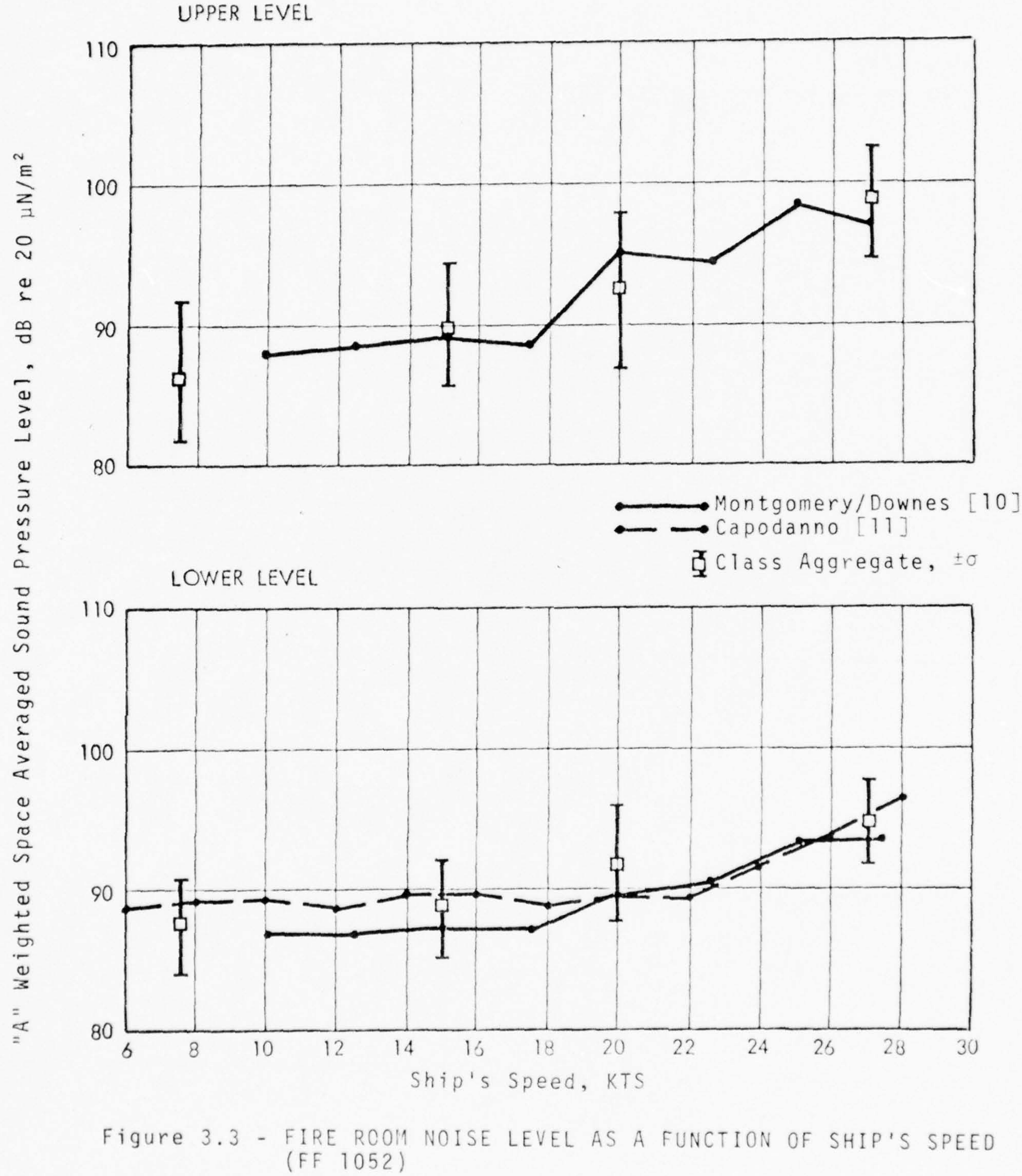

Figure 3.3 - FIRE ROOM NOISE LEVEL AS A FUNCTION OF SHIP'S SPEED (FF 1052)

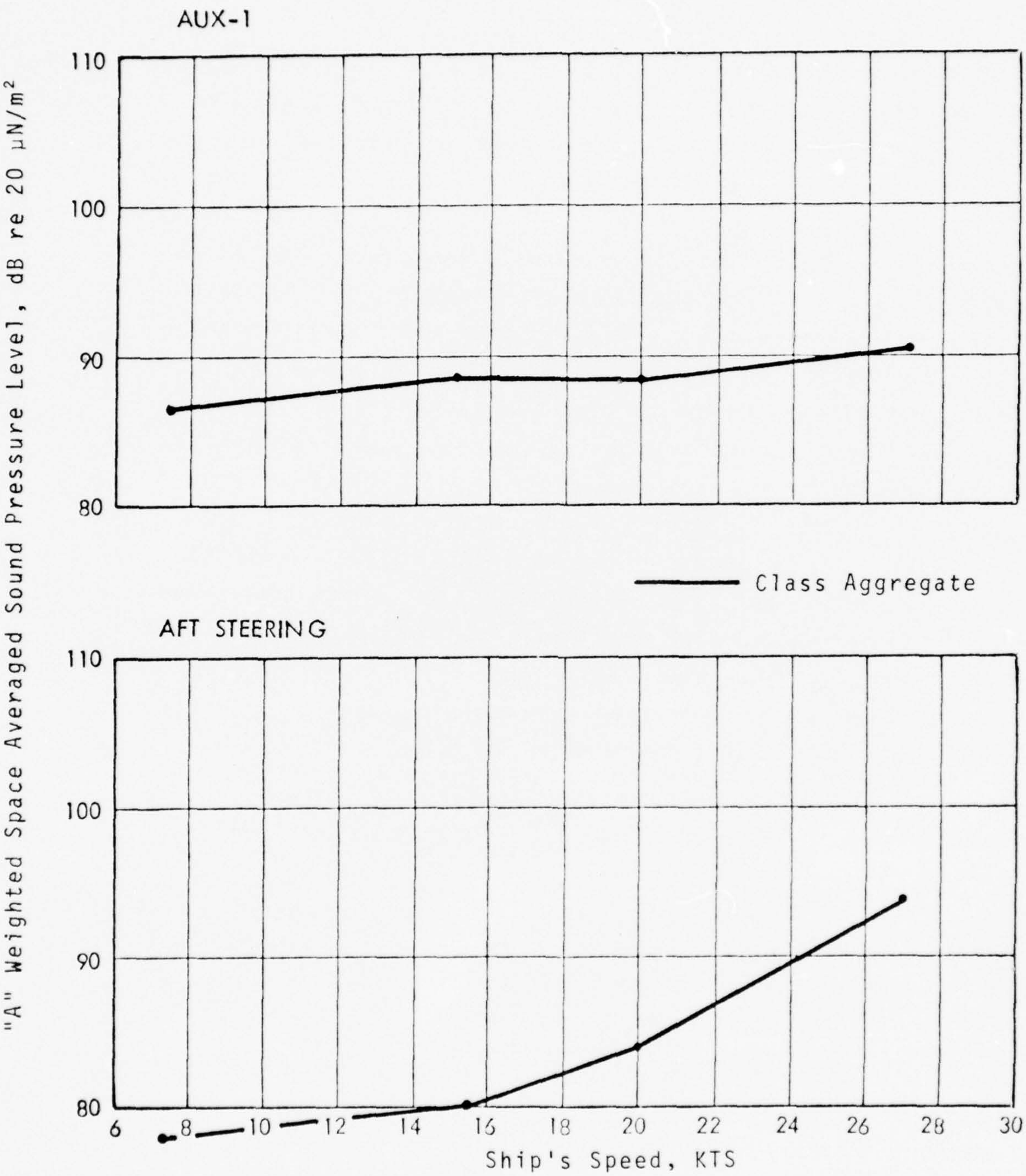

Figure 3.4 - AUXILIARY MACHINERY ROOM AND AFT STEERING ROOM NOISE LEVELS AS A FUNCTION OF SHIP's SPEED (FF 1052)

15 knots are characteristically small. However, the choice to consider them separately instead of grouping was influenced by two other factors; the availability of data and the time spent in each speed range. Both of these factors are discussed separately in subsequent sections of this report*.

With respect to auxiliary machinery room 1, the speed dependence was not significant with respect to the variability in the data. However, the data were available for the four chosen speeds and were treated separately mainly to illustrate the variety of measurement procedures used by different organizations. For exposure calculations and evaluation of noise control strategies, the underway data for auxiliary machinery room 1 are all averaged and treated as a common sub-mode. Noise in auxiliary machinery room 2 on the FF 1052 is dependent mainly on whether the diesel generator is on or off and to a lesser degree on whether the pumps and air conditioning compressor are on-line. Therefore, the speed dependent sub-modes are not applicable.

3.2.3 Machinery Line-Ups for Operational Modes

The approach used in this study is to consider each unique machinery line-up and power setting as a separate operational mode.

This approach was instituted because of the desire to evaluate the needs for and/or the benefits resulting from noise control

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* The use of findings and conclusions to justify the selection of operational modes points out that an iterative procedure was necessary and was used in many aspects of this study.

treatments for individual equipment items. Application of this procedure as originally envisioned was both impractical and counter productive for the following reasons:

1. The "nominal" machinery line-ups were well defined and invarient for cold iron, auxiliary steaming, ranges of underway speeds, and certain special situations, i.e., the selected operational modes.

2. The variations from nominal machinery line-ups are virtually infinite in number, but with little effect on the noise levels. For example, the forced draft blower system on the FF 1052 is under automatic control and the blowers change speeds frequently. Similarily, two of three turbine generators in auxiliary machinery room 1 are usually on-line, but the load is frequently shifted around by the engineering officer.

The nominal machinery lineups for the FF 1052 engineering spaces as a function of operating sub-mode are presented in Tables 3.1 through 3.3. The machinery lineups for the DD 963 spaces are presented in Tables 3.4 through 3.6. Note that the selection of the particular unit in a set is arbitrary. In fact, the engineering officer will tend to shift the load around so as to equalize the time on-line.

These Tables 3.1 through 3.6 also give the equipment shaft power and rotational speeds for reference and for subsequent noise diagnosis.

TABLE 3.1 NOMINAL MACHINERY LINEUPS ENGINE ROOM, FF1052

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
Main Reduction Gear	-	0-240	35K	-	-	Op	Op	Op	Op
Propulsion L.P. Turbine	-	0-6545		-	-	Op	Op	Op	Op
Propulsion H.P. Turbine	-	0-7889		-	-	Op	Op	Op	Op
Main Air Ejector	-	N/A	N/A	-	-	Op	Op	Op	Op
Main Circulating Pump	-	875/440	100/25	-	-	Op	Op	Op	Op
Main Condensate Pump	1A	1150	20	-	Op	Op	Op	Op	Op
Main Condensate Pump	1B	1150	20	-	-	-	-	-	Op
Main L.O. Service Pump	1A	1750/875	40/20	-	-	-	-	-	-
Main L.O. Service Pump	1B	1750/875	40/20	-	-	Op	Op	Op	Op
Main L.O. Purifier	1A	7200	1.5	-	-	Op	Op	Op	Op
Distilling Plant, Feed Pump	1	3500	10	-	Op	Op	Op	Op	Op
Distilling Plant, Feed Pump	2	3500	10	-	-	Op	Op	Op	Op
Brine Eductor	1	N/A	N/A	-	Op	Op	Op	Op	Op
Brine Eductor	2	N/A	N/A	-	-	Op	Op	Op	Op
Fire Pump	3	3500	100	Op*	Op	Op	Op	Op	Op
Air Cond. Comp.	1		100	Op	Op	Op	Op	Op	Op
Air Cond. C.W. Circ. Pump	1	3500	20	Op	Op	Op	Op	Op	Op
Air Cond-Comp.	2		100	-	-	Op	Op	Op	Op
Air Cond. C.W. Circ. Pump	2	3500	20	-	-	Op	Op	Op	Op
Vent Supply Fan	-	1150/1750	15	Op Lo	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi
Vent Exhaust Fan	-	1150/1750	15	Op Lo	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi

* OP - Operate, Op Lo - Operate Low Speed, Op Hi - Operate High Speed

TABLE 3.2 NOMINAL MACHINERY LINEUPS FIRE ROOM, FF1052

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
Boiler	1A	N/A	Steam	-	Op	Op	Op	Op	Op
Boiler	1B	N/A	Steam	-	-	-	-	Op	Op
Forced Draft Blower	1A1	0-7400	Steam	-	Op	Op	Op	Op	Op
Forced Draft Blower	1A2.	0-7400	Steam	-	-	Op	Op	Op	Op
Forced Draft Blower	1B1	0-7400	Steam	-	-	-	-	-	Op
Forced Draft Blower	1B2	0-7400	Steam	-	-	-	-	-	Op
Main Feed Pump	1A	7300	Steam	-	Op	Op	Op	Op	Op
Main Feed Pump	1B	7300	Steam	-	-	Op	Op	Op	Op
Main Feed Pump	1C	7300	Steam	-	-	-	-	-	-
Main Feed Booster Pump	1A	1150	30	-	Op	Op	Op	Op	Op
Main Feed Booster Pump	1B	1150	30	-	-	Op	Op	Op	Op
Main Feed Booster Pump	1C	1150	30	-	-	-	-	-	-
Fuel Oil Service Pump	1A	1750/1150	40	-	Op	Op	Op	Op	Op
Fuel Oil Service Pump	1B	1750/1150	40	-	-	-	-	-	-
F.W. Drain Pump	1A	3500	3	-	-	Op	Op	Op	Op
F.W. Drain Pump	1B	3500	3	-	-	-	-	-	-
Fire Pump	2	3500	100	Op	Op	Op	Op	Op	Op
Prairie Masker Air Comp.	1A	40,400	Steam	-	-	-	-	-	-
Prairie Masker Air Comp.	1B	40,400	Steam	-	-	-	-	-	-
Aux. Gland Exhaust Fan	-	3500	5	Op	Op	Op	Op	Op	Op
Vent Supply Fans		1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi
Vent Exhaust Fans	-	1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi

TABLE 3.3 NOMINAL MACHINERY LINEUPS AUXILIARY MACHINERY ROOM 1, FF 1052

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
SS Turbo-generator	1A	1200	750 KW	-	-	-	-	-	-
SSTG Circulating Pump	1A	3500	7.5	-	-	-	-	-	-
SSTG Cond. Conditioning Pump	1A	1750	7.5	-	-	-	-	-	-
SS Turbo-generator	1B	1200	750 KW	-	Op	Op	Op	Op	Op
SSTG Circulating Pump	1B	3500	7.5	-	Op	Op	Op	Op	Op
SSTG Cond. Conditioning Pump	1B	1750	7.5	-	Op	Op	Op	Op	Op
SS Turbo-generator	1C	1200	750 KW	-	-	Op	Op	Op	Op
SSTG Circulating Pump	1C	3500	7.5	-	-	Op	Op	Op	Op
SSTG Cond. Conditioning Pump	1C	1750	7.5	-	-	Op	Op	Op	Op
SSTG Gland Exhaust Fan	1	3500	2	-	-	Op	Op	Op	Op
Fire Pump	1	3500	100	Op	Op	Op	Op	Op	Op
L.P. Air Compressor	1	800	30	Op	Op	Op	Op	Op	Op
H.P. Air Compressor	1	880	25	-	-	-	-	-	-
Fin Stabilizer	1(S)			-	-	Op	Op	Op	Op
Fin Stabilizer	2(P)			-	-	Op	Op	Op	Op
F.O. Transfer Pump	1	1150/575	20/10	-	-	-	-	-	-
ASROC Circulating Pump	1	3500	20	Op	Op	Op	Op	Op	Op
ASROC Circulating Pump	2	3500	20	-	-	-	-	-	-
SS 400 Hz. M/G Set				Op	Op	Op	Op	Op	Op
Vent Supply Fan		1150/1750	15	Op Lo	Op Lo	Op Lo	Op Lo	Op Lo	Op Lo
Vent Exhaust Fan		1150/1750	15	Op Lo	Op Lo	Op Lo	Op Lo	Op Lo	Op Lo

TABLE 3.4 NOMINAL MACHINERY LINEUPS ENGINE ROOM1, DD 963

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
Main Reduction Gear	2	0-168	41.7 K	-	-	Op	Op	Op	Op
Attached LO Pump	2	-	1140gpm	-	-	Op	Op	Op	Op
Attached CRP Pump	2	-	163 gpm	-	-				
Main Prop Turbine	2A	0-3600	21.5K	-	-	Op	Op	Op	Op
Main Prop Turbine	2B	0-3600	21.5K	-	-	-	-	-	Op
Main Eng. Cooling Fan	2A	1800	60	-	-	Op	Op	Op	Op
Main Eng. Cooling Fan	2B	1800	60	-	-	-	-	-	Op
FO Booster Pump	2A	1800	10/67	-	-	Op	Op	Op	Op
FO Booster Pump	2B	1800	10/67	-	-	-	-	-	Op
H.O.P.M.	2	1200	100/10	-	-	Op	Op	Op	Op
L.O. Service Pump	2A	900	50	-	-	-	-	-	-
L.O. Service Pump	2B	900	50	-	-	-	-	-	-
L.O. Purifier	2	15,000	2	-	-	Op	Op	Op	Op
Gas Turb. Generator	1	13.5K	3600	-	Op	Op	Op	Op	Op
Gen. Cooling Fan	1			-	Op	Op	Op	Op	Op
Gen. SW Cooling Pump	1	3600	30	-	Op	Op	Op	Op	Op
Fire Pump	2	3550	150	Op	Op	Op	Op	Op	Op
Bilge Pump	1			-	-	-	-	-	-
Air Compressor	1	1165/2	30	Op	Op	Op	Op	Op	Op
Boiler	1	-	-	Op	Op	Op	Op	Op	Op
Boiler Feed Pump	1		10	Op	Op	Op	Op	Op	Op
Boiler Recirc. Pump	1			Op	Op	Op	Op	Op	Op
Vent Supply Fans		1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi
Vent Exhaust Fans		1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi

TABLE 3.5 NOMINAL MACHINERY LINEUPS ENGINE ROOM 2, DD 963

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
Main Reduction Gear	1	0-168	41.7K	-	-	Op	Op	Op	Op
Attached LO Pump	1	-	1140gpm	-	-	Op	Op	Op	Op
Attached CRP Pump	1	-	163gpm	-	-	Op	Op	Op	Op
Main Prop. Turbine	1A	0-3600	21.5K	-	-	Op	Op	Op	Op
Main Prop. Turbine	1B	0-3600	21.5K	-	-	-	-	-	Op
Main Eng. Cooling Fan	1A	1800	60	-	-	Op	Op	Op	Op
Main Eng. Cooling Fan	1B	1800	60	-	-	-	-	-	Op
FO Booster Pump	1A	1800	10/67	-	-	Op	Op	Op	Op
FO Booster Pump	1B	1800	10/67	-	-	-	-	-	Op
H.O.P.M.	1	1200	100/10	-	-	-	-	-	-
L.O. Service Pump	1A	900	50	-	-	-	-	-	-
L.O. Service Pump	1B	900	50	-	-	-	-	-	-
LO Purifier	1	15,000	2	-	-	Op	Op	Op	Op
Gas Turb. Generator	2		3200	-	Op	Op	Op	Op	Op
Gen. Cooling Fan	2			-	Op	Op	Op	Op	Op
Gen. SW Cooling Pump	2	3600	30	-	Op	Op	Op	Op	Op
Fire Pump	5	3550	150	Op	Op	Op	Op	Op	Op
Bilge Pump	2	3600	15	-	-	-	-	-	-
Air Compressor	2	1165/2	30	-	-	-	-	-	-
Boiler	2	-	-	-	-	Op	Op	Op	Op
Boiler Feed Pump	2		10	-	-	Op	Op	Op	Op
Boiler Recirc. Pump	2			-	-	Op	Op	Op	Op
Vent Supply Fans	-	1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi
Vent Exhaust Fans	-	1150/1750	15	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi	Op Hi
Sea Water Serv. Pump	3	1780	125	-	-	-	-	-	-

TABLE 3.6 NOMINAL MACHINERY LINEUPS AUXILIARY MACHINERY ROOM 1, DD 963

Machinery Item		Speed	Power	In-Port Mode		Underway Mode			
Unit Description	No.	rpm	HP	Cold Iron	Aux Steam	8 Kts	15 Kts	20 Kts	27 Kts
Air Cond. Plant	1	3600	150	Op	Op	Op	Op	Op	Op
C.W. Pump	1	3600	50	Op	Op	Op	Op	Op	Op
Air Cond. Plant	2	3600	150	-	-	Op	Op	Op	Op
C. W. Pump	2	3600	150	-	-	Op	Op	Op	Op
Fire Pump	3	3550	150	-	-	Op	Op	Op	Op
Sea Water Serv. Pump	1	1780	125	Op	Op	Op	Op	Op	Op
FO Xfer Pump	1	1800	10	-	-	-	-	-	-
FO Purifier	1	4325	40	-	-	-	-	-	-
HP Air Compressor	1	1800	50	-	-	-	-	-	-
Comp. Air Dryer	1	N/A	N/A	-	-	-	-	-	-
Distilling Plant	1	N/A	N/A	-	Op	Op	Op	Op	Op
Cond. Pump	1	1800	1-5	-	Op	Op	Op	Op	Op
SW Pump	1	3500	10	-	Op	Op	Op	Op	Op
Brine Pump	1		3.5	-	Op	Op	Op	Op	Op
Distilling Plant	2	N/A	N/A	-	-	-	-	-	-
Cond. Pump	2	1800	1-5	-	-	-	-	-	-
SW Pump	2	3500	10	-	-	-	-	-	-
Brine Pump	2		3.5	-	-	-	-	-	-
Vent Supply Fan	-	1150/1750	15	Op Lo	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi
Vent Exhaust Fan	-	1150/1750	15	Op Lo	Op Lo	Op Hi	Op Hi	Op Hi	Op Hi

3.2.4 Percent Time Spent in Operating Mode

The percent time spent in each of the operational modes and sub-modes is an important parameter in evaluating the relative importance of each mode. If an acceptable algorithm were available combining the personnel noise dose for all modes, then the calculation of the average yearly noise dose would be possible. At this time, the value of this descriptor is limited to evaluating noise control strategies based on the importance of each mode.

The fractional time spent underway and in-port, plus the break-down by sub-mode was obtained from two NAVSEA documents [12, 13] and the smooth log of a single FF 1052 ship. The results shown in Figure 3.5 are remarkably similar, suggesting either that the class is homogeneous or that the ship surveyed has been assigned average duty.

No comparable data were compiled for the DD 963 class. However, there is no evidence that the new destroyer class ships will be at sea either more or less than the FF 1052 ships. Therefore, the results shown in Figure 3.5 will be used for the DD 963 class.

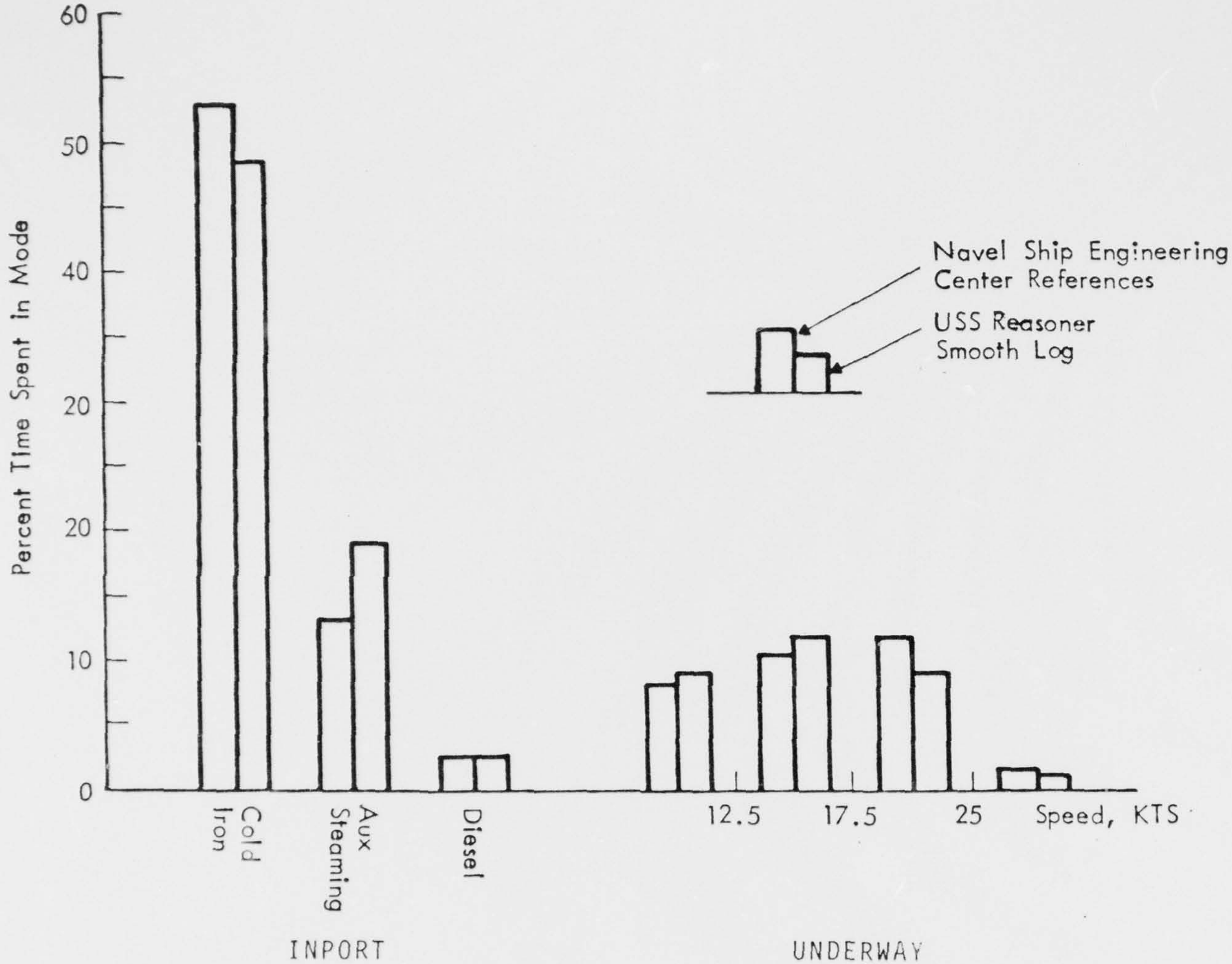

Figure 3.5 - SHIP'S OPERATING MODES (FF 1052)

3.3 Man--The Personnel Assignment Data Base

3.3.1 Background

Early in the data evaluation phase of the program, efforts were undertaken to determine engineering personnel assignments from naval sources and documents. Two basic types of crew assignments were found to control personnel exposure in noisy engineering spaces, i.e., normal work duty and watch station duty. In addition, the definition of different readiness conditions was found to influence the total duration per day of exposure to excessive noise for a watch stander. The table below outlines the general case.

Readiness Condition Watch Sections

Condition I (General Quarters)	All personnel at Battle Stations
Condition III (Wartime Steaming)	One watch in three
Condition IV (Peacetime Cruising)	One watch in four
Condition V (In-Port/At Anchor)	One watch in five

These condition watches provide for the specific watch organization on board ship that is necessary to insure the degree of readiness needed.

Initially, very little information regarding normal work assignments in engineering spaces could be found. Most of the information supplied by the Navy dealt with watch standers. A case in point is the engine rooms for DD 963 class ships. Early information supplied to BBN designated these spaces as being unmanned. Later investigations revealed that the "unmanned" status was in fact referring to watch stations, not normal crew work assignments. In fact, watch assignments are made in the engine rooms at the present time. Clearly, a need exists to identify, inasmuch as possible, the actual number of crew members assigned to engineering spaces with a breakdown of their time and location at watch and work during each readiness condition.

3.3.2 Personnel Assignment Questionnaire

Personnel assigned to engineering spaces perform duties which vary accordingly to the crewman's rating and training as well as the ship's operating conditions (i.e., in-port or cruising). Since the evaluation of noise exposure is a function of the total time spent in noisy environments and compartment location (when noise levels vary within the engineering space), it is necessary to quantify in some manner the assignments of personnel for a given mode. Admittedly, such a characterization is very difficult to obtain on a man-by-man basis, however, statistical descriptors that identify these two variables over the long term and over a ship class are desirable so that average exposure levels may be computed.

The development of personnel assignment descriptors is critical since, in the final analysis, the noise control efforts which might be undertaken have as their primary objective the abatement of personnel noise exposure rather than simply noise level reductions. Furthermore, the evaluation of a noise exposure problem or compliance with a hearing conservation standard, be it BUMED, OSHA or any other noise regulation, requires not only an understanding of the noise environment but also the relationship of that noise environment to the personnel exposed to,it as was pointed out in Chapter Two.

It follows then that certain data base requirements, as described in Section 2.2.2, are necessary to describe the personnel assignment characteristics. The following information is sought:

(1) The total number of personnel assigned to the engineering spaces for each destroyer class.

(2) The breakdown of the above total among the different spaces. That is, the number of people assigned to the boiler room(s), engine room(s), auxiliary room(s), etc.

(3) In each space, the breakdown on personnel according to billet title and rate.

(4) Identification of all permanently and conditionally manned watch stations in each space.

(5) Definition of the total time (over a 24-hour day) that specific individuals are assigned to watch stations. Identification of watch stander (by billet title and rate), watch station, and total time at the watch station.

(6) When the actual total time assignment (over a 24-hour day) for an engineering watch station differs according to the readiness condition of the ship, given an indication of the respective time allotments. The readiness conditions considered are defined in the beginning of this section.

(7) For each engineering crewman (identified by billet title and rate), working under the above readiness conditions, what is the total time (over a 24-hour day) per type of work designation spent performing normal work and other duties exclusive of watch (i.e., 4 hours, on the average, performing planned maintenance, etc.).

(8) The most difficult and yet essential time and location data for normal work and other duties must be obtained using a quasi time-motion study or survey. Identification would include the sub-areas and time durations where normal work activities, rest, and other duties are performed. For example, a particular crewman (identified by billet title and rank) may spend 3 hours of his work time on the lower level and 5 hours on the upper level. 80% of the upper level time may be spent in the forward section. This information usually must be obtained on a long term basis (i.e., over the course of a week or month), in order to identify the average hours spent per location.

In order to obtain this desired information, a preliminary questionnaire was prepared. The purpose of the questionnaire was mainly to test the premise for statistically quantifying time and location data for the engineering crew during normal work duties could be obtained. A copy of the preliminary questionnaire and accompanying question list for the person administering the survey are contained in Appendix A.

3.3.3 The Data Base -- A Summary

The following sections summarize the data that has been extracted from the questionnaires for the two ship classes.

3.3.3.1 FF 1052 (KNOX) Class

Two 1052 class ships were surveyed and the following data represent the average manning per ship:

24.5	Fire Rooms Personnel
18.0	Engine Rooms Personnel
10.0	Aux. Machine Room No. 1 Personnel
5.0	Aux. Machine Room No. 2 Personnel
57.5	Total Average Engineering Spaces Personnel

The Personnel Survey for the FF 1052 class ships was conducted in the engine and fire rooms. A total of twelve fire room personnel and nine engine room personnel were questioned as to time duration and general location of work during both watch and normal work duties. Tables 3.7 through 3.18 show the data base which resulted from the surveys. The location codes correspond to the measurement locations identified in Section 3.4.2 (Selection and numbering of Locations within compartments).

3.3.3.2 DD 963 (SPRUANCE) Class

A single DD 963 class ship was surveyed to obtain personnel time and location information. The Personnel Survey was conducted in the forward main engine room (No. 1) and in the forward auxiliary machinery room (No. 1). A total of five engine room personnel and two auxiliary machinery room personnel were questioned and observed as they went about their work and watch duties while the ship was underway. Time and location information was gathered as well as their comments about off-duty noise exposure. It is interesting to note that the results of the off-duty survey indicate that the majority received their greatest exposure to high noise levels while-on duty even though a few participated in sport or trap shooting activities on occasion.

The results of the on-duty work and watch noise exposure times and locations are presented in Tables 3.19 through 3.30.

TABLE 3.7. FF 1052 CLASS FIRE ROOM *WORK* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	3, 3.5, 1	FL, FU, FT
2	BTFA	4, 2.5, 0.5	FL1W, FU, FT
3	BTFN	4, 3.5, 0.5	FL, FU, FT
4	BTFN	5, 3	FL5, FU2W
5	BT3	5, 2, 2	FL1W, FU, FT
6	BTFN	2, 8, 1	FL, FU1W, FT
7	BT2	4, 1, 0.5, 3, 1	FL, FU4, FU1W, FU2W, FT
8	BTFN	5, 5, 1,1	EL, FL, AU, X
9	BT1	1, 0.5, 0.5, 1	FL, FU1W, FU, FT
10	BTFN	4, 4, 4	FL, FU, FM
11	BT1	4, 2, 2, 1	FL1W, FU1W, FU2W, FT1
12	BTFN	3, 3, 1, 1	FL1W, FU, FU2W, FT1

TABLE 3.8. FF 1052 CLASS FIRE ROOM *WATCH* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	8	FU
2	BTFA	8	FL1W
3	BTFN	3, 3	FL, FU
4	BTFN	7, 5	FL, FU2W
5	BT3	4, 4	FL, FU
6	BTFN	12	FU1W
7	BT2	6,6	FL, FU
8	BTFN	8	FL1W
9	BT1	4	FU2W
10	BTFN	3, 3, 3	FL, FU, FM
11	BT1	4, 4	FL, FU
12	BTFN	8	FU1W

TABLE 3.9. FF 1052 CLASS FIRE ROOM *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	3, 4, 1	FL, FU, FT
2	BTFA	9	FL1W
3	BTFN	4, 3.5, 0.5	FL, FU, FT
4	BTFN	-	-
5	BT3	4, 4	FL, FU
6	BTFN	4, 4	FL,FU
7	BT2	-	
8	BTFN	5, 5, 1, 1	EL, FL, AU, X
9	BT1	1, 0.5, 0.5, 1	FL, FU1W, FU, FT
10	BTFN	4, 4, 4	FL, FU, FM
11	BT1	-	-
12	BTFN	3, 3	FL, FU

TABLE 3.10. FF 1052 CLASS FIRE ROOM *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	4	ET1W
2	BTFA	4	ET1W
3	BTFN	4	ET1W
4	BTFN	4	ET1W
5	BT3	4	ET1W
6	BTFN	4	ET1W
7	BT2	-	-
8	BTFN	4	ET1W
9	BT1	-	-
10	BTFN	1, 1, 1, 1, 1, 1	EU, EL, FU, FL, AU, X
11	BT1	-	-
12	BTFN	10	FU1W

TABLE 3.11. FF 1052 CLASS FIRE ROOM *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	1.5, 2, 0.5	FL, FU, FT
2	BTFA	-	-
3	BTFN	-	-
4	BTFN	1	FL1W
5	BT3	-	-
6	BTFN	-	-
7	BT2	4	FL1W
8	BTFN	-	-
9	BT1	-	-
10	BTFN	-	-
11	BT1	3, 3	FL, FU
12	BTFN	3, 3	FL, FU

TABLE 3.12. FF 1052 CLASS FIRE ROOM *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	BTFA	12	FU
2	BTFA	12	FL
3	BTFN	6, 6	FL, FU
4	BTFN	6, 6	FL, FU
5	BT3	6, 6	FL, FU
6	BTFB	6, 6	FL, FU
7	BT2	12	FU2W
8	BTFN	6	FL
9	BT1	12	FU2W
10	BTFN	12	FU2W
11	BT1	3, 3	FL, FU
12	BTFN	-	-

TABLE 3.13. FF 1052 CLASS ENGINE ROOM *WORK* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	4, 4	EU8, EU11
2	EN	8	X1W
3	MM2	4, 4	EL, EU
4	MM	2, 5, 1	EL, EU3, ET1W
5	FN	2, 5, 0.5	EL1W, EU, ET
6	FN	0.5, 6, 1.5	EL1W, EU, ET1W
7	MMFN	6,2	EL, EU
8	MMFN	2, 4, 1, 1	EL, EU, ET1W, AU
9	MMC	8	ET1W

TABLE 3.14. FF 1052 CLASS ENGINE ROOM *WATCH* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	4, 4	EU8, EU11
2	EN	8	EU1W
3	MM2	8	ET1W
4	MM	8	EU1W
5	FN	8	ET1W
6	FN	8	ET1W
7	MMFN	5, 1.5, 1.5	ET1W, EL, EU
8	MMFN	8	EL
9	MUC	8	ET1W

TABLE 3.15. FF 1052 CLASS ENGINE ROOM *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	4, 4	X1W, X3
2	EN	8	X1W
3	MM2	6.5, 6.5	EL, EU
4	MM	2, 4, 2	EL, EU1W, EU
5	FN	8	EU
6	FN	8	ET1W
7	MMFN	7, 0.5, 0.5	ET1W, EL, EU
8	MMFN	3, 5	EL, EU
9	MMC	8	ET1W

TABLE 3.16. FF 1052 CLASS ENGINE ROOM *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE -*COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	4, 4	X1W, X3
2	EN	4, 4	EL, EU
3	MM2	6.5, 6.5	EL, EU
4	MM	2, 2, 4	EL, EU, ET1W
5	FN	8	ET1W
6	FN	8	ET1W
7	MMFN	7, 0.5, 0.5	ET1W, EL, EU
8	MMFN	3,5	EL, EU
9	MMC	4,4	ET, AU

TABLE 3.17. FF 1052 ENGINE ROOM *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	-	-
2	EN	-	-
3	MM2	6, 6	AU3, AU9
4	MM	-	-
5	FN	-	-
6	FN	-	-
7	MMFN	-	-
8	MMFN	-	-
9	MMC	-	-

TABLE 3.18. FF 1052 CLASS ENGINE *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	EN3	-	-
2	EN	-	-
3	MM2	6, 6	AU3, AU9
4	MM	-	-
5	FN	-	-
6	FN	-	-
7	MMFN	-	-
8	MMFN	-	-
9	MMC	-	-

TABLE 3.19. DD 963 CLASS ENGINE ROOM NO. 1 *WORK* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	FN	2, 2, 4	E11, E12W, E15
2	FA	3, 2, 3	E11, E12W, E14
3	FA	4, 4	E12W, E13W
4	EN2	2, 3, 3	E12W, E13W, E14
5	FN	3, 2, 3	E11, E12W, E14

TABLE 3.20. DD 963 CLASS ENGINE ROOM NO. 1 *WATCH* TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	FN	3, 5	E12W, ER1
2	FA	3, 5	E12W, ER1
3	FA	8	ECC
4	EN2	8	E12W
5	FN	4, 4	E11, E12W

TABLE 3.21. DD 963 CLASS ENGINE ROOM NO. 1 *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	FN	8	ER1
2	FA	8	ER1
3	FA	4	ER1
4	EN2	8	ER1
5	FN	8	ER1

TABLE 3.22. DD 963. CLASS ENGINE ROOM NO. 1 *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	FN	8	ER1
2	FA	8	ER1
3	FA	8	ECC
4	EN2	4, 4	ECC, ER1
5	FN	8	ER1

TABLE 3.23. DD 963 CLASS ENGINE ROOM NO. 1 *WORK* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	FN	-	-
2	FA	8	ER1
3	FA	4	ER1
4	EN2	8	ER1
5	FN	-	-

TABLE 3.24. DD 963 CLASS ENGINE ROOM No. 1 *WATCH* TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	FN	-	-
2	FA	8	ER1
3	FA	8	ECC
4	EN2	4, 4	ECC, ER1
5	FN	-	-

TABLE 3.25. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WORK TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No	Rate	Respective Hours	Respective Locations
1	EN2	3.5, 3.5	AR1, GR3
2	FA	8	AR1

TABLE 3.26. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WATCH TIMES AND LOCATIONS DURING *UNDERWAY* MODE

Man No.	Rate	Respective Hours	Respective Locations
1	EN2	8	E12W
2	FA	8	AR1

TABLE 3.27. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WORK TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No.	Rate	Respective Hours	Respective Locations
1	EN2	3.5, 3.5	AR1, GR3
2	FA	8	AR1

TABLE 3.28. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WATCH TIMES AND LOCATIONS DURING IN-PORT MODE - *COLD IRON*

Man No	Rate	Respective Hours	Respective Locations
1	EN2	4, 2, 2	ECC, AR1, ER1
2	FA	8	AR1

TABLE 3.29. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WORK TIMES AND LOCATIONS DURING IN-PORT MODE - *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	EN2	3.5, 3.5	AR1, GR3
2	FA	8	AR1

TABLE 3.30. DD 963 CLASS AUXILIARY MACHINERY ROOM NO. 1
WATCH TIMES AND LOCATIONS DURING IN-PORT MODE- *AUX. STEAM*

Man No.	Rate	Respective Hours	Respective Locations
1	EN2	4, 2, 2	ECC, AR1, ER1
2	FA	8	AR1

3.4 Hazard -- The Description of Compartment Noise Levels

3.4.1 Background

Various Navy Bureau Centers and Laboratories perform airborne noise measurements aboard ships. The type of measurements made depend largely on the mission of each organization, with little or no effort expended to coordinate or standardize the measurements to benefit other activities or anticipated purposes. Fortunately, the ships themselves serve as standardizing influences and measurement locations are similar. In addition, most organizations make A-weighted noise level measurements which are useful in evaluating the noise hazard.

The data sources and types of measurements available to describe shipboard compartment noise levels are summarized in Table 3.31. The table gives a brief statement of the basic purpose of the measurement; the listing is intended to show the variety of goals and not to precisely reflect the charter of the performing organization. The measurement bandwidths, ships speeds and compartments surveyed are also listed.

Each Navy organization involved has not surveyed the same number of ships, nor performed the survey with the same thoroughness. For the FF 1052 class, the data sources and the numbers of useful dB(A) measurements are listed in Table 3.32. Again, this table demonstrates the variety of ship's conditions and measurement techniques employed.

TABLE 3.31

SUMMARY OF NAVY SHIPBOARD COMPARTMENT
AIRBORNE NOISE MEASUREMENTS

Navy Organization	Purpose of Measurements	Measurement Parameters		
		Measurement Type*	Ships Speed, Knots	Compart. Surveyed
NSRDC	Verify compliance with ships compartment category specifications	Oct, dB(A)	5,10,15 20,24, max.	All
NSRDC	Reduce Engineering Space Noise Levels	1/3 Oct dB(A) N.B.	20,26	Engr.
EPMU	Verify ship's readiness via inspection	dB(A)	5,7,10, 15,16,20 22,25,27	Engr.
NEHC	Determine personnel exposure	dB(A) Dose	0,2,4,6, ---28	Engr.
NUC	Evaluate hearing protection, recommend noise control	1/3 Oct	18,21, 22.5, 26,28	Engr.
SEC	Develop requirements and engineer noise control hardware	1/3 Oct dB(A) N.B.	10,12.5 ---27.5	Engr.

* Oct: Octave bands of frequency
1/3 Oct: 1/3 octave bands of frequency
dB(A): "A-weighted" sound level
N.B.: Narrow band
Dose: Noise exposure measurement

TABLE 3.32

NUMBERS OF USEFUL dB(A) MEASUREMENTS FROM DIFFERENT SOURCES - FF 1052 CLASS

Data Source	Underway Speed, Knots 8	15	20	27	Other	Data Source	Underway Speed, Knots 8	15	20	27	Other
BBN-1(1082)	14	16	24	16	-	NAVSHIPS-1(1063)	7	7	7	-	1
BBN-1(1070)	17	17	17	-	-	-2(1066)	5	-	5	-	2
NUC-1/3(1069)	-	22	23	23	-	-2(1069)	5	-	-	5	-
NEHC-1(1093)	35	23	55	-	-	-2(1071)	3	4	2	-	-
-2(1093)	82	35	5	6	21	-2(1073)	8	-	-	8	1
-2(1089)	-	16	44	66	7	-2(1076)	6	-	6	-	-
EPMU 5-1	-	40	40	-	4	-2(1086)	7	-	-	6	-
-2	34	-	34	-	5	-2(1087)	5	-	-	7	-
-3	40	39	-	39	2	-2(1088)	7	7	7	-	-
-4	16	-	-	19	6	-3(1070)	7	8	-	-	-
-5	-	-	-	9	1	EPMU2-1(1094)	48	-	-	-	-
-6	41	8	-	-	1	-2(1091)	-	9	18	-	3
-7	36	51	-	52	3	-3(1085)	37	-	21	-	4
-8	-	-	-	34	8	-4(1084)	-	29	-	-	6
-9	-	-	-	18	-	-5(1081)	8	7	7	32	4
-10	-	33	-	-	5	-6(1056)	13	-	-	-	19
-11	-	48	-	39	8	-7(1078)	-	-	35	24	4
-12	-	-	-	22	4	-8(1059)	-	30	-	22	4
-13	31	-	-	40	4	-9(1072)	-	56	-	-	3
-14	-	3	-	4	-						
NSRDC-1(1085)	-	15	-	20	6						
-2(1056)	35	8	18	1	6						
-3(1075)	-	-	8	8	-						
-4(1091)	13	-	9	-	4						
-5(1095)	13	-	10	-	-						

*See Acoustic Data Source Reference, Appendix C

3.4.2 Selection and Numbering of Locations within Compartments

Combining the man's duty and his noise hazard to arrive at exposure requires the selection of typical locations in the ship engineering compartments. The selection of locations should be based on either the man's duty, or the noise environment, or both. For example, the watch stations and work benches in the engineering compartments are logical locations because much is known about time spent. Similarly, a high intensity noise area, like under a vent exhaust fan, is appropriate even though the time spent there may be small. The available Navy data have been collected generally at both watch stations and in proximity to noise producing equipments. To simplify the noise data analysis, from 6 to 11 commonly used locations on each major level of each engineering space have been selected and given a code number. Fewer locations have been selected for the less frequented deck levels. The coding indicates the compartment, the level, the location number and whether the location is a watch or work area, as follows:

```
E   U   2   W
|   |   |   \Work Bench or Watch Station Area
|   |   \Second Location
|   \Upper Level
\Engine Room
```

A summary of the measurement locations for the FF 1052 class and the DD 963 class are presented in Appendix B. These locations are also shown pictorially in Appendix B.

3.4.3 The Data Base -- A Summary

The following sections summarize "A-weighted"noise level data for the engineering spaces aboard the two ship classes investigated.

3.4.3.1 FF 1052 (KNOX) Class

The FF 1052 class literature contains the major share of the noise level data analyzed in this study. The FF 1052 measurements were averaged for each location and the sample standard deviation σ computed. For most locations, the standard deviation ranges between ± 2 and ± 4 dB, indicating a fairly consistent data base. Due to the extensive nature of location noise data, the analysis is presented in Appendix D. A summary of the "average noise level" for each deck level (and operating mode) is presented in Table 3.33 together with the standard deviation of the data samples. The "average noise level" for each deck is computed by averaging the noise level from all locations identified on that deck.

Interestingly, the standard deviations for the by-deck-level averages are not much greater than the standard deviations for the individual measurement locations. In Table 3.33, large sample standard deviations are usually associated with machinery line-up options. For example, locations in the third level of the fire room vary greatly because the measurements are taken with different combinations of forced draft blowers on-line.

The values in Table 3.33 show definite trands, namely:

- The engine room "A weighted" sound levels become greater and greater for lower and lower deck levels. This is attributed to the reduction gear and other hull mounted accessories.

- The fire room "A weighted" sound levels become greater with higher deck levels. This is attributed to the forced draft blowers.

TABLE 3.33

SUMMARY OF FF1052 COMPARTMENT NOISE LEVELS BY DECK AND OPERATING MODE, dB(A) ± ONE STANDARD DEVIATION

Ships perating Mode	Location															
	Engine Room				Fire Room					Aux 1		Aux 2				
	Cont	Third	UP	DN	Main	Third	Cont	UP	DN	UP	DN	DG	Cont	Pump Room	A/C Room	Aft Steer
n-Port Cold Iron DG Off	64	84 ± 5.4	84 ± 3.4	86 ± 5.1	(82)*	86 ± 3.5	(72)	82 ± 4.6	85 ± 8.5	(85)	(88	69 ± 7	70 ± 9	83 ± 10	89 ± 5	N/A
G On	64	84 ± 5.4	84 ± 3.4	86 ± 5.1	(82)	86 ± 3.5	(72)	82 ± 4.6	85 ± 8.5	(85)	(88	106 ± 2.6	77 ± 4	94 ± 2.6	90 ± 5	N/A
ir Start	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120 ± 5	N/A	N/A	N/A	N/A
ux Steaming	72	88 ± 4.1	88 ± 4.3	92 ± 4.5	(88)	94 ± 4	(72)	89 ± 2.6	88 ± 2.8	(85)	(88)	69 ± 7	70 ± 9	83 ± 10	89 ± 5	N/A
nderway 8±4 Knots	70 ± 2	88 ± 4	89 ± 3	92 ± 3	88 ± 3	91 ± 3	72 ± 4	89 ± 3.5	88 ± 4	85 ± 4	88 ± 3	69 ± 7	70 ± 9	83 ± 10	89 ± 5	78 ± 5
15±2 Knots	70 ± 3	91 ± 3	92 ± 3	94 ± 5	88 ± 8	93 ± 4	75 ± 5	89 ± 4	88 ± 3	87 ± 3.5	88 ± 2.5	69 ± 7	70 ± 9	83 ± 10	89 ± 5	82 ± 6
20±5-2 Knots	73 ± 3	91 ± 2.4	93 ± 2.5	96 ± 2.4	95	97 ± 5	74 ± 4	94 ± 5	92 ± 4	87 ± 2.9	89 ± 2.5	69 ± 7	70 ± 9	83 ± 10	89 ± 5	84 ± 6.7
27±1 Knots	73 ± 2	96 ± 3	96 ± 3.7	99 ± 3.1	96 ± 2	103 ± 2.6	74 ± 2	98 ± 5	94 ± 5.5	88 ± 3.5	92 ± 3.7	69 ± 7	70 ± 9	83 ± 10	89 ± 5	94 ± 4
P/M Venting	N/A	N/A	N/A	N/A						N/A	N/A	N/A	N/A	N/A	N/A	N/A

( )* Estimate based on other deck level averages.

- A speed dependent increase occurs in both the engine room and fire room, starting at 15 knots. The difference in sound levels for the 27 and 15 knots sub-modes averages 5 dB in the engine room and 7 dB in the fire room. This excludes the control enclosures.

The physical significance of the average deck noise levels are illustrated in Figures 3.6 and 3.7. These figures show average noise levels in the lower level of the engine room and upper level of the fire room of the FF 1052 at 20 knots with constant sound level contours. The non-uniformity of the noise suggests that the average sound level *is not* a very accurate descriptor of the hazard. However, in situations where the personnel work assignment, for an entire day or a period can only be described in terms of a deck level, these average deck noise level values may be used to approximate noise exposure.

3.4.3.2 DD 963 (SPRUANCE) CLASS

The noise level data for the DD 963 Class are limited to a single source [6]. The location data are contained in Appendix D. As was the case with the FF 1052 class, "average noise level" values (and each mode) were computed. These are presented in Table 3.34.

Since only two measurement locations were utilized for each of three deck levels, and since the variability on a given deck was as great as the variability in the entire compartment, no effort was made to describe the average deck level. The resulting measurement standard deviations range from ± 2 to ± 4.5 dB (with an exception in the cold iron sub-mode). This variability is similar to the variability calculated from the FF 1052 deck level data. Therefore, the same observations about the dependence on machinery line-ups and the accuracy of using average sound levels apply.

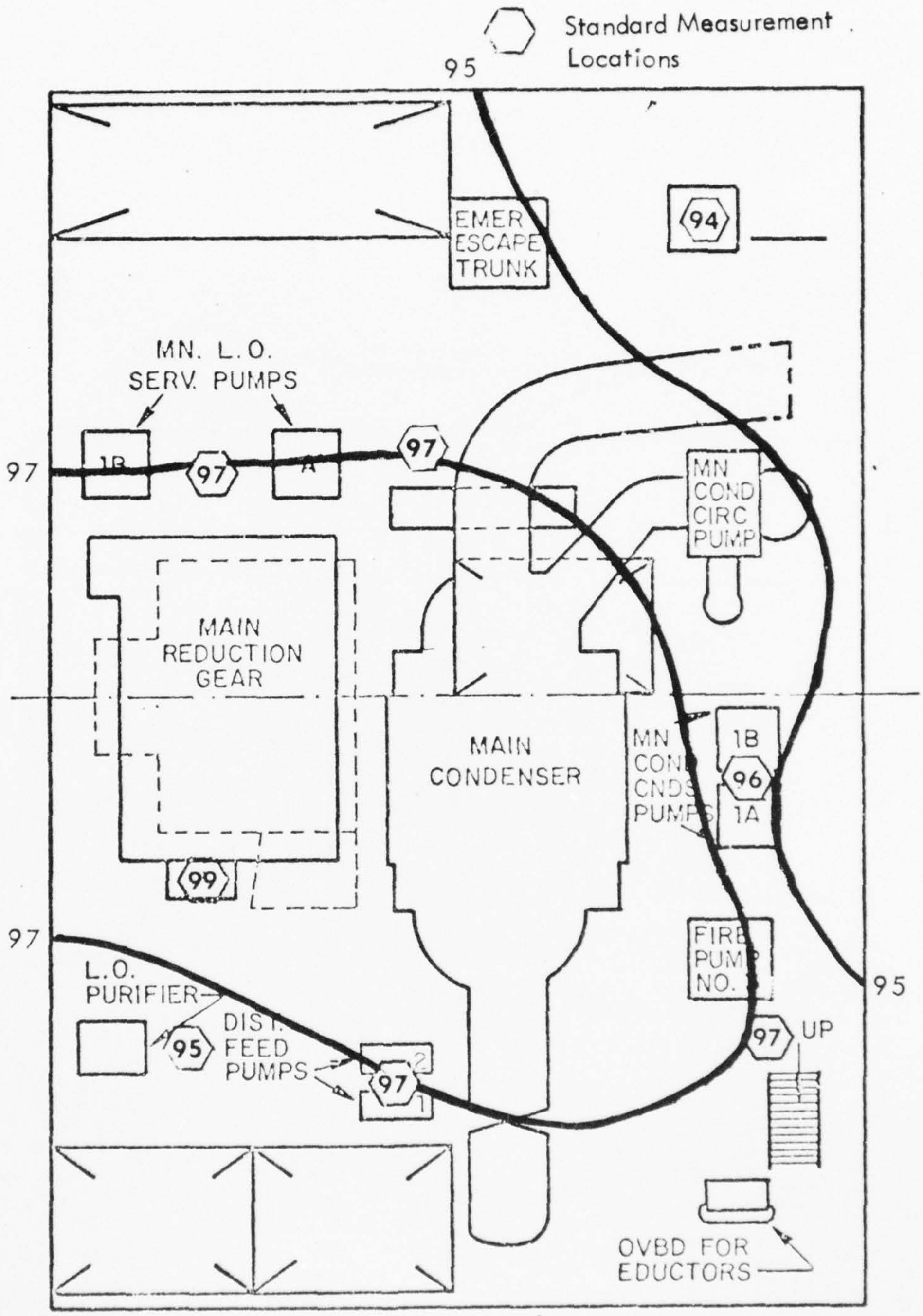

FIGURE 3.6

ENGINE ROOM - LOWER LEVEL. 20 KT NOISE CONTOURS, dBA

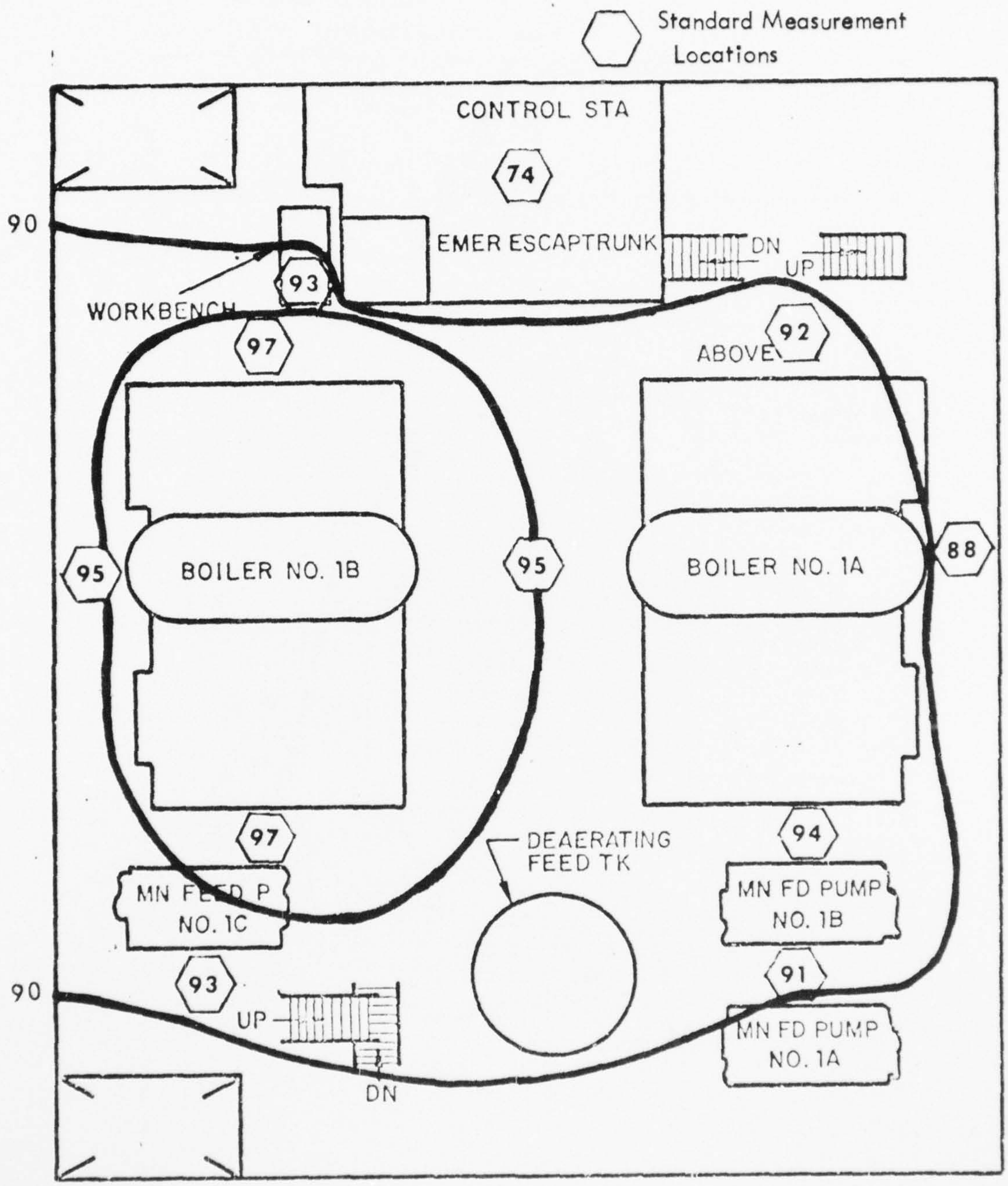

FIGURE 3.7
FIRE ROOM - UPPER LEVEL. 20 KT NOISE CONTOURS, dBA

TABLE 3.34

SUMMARY OF DD-963 COMPARTMENT NOISE LEVELS BY OPERATING MODE, dB(A) ± ONE STANDARD DEVIATION

Ships Operating Mode	Location		
	Engine Room 1	Engine Room 2	Auxiliary Machinery Room 1
In-Port Cold Iron	87 ± 6.4	85 ± 4.7	87 ± 4.1
Aux. Power	92 ± 2.9	89 ± 4.1	87 ± 4.1
Underway 8±4 Knots	(92)*	(88)*	87 ± 4.1
15±2 Knots	92 ± 2.2	88 ±1.9	87 ± 4.1
20+5-2 Knots	92 ± 3.5	88 ± 3.4	87 ± 4.1
27±1 Knots	93 ± 3.7	91 ± 4.5	87 ± 4.1

( )* Estimate from other operating modes. Note that differences in engine room levels are due to auxiliary machinery selection and slight differences in measurement locations as well as compartment characteristics.

The speed dependent trend is much less pronounced for the DD 963 compartment noise levels than for the FF 1052 levels. An obvious explanation is that the propulsion turbines and reduction gears are not the dominant noise sources. In fact, they don't appear to be making significant contributions to average compartment levels until the highest speed sub-mode, 27 ± 1 knots.

3.5 An Assessment of the Data Base Extent and Accuracy

This study was to have been based entirely on existing Naval data for both noise levels and manning information. Having thoroughly reviewed existing documents on noise level and manning, it is proper to assess the extent and accuracy of the data base.

3.5.1 Assessment of Noise Level Data Base

The shipboard noise measurements were adequate in extent for evaluating exposure for the FF 1052 class ships. In fact, virtually too much data exists. The EPMU inspections repeat the same measurements aboard identical ships, and even aboard the same ships. Infrequently are found cases of abnormal noise levels. Worse, there is no criteria for judging abnormal levels. Whereas a plethora of data exist, their accuracy could be improved. Identification of machinery line-ups could reduce the scatter in the data and, perhaps, reduce the standard deviation of the measurements below ± 2dB.

For the DD 963, the data base was marginal in that only one limited measurement program had been performed. Ship's inspections by EPMU-2 and EPMU-5 were available too late for the study.

3.5.2 Assessment of Personnel Assignment Data Base

Initial efforts to determine what was actually known within the Navy regarding time-weighted personnel exposure to engineering space noise revealed that very little had been done in this area. Noise

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OCCUPATIONAL NOISE EXPOSURE ON FF 1052 (KNOX) AND DD 963 (SPRUA--ETC(U)
JAN 77 B A KUGLER, M E HALE, P E RENTZ
UNCLASSIFIED BBN-3410 NL

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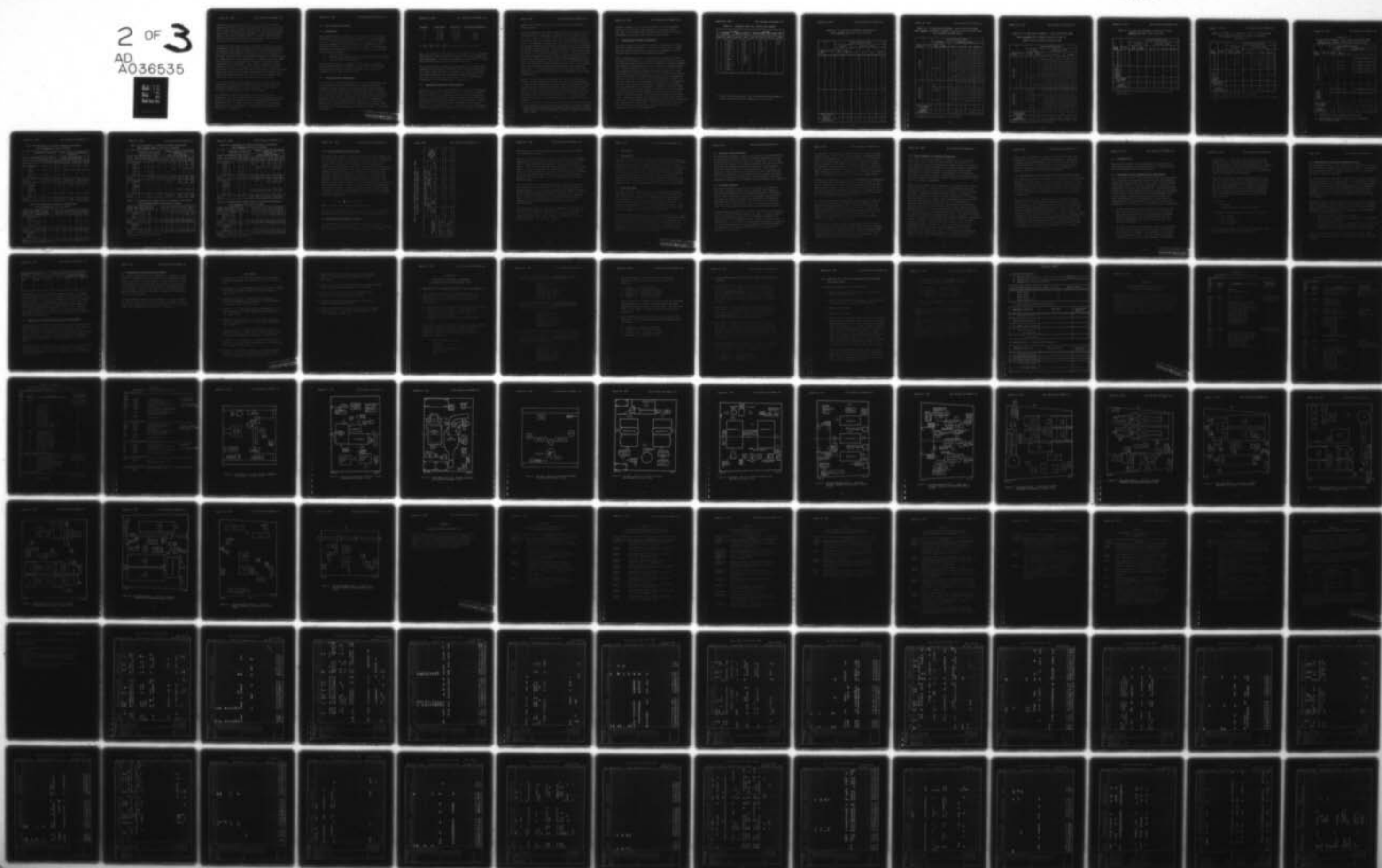
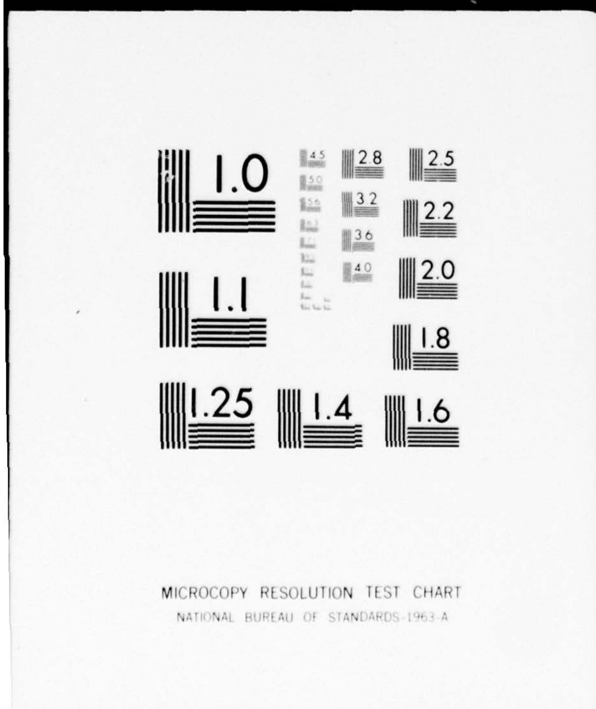


3653


1.0
4.5
5.0
5.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART
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dosimetry approaches which were reported, had been incorrectly implemented with the results yielding noise dose data about a work area or watch station rather than the daily noise dose of individuals within the Engineering Department. It should be mentioned, however, that noise dosimetry data on a personal exposure basis would be an important calibrating step during a noise exposure study utilizing the model as reported herein.

The personnel duty questionnaire, developed to obtain the vital information link between the man and the noise hazard, was in fact an unsophisticated approach carried out on a very limited scale. The obvious difficulties in identifying location and duration of personnel activity within each engineering space were evident during the administration of the questionnaire. However, even as a first order approach, it has provided a beginning and merits further consideration for refinement. Such a quasi time-motion study is necessary in order for the Navy to be able to use the location noise data, as collected by the various EPMU units, to flag locations which will require more in-depth engineering noise analysis and control and actually result in reducing the risk of hearing loss rather than just reducing noise levels across the board.

Due to limited time on board ship; it was not possible for the consultant to interview all members of each division within the Engineering Departments. In fact no members of the E and R Divisions were surveyed for either class of ships.

The Engineering Officers were asked certain questions (see Appendix A) to gain an overall picture of crew assignments on each ship, the number of personnel in each engineering space, ship's operations, etc. At times there were differences in the data as reported by E.O.'s and crewmen. Recommendations regarding this point occur in Chapter 6.

IV. NOISE EXPOSURE EVALUATION

4.1 Introduction

This section presents a summary of the personnel noise exposure problem for the FF 1052 and DD 963 class ships. The computation of noise exposure is based on the data base presented in Chapter Three and Appendix D and was performed in accordance with the guidelines outlined in the noise exposure model. Noise exposure computations are, provided as a function of operational modes for the following standards:

1. Navy Space Category D.
2. Present OSHA Noise Standard and BUMED Instruction 6260.6B
3. Proposed OSHA Noise Standard.

An illustrative example computation of the "yearly averaged" noise exposure problem in shipboard situations is also provided to show how the exposure levels for operational modes *may* be combined given an appropriate criteria.

4.2 Daily Noise Dose Methodology

In order for one to determine whether or not the engineering crew is in compliance with a specified noise standard, acoustical measurements must be made to evaluate personnel noise exposure. At first this may sound like a straightforward task but in fact it is not as easy as it appears. Time varying noise is typical of most situations found on board ship. The reasons being that some machines are operating intermittently and that the crewmen are moving in and out of different noise level areas. For example, assume that a crewman works in four different noise areas. Under the current OSHA noise standard, his daily noise dose is calculated as follows:

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Location	Noise Level	Duration,C	Allowable Duration, T
1	87 dBA	3.2 Hrs	∞
2	92 dBA	2.5 Hrs	6 Hrs
3	97 dBA	0.5 Hrs	3 Hrs
4	100 dBA	1.8 Hrs	2 Hrs

$$d = \frac{3.2}{\infty} + \frac{2.5}{6} + \frac{0.5}{3} + \frac{1.8}{2} = 0 + 0.42 + 0.17 + 0.90 = 1.49$$

Thus, the crewman's noise exposure is 49% greater than the current OSHA standard allows. This is a clear violation even though the actual duration at any single noise area did not exceed the allowable exposure duration for each area noise level.

The calculation of the daily noise dose under the proposed OSHA standard for exposures to different noise levels is identical to the current OSHA standard. The example just given would yield 75% overexposure under the proposed standard as opposed to the 49% under the current OSHA regulations. For a more complete explanation of the standards refer to Section 2.1.

4.3 Engineering Personnel Noise Exposure

Through the use of the questionnaire and certain other questions which resulted from its administration, it has been determined that, at least for the engineering group, Readiness Conditions IV and V are impractical for defining watch stations since this group is usually short of personnel. Thus, Conditions I and III are, in fact, the main factors in determining watch station exposure to excessive noise. In addition, since the ships seem to be in Condition I less than 5% of the time during the year, it appears that Condition III is the most critical watch section exposure factor.

For the purposes of this report (which reflects the results of the questionnaire) it is generally assumed that watch Condition III, i.e., four hours on and eight hours off with one watch in three, defines the time and location aspects of noise exposure while on watch. Accordingly, depending upon which watch a crewman stands in an engineering space, he generally experiences one of two different daily noise exposure modes. The most severe is when his watch time is totally separate from his normal work time. In this case he may be exposed to at least sixteen hours of noise (in many cases more). The second exposure mode occurs when at least four hours of his watch falls during his normal work day, thus reducing his overall daily exposure duration by four hours. If it is assumed that the four hour reduction includes exposure to four hours of his noisiest work, then his daily noise dose can be bounded by an upper and lower limit. The resulting range of his noise dose then can be expected to include his actual normal noise exposure for each ship operating mode.

Table 4.1 gives the survey man-number for each room versus his rating. The man-number and room are used in the following tables to identify each individual surveyed. Table 4.2 gives the FF 1052 class personnel overexposed under the Category "D" noise limit.* Tables 4.3 and 4.4 are also for FF 1052 class personnel and show the daily noise dose range for each man as a function of the ship operating mode. Table 4.3 is for the current OSHA/BUMED noise standard and Table 4.4 indicates the case for the proposed OSHA standard.

---

* As was pointed out in Section 2.1.1, Category D is not a personnel noise exposure standard by a compartment noise standard. In that sense, crewman are classified as "overexposed" under this standard as soon as they enter a compartment or area whose noise levels are above 90 dBA.

Likewise, Tables 4.5, 4.6, and 4.7 present the noise exposure results for the DD 963 class personnel. These data reflect the cases for noise exposure criteria under Category D, current OSHA/BUMED and proposed OSHA standards respectively.

4.4 Engineering Personnel Overexposure

The daily noise dose reveals the extent of overexposure to noise for each crewman overexposed. It may also be desirable to know what percentage or how many crewmen are overexposed on a space-by-space basis across the ships operating modes.

Such a comparison under the different noise criteria, is given in Tables 4.8 through 4.13. These tables appear as pairs with the even numbered tables presenting the percentage of surveyed personnel overexposed to engineering space noise under the different standard. Since individual surveys of all crewmen in each space were not possible because of constraints beyond the control of those administering the questionnaires, it is not possible to report the actual total number of engineering personnel who are overexposed under the various cases which have been considered. However, if one can assume that the percentage of overexposure holds generally for the entire engineering complement assigned to noisy spaces, then by extrapolation it is possible to estimate the total number of crewmen, for an average manning situation, who are overexposed under the different noise standards. Tables 4.9, 4.11, and 4.13 show the estimated numbers of overexposed personnel for each ship class. These data reflect the estimated situation for Divisions A, B, and M of the Engineering Departments on the FF 1052 class ships and M Division on the DD 963's. Thus Divisions E and R have not been evaluated for either class and are not reflected in the extrapolated results of overexposure.

TABLE 4.1 PERSONNEL RATE* VS. LOCATION MAN NUMBER

FF 1052				DD 963			
FIREROOM		ENGINE ROOM		ENGINE ROOM		AUX. MACH. RM.	
Man No.	Rate	Man No.	Rate	Man No.	Rate	Man No.	Rate
1	BTFA	1	EN3	1	FN	1	EN2
2	BTFA	2	EN	2	FA	2	FA
3	BTFN	3	MM2	3	FA		
4	BTFN	4	MM	4	EN2		
5	BT3	5	FN	5	FN		
6	BTFN	6	FN				
7	BT2	7	MMFN				
8	BTFN	8	MMFN				
9	BT1	9	MMC				
10	BTFN						
11	BT1						
12	BTFN						

* E and R Division personnel from the Engineering Deparments of either ship class were not evaluated in this study.

TABLE 4.2 FF 1052 CLASS PERSONNEL EXCEEDING THE SPACE CATEGORY "D" noise limit of 90 dBA

Duty Room	Man No. i	SHIPS OPERATING MODE					
		In-Port		Underway, Knots			
		Cold Iron	Aux. Steams	5-10	14-16	20	26-28
	1			X	X	X	X
	2			X	X	X	X
	3			X	X	X	X
	4				X	X	X
	5			X	X	X	X
	6			X	X	X	X
	7			X	X	X	X
	8	X		X	X	X	X
	9			X	X	X	X
	10	X			X	X	X
	11			X	X	X	X
	12			X	X	X	X
	1	X			X	X	X
	2	X		X	X	X	X
	3	X		X	X	X	X
	4	X		X	X	X	X
	5			X	X	X	X
	6			X	X	X	X
	7	X		X	X	X	X
	8	X		X	X	X	X
	9						
Total Number Surveyed		21	13	21	21	21	21
Number Overexposed		8	0	17	20	20	20

TABLE 4.3 FF 1052 CLASS PERSONNEL - DAILY NOISE DOSE RANGE UNDER <u>CURRENT</u> OSHA/BUMED STANDARDS (INCLUDE 90 dBA AND ABOVE) FOR THE REPORTED EXPOSURE TIMES

Duty Room	Man No. i	SHIPS OPERATING MODE*					
		In-Port		Underway, Knots			
		Cold Iron	Aux. Steam	5-10	14-16	20	26-28
Fire Room	1	0	0	0.2	2.0-2.6	3.3-4.3	6.2-8.1
	2	0	0	0.0.1	1.6-2.1	2.4-3.2	3.9-5.0
	3	0	0	0.0.1	1.6-2.1	2.6-3.5	4.9-6.1
	4	0	0	0	0.4-0.9	1.6-2.2	2.3-3.2
	5	0	0	0.0.4	2.2-2.7	3.7-4.5	6.5-7.5
	6	0	0	2.4-3.0	3.5-4.3	6.7-8.1	9.4-11.4
	7	0	0	0-0.6	2.5-3.1	4.3-5.1	7.5-8.7
	8	0.1-0.7	0	0.2-1.1	1.9-2.9	2.8-4.2	4.2-6.4
	9	0	0	0-0.2	0-0.6	0-1.1	0-1.7
	10	0.1	0	0	1.4-2.1	4.0-5.1	6.0-9.3
	11	0	0	0-0.5	1.9-2.4	3.3-4.0	5.3-6.3
	12	0	0	1.1-1.3	1.9-2.8	3.4-4.9	4.8-7.3
Engine Room	1	0	-	0	2.2-3.0	2.6-3.9	6.0-8.0
	2	0.5	-	1.1	1.3	1.6	2.3
	3	0.9-1.7	0.8-1.5	0.5-1.4	0.7-1.7	0.9-2.3	1.4-3.7
	4	0.3-0.5	-	1.1-1.6	1.7-2.5	2.1-3.2	3.0-4.6
	5	0	-	0.4-0.8	0.6-1.1	0.8-1.6	1.3-2.6
	6	0	-	0.3-0.8	0.4-1.1	0.6-1.5	0.9-2.3
	7	0	-	1.2-2.1	1.5-2.5	2.0-3.4	3.2-5.4
	8	0.4-0.8	-	2.1-2.8	2.5-3.3	3.3-4.4	5.3-7.1
	9	0	-	0	0	0	0
TOTAL NUMBER SURVEYED		21	13	21	21	21	21
NUMBER OVEREXPOSED		0-1	0-1	6-8	15-18	16-20	18-20

* Assumes full daily exposure for each mode.

TABLE 4.4 FF 1052 CLASS PERSONNEL - DAILY NOISE DOSE RANGE UNDER PROPOSED OSHA STANDARD (INCLUDE 85 dBA AND ABOVE) FOR THE REPORTED EXPOSURE TIMES

Duty Room	Man No. i	SHIPS OPERATING MODE*					
		In Port		Underway, Knots			
		Cold Iron	Aux. Steam	5-10	14-16	20	26-28
Fire Room	1	0	1.1-1.4	1.5-1.9	2.0-4.3	3.3-4.3	6.2-8.1
	2	0	1.0	1.2-1.6	1.6-2.1	2.4-3.2	3.9-5.0
	3	0	1.1	1.2-1.6	1.6-2.1	2.6-3.5	4.9-6.1
	4	0	1.1	0.3-0.8	0.4-0.9	1.6-2.2	2.3-3.2
	5	0	1.1	1.6-2.0	2.2-2.7	3.7-4.5	6.5-7.5
	6	0	1.1	2.7-3.2	3.5-4.3	6.7-8.1	9.4-11.4
	7	0	0-0.3	1.9-2.4	2.5-3.1	4.3-5.1	7.5-8.7
	8	0.1-0.7	0.5	1.7-2.6	2.0-3.1	3.0-4.3	4.3-6.5
	9	0	0	0-0.4	0-0.6	0-1.1	0-1.7
	10	0.2	0	1.7-2.2	2.1-2.8	4.0-5.1	6.0-8.3
	11	0	0.7-1.1	1.4-1.8	1.9-2.4	3.3-4.0	5.3-6.3
	12	0	0.5	1.4-2.0	1.9-2.8	3.4-4.9	4.8-7.3
Engine Room	1	0.3-0.6	-	1.3-1.7	2.2-3.1	2.6-3.9	6.0-8.0
	2	0.8	-	1.1	1.3	1.6	2.3
	3	1.8-2.6	1.9-2.6	0.5-1.4	0.7-1.7	0.9-2.3	1.4-3.7
	4	0.7-1.1	-	1.4-2.1	1.7-2.5	2.1-3.2	3.0-4.6
	5	0.3-0.6	-	0.4-0.8	0.6-1.1	0.8-1.6	1.3-2.6
	6	0	-	0.3-0.8	0.4-1.1	0.6-1.5	0.9-2.3
	7	0.2	-	1.2-2.1	1.5-2.5	2.0-3.4	3.2-5.4
	8	0.7-1.5	-	2.2-2.9	2.5-3.4	3.3-4.5	5.3-7.1
	9	0	-	0	0	0	0
TOTAL NUMBER SURVEYED		21	13	21	21	21	21
NUMBER OVEREXPOSED		1-3	6-7	15 - 16	15 - 18	16 - 20	18 - 20

*Assumes full daily exposure for each mode.

TABLE 4.5 DD 963 CLASS PERSONNEL EXCEEDING THE SPACE CATEGORY "D" NOISE LIMIT OF 90 dBA

Duty Room	Man No. i	SHIPS OPERATING MODE					
		In Port		Underway, Knots			
		Cold Iron	Aux. Steam	8*	15	20	27
Engine Room No. 1	1			*	X	X	X
	2		X	*	X	X	X
	3		X	*	X	X	X
	4		X	*	X	X	X
	5			*	X	X	X
Auxiliary Machinery Room No. 1	1	X	X		X	X	X
	2						
TOTAL NUMBER SURVEYED		7	5	2	7	7	7
NUMBER OVEREXPOSED		1	4	0	6	6	6

* Noise level data for this mode are not available for the engine rooms.

TABLE 4.6 DD 963 CLASS PERSONNEL - DAILY NOISE DOSE RANGE UNDER CURRENT OSHA/BUMED STANDARDS FOR REPORTED EXPOSURE TIMES

Duty Room	Man No. i	SHIPS OPERATING MODE*					
		In Port		Underway, Knots			
		Cold Iron	Aux. Steam	8**	15	20	27
Engine Room No. 1	1	0	-	-	1.6-2.1	1.5-2.1	1.9-2.8
	2	0	0.5-1.1	-	1.4-2.2	1.3-2.1	1.7-2.5
	3	0	0.3	-	0.7-1.6	0.6-1.5	0.7-1.6
	4	0	0.3-0.8	-	2.1-2.9	2.0-2.8	2.1-2.9
	5	0	-	-	0.8-1.6	0.8-1.5	0.8-1.5
Auxiliary Machinery Room No. 1	1	0-0.8	0.1-0.9	-	0.7-1.3	1.2-1.8	0.7-1.3
	2	0	0	0	0	0	0
TOTAL NUMBER SURVEYED		7	5	1	7	7	7
NUMBER OVEREXPOSED		0	0-1	0	3-6	4-6	3-6

* Assumes full daily exposure for each mode.

** Noise level data for this mode are not available for the engine rooms.

TABLE 4.7

DD 963 CLASS PERSONNEL - DAILY NOISE DOSE RANGE UNDER PROPOSED OSHA STANDARD FOR REPORTED EXPOSURE TIMES

Duty Room	Man No.	SHIPS OPERATING MODE*					
		IN PORT		UNDERWAY KNOTS			
		Cold Iron	Aux. Steam	8**	15	20	27
Engine Room No. 1	1	0	-	-	1.7-2.3	1.6-2.3	2.1-2.9
	2	0	1.5-2.1	-	1.6-2.4	1.5-2.2	2.0-2.7
	3	0	0.5	-	0.7-1.6	0.6-1.5	0.7-1.6
	4	0	1.0-1.6	-	2.1-2.9	2.0-2.8	2.1-2.9
	5	0	-	-	1.3-2.1	1.2-1.9	1.4-2.1
Auxiliary Machinery Room No. 1	1	0.4-1.2	0.7-1.5	-	1.0-1.6	1.5-2.0	1.0-1.6
	2	0.9-1.2	0.9-1.2	0.9-1.2	0.9-1.2	0.9-1.2	0.9-1.2
Total Number Surveyed		7	5	1	7	7	7
Number Overexposed		0-2	2-4	0-1	4-7	5-7	4-7

* Assumes full daily exposure for each mode.

** Noise level data for this mode are not available for the engine rooms.

TABLE 4.8 PERCENTAGE OF SURVEYED PERSONNEL OVEREXPOSED UNDER CATEGORY "D" NOISE CRITERION

Ship Class	Work Room	PERSONNEL ASSIGNMENT: Manpower Doc(SMD)	Ave. Manning	Total Surveyed	PERCENT RANGE OF OVEREXPOSED PERSONNEL,% — SHIPS OPERATING MODE: Cld. Irn.	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	Engine Room	26	18.0	9	67%	0	78%	89%	89%	89%
	Fire Room	30	24.5	12	17%	0	83%	100%	100%	100%
	Aux.1	9	10.0	0	-	-	-	-	-	-
	Aux.2	-	5.0	0	-	-	-	-	-	-
ALL			57.5	21	38%	0	81%	95%	95%	95%
963	Engine Room 1	-	9	5	0	100%	-	100%	100%	100%
	Engine Room 2	-	3	0	-	-	-	-	-	-
	Aux. 1	-	8	2	50%	50%	0	50%	50%	50%
	Aux. 2	-		0	-	-	-	-	-	-
ALL		-	20	7	14%	80%	0	86%	86%	86%

TABLE 4.9 EXTRAPOLATED PERSONNEL* OVEREXPOSURE UNDER CATEGORY "D" NOISE CRITERION

Ship Class	Work Room	Ave. Manning	Percent Surveyed	Cold Iron	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	Engine Room	18.0	50%	12	0	14	16	16	16
	Fire Rm	24.5	50%	4	0	20	24	24	24
	Aux. 1	10.0	0%	-	-	-	-	-	-
	Aux. 2	5.0	0%	-	-	-	-	-	-
ALL		57.5	37%	22	0	47	55	55	55
963	EngRm.1	9	56%	0	9	-	9	9	9
	EngRm.2	3	0%	-	-	-	-	-	-
	Aux. 1 Aux. 2	8	25%	4	4	0	4	4	4
ALL		20	35%	3	16	0	17	17	17

* Exclusive of Divisions E and R.

TABLE 4.10 PERCENTAGE OF SURVEYED PERSONNEL OVEREXPOSED UNDER CURRENT BUMED & OSHA NOISE STANDARDS

Ship Class	Work Room	PERSONNEL ASSIGNMENT			PERCENT RANGE OF OVEREXPOSED PERSONNEL,%					
		Manpower Doc(SMD)	Ave. Manning	Total Surveyed	SHIPS OPERATING MODE					
					Cld. Irn.	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	Engine Room	26	18.0	9	0-11%	0-11%	44-56%	56-89%	56-89%	78-89%
	Fire Room	30	24.5	12	0	0	17-25%	83%	92-100%	92-100%
	Aux. 1	9	10.0	0	-	-	-	-	-	-
	Aux. 2	-	5.0	0	-	-	-	-	-	-
ALL			57.5	21	0- 5%	0- 8%	29-38%	71-86%	76-95%	86-95%
963	Engine Room 1	-	9	5	0	0-33%	-	60-100%	60-100%	60-100%
	Engine Room 2	-	3	0	-	-	-	-	-	-
	Aux. 1	-	8	2	0	0	0	0-50%	50%	0-50%
	Aux. 2	-		0	-	-	-	-	-	-
ALL		-	20	7	0	0-20%	0	43-86%	57-86%	43-86%

TABLE 4.11 EXTRAPOLATED AVERAGE RANGE OF PERSONNEL* OVEREXPOSED UNDER CURRENT BUMED & OSHA NOISE STANDARDS

Ship Class	Work Room	Ave. Manning	Percent Surveyed	Cold Iron	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	EngRm	18.0	50%	0- 2	0- 2	8-10	10-16	10-16	14-16
	FireRm	24.5	50%	0	0	4- 6	20	23-24	23-24
	Aux. 1	10.0	0%	-	-	-	-	-	-
	Aux. 2	5.0	0%	-	-	-	-	-	-
ALL		57.5	37%	0- 3	0- 5	17-22	41-49	44-55	49-55
963	EngRm.1	9	56%	0	0- 3	-	6- 9	6- 9	6- 9
	EngRm.2	3	0%	-	-	-	-	-	-
	Aux. 1 Aux. 2	8	25%	0	0	0	0- 4	4	0- 4
ALL		20	35%	0	0- 4	0	9-17	11-17	9-17

* Exclusive of Divisions E and R.

TABLE 4.12 PERCENTAGE OF SURVEYED PERSONNEL OVEREXPOSED UNDER PROPOSED OSHA NOISE STANDARD

Ship Class	Work Room	PERSONNEL ASSIGNMENT: Manpower Doc(SMD)	Ave. Manning	Total Surveyed	PERCENT RANGE OF OVEREXPOSED PERSONNEL,% — SHIPS OPERATING MODE: Cld. Irn.	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	Engine Room	26	18.0	9	11-33%	11%	56-67%	56-89%	56-89%	78-89%
	Fire Room	30	24.5	12	0	42-50%	83%	83%	92-100%	92-100%
	Aux. 1	9	10.0	0	-	-	-	-	-	-
	Aux. 2	-	5.0	0	-	-	-	-	-	-
ALL			57.5	21	5-14%	46-54%	71-76%	71-86%	76-95%	86-95%
963	Engine Room 1	-	9	5	0	67%	-	80-100%	80-100%	80-100%
	Engine Room 2	-	3	0	-	-	-	-	-	-
	Aux. 1	-	8	2	0-100%	0-100%	0-100%	50-100%	50-100%	50-100%
	Aux. 2	-		0	-	-	-	-	-	-
ALL		-	20	7	0-29%	40-80%	0-100%	57-100%	71-100%	57-100%

TABLE 4.13 EXTRAPOLATED AVERAGE RANGE OF PERSONNEL*OVEREXPOSED UNDER PROPOSED OSHA NOISE STANDARD

Ship Class	Work Room	Ave. Manning	Percent Surveyed	Cold Iron	Aux. St.	5-10 Kts.	14-16 Kts.	20 Kts.	26-78 Kts.
1052	EngRm	18.0	50%	2- 6	2	10-12	10-16	10-16	14-16
	FireRm	24.5	50%	0	10-12	20	20	23-24	23-24
	Aux. 1	10.0	0%	-	-	-	-	-	-
	Aux. 2	5.0	0%	-	-	-	-	-	-
ALL		57.5	37%	3-8	26-31	41-44	41-49	44-55	49-55
963	EngRm1	9	56%	0	6	-	7- 9	7- 9	7- 9
	EngRm2	3	0%	-	-	-	-	-	-
	Aux. 1 Aux. 2	8	25%	0- 8	0- 8	0- 8	4- 8	4- 8	4- 8
ALL		20	35%	0- 6	8-16	0-20	11-20	14-20	11-20

* Exclusive of Divisions E and R.

4.5 Yearly Averaged Daily Noise Dose

The above results point out that for the FF 1052 class engine room personnel, man number 4 (M Division, MM Rating) falls approximately in the middle by rank ordering daily noise dose ranges. Thus, roughly half of that areas' personnel receive greater noise exposure and half receive less. Using man number 4 as an example, it is instructive to look at an operating mode-weighted or "yearly averaged" daily noise dose. All existing time weighted noise exposure criteria are addressed to exposure on a diurnal basis (except in the proposed OSHA standard for an individual who is exposed to excessive noise for only one day in any week). The yearly averaging approach takes into consideration the fact that the ship's operating modes vary in a certain general way throughout the course of a year. Using the NAVSEC "percent of time in mode" information presented and discussed in Section 3.2, it is possible to arrive at a yearly averaged daily noise dose (Y.N.D.) with the following formulation:

$$Y.N.D. = \sum^{\gamma} (d)_{\gamma} \; (\%\ Time)_{\gamma}$$

where γ refers to the different operating modes.

The yearly averaged daily noise dose ranges for the example crewmen are given in Table 4.14 using the OSHA and BUMED criteria.

4.6 Summary of Noise Exposure Problems

It is apparent from the foregoing evaluations that the noise exposure of personnel under the three criteria considered is excessive for both ship classes. However, the extent of exceedance

TABLE 4.14 YEARLY AVERAGED DAILY NOISE DOSE RANGE VS. NOISE CRITERIA-FF 1052 CLASS-ENGINE ROOM-MAN NO. 4

NOISE EXPOSURE CRITERION	MODE AVERAGED FRACTIONAL NOISE DOSE						YEARLY AVERAGED DAILY NOSE DOSE
	IN PORT		UNDERWAY, Knots				
	Cold Iron	Aux. Steam	5-10	14-16	20	26-28	
Current OSHA/BUMED (90 dBA @ 8 hrs. Expos. > 90 dBA)	.16-.27	-	.09-.13	.18-.26	.25-.28	.02-.04	0.70-1.08
Proposed OSHA (85 dBA @ 16 hrs. Expos. ≥ 85 dBA)	.37-.58	-	.11-.17	.18-.26	.25-.38	.02-.04	0.93-1.43

differs both as to noise overexposure and percentage and number of overexposed personnel.

The daily noise dose under the current OSHA/BUMED noise standards ranges from 0-11.4 (2.22 mean and 2.3 standard deviation) for the FF 1052 class engineering personnel across the ships operating modes. For the DD 963 class personnel, the daily noise dose ranges from 0 - 2.9 (1.13 mean and 0.88 standard deviation). That means that the FF 1052 engineering personnel exceed the current standards by as much as 1,000% (122% average) while the excess exposure peaks at 190% (13% average) for the DD 963 class considering all operating modes.

As far as percent of engineering personnel overexposed, the two ship classes are more even with the FF 1052 having a slightly greater problem. For the current standards, the percentage ranges of overexposed engineering personnel for certain spaces in both the FF 1052 and DD 963 classes are from 0-100% for all operating modes. The FF 1052 averages 49% overexposed while the DD 963 averages 42% overexposed engineering personnel across the operating modes.

Considering the number of overexposed engineering crewmen on each ship for the two classes, there are expected to be an average of 28 on the FF 1052 and 8 on the DD 963's, averaged across the ship's operating modes. These numbers are exclusive of E and R Division personnel for both ship classes.

V. CONCLUSIONS

5.1 Introduction

The nature of the assessment model for occupational noise exposure reflects the fact that the computation of noise exposure in complex environments, such as the shipboard situation, is not a simple exercise but a complicated procedure due to the number of parameters that must be evaluated. This complexity demands that some level of accuracy be maintained so that the effect of various standards may be properly assessed. Furthermore, the substantial cost associated with shipboard noise control suggest that an accurate diagnosis of the machinery space noise problems in each ship class should be made before classwide corrective actions are initiated.

5.2 Noise Data Base

Although no central standardization was found among the various Navy sources which acquire airborne noise data aboard ships, the data collected were found to be adequate for the computation of noise exposure in the case of the FF 1052 class. Noise data on the new DD 963 class are very limited due to its relatively recent commissioning and are considered marginal in extent. Only noise data correlated to the ship's operating modes were of value in the determination of personnel noise exposure.

Diagnostic noise source data, vital to the understanding and control of the noise problem, was found to be limited in quantity and extent. For example, noise data for only a single DD 963 class ship was found to exist and was confined to the engine compartments only. An important result of this study has been the classification and aggregation of all the airborned noise data available within the Navy for the two ship classes investigated.

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5.3 Duration of Duty Data Base

The data base necessary to describe the personnel work assignments, on a location by location basis in machinery compartments, is non-existent within the Navy; at least, the researchers were not able to uncover any sources. The time and location data reported herein were collected during this project by means of a questionnaire which was administered on a very limited scale. As a result, the accuracy of this input may be construed as a first approximation. However, the viability of acquiring these data has been demonstrated. It is suggested that EPMU units modify slightly their data acquisition procedures to accommodate this requirement (See Chapter 6).

5.4 Personnel Exposure

The reported results of personnel noise exposure in shipboard machinery compartments shows that, in general, crew exposures are excessive regardless of the standard considered. Most important to realize, however, is that by following the procedures of the model, an accurate, *quantitative description* of individual noise exposure can be obtained. The accuracy of the exposure descriptor is of course a function of the accuracy of the data base. This description was the first objective of this program.

A quantitative description of crew noise exposure does not result from the current procedures used by the Navy. Although BUMEDINST 6062.6B specifically calls for noise exposure assessment, the current practice is basically limited to area or location noise measurements. Little effort is being made to quantify the duration of the individuals duty in various hazardous noise environments. The parameter of duration is essential in the computation of personnel noise exposure.

The personnel noise exposure computations show a number of significant results. First of all, as anticipated, the magnitude and extent of overexposure are strongly dependent on the operational modes of the ship; higher speeds result in higher noise levels and an increase in the number of crewmen overexposed. This fact is especially evident for the FF 1052 class where the number of people overexposed varies from 0 to 1 at cold iron and up to 18-20 when underway at 27 knots (see Table 4.3). Similarly, the magnitude of overexposure may vary by 600% from low to high speeds.

Secondly, the variation in the extent and magnitude of overexposure, as calculated under different standards, is most evident in port and at low speeds. For example, while in-port, the present OSHA/BUMED standard results in 0-1 men overexposed for cold iron and 0-1 men for auxiliary steaming (see Table 4.3). However, the proposed OSHA standard gives 1-3 men overexposed for cold iron and 6-7 men for auxiliary steaming (Table 4.4).

At medium to high speed, specifically the 15 knots, 20 knots and the 27 knots sub-modes,all standards show the majority of the surveyed crew overexposed to noise. For the FF 1052 class the number of crewmembers overexposed varies from 71 to 95% of all crew members surveyed; the corresponding figures for the DD 963 range from 43 to 100% (See Tables 4.8, 4.9 and 4.10). The magnitude of overexposure for some individuals are as high as 1000%! (See Table 4.1, 4.2, and 4.3).

The results of the noise exposure computations shows the flexibility of the model in comparing operational modes and standards on an individual or overall crew basis. The resulting knowledge of the magnitudes of overexposure is an important element to be considered when decisions are to be made concerning the noise control required to meet a specified standard.

5.5 Noise Standards vs. Duration of Exposure

As is often the case in research, the results of a study assessment provide some answers but also generate more questions; in this instance, questions regarding the interpretation of standards. For example, the OSHA standards were developed assuming an extended exposure,over a number of years, to occupational noise levels. Furthermore, the OSHA standards are predicated on the assumption that after every daily exposure a significant recovery period occurs. The Navy shipboard environments however, differ in a number of ways from the foregoing assumptions.

First of all, crewmen are not exposed to the excessive noise levels for the long term. In fact, due to the varied operational modes of the ship, excessive exposure may be limited to only a few months per year. Secondly, and again over the long term, engineering space crew members are limited in their exposure due to the length of their tour of duty. Both of these considerations would indicate that the shipboard noise environment is not as severe as the industrial environment for which the OSHA standard was developed. However, there are two other considerations which suggest just the opposite conclusion. First, while exposed to excessive noise levels, the ship's crew often must perform their duties for extended periods of time, well beyond the industrial experience. Work days of 12 hours, 16 hours, or more are not uncommon and for some readiness conditions are normal. Secondly, the ship's personnel, while at sea, represents a captive audience. The recovery time assumed by OSHA for the industrial worker often does not occur on board ship since many non-engineering spaces, where the crew spends their off-duty hours, are also comparatively noisy. The foregoing considerations, coupled with the lack of sufficient noise exposure data to account for the off-duty contributions during the different operating modes, make it difficult to compute an actual daily noise dose accounting for both on and off-duty contributions. Therefore, although the procedures suggested in this report do provide an accurate method for computing personnel noise exposure under present standards, the applicability of these standards to the shipboard situation may be seriously questioned.

5.6 Applicability of the Noise Exposure and Noise Control Model

Even though this project is limited to the evaluation of engineering spaces on two ship classes (FF 1052 and DD 963) the model for the assessment of noise exposure, noise control, and costs is *general* and applicable to any ship class in the fleet. The model may also be easily applied to noise exposure evaluation over the entire 24-hour day provided that an appropriate 24-hour noise standard is available.

The strength of the model reported herein is derived from two factors: (a) The accuracy of the data base and; (b) the systematic approach to the computation and evaluation of the exposure problem and costs associated with any noise control effort. The data base format allows for an organized evaluation of the data and easy addition of new information as it becomes available. The computation and evaluation procedure lends itself to computerization, if desired. The noise reduction requirements procedure, source evaluation, and cost analysis provide the user with the ability to undertake cost estimation and cost trade-off studies in order to optimize the cost-benefit relationship for noise abatement.

VI. RECOMMENDATIONS

This chapter contains the recommendations for improved data acquisition procedures and further research in personnel noise exposure/shipboard noise control problems.

6.1 Improvement in Navy Shipboard Noise Measurements

One of the main results of this study has been the documentation of the variation in procedures used by the Navy for gathering compartment airborne noise data aboard ships. These variations in procedure seriously limit the usefulness of the data by any organization other than the performing one. Nonconsistent data acquisition procedures degrade the data by adding the variability of such factors as machinery line-ups and measurement location to the inherent ship-to-ship and time-to-time variability. These shortcomings may be alleviated by a modest amount of standardization and extra effort on the part of the measuring organizations. Specifically, the following steps are recommended:

1. Standard measurement locations should be adopted for each class ship in question. These locations should include work areas, watch stations, and near machinery requiring frequent maintenance. The locations adopted for this study are recommended for the FF 1052 and DD 963 class ships, see Appendix B.

2. The number and type of measurements should be standardized. All noise surveys should inclue "A-weighted" sound level measurements at a minimum of six locations on each level of each engineering space. The EPMU surveys are usually performed this way, but the NSRDC Category "D" compliance

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checks are not. Octave band and one-third octave band analyses are not of universal interest and may be made at the convenience of the measuring organization. Finally, the sound level at a location should be space averaged by moving the microphone about a circle at eye height and visually averaging the meter reading.

3. The noise related ship's operating parameters should be listed with each noise survey. These parameters include the ship's operating mode and the machinery line-up in the particular compartment. The purpose of documenting the exact machinery line-up is to identify variations from the nominal line-up for the particular operating mode. The recommended operating mode classifications are as follows:

   a) In-Port

      - Cold Iron
      - Auxiliary power or auxiliary steaming

   b) Underway (to be adjusted to the ship's full speed)

      - 8 ± 4 knots
      - 15 ± 2 knots
      - 20 ± 5, -2 knots
      - 27 ± 1 knots

4. The "A-weighted" noise level history for each ship class should be maintained and a norm established.

6.2 Improvement of Personnel Assignment Data Base

The questionnaire used in this study was too cumbersome and complex to be utilized for future data acquisition purposes. A detailed and time consuming survey is necessary, however, if only a few ships are used to develop a data base.

On the other hand, if data from a large sample of ships is gathered, then by relying on such a large sample we can significantly reduce the complex nature of the questionnaire. It is our recommendation, therefore, that the EPMU noise survey procedures be standardized throughout the Navy and also be modified to include personnel assignment data. The following is a suggested procedure which should be the focus of further investigation and scrutiny before it is adopted.

During the course of each noise level survey of engineering spaces (may be extended to off-duty spaces with the adoption of an appropriate exposure criteria), the person making the noise measurements should ask the following questions of personnel in the *immediate* vicinity of the measurement site:

1. What is your billet number and rating?
2. Are you a watch stander or do you accompany a watch stander as part of your training?
3. On a daily and weekly basis, approximately how much *work* time (exclusive of watch duty) do you spend at this location?
4. Likewise, how much *watch* time is spent at this location?

Once those collecting these data understand the intent, these questions could be simplified in tabular form as in the following example:

Measurement Location	Crewman's Billet No.	Rate	Watch Stander or Trainee (✓)	Hours per day/week at this Location	
				Work	Watch
FLW1	01850	BT3	✓	2/14	8/32
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

The assumption for this simplified approach is that in surveying an entire ship class, most of the assigned billet numbers or rates will be covered. It will not be necessary to seek out individuals who are not near to the appropriate measurement sites, since for a large number of samples their corresponding billet number and rate will be surveyed near measurement sites on other vessels. It is obvious then that a compilation of these data for a given ship class is essential to be able to evaluate personnel noise exposure in a systematic way.

6.3 Improvement of Personnel Noise Exposure Measurements

The determination of daily noise dose under very complex situations can be simplified using a personal noise dosimeter. The dosimeter must be attached to the crewman while he moves from location to location so that it continuously monitors the varying noise environments to which he is exposed. The noise dosimeter is therefore very useful in calibrating the survey procedures outlined in the model.

Note however that dosimeters cannot be used to find the cause of any excessive exposure. Thus, one is alerted only to the extent of excess exposure and should initiate a detailed survey to determine the relative causes.

6.4 Evaluation of the Cost of Noise Control

The original objective of this program was to determine a first order cost estimate for the implementation of engineering noise control systems on two ship classes. As was pointed out in the introduction, this objective was only partially fulfilled due to the difficulties encountered in the data acquisition portion of the program. However, the framework for an organized data base and computation steps necessary to achieve the final objective have been provided.

It is recommended that the work necessary to at least complete the original work for the two ship classes considered be undertaken. The possibility of other ship classes, for which airborne noise data is available, should also be considered.

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12. NAVSEC, "Combined Plant and Gas Turbin DE Studies, Speed-Time Distributions," NAVSEC.

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APPENDIX A

DESCRIPTION OF PERSONNEL ASSIGNMENTS IN ENGINEERING SPACES ON BOARD NAVY SHIPS

I. QUESTIONS FOR THE ENGINEERING OFFICER: (also see Chapter II)

1. If we consider the fire rooms, the engine rooms, the auxiliary spaces and the after-steering rooms, how many people in total are assigned on a continuous basis to these spaces?

   a. How many people are assigned to each fire room (FF 1052)?
   b. How many people are assigned to each engine room?
   c. How many people are assigned to each of the two auxiliary machinery rooms?
   d. How many people are assigned to the after-steering space?

2. If we could break down the above personnel into subcategories of boiler operators, machinists, enginemen, repair/maintenance personnel, electricians, etc., what is the breakdown by number of the above personnel for these or additional assignments?

   Boiler Operators (FF 1052)
   Machinists
   Enginemen
   Repair/Maintenance Personnel
   Electricians
   Other

3. Identify by name and location all permanently manned watch stations in each of the following spaces:

   Fire Room (FF 1052)
   Engine Room 1
   Engine Room 2 (DD 963)
   Auxiliary Mach. Room 1
   Auxiliary Mach. Room 2
   After-Steering Room

4. Identify by name and location all conditionally manned watch stations for each of the following spaces and the conditions under which they are manned:

   Fire Room (FF 1052)
   Engine Room 1
   Engine Room 2 (DD 963)
   Auxiliary Mach. Room 1
   Auxiliary Mach. Room 2
   After-Steering Room

5. We are interested in knowing the watch station assignments on a twenty-four hour basis. For example, we are interested in knowing the total time that a watch stander is assigned to a specific watch station. Identify watch station and total time (on a 24 hour basis).

   Fire Room (FF 1052)
   Engine Room 1
   Engine Room 2 (DD 963)
   Auxiliary Mach. Room 1
   Auxiliary Mach. Room 2
   After-Steering Room

6. Our understanding is that there are four readiness conditions which are usually operative on Navy ships. These are:

   a. Condition I. (General Quarters)
   b. Condition III. (War-Time Steaming)
   c. Condition IV. (Peace-Time Cruising)
   d. Condition V. (In-Port/At Anchor)

   Please describe the differences in total time per individual watch stander that is spent under each one of the above readiness conditions based on a 24-hour day. How might this relate to the number of watch sections specified on the watch bill?

7. Under the same readiness conditions, please describe the differences in total time per man spent performing normal work duties.

   a. Condition I. (General Quarters)
   b. Condition III. (War-Time Steaming)
   c. Condition IV. (Peace-Time Cruising)
   d. Condition V. (In-Port/At Anchor)

II. SHIPS OPERATING MODE QUESTIONS TO BE ASKED THE ENGINEERING OFFICER:

1. We are interested in defining the operating parameters of your vessel. We would like to obtain a rough breakdown, over the course of one year, for the time spent in-port/ at anchor and the time spent cruising. This information can be given to us in terms of percentages. For example, 40% of the time may be spent in-port and 60% of the time cruising.

2. Within these two main categories (in-port and underway) we would like you to breakdown the in-port condition between cold iron and auxiliary steaming. That is, what percent of the in-port time was spent at cold iron and what percent was spent under auxiliary steaming conditions.

3. If possible, and again over the course of one year, we would like to breakdown the underway or cruising condition as a function of speed. We are interested in knowing what percent of total cruising time can be associated with speeds between 0 and 10 knots, 10 knots and 20 knots, and 20 knots and 30 knots. If you have some other convenient speed breakdown, it will also be extremely helpful.

4. Another description of the underway conditions as a function of time is defined by the Readiness Conditions. We would like to ascertain the amount of underway time for:

   a. Condition I. (General Quarters)
   b. Condition III. (War-Time Steaming)
   c. Condition IV. (Peace-Time Cruising)

III. QUESTIONS TO BE ASKED OF ENGINEERING SPACE PERSONNEL (use survey form)

1. Questions regarding work or duty stations.

   a. What is your regular work station? This refers to the total space or room?

   b. What is your regular work assignment? That is, what is it that you do as a normal work activity?

   c. What is your rating?

   d. What is your division?

   e. We would like to breakdown your work area and your work time as much as possible. We would like to know the approximate amount of time that you spend at different areas in your work room. You may respond by percent or by the approximate number of hours. We would also like to know of any usual locations or sub-areas within the work room where you may tend to spend more time. For example: Perhaps an area of your work station would be the lower level. Perhaps you spend ten percent of your time there and perhaps most of your time at the lower level is spent near the pumps.

      (NOTE TO THE INTERVIEWER: Please insist that some response is given even though it may be difficult to quantify this information. It might be possible for them to develop approximations given a week's period of time, rather than just one day.)

f. We would like to know the work room variation for the following different Readiness Conditions:

(1) Condition I. (General Quarters)
(2) Condition III. (War-Time Steaming)
(3) Condition IV. (Peace-Time Cruising)
(4) Condition V. (In-port/At Anchor)

What are your work area differences and what are the total work hours (excluding watch) for a 24-hour day?

2. Repeat the above questions for watch stations and the variation that occurs for the watch stations with the different Readiness Conditions listed above.

(NOTE TO INTERVIEWER: It is possible that the watch station locations change depending on the Readiness Conditions. Be sure to ascertain this point and get a breakdown of the total hours per day that the individual spends on watch for the different conditions. This may be reported as four hours plus four hours with some possible duration of time separating the two watch assignments within the same given day.)

PERSONNEL SURVEY

I. WORK OR DUTY STATIONS:

A. Regular Work Station ______________________ Rating ______________

B. Regular Work Assignment ______________________ Division ______________

C. Breakdown by Area and Work Time

AREA OF WORK STATION	APPROX. TIME(% OR HRS.)	USUAL LOCATIONS
Lower Level Upper Level Third Level Other (Specify)		

D. Work Station Variation with Condition

READINESS CONDITION	WORK AREA	TOTAL HOURS PER DAY
I (General Quarters)		
III (Wartime Steaming)		
IV (Peace Time Cruising)		
V (Inport/at Anchor) A. Cold Iron		
B. Aux. Power		

II. WATCH STATIONS: Variation with Condition

READINESS CONDITION	WATCH LOCATION	TOTAL HOURS PER DAY
I (General Quarters)		
III (Wartime Steaming)		
IV (Peace Time Cruising)		
V (In Port/At Anchor) A. Cold Iron		
B. Aux. Power		

APPENDIX B

STANDARD MEASUREMENT LOCATIONS FOR FF 1052 AND DD 963 ENGINEERING SPACES

This Appendix presents a summary and pictorial description of the standard measurement locations and coding used to analyze the noise level data. The measurement selection and numbering procedure is described in Section 3.4.2. Table B.1 shows the FF 1052 locations and Table B.2 shows the DD 963 locations. Figures B.1 through B.6 illustrate the machinery arrangement on the FF 1052 class. Figures B.7 through B.14 illustrate the machinery arrangement on the DD 963 class.

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TABLE B.1

MEASUREMENT LOCATION DESCRIPTIONS, FF 1052

(a) Engine Room

Meas Loc. Code	Level	Machinery	Watch or Work Station
ET1W	Third	-	Control Booth
ET2	"	Catwalk	-
ET3	"	Above Main Red Gear	-
EU1W	Upper	Dist Plant 1, 2	Evaporator Watch
EU2W	"	-	Workbench(Port)
EU3	"	Air Cond Comp 1, Port Fwd	-
EU4	"	Air Cond Comp 2, Port Aft	-
EU5	"	Dist Plant 1, Outboard, Stbd	-
EU6	"	Main Cond Air Eject, L Fwd	-
EU7	"	Main Red Gear, Aft	-
EU8	"	Main Red Gear, Port	-
EU9	"	Main Red Gear, Stbd	-
EU10	"	L.P. Turbine, Stbd	-
EU11	"	H.P. Turbine, Port	-
EL1W	Lower	-	Tel Hood,Log Desk
EL2W	"	-	L.O. Purifier Bench
EL 3	"	Main L.O. Serv Pumps 1A,1B	-
EL 4	"	Main Cond Conds Pumps 1A,1B	-
EL 5	"	Dist Feed Pumps 1,2, Stbd	-
EL 6	"	L.O. Purifier, Stbd	-
EL 7	"	Fire Pump 3, Stbd	-
EL 8	"	Main L.O. Cooler, Port	-

TABLE B.1 (Cont'd)

MEASUREMENT LOCATION DESCRIPTIONS, FF 1052

(b) Fire Room

Meas Loc. Code	Level	Machinery	Watch or Work Station
FM1W	Main	Forced Draft Blower 1A2	Forced Draft Blower 1A2
FM2W	Main	Forced Draft Blower 1B2	Forced Draft Blower 1B2
FT1	Third	Boilers 1A, 1B	-
FT2	"	Catwalk Perim 1A	-
FT3	"	Catwalk Perim 1B	-
FU1W	Upper	Boilers 1A, 1B	Upperlevelman
FU2W	"	Control Station, Port	Log Desk
FU3W	"	-	Workbench, Port
FU 4	"	Main Feed Pumps 1A, 1B	-
FU 5	"	Boiler 1B Aft	-
FU 6	"	Boiler 1A Fwd	-
FU 7	"	Boiler 1A Stbd	-
FU 8	"	1B Stbd	-
FU 9	"	1A Port	
FU 10	"	1B Port	
FU 11	"	Main Feed Pump 1C, Stbd	
FL1W	Lower	Boilers 1A, 1B	Burnerman
FL2W	"	-	Burner Clean Bench
FL3W	"	-	Telephone & Log Bench
FL4	Lower	Main FO Srv Pump 1A, 1B	-
FL5	"	Main Fd Bstr Pumps 1A, 1B	-
FL6	"	Fire Pump 2, Port Aft	-
FL7	"	Boiler 1B Aft	-
FL8		Boiler 1B Stbd	-
FL9		Boiler 1A Fwd	-
FL10		Boiler 1A Stbd Fwd	-
FL11		Boiler 1B Port	-
FL12		Prairie-Masker A Compressor	-

TABLE B.1 (Cont'd)

MEASUREMENT LOCATION DESCRIPTIONS, FF 1052

(c) Auxiliary Machinery Room No. 1

Meas Loc. Code	Level	Machinery	Watch or Work Station
AU1W	Upper	-	Tel & Log Desk
AU2W	"	-	Workbench, Stbd
AU3	"	SSTG 1A-1B	-
AU4	"	SSTG 1B Aft	-
AU5	"	SSTG 1A Aft	-
AU6	"	SSTG 1B-1C	-
AU7	"	SSTG 1C Aft	-
AU8	"	SSTG 1A Fwd	-
AU9	"	SSTG 1B Fwd	-
AU10	"	LP Air Comp, Port Aft	-
AU11	"	HP Air Comp, Port	-
AL1	Lower	SSTG Cond 1A, 1B	-
AL2	"	SSTG Cond 1B, 1C	-
AL3	"	SSTG Cond 1A Stbd	-
AL4	"	SSTG Cond 1C Port	-
AL5	"	ASROC CIic Pumps 1, 2	-
AL6	"	Fin Stab 1, Stbd	-
AL7	"	Fin Stab 2, Port	-
AL8	"	Fire Pump 1	-

(d) Auxiliary Machinery Room No. 2

X1W	-	SS Diesel Generator Space	SSDG Watch
X2W	-	Switchboard space	SWBD Log Desk
X3	-	LP-HP Air Compressor Space	-
X4	-	JP5 Pump, Firepump Space	-
X5	-	400 Cycle MG Space	-
X6	-	Catwalk, SSDG	-

(e) Aft Steering Room

S1W	-	-	Watch Station
S2	-	Space Average	-

TABLE B.2

MEASUREMENT LOCATION DESCRIPTIONS, DD 963

(a) Engine Room

Meas Loc. Code	Level	Machinery	Watch or Work Station
E11	Third	SS Air Comp, Boiler	-
E12W	Upper	Turbine Module-Generator	Control Console
E13W	Upper	Generator No. 1	Local Control Panl
E14	Lower	Fire Pump 2, FO Pumps 2A,2B	-
E15	Lower	LO Purifier, LO Pumps 2A,2B Main Reduction Gear	-
E16	Third	Above Main Reduction Gear Below Vent Exhaust	-
Er1	Space Avg.	Engine Room No. 1	-

(b) Engine Room No. 2

Meas Loc. Code	Level	Machinery	Watch or Work Station
E21	Third	SS Air Comp, Boiler	-
E22W	Upper	Turbine Module-Generator	Control Console
E23W	Upper	Generator No. 2	Local Control Panl
E24	Lower	Generator No. 2	Workbench
E25	Lower	LO Purifier LO Pumps 1A,1B Main Reduction Gear	-
E26	Upper	Main Reduction Gear	-
ER2	Space Avg.	Engine Room No. 1	-

(c) Auxiliary Machinery Room No. 1

Meas Loc. Code	Level	Machinery	Watch or Work Station
A1	Upper	HP Air Compressor	Workbench
A2	Lower	FO Trans Pump, FO Purifier	-
A3	Lower	Dist. Plant 1	Local Control Panl
A4	Upper	Air Conditioning Plants 1,2	-
AR1	Space Avg.	Aux. Machinery Room No. 1	-

(d) No. 3 Generator Room

Meas Loc. Code	Level	Machinery	Watch or Work Station
GR3	Space Avg.	Average of Nos. 1 and 2 Generators' Noise	-

(e) Engineering Central Control Room

Meas Loc. Code	Level	Machinery	Watch or Work Station
ECC	Space Avg.	Central Control Room	

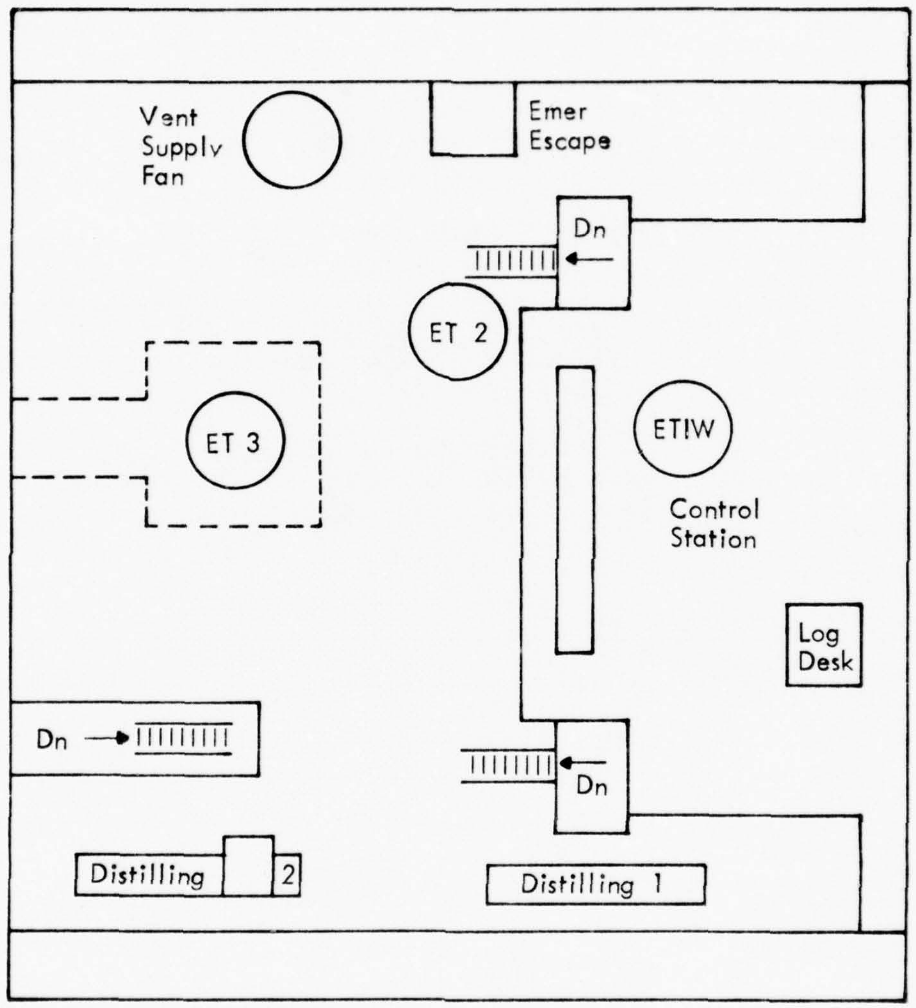

Figure B-1 - ENGINE ROOM - THIRD LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

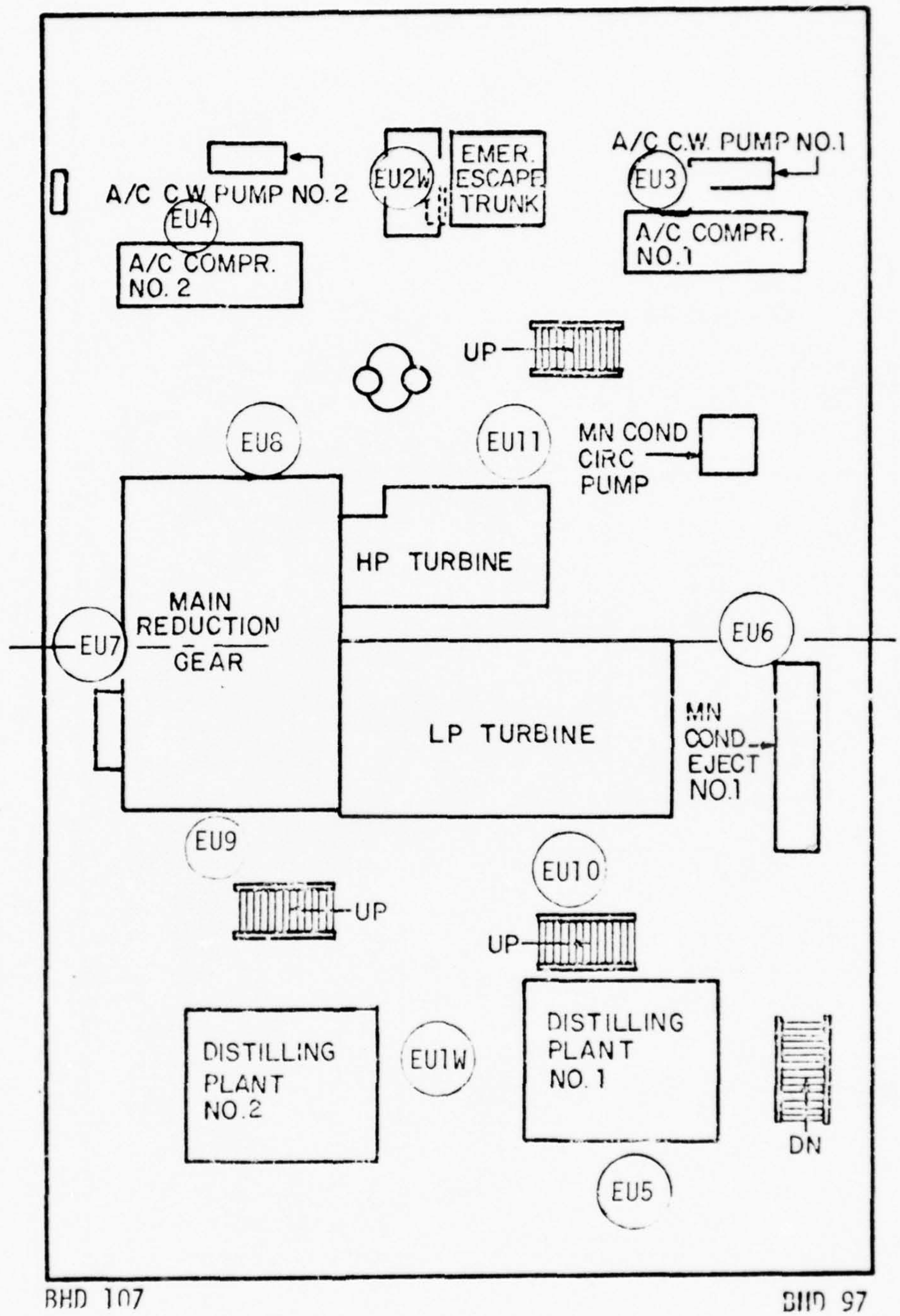

Figure B-2 - ENGINE ROOM - UPPER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

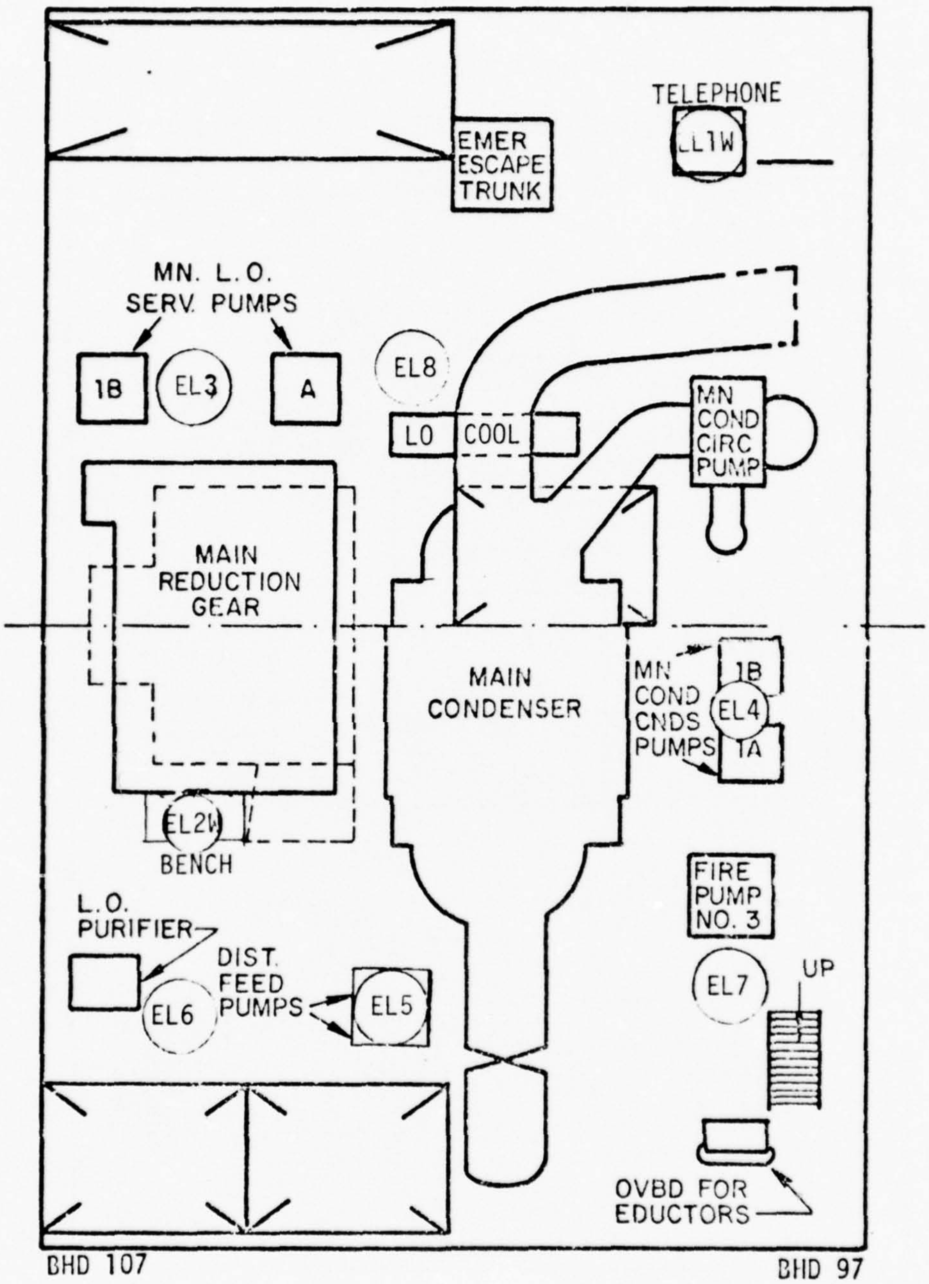

Figure B-3 - ENGINE ROOM - LOWER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

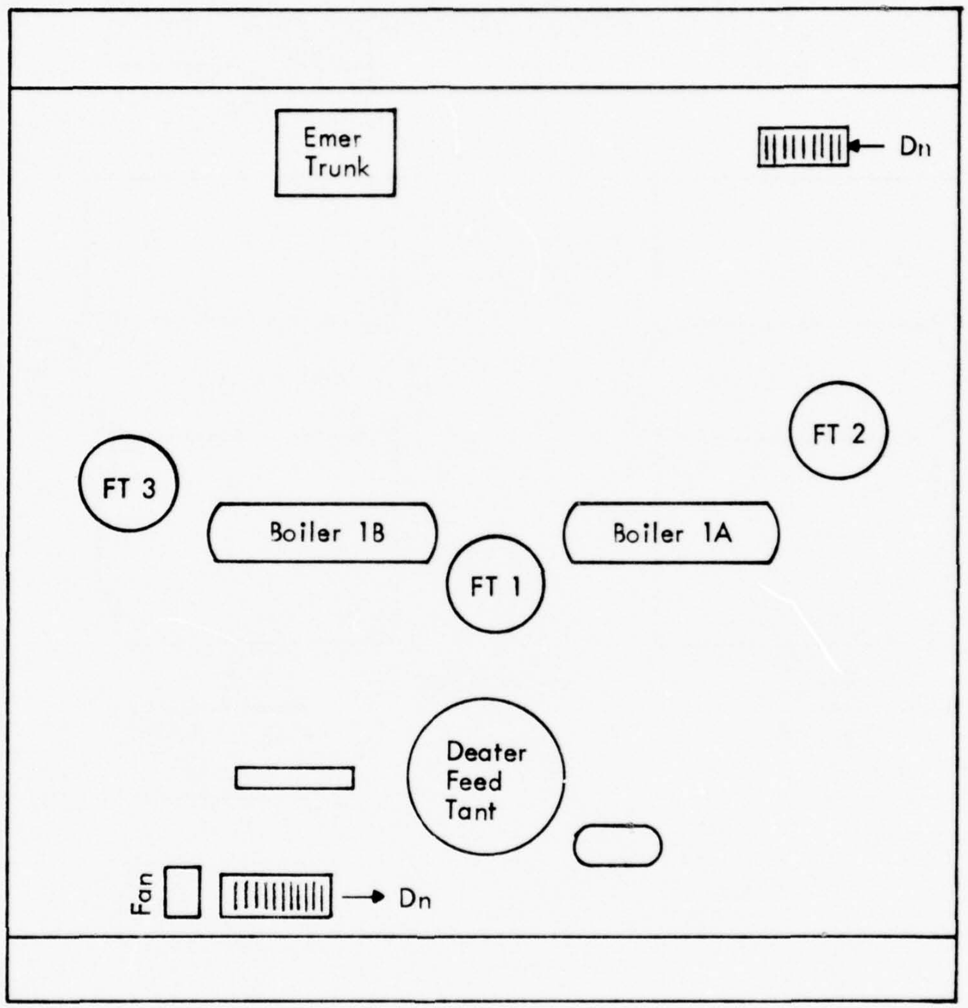

Figure B-4 - FIRE ROOM - THIRD LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

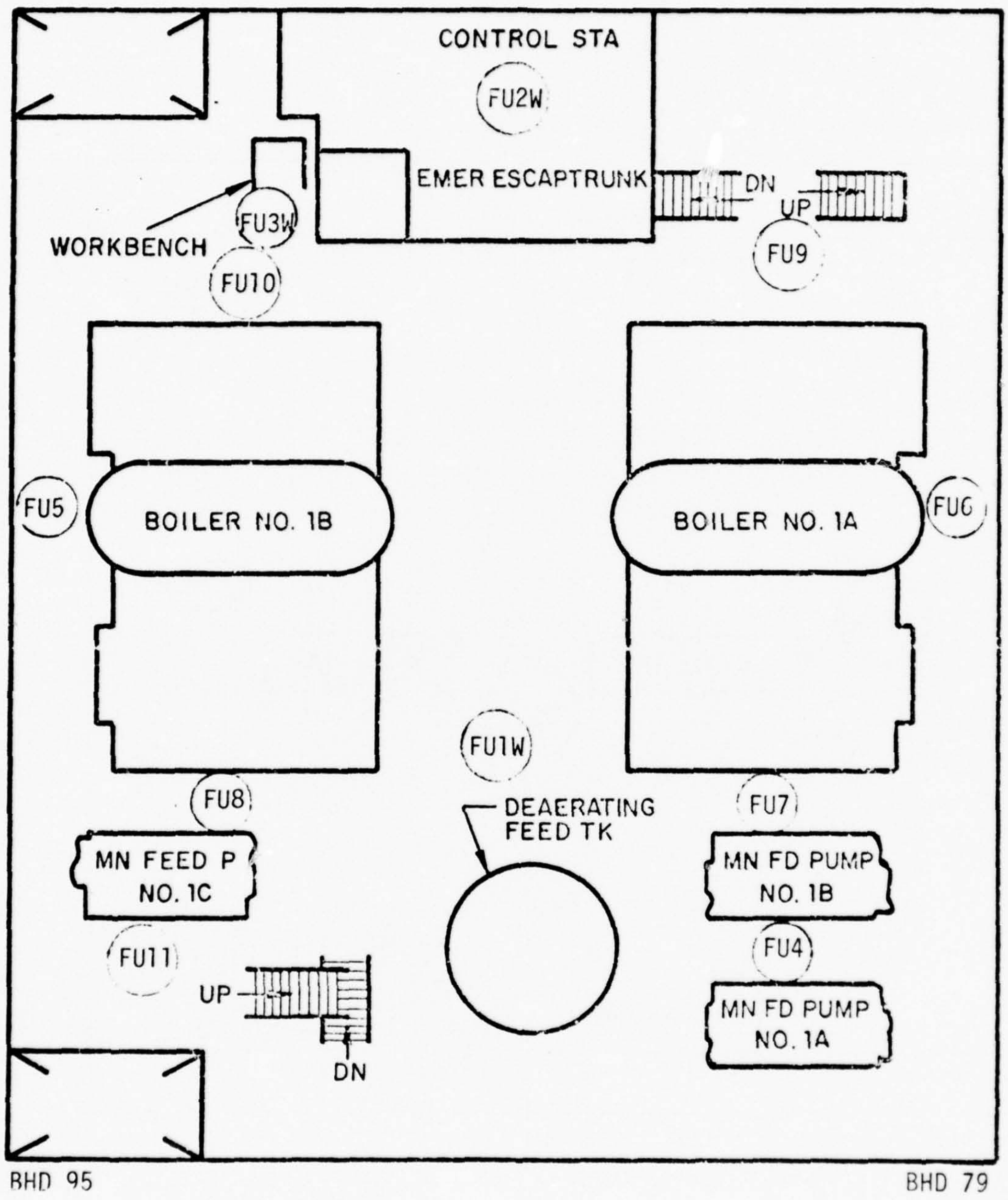

Figure B-5 - FIRE ROOM - UPPER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

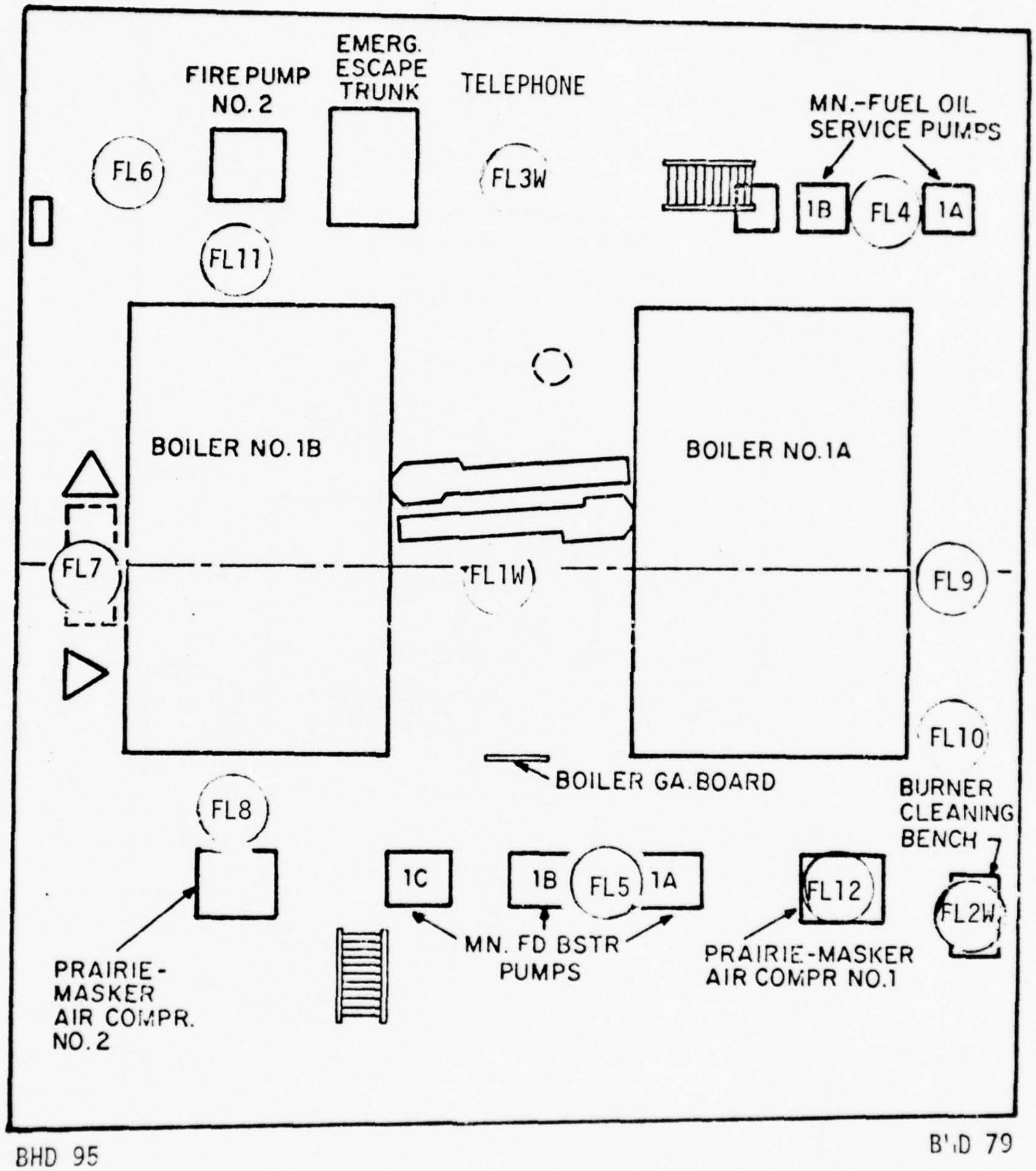

Figure B-6 - FIRE ROOM - LOWER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

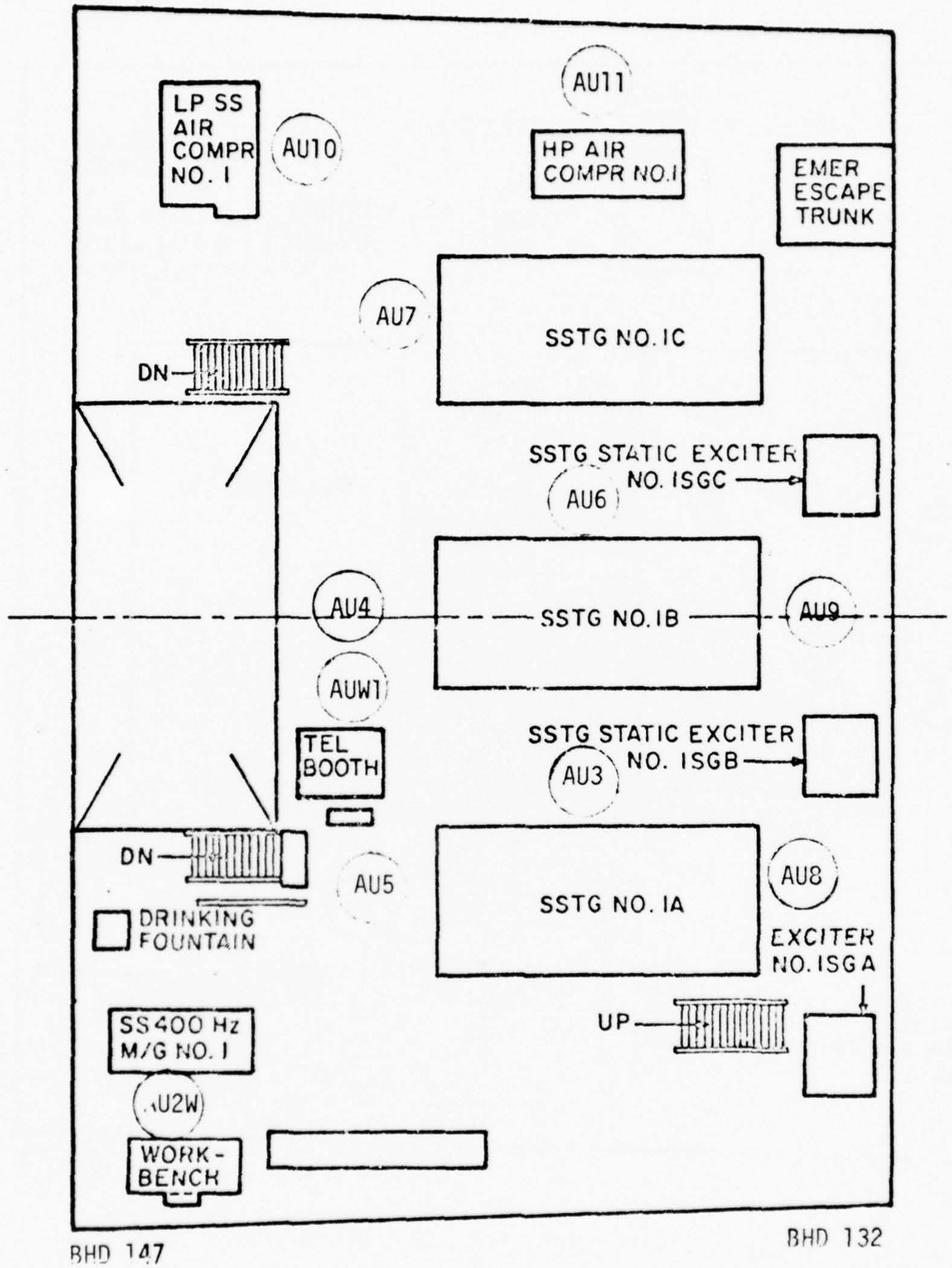

Figure B-7 - AUXILIARY MACHINERY ROOM NO. 1 - UPPER LEVEL MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

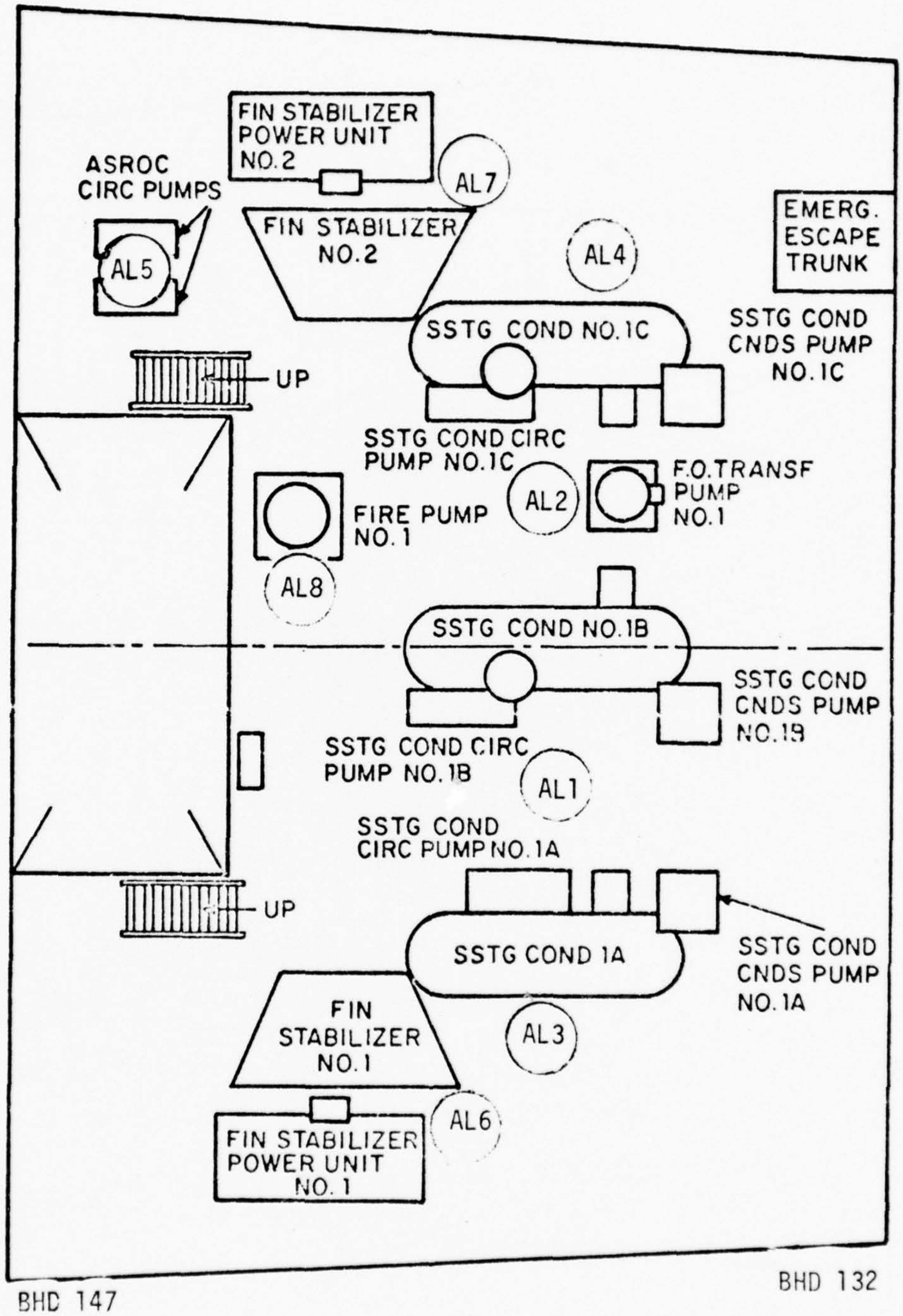

Figure B-8 - AUXILIARY MACHINERY ROOM NO. 1 - LOWER LEVEL MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, FF 1052

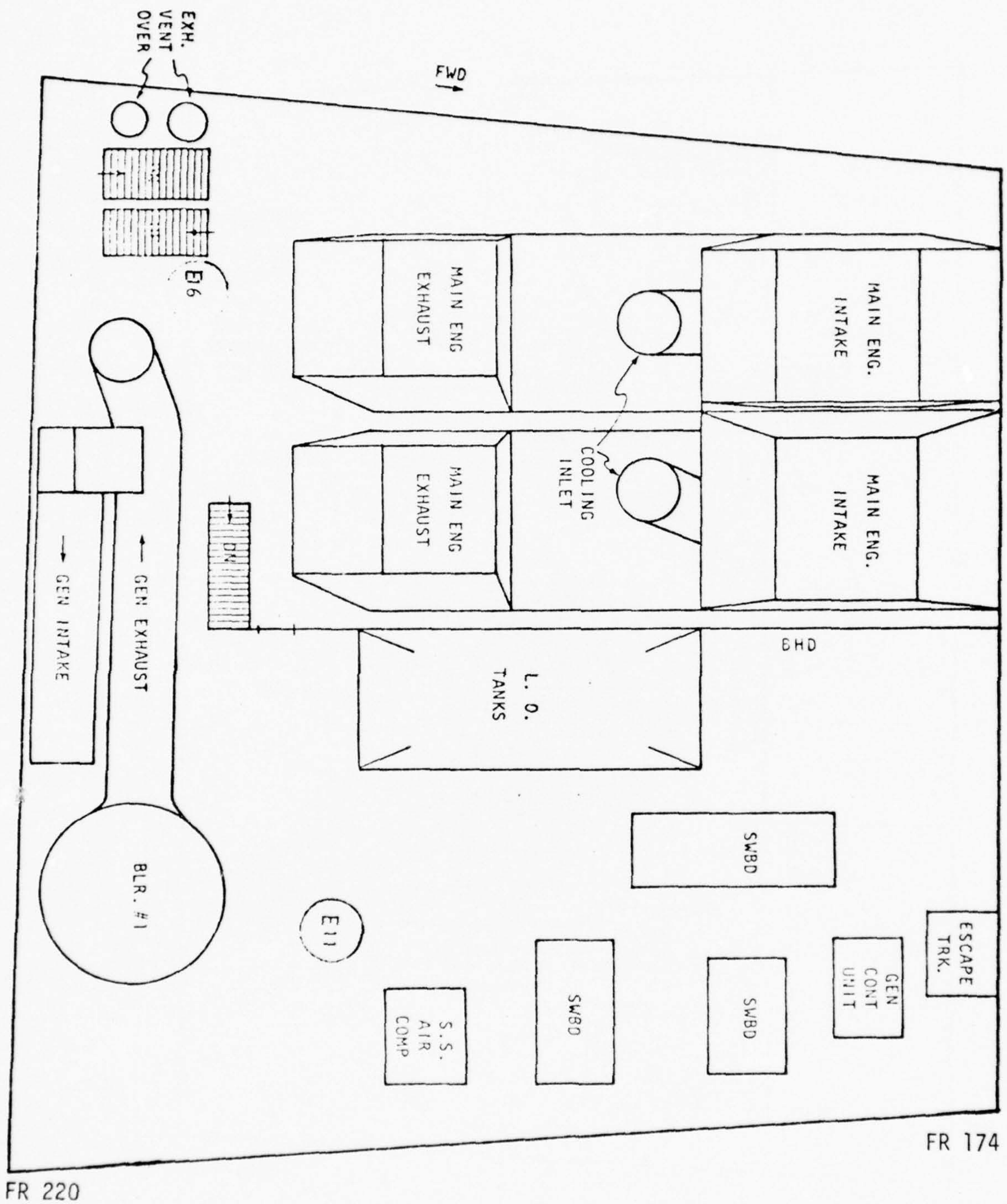

Figure B-9 - MAIN ENGINE ROOM NO. 1 - THIRD LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

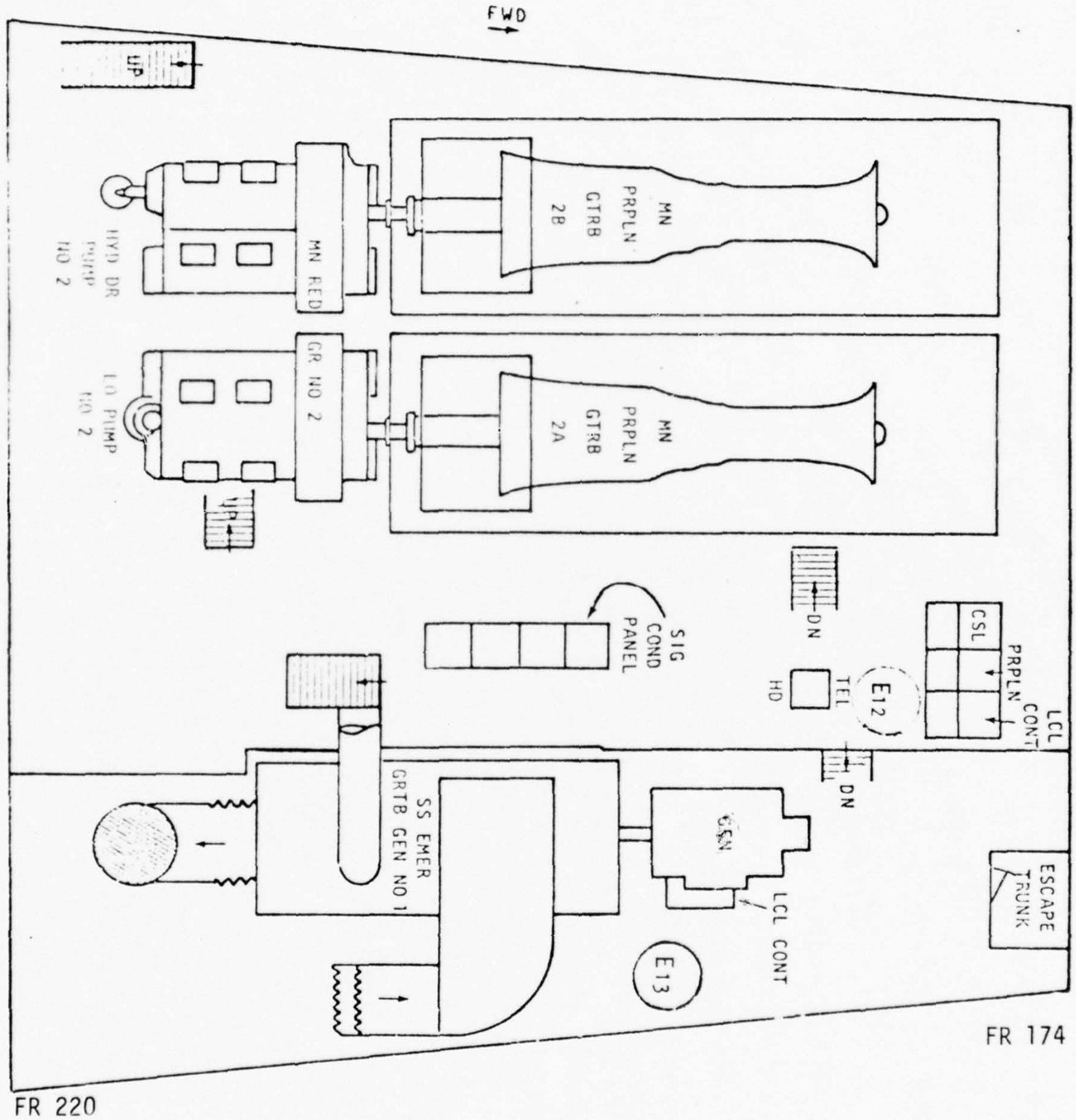

Figure B-10 - MAIN ENGINE ROOM NO. 1 - UPPER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

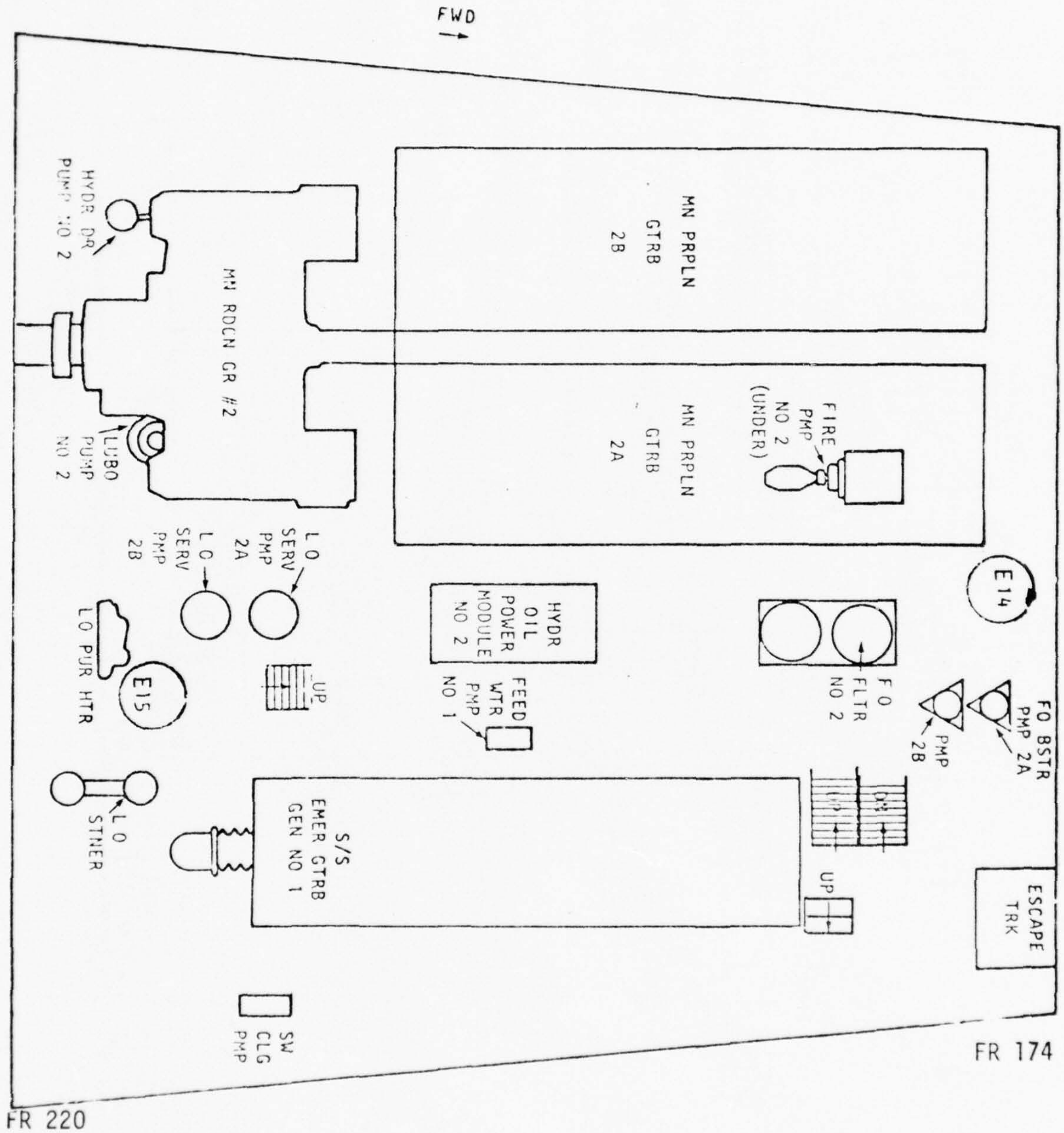

Figure B-11 - MAIN ENGINE ROOM NO. 1 - LOWER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

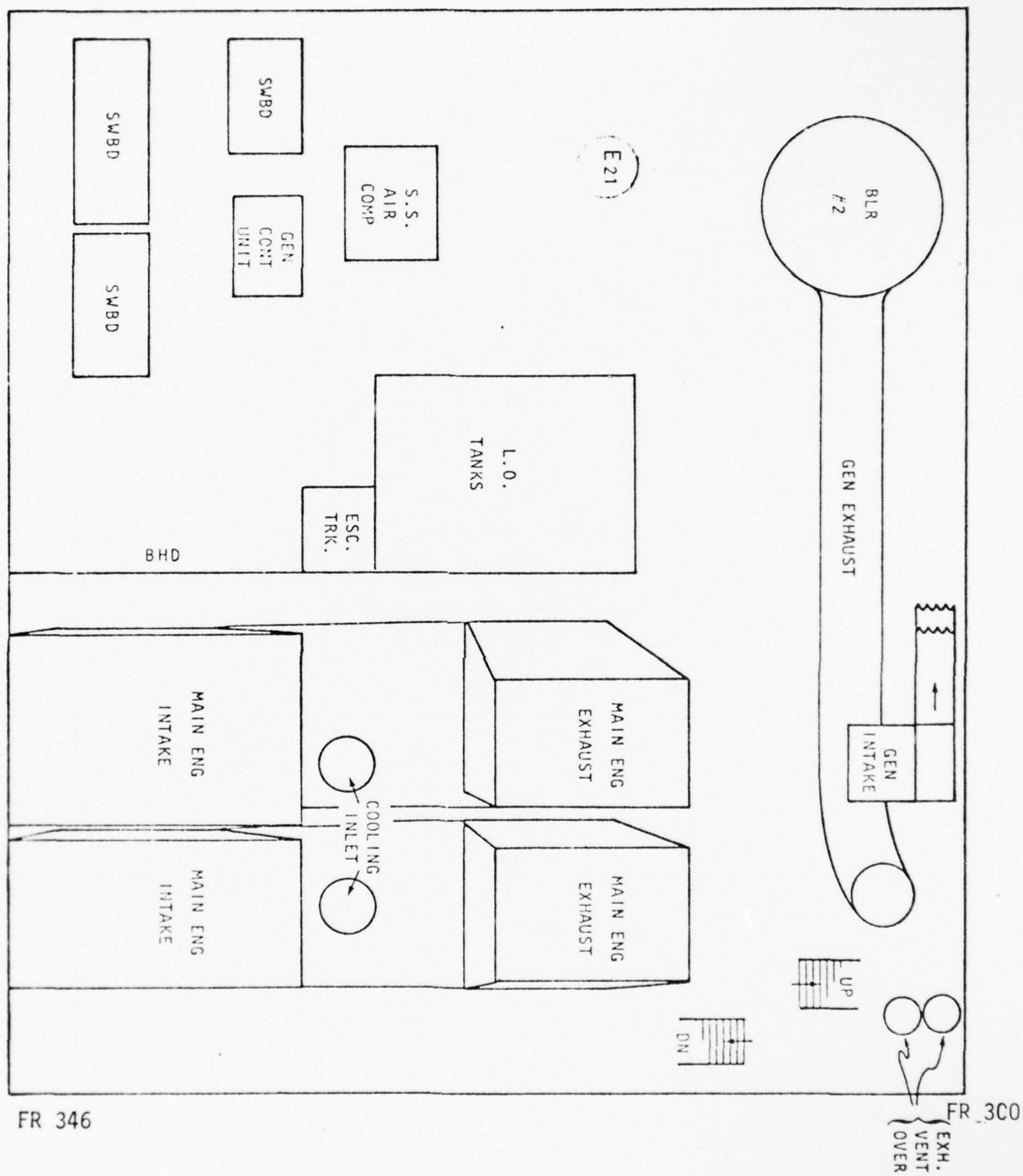

Figure B-12 - MAIN ENGINE ROOM NO. 2 - THIRD LEVEL MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

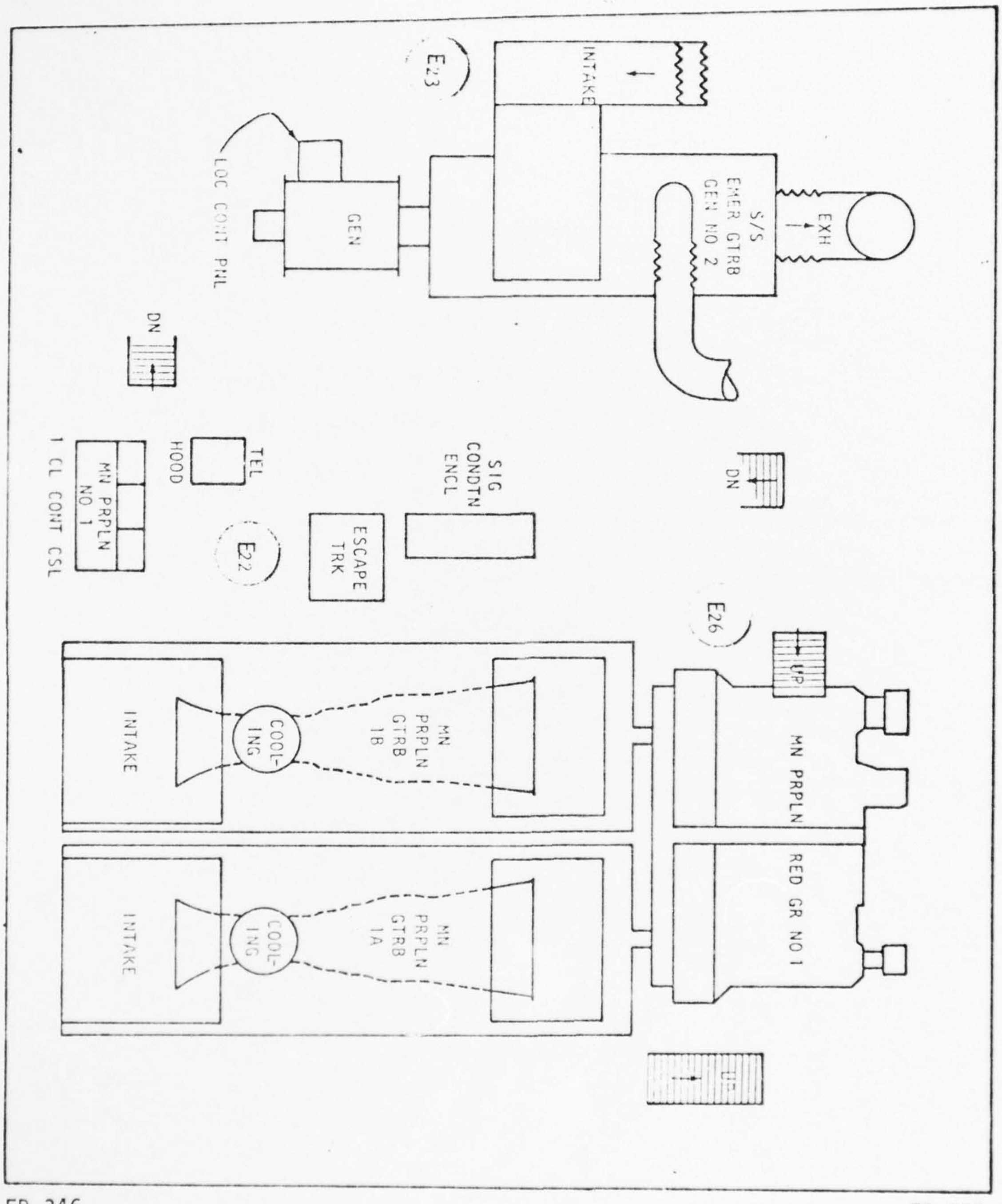

Figure B-13 - MAIN ENGINE ROOM NO. 2 - UPPER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

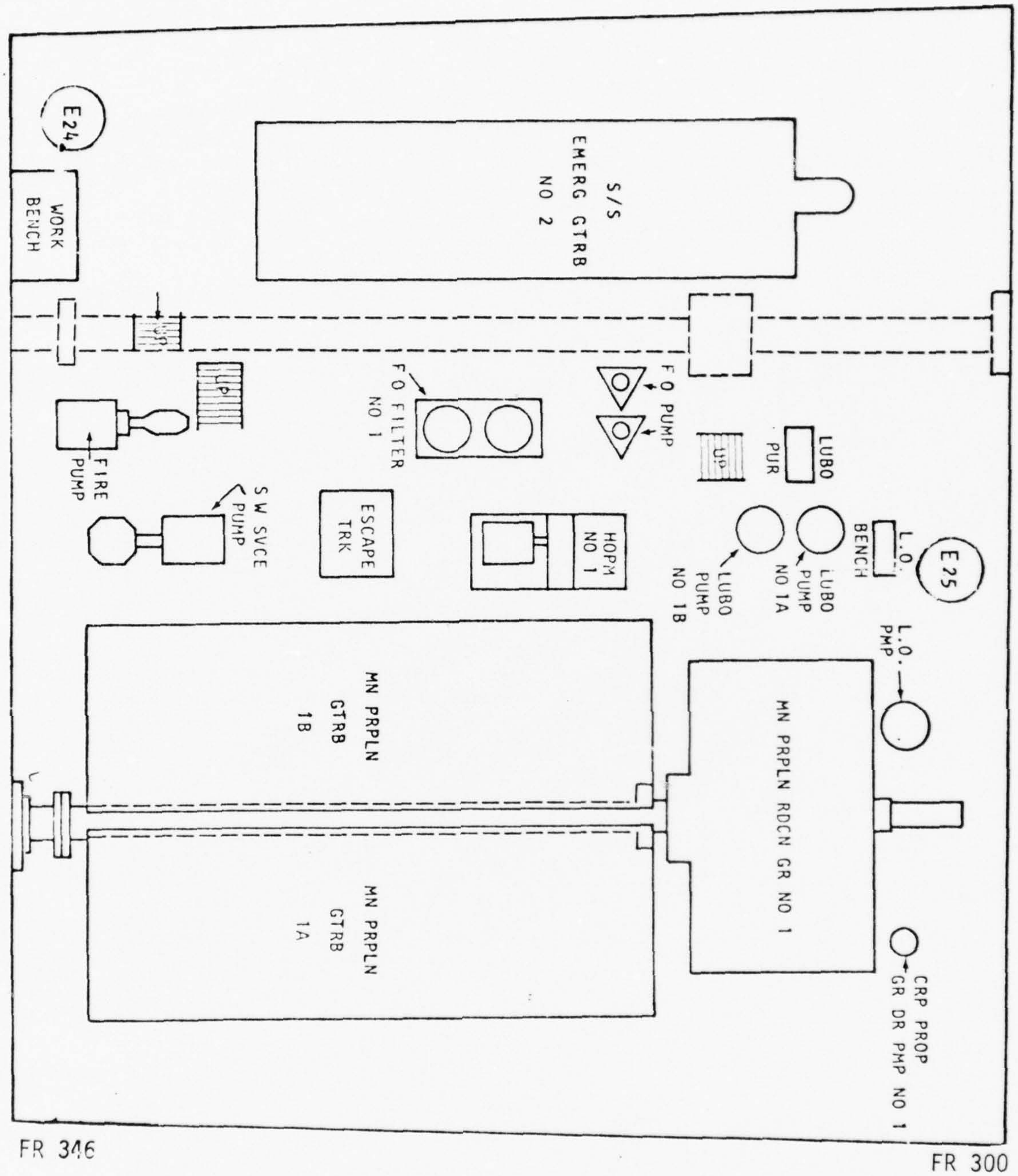

Figure B-14 - MAIN ENGINE ROOM NO. 2 - LOWER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

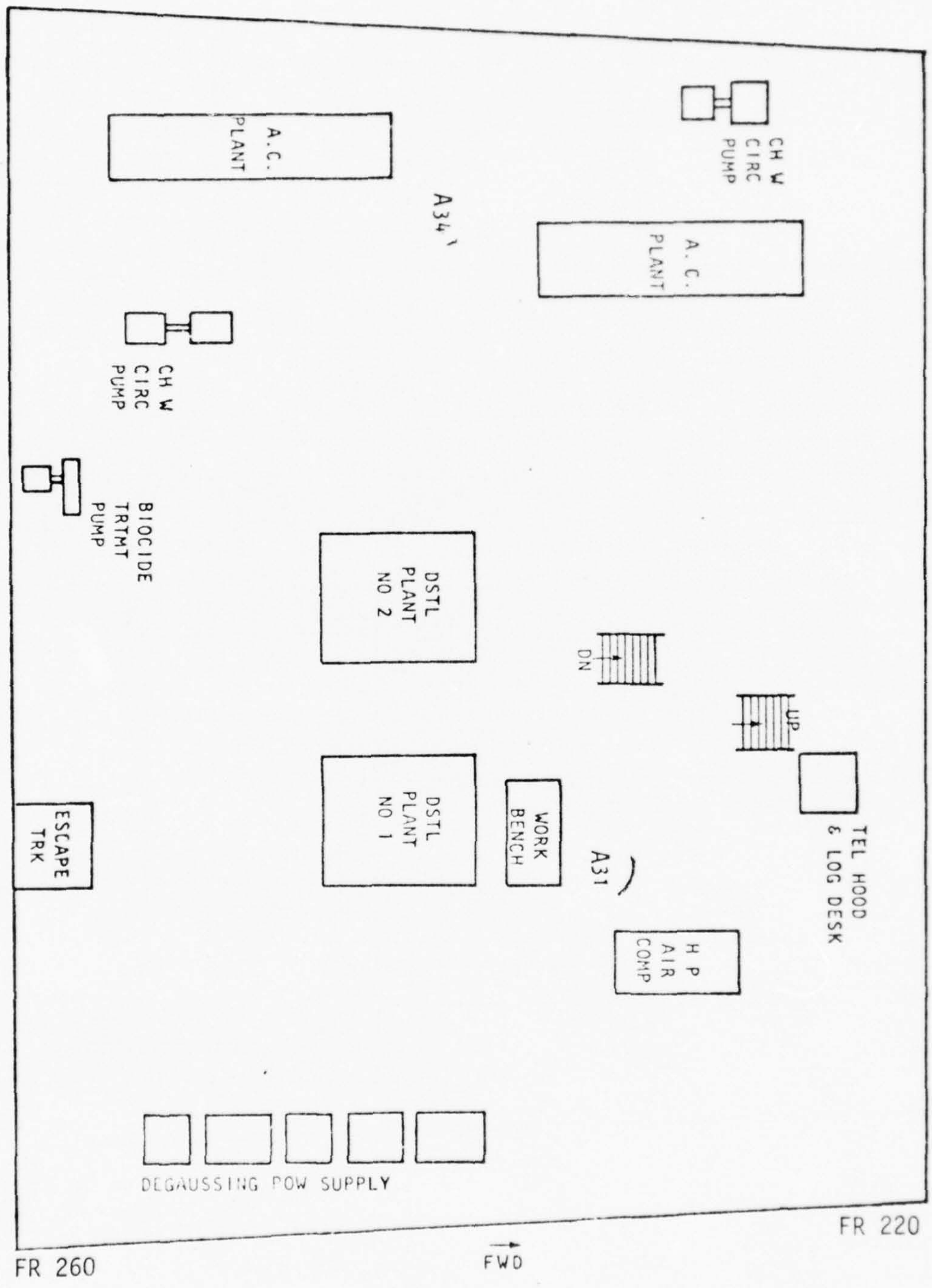

Figure B-15 - AUXILIARY MACHINERY ROOM NO. 1 - UPPER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

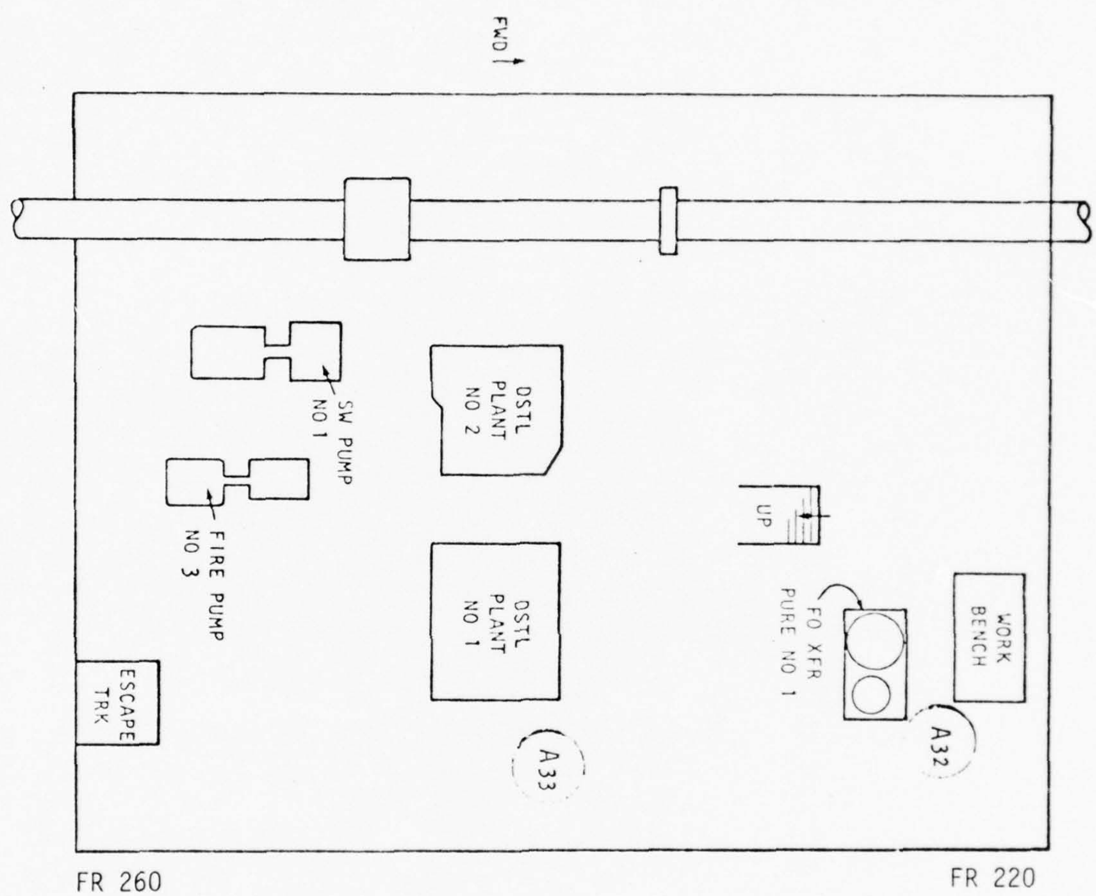

Figure B-16 - AUXILIARY MACHINERY ROOM NO. 1 - LOWER LEVEL, MACHINERY ARRANGEMENT AND MEASUREMENT LOCATIONS, DD 963

APPENDIX C

ACOUSTIC DATA BASE REFERENCE LIST

This appendix presents a list of all the Navy reports used to form the data base in this study. The list is organized separately for each organization conducting the work, and a ship's hull number key is identified for each applicable report. The objective of the key is to provide a quick identification of the data source in Appendix D.

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TABLE C-1

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
BOLT BERANEK AND NEWMAN INC.

Key	Reference
BBN-1 (1082,1070)	Bolt Beranek and Newman Inc. Report 3222, "Hearing Conservation Program Prototype Phase Final Report," J. Lehr, D. Nelson, M. Sutterlin, June 1976, 159 pages.
BBN-2 (1082)	Bolt Beranek and Newman (BBN) Technical Memorandum 257, "Noise and Vibration Measurements on USS Elmer Montgomery, DE 1082," by D. L. Nelson, August 1975.
BBN-3 (DD965)	Bolt Beranek and Newman (BBN) Technical Memorandum No. W340, "Appendix A To Report of Airborne Noise Trial Aboard USS Kinkaid (DDG 965) to Support DDG 47 Contract Design," J. J. Lehr, A. P. Asti, D. L. Nelson, M. W. Sutterlin
BBN-4	Bolt Beranek and Newman (BBN) Technical Memorandum W282, "USS South Caroline (DLGN 37) Engine Room Noise" by W. R. Riblett and J. J. Lehr, 8 August 1975.

TABLE C-2

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
ENVIRONMENTAL PREVENTIVE MEDICINE UNITS 2 & 5

Key	Reference
EPMU5-1,14	Shipboard Sound Level Survey, 1052 Class Ship, EPMU-5 Ship Inspections.
EPMU2-1 (1094)	Shipboard Sound Level Survey, USS Pharris (FF 1094), 11 June 1974.
EPMU2-2 (1091)	Shipboard Sound Level Survey, USS Miller (FF 1091), 14 October 1976
EPMU2-3 (1085)	Shipboard Sound Level Survey, USS D. B. Beary (FF 1085), 15 January 1976.
EPMU2-4 (1084)	Shipboard Sound Level Survey, USS McCandless (FF 1084), 12 July 1974.
EPMU2-5 (1081)	Shipboard Sound Level Survey, USS Aylwin (FF 1081), 5 December 1975.
EPMU2-6 (1056)	Shipboard Sound Level Survey, USS Connole (FF 1056), 14 July 1975.
EPMU2-7 (1078)	Shipboard Sound Level Survey, USS J. Hewes (FF 1078), 21 January 1976.
EPMU2-8 (1059)	Shipboard Sound Level Survey, USS W. S. Sims (FF 1059), 12 November 1974.
EPMU2-9 (1072)	Shipboard Sound Level Survey, USS Blakely (FF 1072), 20 September 1976.

TABLE C-3

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
NAVAL SHIPS SYSTEMS COMMAND

Key	Reference
NAVSHIPS-1 (1063)	Puget Sound Naval Shipyard Report T-10098, "Acoustical Characteristics of USS Reasoner (DE-1063)," September 1972.
NAVSHIPS-2 (1066, 1067, 1069,1071, 1073,1076, 1086,1087, 1088)	Puget Sound Naval Shipyard Report T-10121, "Structureborne and Airborne Noise Characteristics of US Destroyer Escorts DE 1052 Class," October 1973.
NAVSHIPS-3 (1070)	Puget Sound Naval Shipyard Report T-10084, "Acoustical Characteristics of USS Downes (DE-1070)," April 1972.
NAVSHIPS-4 (DD 963)	"Test Report DD 963 Class Destroyer" Procedure No. 902L002, 1 July 1975, Ingall Shipbuilding
NAVSHIPS-5	Ship Information Book, DD 963, NAVSHIPS 0905-496-201.
NAVSHIPS-6	Propulsion Systems Operating Guides, DD 963 Class Ship, NAVSHIPS 0905-496-3010.
NAVSHIPS-7	Ship Information Book, DE 1052.
NAVSHIPS-8	Steady State Airborne Noise Criteria For Shipboard Spaces, NAVSHIPS 0907-004-4010, by L. A. Herstein, 1 April 1970.
NAVSHIPS-9	Operating Guide, DE 1052-1054, 1062, 1066, 1070, NAVSHIPS 0906-006-8012.

TABLE C-4

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
NAVY INDUSTRIAL ENVIRONMENTAL HEALTH CENTER

Key	Reference
NEHC-1 (1093)	NAVENVIRHLTHCEN 413/MMD mph, 6262.16,Ser 5-59, "Noise Survey on Board USS Capadanno (DE-1093) 17-22 January 1975: Report of," 12 March 1975.
NEHC-2	NEHC-415/MDD: er, 6262.16, Ser 4-141, "DE 1052 Class Noise Control Program; forwarding of letter report on," May 10, 1974.
NEHC-2 (1089)	Attachment to NEHC-415/MDD: er, 6262.16, Ser 4-141, "Noise Survey of USS Jesse L. Brown (DE-1089), Conducted 23-25 July 1973, J. E. Shultz and LTJG M. D. Densley.
NEHC-2 (1093)	Attachment to NEHC-415/MDD: er 6262.16, Ser 4-141, "Noise Survey of USS Capodanno (DE 1093) conducted 12-14 December 1973, LTJG M. D. Densley.

TABLE C-5

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Key	Reference
NSRDC-1 (1085)	Naval Ship Research and Development Center Report C-4104, "Past Construction Acoustic Evaluation of USS Donald B. Beary (DE-1085)(U), by R. W. Tomkins, D. Silawsky, J. T. Allender, and E. E. Pettersen, April 1973, Confidential.
NSRDC-2 (1056)	Naval Ship Research and Development Center Technical Report Number TR-55, "Acoustic Characteristics of USS Connole (DE-1056)(U)," R. E. Myers, P. D. Haynes, July 1972, Confidential.
NSRDC-3 (1075)	Naval Ship Research and Development Center Technical Report No. TR 63 "Acoustic Characteristics of USS Trippe (DE 1075)," R. V. Butler, 15 November 1971, Confidential.
NSRDC-4 (1091)	David W. Taylor Naval Ship Research and Development Center Report 76-0068, "Post Construction Acoustical Evaluation of USS Miller (FF 1091)(U)," R. E. White, R. L. Wolfe, J. T. Allender, J. R. Otis, H. W. Murray, May 1976, Confidential.
NSRDC-5 (1095)	David W. Taylor Naval Ship Research and Development Center Report C-4685, "Post Construction Acoustical Evaluation of USS Truet (DE 1095)(U)," J. R. Otis, J. T. Meekins, J. O. Valentine, R. L. Wolfe, September 1975, Confidential.
NSRDC-6	"Airborne Noise Level Comparison, DE 1056, 1047, 1045, 1044, 1043, AGDE-1, Unpublished Aggregate of Published Data, William H. Barnes III, 1927 Branch.

TABLE C-5 (Cont'd)

Key	Reference
NSRDC-7	NSRDC Technical Paper "Surface Vibration Reduction of Marine Propulsion Gear Boxes," E. V. Thomas & A. J. Roscoe III, David Taylor Naval Ship R&D Center, Annapolis, Md. 21402, 20 pages.
NSRDC-8	NSRDC Data, USS California, E. V. Thomas, 21 pages.
NSRDC-9	Naval Ship Research and Development Center Report NSRDC TM-27-75-145, "Report of Airborne Noise Health Hazards Reduction in Machinery Spaces Aboard USS Mount Vernon LSD 39," by E. V. Thomas, 8 April 1975.
NSRDC-10	Naval Ship Research and Development Center Letter, 2742: EVT, 9073," Report of Airborne Noise Health Hazards Reduction in Machinery Spaces Aboard USS Mount Vernon LSD 39; Report TM-27-75-145, Forwarding of," from Commander NSRDC to Commander SEC 6145.

TABLE C-6

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
NAVAL UNDERSEA CENTER

Key	Reference
NUC-1 (1069)	Naval Undersea Center (NUC) Memorandum Ser 401-51, "Fireroom Environmental Noise Survey USS Bagley, DE 1069, by Edward R. Rubin, Oct. 29, 1973.
NUC-2 (1069)	Naval Undersea Center (NUC) Engine Room Environmental Noise Survey Data, USS Bagley (DE 1069), 11 pages.
NUC-3	Naval Undersea Center (NUC) Memorandum Ser 401-52, "Fireroom Environmental Noise Survey USS Ramsey, DEG-2," by George L. McLennan, Oct. 29, 1973.
NUC-4	Naval Undersea Center (NUC) Engine Room Environmental Noise Survey Data, USS Ramsey (DEG-2), 6-12-1973, 3 pages.
NUC-5	Naval Undersea Center (NUC) Memorandum Ser 401-53, "Fireroom Environmental Noise Survey USS Hoel, DDG-13," Edward R. Rubin, Oct. 29, 1973.
NUC-6	Naval Undersea Center (NUC) Briefing Charts, "Summary of Analysis of NUC-Developed Ear Protection Effectiveness on Eight Ships," 3 Feb. 1975, 6 pages.
NUC-7	Naval Undersea Technical Note, NUC TN 1464, "Preliminary Study of the Effects of Ear Protectors on Recognition of Shipboard Machinery Sounds," by David R. Lambert, January 1975, 20 pages.

TABLE C-7

NAVY AIRBORNE NOISE EXPOSURE DATA SOURCE
NAVAL SHIP ENGINEERING CENTER

Key	Reference
SEC-1	Naval Ship Engineering Center Letter, 6105F/DPL, 073, Ser. 16, "Hearing Conservation Program, Post-RAV Machinery Space Airborne Noise Trials of USS Elmer Montgomery (FF 1082).
SEC-2	Naval Ship Engineering Center Data, "Combined Plant & Gas Turbine DE Studies, Speed-Time Distribution," Figure 29.
SEC-3	Naval Ship Engineering Center Report No. 6159-003, Projected 1975 Through 1982 Shipboard Oily Waste Generation Rates for Eight Navy Port Complexes," January 1974.
SEC-4	Naval Ship Engineering Center Letter 6145A/MCH, 9400/9420, ETA 4043001, Ser 167, "LSD 36 Class Engine Room Noise Review," 3-18-74.
SEC-5	Naval Ship Engineering Center Letter 6145D/MH, LSD 36C1/9400, Ser 245, "LSD 36 Class Result of Noise Reduction Effort on USS Mount Vernon (LSD 39)," 4-17-1975.
SEC-6	Final Ship Manning Document for DD963 Class Ship, Q001 AG, 22 May 1976, Ingalls Ship Co.

APPENDIX D
SHIPBOARD COMPARTMENT A-WEIGHTED SOUND LEVEL DATA

This appendix presents all the A-weighted shipboard noise data which have been used in this study. The data have been collected from the various Navy sources and segregated by ships operational sub-modes and measurement location. The statistical mean and standard deviation have been calculated for each measurement location under each operational sub-mode.

Each measurement location is identified in accordance with numbering procedure described in Section 3.4.2 and illustrated pictorally in Appendix B. The full description of the noise level data sources used is provided in Appendix C.

The data presented for the following conditions:

Class	Compartment	Sub-Mode
FF 1052	Engine Room, Fire Room, Aux 1, Aft Steering	8, 15, 20 and 27 knots
FF 1052	Aux Machinery Room 2	DG on, DG off, Air Start
FF 1052	Engine Room, Fire Room	Cold Iron Aux Steaming
DD 963	Engine Room 1, Engine Room 2, Aux 1 Aux 2	16, 20, 25 and 27 knots

Finally, data values which were greater than two standard deviations from the mean were identified, removed from the sample and the statistical properties recalculated. This procedure serves to spotlight measurements which were significantly different from the average.

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These measurements could be different from the average for the following causes:

1. The measurement was made incorrectly usually a ±10 dB discrepancy.
2. The machinery line-up was not normal for that operating sub-mode, for example prairie/masker in operation and venting into the fire room of the FF 1052 class ship causes.
3. A particular machinery item is noisy, two examples being a cavitating fire pump and a steam leak.

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 8±4 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
BBN-1(1082)				90	85				91							96		95				
BBN-1(1070)			87	89	84				91		88					93		93			95	
NUC-1/3(1069)																						
NEHC-1(1093)		82	81	85	83	85	84	85	86	83	84	83		86	86		88	89			90	86
-2(1093)	71	92	92	92	91	88	89	95	92	91	91	92	92	91	91	93	92	97	94	94	97	95
-2(1089)																						
EPMU 5-1																						
-2	71	91		92	88				90		89	91			94		92		96		103*	
-3	68	85		91	85				91		85	86			90		90	91	95		95	
-4	68			91	88	91																
-5																						
-6				88		98*			87	87			87	84	87		90			88		88
-7	71	90		87		90	89		92	88	89	87		87			91	93	93	91	94	
-8																						
-9																						
-10																						
-11																						
-12																						
-13	73	91		89	82	82	84		90	85		86					92	97		96		
-14																						
NSRDC-1(1085)																						
-2(1056)	68		86	90		85	90	91	89	89		89			85		92	89		94	94	
-3(1075)																						
-4(1091)	71			93					91						91						96	
-5(1095)										86				87	88						96	

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 8±4 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
NAVSHIPS-1(1063)	68			91																		
-2(1066)	71			94																		
-2(1069)	69			92																		
-2(1071)																						
-2(1073)	70			89																		
-2(1076)	71			91																		
-2(1086)	70			90																		
-2(1087)	69			91																		
-2(1088)	68			88																		
-3(1070)	69			90						97*					76*							
EPMU2-1(1094)	72	85	87	90	84	88		92		87	88	87	89		88						95	92
-2(1091)																						
-3(1085)																						
-4(1084)																						
-5(1081)				92				93	88				92		87		90	91			94	
-6(1056)																						
-7(1078)																						
-8(1059)																						
-9(1072)																						
Statistics																						
n	18	7	5	23	9	7	5	5	12	8	7	8	4	5	10	3	9	9	4	5	10	4
u	70	88	87	90	86	87	88	87	91	87	88	88	90	87	89	94	91	93	95	93	95	90
s	2	4	4	2	3	5	3	4	2	2.5	3	3	3	3	5	2	1	3	1	3	3	4

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 8±4 KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
BBN-1(1082)			95			91		86	86		88		92	85			88							87				
BBN-1(1070)			92			91		88	90		91		91	82			87							82				
NUC-1/3(1069)																												
NEHC-1(1093)			91	87	86	88		85	89	85	84	89	86	83	86	86	86		84				83	84				85
-2(1093)			94	87	86	92	73	88	92	90	90	88	93	90	90	93	88	89	90	88	91			89	89	88	92	88
-2(1089)			*105	92	96	*101	73	*92	95	94	96	99	*102	*108	92	96	*96	96	92	90	96			*99	92	95	93	*97
EPMU 5-1																												
-2				95		92	76	88	89				91	86			86	84			87			91			85	
-3			95	92	93	89	68		89			87	89			91	91			96				88	91	92	88	
-4						91	78	89									90	91		98	84							
-5																												
-6						88	68	83	84	85	80			80		89	84	81		84	87		86	88	79		82	83
-7	84	*68	93	90		87	74	85	86	84	90			86		89	85			92	86	94	85	86	85		88	85
-8																												
-9																												
-10																												
-11																												
-12																												
-13	88	90	92	89	90	90	72	85	94	90	90			83		90			86	84	94	95	89		88			
-14																												
NSRDC-1(1085)																												
-2(1056)						91	78	87	86	83	85					87	87	82	84	84		92						
-3(1C75)																												
-4(1091)	85					92			90								90											
-5(1095)							73	83					91			84	85											

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 8±4 KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
NAVSHIPS-1(1063)						92	68										92											
-2(1066)							78										88											
-2(1069)						90	72										88											
-2(1071)						88	65										83											
-2(1073)						91	72										87											
-2(1076)						95	71										85											
-2(1086)						93	73										88											
-2(1087)						88	67										86											
-2(1088)						87	65										81*											
-3(1070)						88	75																					
EPMU2-1(1094)	88	92	92	89	94	82*	72			85		88		86		89	86	86	85	89			82	93	86		89	
-2(1091)																												
-3(1085)			93	91	87	89	73		92	87	93	93	91	90	85	90	88	89		98	88		87	87	90		90	89
-4(1084)																												
-5(1081)																												
-6(1056)																												
-7(1078)																												
-8(1059)																												
-9(1072)																												
Statistics n	4	2	9	9	7	22	22	11	13	9	9	6	8	10	4	11	22	8	6	10	8	3	6	10	7	3	8	6
u	86	91	94	90	90	90	72	86	89	87	90	91	91	85	88	90	87	87	87	90	89	94	85	89	89	92	88	86
s	2	1.4	1.4	2.6	4	2.1	4	2.[illegible]	3.3	4.5	3.7	4.3	2.1	3.3	3.3	3.3	2.2	5	3.4	5.5	4.2	1.5	2.6	4.6	2.6	3.5	3.6	5

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 8±4 KTS

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
BBN-1(1082)																					
BBN-1(1070)																					
NUC-1/3(1069)																					
NEHC-1(1093)																					
-2(1093)	83	85	81		81	81		78		91	75	78	81		88		78				
-2(1089)																					
EPMU 5-1																					
-2	87		88					90	88		86	88	88	87	90				87	76	
-3	76		88	87				88	86		89	88	87	87	89				86	88	
-4	78	87								87			88							76	
-5																					
-6		82	89	86		83	83	89	86	79		89		90	89				90	80	80
-7																					
-8																					
-9																					
-10																					
-11																					
-12																					
-13																					
-14																					
NSRDC-1(1085)																					
-2(1056)	87	88							89	89	82	90		89	88		91				
-3(1075)																					
-4(1091)		85		89					90	86											
-5(1095)		83															86	96		72	

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 8±4 KTS

Mode-Underway

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
NAVSHIPS-1(1063)	90																		95		
-2(1066)	86																				
-2(1069)																					
-2(1071)	84																		88	75	
-2(1073)	87																				
-2(1076)																			91	74	
-2(1086)																					
-2(1087)	86																		89		
-2(1088)	75																				
-3(1070)	84	84	85		85	85	84	83	83	88		86	86	86	89	88			84		
EPMU2-1(1094)																					
-2(1091)		83	85	82	83	85	83	84	84	83		86	86	87	89	85			84		
-3(1085)																					
-4(1084)																					
-5(1081)	85	92	90	96	89	90				90	91	92	93		92	93			93		
-6(1056)																					
-7(1078)																					
-8(1059)																					
-9(1072)																					
Statistics n	13	9	7	5	4	5	3	6	7	8	5	7	7	6	8	3	3	1	10	7	1
u	84	86	87	88	85	85	83	85	87	87	85	88	87	88	89	88	85	96	89	77	80
s	4.6	3.1	3.1	5.2	3.4	3.4	0.6	4.5	2.5	4	6.5	2.2	3.6	1.5	1.3	4	6.5	–	3.7	5.3	–

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
BBN-1(1082)			91	91	89				91							97		95				91
BBN-1(1070)			89	90	89				92							94		95			94	92
NUC-1/3(1069)	71			96			92		92	96					91			95			98	
NEHC-1(1093)		92	92	93	91										90							
-2(1093)		95	94	92	92	92	94	100	95	95	92	95	97	93	92	96	95	97	99		100	96
-2(1089)																						
EPMU 5-1						89	89	92		91	92	93	89			93	94	91	93	93		93
-2																						
-3	68	85		89	85				92		90	90			91		93	91	93		94	
-4																						
-5																						
-6									90	88				86	88		92			88	96	90
-7	68	91		89		90	88		90	93	96	92		90			94	93	93	93	94	
-8																						
-9																						
-10				91	84	92	97	90									96	92	92		95	
-11	68			90		89			89	91	94	91	91			98	95	93	95	93	96	
-12																						
-13																						
-14																						
NSRDC-1(1085)																						
-2(1056)	71		94	90		90	92	90	92	97					93		99	94			96	
-3(1075)				91	88										90						96	
-4(1091)																						
-5(1095)																						

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room Mode-Underway SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
NAVSHIPS-1(1063)	72			91																		
-2(1066)																						
-2(1069)																						
-2(1071)	75			91																		
-2(1073)																						
-2(1076)																						
-2(1086)																						
-2(1087)																						
-2(1088)	69			88																		
-3(1070)	67			90						98					84							
EPMU2-1(1094)																						
-2(1091)																						
-3(1085)																						
-4(1084)	67	91	90	92	88				88	89	89				88	94	93	90			95	96
-5(1081)	72	86	89							93	94	96		88								
-6(1056)																						
-7(1078)																						
-8(1059)	72	97	94		90		95	93	93	*108	*101	*100	92	94	90	*110	*102	93	103		99	98
-9(1072)	68	92	90	94	87	91	90	95	91	98	90	94	94		91		97	91		97	95	95
Statistics n	13	8	9	17	10	7	8	6	12	11	8	7	5	5	10	6	10	13	7	5	13	8
u	70	91	92	91	88	91	91	93	91	94	[illegible]	93	93	90	90	95	95	93	96	93	96	94
s	3	4	2	2	3	1	3	4	2	3.5	2.4	2.2	3	3	1.6	2	2.1	2	4	3	2	3

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	FM1	FM2		FT1	FT2	FT3		FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11		FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
BBN-1(1082)	88			96				92		87	87				93	87									88		87				
BBN-1(1070)	90			97				97		91	91				99	83									95		88				
NUC-1/3(1069)		90				90				89	92	92	82					88		88	87		85	94	93	90		82			
NEHC-1(1093)					88	86		88		86	90	85	86	89		85	90	86		87		86				83	85	86	87		89
-2(1093)																				90		90									
-2(1089)																															
EPMU 5-1											91	96	88		101		89	96		91		93	88	91	90	92			86		*97
-2																															
-3				101	97	96		96	73		93			*102	97			94		91			96				87	92	89	84	
-4																															
-5																															
-6																															
-7				93	91	91		87	76	87	87	92	92			86		86		85			92	86	94	88	86	87		91	93
-8																															
-9																															
-10									67	84	84							89		92	86	82	83	84	91		86				*81
-11	83	86		93	94			92	75		90	89	89	90	91	91	89	90		88	84			87		88	88	86		88	87
-12																															
-13																															
-14	89	82																		89											
NSRDC-1(1085)																															
-2(1056)	91	70																													
-3(1075)								87		83	86														91						
-4(1091)																															
-5(1095)																															

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room Mode-Underway SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
NAVSHIPS-1(1063)						88	71										86											
-2(1066)																												
-2(1069)																												
-2(1071)							87																					
-2(1073)																												
-2(1076)																												
-2(1086)																												
-2(1087)																												
-2(1088)						91	69										87											
-3(1070)						85	76																					
EPMU2-1(1094)																												
-2(1091)						89	78	89				84	92				86		80					88				86
-3(1085)																												
-4(1084)			91			88	72	85		86		88	89	89			88			94			86	~~84~~	91		89	86
-5(1081)																												
-6(1056)																												
-7(1078)																												
-8(1059)	94	100																										
-9(1072)			92	94	87	92	78	83	87	88	84	89	92	83		88	97*	86	87	88	88		89	88	86		86	89
Statistics n	6	5	7	5	5	13	11	10	11	7	6	5	8	7	3	8	13	4	6	7	6	7	7	10	7	3	5	6
u	89	86	95	93	90	90	75	86	89	90	87	88	94	86	89	90	88	86	86	90	88	92	88	87	87	87	88	88
s	3.7	11	3.5	3.4	3.9	3.6	5.4	2.7	2.9	3.9	3.6	2.4	4.2	3	0.6	3.6	2.2	1.3	4.8	4.8	3.6	2.4	2.9	1.4	3.4	1.5	2.7	3.7

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
BBN-1(1082)																					
BBN-1(1070)																					
NUC-1/3(1069)																					
NEHC-1(1093)																					
-2(1093)	93	91	92			92			91	90	92	92	92	90	93	92	92				
-2(1089)	87	87			85	90		87	86	86	85	89	90	89	91	91	89	91	93		
EPMU 5-1			89	91	88	87	92			92	92	88	87		92	88	88	85			
-2																					
-3	78		88	87				88	86		88	88	88	90	88				86	92	
-4																					
-5																					
-6																					
-7	81	85			87	89	85			92	85	91		89	86	87	88	92	94	77	81
-8																					
-9																					
-10	81	86			82	85	86			92	85			84	88	88			88	83	
-11	86		91	88						86	88	89	90	92	95	86	88	89			
-12																					
-13																					
-14																					
NSRDC-1(1085)																					
-2(1056)																				79	
-3(1075)																					
-4(1091)																					
-5(1095)																					

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 15±2 KTS

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
NAVSHIPS-1(1063)	88																		94		
-2(1066)																					
-2(1069)										92											
-2(1071)																					
-2(1073)																					
-2(1076)																					
-2(1086)																					
-2(1087)	87																		90		
-2(1088)	85									92											
-3(1070)																					
EPMU2-1(1094)																					
-2(1091)																					
-3(1085)	78		85	85		87				84		87	90		88	87			86		
-4(1084)																					
-5(1081)																					
-6(1056)																					
-7(1078)	78		87	87	88	90					88	90	91						89		
-8(1059)		80	87	91	85	88	88	86	86			88	87	88	84			86	87		
-9(1072)																					
Statistics n	11	5	7	6	6	8	4	3	4	9	8	9	8	7	9	7	5	5	9		
u	84	86	89	88	86	89	88	87	87	90	88	89	89	89	90	85	89	89	90		
s	5	4	3	3	2	2	3	1	3	3	3	2	2	3	4	2	2	3	3		

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 20 +5 -2 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
BBN-1(1082)			94	92	92				93		101					101		97			98	
BBN-1(1070)			93	93	89				95		99					98		99			98	
NUC-1/3(1069)	78			93			94		92	104*					93			95			98	
NEHC-1(1093)		89	89	94	88	88		94	94	95	92		89	90	93		94	92			94	93
-2(1093)				93	92										92							
-2(1089)	67	90	92	92	90	93	93	93	90	95	93	94	91	92	95	99	102	96	98		96	99
EPMU 5-1						92	92	92		93	95	93	91			97	96	94	95	95		98
-2	73	95		94	91				95		92	96			96		96		98		107*	
-3																						
-4																						
-5																						
-6																						
-7																						
-8																						
-9																						
-10																						
-11																						
-12																						
-13																						
-14																						
NSRDC-1(1085)																						
-2(1056)																						
-3(1075)				94	89										92						97	
-4(1091)	73			93					95						101*						97	
-5(1095)	71									94				94	93						97	

SHIP NOISE LEVEL DATA (dBA) Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 20 $^{+5}_{-2}$ KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
NAVSHIPS-1(1063)	71			93																		
-2(1066)	107*			84*																		
-2(1069)																						
-2(1071)	76																					
-2(1073)																						
-2(1076)	91*			91																		
-2(1086)																						
-2(1087)																						
-2(1088)	72			94																		
-3(1070)																						
EPMU2-1(1094)																						
-2(1091)	72		93	93	95				93		98			93	86*		98	97				
-3(1085)	75	92	92	97	88	86	90	97	92	96	93	96	94		91		97	94	98	96	97	97
-4(1084)																						
-5(1081)	72	86	89							93	94	96		88								
-6(1056)																						
-7(1078)	75	90	91	91	91	89	92	92	91	92	93	93		91	92		96	95	96	94	93	99
-8(1059)																						
-9(1072)																						
Statistics n	12	6	8	15	10	5	5	5	10	7	10	6	4	6	9	4	7	9	5	3	10	5
u	73	90	92	93	91	90	92	94	93	94	95	95	91	91	93	99	97	96	97	95	97	97
s	2.8	3	2	1.5	2	2	2	2	2	1.4	3	2	2	2	1.6	2	3	2	2	1	1.7	3

SHIP NOISE LEVEL DATA (dBA) Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 20 $^{+5}_{-2}$ KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
BBN-1(1082)			98			99		98	90				94	94			90					94		89				
BBN-1(1070)			97			98		91	95				98	88			90					97		90				
NUC-1/3(1069)		95			93	95		96	91	97	86					93	91	89		99	90	94	95		86			
NEHC-1(1093)			108	103	97	103		94	94	95	92	98	102	90	93	95	98	96	95	90		93	95	97	92	93	92	100
-2(1093)									89								90											
-2(1089)			95	99	88	87	68	79*	93	84	87	90	87	84		86	87	91	84	90		90	86	85	93	91	91	
EPMU 5-1									92	102	88		106		101	103			96	90	92	95	98			86	97	98
-2				101		96	78	94	93				97	102			94	91			91			95			96	
-3																												
-4																												
-5																												
-6																												
-7																												
-8																												
-9																												
-10																												
-11																												
-12																												
-13																												
-14																												
NSRDC-1(1085)																												
-2(1056)						94	75	93	82							88	88	83	85	84		92		86				
-3(1075)						88		83*	88													93						
-4(1091)						97			96								91											
-5(1095)							73	92					94			87	88											

SHIP NOISE LEVEL DATA (dBA) Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 20 $^{+5}_{-2}$ KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
NAVSHIPS-1(1063)						93	72										89											
-2(1066)							79										89											
-2(1069)																												
-2(1071)							85*																					
-2(1073)																												
-2(1076)						94	72										97											
-2(1086)																												
-2(1087)																												
-2(1088)						97	72										90											
-3(1070)																												
EPMU2-1(1094)																												
-2(1091)			93																									
-3(1085)																												
-4(1084)																												
-5(1081)																												
-6(1056)																												
-7(1078)																												
-8(1059)																												
-9(1072)																												
Statistics n		1	5	3	3	12	8	7	11	4	4	2	7	5	2	6	14	5	4	5	3	8	4	6	3	3	4	2
u		95	98	101	93	95	74	94	91	85	88	94	97	92	97	92	91	90	90	91	91	94	94	90	90	90	94	99
s		–	6	2	5	5	3.6	2.4	4	8	3	6	6	7	6	7	3	5	6	5	1	2	5	5	4	4	3	2

SHIP NOISE LEVEL DATA (dBA) Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 20 $^{+5}_{-2}$ KTS

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11		AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8		S1W	S2
BBN-1(1082)		87	91	87		90				89			90	90									
BBN-1(1070)																							
NUC-1/3(1069)																							
NEHC-1(1093)	84	81	87	86	83	86	86			87	85		85	85	86	89	95			85			
-2(1093)																							
-2(1089)																							
EPMU 5-1			90	92	89	88	92			92	92		90	88		92	87	88	87				
-2	88		91					92	91		87		92	91	90	92				89		88	
-3																							
-4																							
-5																							
-6																							
-7																							
-8																							
-9																							
-10																							
-11																							
-12																							
-13																							
-14																							
NSRDC-1(1085)																							
-2(1056)	85	88						87										88	90			85	80
-3(1075)																							
-4(1091)																						93	
-5(1095)																							

SHIP NOISE LEVEL DATA (dBA) Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 20 +5 -2 KTS

Data Source \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
NAVSHIPS-1(1063)	92																		92		
-2(1066)	89																				
-2(1069)																					
-2(1071)																					
-2(1073)	86																				
-2(1076)																					
-2(1086)																					
-2(1087)	87																		91		
-2(1088)																					
-3(1070)																					
EPMU2-1(1094)		85	85			85				89		85			86				87		
-2(1091)																					76
-3(1085)																					
-4(1084)																					
-5(1081)																					
-6(1056)		88	90	86	87	88	83	88	89	81	82	89	90	89	89				90		
-7(1078)																					
-8(1059)																					
-9(1072)																					
Statistics																					
n	7	5	6	4	3	5	3	3	2	5	4	6	5	3	5	2	2	2	6	3	2
u	87	86	89	88	86	87	87	89	90	88	87	89	89	88	90	91	88	89	89	87	78
s	3	3	3	3	3	2	5	3	2	4	4	3	2	2	3	6	5	2	3	2	3

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room Mode-Underway SHIP SPEED 27±1 KTS

Data Source \ Measurement Location	ET1W	ET2	ET3	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8
BBN-1(1082)				100	97				100							107		104				
BBN-1(1070)																						
NUC-1/3(1069)	71			91			94		93	96					95			101			100	
NEHC-1(1093)																						
-2(1093)				100	99										101							
-2(1089)	74	94	100	98	99	96		97	95	105	100	101	97	98	96	104	107	99	102	102	100	103
EPMU 5-1																						
-2																						
-3	74	92		94	93				95		101	102			97		103	98	102		96	
-4	74			9	94	95									97	98	96				96	
-5				94																		
-6																						
-7	72	96		95		96	96		94	103	107	98		96			101	98	99	99	97	
-8	74	98		94			91		99	99							98	97		102		
-9																						
-10																						
-11	72	94		92	92	91	93		93	99	97	96	93	95		99	100	98	99	97	98	
-12	70	96		95		93	94		93								98	101		100		102
-13	74	94		93	93	93	92		94	98		99					92	99		100		
-14	75			95											99							
NSRDC-1(1085)				92					92		94				98	102	99				95	
-2(1056)																						
-3(1075)				93	92										93						97	
-4(1091)																						
-5(1095)																						

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room Mode-Underway SHIP SPEED 27±1 KTS

Measurement Location / Data Source	NAVSHIPS-1(1063)	-2(1066)	-2(1069)	-2(1071)	-2(1073)	-2(1076)	-2(1086)	-2(1087)	-2(1088)	-3(1070)	EPMU2-1(1094)	-2(1091)	-3(1085)	-4(1084)	-5(1081)	-6(1056)	-7(1078)	-8(1059)	-9(1072)	Statistics n	u	s
ET1W			71		74		72	71												14	73	1.6
ET2																				7	95	2
ET3																				1	100	—
EU1W			92		90		88	90												19	94	3.2
EU2W																				8	95	3
EU3																				6	94	2
EU4																				6	93	1.8
EU5																				1	97	—
EU5																				10	95	2.7
EU7																				6	100	3.4
EU8																				5	100	5
EU9																				5	99	2.4
EU10																				2	95	2.8
EU11																				3	96	1.5
EL1W																				8	97	2.5
EL2W																				5	102	3.7
EL3																				9	99	4.2
EL4																				9	99	2.2
EL5																				4	101	1.7
EL6																				6	100	1.9
EL7																				8	97	1.9
EL8																				2	103	0.7

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room Mode-Underway SHIP SPEED 27±1 KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
BBN-1(1082)			103			100		98	96								95					94		92				
BBN-1(1070)																												
NUC-1/3(1069)	96				99	99		100	93	102	101					99	96	93		99	94	97	97		97			
NEHC-1(1093)																												
-2(1093)									103								97		96									
-2(1089)			105	105	104	101	75	101	102	105	105	106	111	99	100	100	95	95	93	100	93	98	100	95	100			
EPMU 5-1																												
-2																												
-3			105	104	101	102	78		98			106	104			99	97			101				95	100	95	93	
-4						98	72	99									95	91		91	95							
-5			104			98	73										96		92									
-6																												
-7	96	98	102	101	101	97	76	96	93	102	105			96		95	92			96	95	96	94	93	99		94	94
-8	93	95	99	100	101	98	75		93	98	100					98	92				93	93	99		98			
-9	98	94	102	103	97	98	74		90	94		97				93	91		89	93	90		94	91			97	
-10																												
-11	92	97	103	107		101	75		100	101	105	102	102	108	100	98	95	92			93			94	98		96	92
-12	98	94	100	104		98	74		90							93	89			94	91	97						
-13	98	96	102	105	105	100	74	96	94	100	103			95		99	93		94	96	94	100	99		100			
-14																												
NSRDC-1(1085)						98		95									92	94						91				
-2(1056)																												
-3(1075)						90		85	90													92						
-4(1091)																												
-5(1095)																												

SHIP NOISE LEVEL DATA (dBA)

Mode-Underway

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 27±1 KTS

Data Source \ Measurement Location	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
NAVSHIPS-1(1063)																												
-2(1066)																												
-2(1069)						93	72										92											
-2(1071)																												
-2(1073)						91	71										87											
-2(1076)																												
-2(1086)						91											88											
-2(1087)						97	73										92											
-2(1088)																												
-3(1070)																												
EPMU2-1(1094)																												
-2(1091)																												
-3(1085)																												
-4(1084)																												
-5(1081)			94*	95*	91*	91	72	85	87	93	93	95	94	86*		90	85*		84	87*	87		91*	86*	90*		90	
-6(1056)																												
-7(1078)	95	95	111*	107	105	100	73	101	97	106	105	103	108	99		98	95	95	93	102			100	95	101		98	96
-8(1059)				105	108	98	76	93	95	98	92	95	98	92	92	93	98	93	87	97		94	96	92	96			94
-9(1072)																												
Statistics																												
n	8	7	10	10	9	21	16	11	15	10	9	7	8	6	3	12	20	7	8	10	10	9	8	9	9	1	7	4
u	96	96	103	104	102	97	74	95	95	100	101	101	102	97	97	96	93	93	91	97	92	96	97	93	99	95	94	94
s	2	2	3.2	2.3	3.4	4	2	6	5	4	5	5	5.8	3.3	5	3	3	2	4	3.3	3	3	2.5	1.7	1.6	—	3	2

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 27±1 KTS Mode-Underway

Measurement Location / Data Source	BBN-1(1082)	BBN-1(1070)	NUC-1/3(1069)	NEHC-1(1093)	-2(1093)	-2(1089)	EPMU 5-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	NSRDC-1(1085)	-2(1056)	-3(1075)	-4(1091)	-5(1095)
AU1M						90			78	78															
AU2M						85				86	88		87	89					85		84				
AU3						89			95										88						
AU4						91			96																
AU5						85							87												
AU6						91							90	92							85				
AU7						90							87												
AU8						87			92												85				
AU9						89			91																
AU10						90				91			92						90		85				
AU11						90			91				82	92					84						
AL1	91					90			97				89	91					89						
AL2	90					94			94	92				98					86		88				
AL3						88			97				92												
AL4						94			97				86						84						
AL5						99							88												
AL6						89							89	94					86						
AL7						96							92	95											
AL8						95			94				94								86				
S1M						96			95	96	96		94	94						99	87	93			
S2						98							94	94							87				

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX-1, AFT STEER SHIP SPEED 27±1 KTS

Mode-Underway

Data Source / Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8	S1W	S2
NAVSHIPS-1(1063)																					
-2(1066)																					
-2(1069)																					
-2(1071)	86																		90	82*	
-2(1073)																					
-2(1076)																			90	78*	
-2(1086)								88												87	
-2(1087)																					
-2(1088)																					
-3(1070)																					
EPMU2-1(1094)																					
-2(1091)																					
-3(1085)																					
-4(1084)		84	88			92		87	86	85	86	90	90			86			89		
-5(1081)																					
-6(1056)																					
-7(1078)																					
-8(1059)																					
-9(1072)																					
Statistics																					
n	4	8	4	2	2	5	2	5	3	6	6	7	8	3	4	3	4	3	7	10	4
u	83	86	90	91	86	90	89	88	89	89	88	91	92	92	90	91	90	94	91	94	93
s	6	2	3	1	2	3	2	3	3	3	4	3	4	5	6	7	3	2	3	3.9	5

SHIP NOISE LEVEL DATA (dBA)

Mode-In Port

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED 0 KTS

Data Source \ Measurement Location	ET1M	ET2	ET3	EU1M	EU2M	EU3	EU4	EU5	EU5	EU7	EU8	EU9	EU10	EU11	EL1M	EL2M	EL3	EL4	EL5	EL6	EL7	EL8
Cold Iron																						
BBN-1(1082)		85	83	81	84	88		85	88	85	84		89			85		88			90	
RUNS 429,430																						
BBN-1(1070)			91	92	82				86		78					82	82	89			85	
RUNS 153,132																						
NEHC-2(1056)	64	78		82	82	78	86	85	84	81	83	80	83	81	80	84	84	94	88	83	99	82
Auxiliary																						
Steaming																						
EPMU2-6(1056)	72		91	94	87	90	92		93	93			94		91		90	96		102	97	
BBN-1(1082)		85	83	87	84	88		90	89	85	85					88		89			92	
RUNS 429,430																						
BBN-1(1070)			91	93	82	83			86		79		90			87		90		90		
RUNS 153, 132																						

SHIP NOISE LEVEL DATA (dBA)

Mode- In Port + P/M

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED 0 KTS

Measurement Location / Data Source	FM1	FM2	FT1	FT2	FT3	FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11	FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
Cold Iron																												
BBN-1(1082) RUNS 230, 233, 234			88	83		87		87	79				81	77			79					91						
Auxiliary Steaming																												
EPMU2-6(1056)			93			90	78	90	90	87	85		90	89		91	86	88		89	86	94	88	87	85			87
BBN-1(1070) RUN 252			96			91		85	90				92	85		89	87	87						91				
BBN-1(1082) RUN 3008			98		89	97*		83	91				91	88			89			93	110*	83		87				89
Prairie Masker Operating																												
NEHC-2(1089) 8±4 Knots			105	92	96	101	73	92	95	94	96	99	102	100	92	96	96	96	92	90	96			99	92	95	93	97
BBN-2(1082) RUN 2007A	85		118	100		110		102	100				105	95			101			94	100	97		99				97

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX-2 SHIP SPEED N/A KTS

Data Source \ Measurement Location	↓DG ON	X1W	X2W	X3	X4	X5	X6			↓DG OFF	X1W	X2W	X3	X4	X5	X6			AIR	↓START	X1W	X2W	X3	X4	X5	X6
BBN-1(1082)																										
BBN-1(1070)																										
NUC-1/3(1069)																										
NEHC-1(1093)																										
-2(1093)																										
-2(1089)		106	77				108				73	81	82			78										
EPMU 5-1		109			97									85							127					
-2		108	73									73		90	91											
-3												92*	90													
-4		108	78									56	90	90							122					
-5		106																								
-6		106																								
-7		104	76				110																			
-8		109	76	97	93						75	74	80	85												
-9																										
-10		109										80	91	84	88											
-11		108	80	95	84							73	90	94		82										
-12		109	75								66	68														
-13		107	80	95	84																					
-14																										
NSRDC-1(1085)		103	69								67	78	70	95												
-2(1056)		104					106				61	64	64		72											
-3(1075)																										
-4(1091)											58	55	88	74												
-5(1095)																										

AD-A036 535 BOLT BERANEK AND NEWMAN INC CANOGA PARK CALIF F/G 6/10
OCCUPATIONAL NOISE EXPOSURE ON FF 1052 (KNOX) AND DD 963 (SPRUA--ETC(U)
JAN 77 B A KUGLER, M E HALE, P E RENTZ

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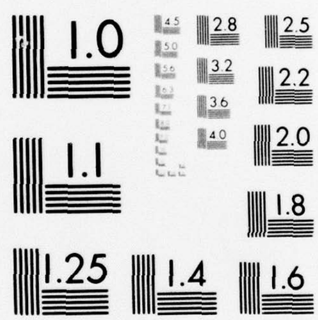

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SHIP NOISE LEVEL DATA (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX-2 SHIP SPEED N/A KTS

Data Source / Measurement Location	↑DG ON X1M	X2M	X3	X4	X5	X6	↑DG OFF X1M	X2M	X3	X4	X5	X6	AIR ↑START X1M	X2M	X3	X4	X5	X6
NAVSHIPS-1(1063)							73											
-2(1066)		86	94															
-2(1069)																		
-2(1071)																		
-2(1073)							61											
-2(1076)																		
-2(1086)																		
-2(1087)																		
-2(1088)																		
-3(1070)																		
EPMU2-1(1094)																		
-2(1091)	108					110	70											
-3(1085)	101	76	93			105												
-4(1084)	104	81	79	89		105	65											
-5(1081)	106	74				105							121					
-6(1056)	102	81	96	93		107							120					
-7(1078)	104	75				107							115					
-8(1059)	101		89			103							120					
-9(1072)	102					102							112					
Statistics n	22	15	7	6	–	11	10	10	9	7	3	2	7					
u	106	77	94	90	–	106	67	70	89	89	84	80	120					
s	2.7	4.1	2.6	5.3	–	2.6	5.8	9.3	10	4.5	10	2.8	5					

SHIP NOISE LEVEL DATA (dBA)

Modes-All

SHIP CLASS DD 963 ENGR'G SPACE Eng Rm 1, 2; Aux 1 SHIP SPEED ALL

Measurement Location	E11	E12	E13	E14	E15	E16	ER1	E21	E22	E23	E24	E25	E26	ER2	A1	A2	A3	A4	AR1
Underway																			
15 KTS, Runs	86	92	95	94	91	93	92	86	86	90	87	90	89	88	84	92	88	83	87
K152, K351																			
20 Knots	85	92	94	93	92	95	92	85	84	89	87	92	92	88	84	92	88	83	87
Run K150A																			
27 Knots	87	92	95	93	94	98	93	86	87	90	88	95	97	91	84	92	88	83	87
Runs K151,																			
K351																			
In-Port																			
Cold Iron	88	82	79	92	84	96	87	84	82	79	92	84	89	85	84	92	88	83	87
Runs K351,																			
K105A+K111																			
+K113+K117																			
+K118+K119																			
Auxiliary Pwr	89	89	94	92	90	96	92	83	87	95	91	87	89	89	84	92	88	83	87
Runs K129+																			
K131,K228,K351																			
Data Source																			
BBN-3																			
(DD-965)																			

APPENDIX E

NOISE SOURCE DIAGNOSIS DATA
FF 1052 AND DD 963 CLASSES

This appendix contains the available noise source diagnosis data, arranged in a form which is suitable for evaluating noise control measures. As discussed in the body of the report, most of the noise level data is not suited for diagnosis because of the large number of sources involved. Some spectral analysis, one-third octave band and narrow band, is useful in pinpointing problem areas, such as a particular gear mesh. However, the most tractable and useful method is noise source isolation. That is, each equipment item is operated by itself and the resulting noise levels measured at the standard locations. With this information, the noise level for any machinery line-up may be calculated. Finally, the effect of controlling the noise from any one piece of equipment may be evaluated.

The only programs which have produced this type of information have been conducted by Bolt Beranek and Newman Inc. under the auspices of the Naval Ship Engineering Center, BBN-1 (1082, 1070), BBN-2 (1082) and BBN-3 (DD 965).

The following tables show the results of these studies, arranged in matrix form, expressed in dBA. Separate tables are presented for the FF-1052 engine room, the FF-1052 fire room, the FF-1052 auxiliary machinery room, and the DD 963 engine rooms.

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INDIVIDUAL MACHINERY CONTRIBUTIONS TO LOCATION LEVELS (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Engine Room SHIP SPEED ALL KTS

Measurement Location / (RUN+) Equipment	ET1W	ET2	ET3	Avg.	EU1W	EU2W	EU3	EU4	EU5	EU6	EU7	EU8	EU9	EU10	EU11	Avg.	EL1W	EL2W	EL3	EL4	EL5	EL6	EL7	EL8	Avg.
Turb/Gear 28KT			92			91				94		96						98	97	100			97		
(1021-429)		96	96															102		99			97		
Air Eject			81		80					88		78						73	72						
Circ Pump													75							79			73		
Cond Pump (131)			71		74	85				81		72						75	72	88			94		
1A & 1B																									
Cond Pump (407)																				73			73		
LO Serv (133)			73		67	83						75						72	83	73			71		
LO Serv (409)						72					80	77											75		
LO Purif (402)					70						78			74				81			79				
Dist Fd Pump*																									
Distl (412)		80	77		83	81	69		88	77	80	81		85				83		82	89		88		
1&2 (132,430)*		81	78		87	83	72		90	82	81	77		88				87	75	84	83		91		
Distl																									
Fire Pump* (405)					77	85			80			76		85				81		82	85		88		
Air Cond (136 425)			74		68	86				81		75							76	79			75		
1 & 2*						(88)																			
Air Cond (426)		82	78			85	87			79	81	81													
Vent Fans*			74		79	84				74		73						75	69	74			73		
Σ Non Prop*																									
Non Prop (152)			83		87	82				89		79						88	83	90			92		
Non Prop Hi (153)			91		93	82				87		80						88	83	90			91		
Non Prop (429)		86	84		88	84	88		91	89	87	85		91				89		89			93		

* Equipment used for non-propulsion sum, + Run Designation, BBN-1 (1082)

INDIVIDUAL MACHINERY CONTRIBUTIONS TO LOCATION LEVELS (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE Fire Room SHIP SPEED ______ KTS

Measurement Location / (RUN+) Equipment	FM1	FM2		FT1	FT2	FT3		FU1W	FU2W	FU3W	FU4	FU5	FU6	FU7	FU8	FU9	FU10	FU11		FL1W	FL2W	FL3W	FL4	FL5	FL6	FL7	FL8	FL9	FL10	FL11	FL12
Boiler 1A(250-6)	90			90		81		89		85	90				90	80				87	84				83		92				
FDB CALC	94			100		92		99			90				84	90				87					86						
Boiler + FDB(300)	95			100		92		99			93				91	90				90					88						
1A & 1B (252)				96				91		85	90				92	85				87	87						91				
Boiler 1B																															
Mn Fd Pumps																															
Mn Fd Bstrs																															
F.O. Serv Pump																															
FW Drain 1A																															
FW Drain 1B																															
Fire Pump 2 (230/205)				72		64		72		80	73				76	67				74	67				89		70		-	88	
P/M 1A																															
P/M 1B												84				94				91	89						91				
Aux Gland Fan																															
Vent Supply																															
Vent Exh (234)																															
All Vents (231)																															
Vent Supply(233)				81	82			83		85	75				75	77				78					80						
Vent Exh (234)				88	79			85		72	78				80	67				76					78						
All Vents (231)				88	(83)			86		85	79				80	77				80					80						

\+ Run Designation, BBN-1 (1082)

INDIVIDUAL MACHINERY CONTRIBUTIONS TO LOCATION LEVELS (dBA)

SHIP CLASS FF-1052 ENGR'G SPACE AUX 1, AFT STEER Modes-ALL

(RUN+) Equipment \ Measurement Location	AU1W	AU2W	AU3	AU4	AU5	AU6	AU7	AU8	AU9	AU10	AU11	AL1	AL2	AL3	AL4	AL5	AL6	AL7	AL8
SSTG 1A (389)		82	90	82		83				81		87	86						
1B																			
1C																			
1A+1B (382)		83	90	87		87				85		91	91						
1A+1C		83	89	91		86				88		90	89						
FIRE PUMP			98																
LPAC (384-382)										94									
HPAC (385-382)																			
FINSTAB 1																			
1&2 (381-382)																			
FINSTAB 2																			
FO XFER(390-386)																			
ASROC CIRC																95			
400 Hz MG																			
VENT FAN (301)		72	76			75				73		73	73						
Σ																			

\+ Run Designation BBN-1 (1082)

* Equipment Used for Summation

INDIVIDUAL MACHINERY CONTRIBUTIONS TO LOCATION LEVELS (dBA)

SHIP CLASS DD 963 ENGR'G SPACE Engine Rooms SHIP SPEED ALL KTS

(RUN)† Equipment / Measurement Location	E11	E12	E13	E14	E15	E16	ER1	E21	E22	E23	E24	E25	E26	ER2
PROP 16KT	(73)	(80)	74	81	83	86		(73)		(74)				
TURB 24KT	78	85	79	86	88	91		78		79				
GEAR 28KT	83	87	82	90	92	95		83	85	82	83	95	97	
FO BSTR*	(60)	(70)	(60)	(78)	(65)	(65)		(60)	(70)	(65)	(74)	(74)	(70)	
FO BSTR														
HOPM* (117)	70	71	71	79	81	67		(70)	(71)	(71)	(79)	(81)	(67)	
LO SERV (113)	67	63	61	61	78	67		(67)	(63)	(61)	(61)	(78)	(68)	
LO SERV														
LO PURIF*	(60)	(70)	(60)	(75)	(81)	(70)		(60)	(70)	(60)	(75)	(80)	(72)	
SSTG+FAN* (127)	(75)	88	91	84	87	84		(75)	82	89	85	83	81	
FAN (122)	66	68	68	64	75	67								
FIRE PUMP*(111)	70	79	76	91	75	73		(70)	(79)	(76)	(90)	(75)	(75)	
SW PUMP														
BILGE PUMP(119)	66	74	73	81	77	68								
SSAC (118)	87	(67)	(70)	60	(60)	65		(84)	(65)	(70)	(60)	(60)	(65)	
AUX BOIL* (127)	81	(70)	(70)	(70)	(70)	74		81	(70)	(70)	(70)	(70)	(72)	
V.FANS HI*(109)	83	76	76	74	79	95		(82)	(76)	(76)	(74)	(79)	(87)	
V.FANS LO (110)	74	66	63	(64)	70	85		(73)	(67)	(67)	(65)	(70)	(71)	
Σ NON PROP	85	89	92	92	90	95		85	85	89	92	88	88	
NON PROP (128/228)	85	89	92	92	91	96		83	87	89	91	87	89	
Σ 16KT.														
	87	90	92	93	93	97								
	87	91	93	94	95	99		86	89	90	92	95	98	

* Equipment Used for Non Prop Sum

\+ Run Designation BBN-3 (DD 965)