**TP 13442E**

# HEARING STANDARDS FOR SEAGOING PERSONNEL

*Prepared by:*
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June 1999

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Prepared for:
Transportation Development Centre
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Technical and Operational Services

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16. Abstract

The project's objective was to support the Canadian Coast Guard (CCG), Department of Fisheries and Oceans (DFO), in the development of defensible, task-oriented, performance-based hearing standards relevant to CCG seagoing occupations. The Canadian Human Rights Commission (CHRC) has imposed restrictions regarding the exclusion of individuals from the CCG because they do not meet the medical hearing requirement.

A project team with expertise in relevant subject areas including acoustics, audiology, signal processing, task analysis, and development of occupational standards was assembled. A comprehensive task analysis methodology (Phases 1 and 2) identified the CCG seagoing occupations and operational tasks most important to safety and program completion, as well as the critical aspects of hearing required to perform these tasks. In Phase 3, acoustic characteristics of the critical tasks were collected from a representative sample of CCG vessels, regions, and operations. In Phase 4, analysis methods based on the latest available technology and standards were applied to the acoustic data. Issues relative to the use of hearing aids in a marine environment, specifically the impact of reliability on safety and performance, were reviewed in Phase 5.

Recommendations were provided for a minimum hearing requirement for three CCG departments: Deck, Engineering, and Logistics. These recommendations were based on the tasks identified for each department, as well as on those identified as a requirement of all departments (i.e., marine emergency duties). Minimum hearing threshold level (HTL) profiles to meet each department's hearing requirements were calculated.

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16. Résumé

Le présent projet avait pour but d'aider la Garde côtière canadienne (GCC), ministère des Pêches et des Océans (MPO), à élaborer des normes justifiables relatives à l'acuité auditive, axées sur les tâches à accomplir ainsi que sur la performance, et visant le personnel navigant de cet organisme. La Commission canadienne des droits de la personne (CCDP) a imposé des restrictions quant à la politique de la Garde côtière d'exclure certaines personnes parce qu'elles ne satisfont pas aux exigences d'ordre médical en matière d'audition.

On a d'abord mis sur pied une équipe de projet formée d'experts dans divers domaines tels l'acoustique, l'audiologie, le traitement des signaux, l'analyse des tâches et l'élaboration de normes professionnelles, puis établi une méthode approfondie d'analyse des tâches. Au cours de la première et de la deuxième étape du projet, on a répertorié les fonctions et les tâches du personnel navigant de la GCC, les plus importantes en ce qui a trait à la sécurité et à l'exécution du programme opérationnel du navire, et cerné les principales caractéristiques en matière d'audition nécessaires à l'exécution de ces fonctions et de ces tâches. À l'étape 3, les données à cet égard ont été recueillies auprès d'un échantillon représentatif de personnes travaillant à bord de différents navires, en mission dans différentes régions et affectées à différentes opérations. À l'étape 4, les données ont été analysées selon des méthodes basées sur une technologie de pointe et sur les normes les plus récentes dans le domaine. Enfin, les questions relatives au port de prothèses auditives par des personnes travaillant dans un environnement maritime, en particulier les effets d'une telle situation sur la sécurité et la performance, ont été étudiées à l'étape 5.

D'après les résultats de l'analyse, on a recommandé des exigences minimales en matière d'audition dans le cas de trois services de la Garde côtière, c'est-à-dire la Passerelle, le Génie et la Logistique. Ces recommandations ont été établies en fonction des tâches répertoriées pour chacun des services et de celles reconnues comme étant communes à l'ensemble des services (par exemple les fonctions d'urgence en mer). On a également déterminé le seuil d'audition minimal nécessaire pour satisfaire aux exigences de chaque service à cet égard.

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# EXECUTIVE SUMMARY

The Canadian Coast Guard (CCG), a division of the Department of Fisheries and Oceans (DFO), provides continuous support for a number of essential services in Canadian waters including icebreaking and ice escort, maintenance of navigational aids, conservation and protection, environmental response, fisheries research, hydrography, and search and rescue. These services are often performed under hostile meteorological conditions, in remote locations, and for extended periods of time. It is essential that Ships' Officers and Ships' Crew meet appropriate minimum medical requirements to ensure safety and performance in a range of operating conditions.

To address minimum medical requirements, CCG investigated its medical standards. The aim is to better define the components of medical fitness essential for safe and effective seagoing operations. The Canadian Human Rights Commission (CHRC) has imposed restrictions regarding the exclusion of individuals from the CCG because they do not meet the medical hearing requirement. The CHRC specifies that *bona fide* occupational requirements (BFORs) must be based on the requirements for tasks performed on the job, rather than only historical precedent and expert operational and clinical opinion. The CHRC further stipulates that medical standards and subsequent testing procedures be based on:

- identification of essential tasks that are the actual requirements of the job;
- identification of relevant skills and capabilities required to perform the essential tasks of the job;
- methods that evaluate the individual's capability to perform the job's essential tasks within reasonable limits of job accommodation; and
- standards that do not exceed the minimum job requirements (Canadian Human Rights Reporter Supplement, 1982, TR/82-3).

The project's objective was to support the CCG in the development of defensible, task-oriented, performance-based hearing standards relevant to CCG seagoing occupations in response to their investigation of the medical standards. Hearing standards were developed for this occupational setting for three reasons:

- to ensure the safety of the individual;
- to ensure the safety of others and the vessel; and
- to ensure that an individual can perform the tasks required to complete the vessel's operational program.

To address the CCG's needs, BC Research assembled a project team with expertise in relevant subject areas including acoustics, audiology, signal processing, task analysis, and development of occupational standards. A comprehensive task analysis methodology (Phases 1 and 2) identified the CCG seagoing occupations and operational tasks most important to safety and program completion, as well as the critical aspects of hearing required to perform these tasks. Acoustic characteristics of the critical tasks were collected in Phase 3 from a representative sample of CCG vessels, regions, and operations. In Phase 4, analysis methods applied to the acoustic data were based on the latest available technology and standards. The methods were later modified to include the newly established Speech Intelligibility Index (SII) (ANSI S3.5-1997). Data were collected and analyzed to include both speech discrimination and signal and alarm detection under a variety of operational conditions. Issues relative to the use of hearing aids in a marine environment, specifically the impact of reliability on safety and performance, were reviewed in Phase 5.

Based on empirical research of the hearing requirements of the CCG seagoing environment, recommendations were provided for a minimum hearing requirement for three CCG departments: Deck, Engineering, and Logistics. The data on which these recommendations are based include the tasks identified for each department, as well those identified as a requirement of all departments (i.e., marine emergency duties). Minimum hearing threshold level (HTL) profiles to meet each department's hearing requirements were calculated. A limiting SII criterion of 0.50 (on a scale of 0 to 1) was selected based on cornerstone research.

The results indicated that speech discrimination tasks were more susceptible to degraded performance due to sensorineural hearing loss than were the signal detection tasks. Therefore, the recommended overall minimum hearing requirement was determined by the speech discrimination limits. The data analyzed in this research were compared to previous research investigating the onset of hearing impairment for speech reception in terms of pure tone HTL profiles; the comparison revealed a similar minimum hearing requirement.

It must be emphasized that the HTL profiles recommended are intended to represent the minimum HTL profile required for passing a first round of audiological testing. Individuals whose pure-tone audiograms meet this limit require no additional testing and should be considered as meeting the medical hearing requirement. However, individuals who do not meet this limit should be directed to additional otological/audiological assessment which should include speech discrimination, signal detection, and localization. Recommendations for testing procedures and the minimum requirement for each of the specific hearing dimensions were not included in the current research; however information on relevant currently available clinical tests is provided. Additional research involving extensive clinical testing and the development of normative data for each hearing dimension is recommended.

The data collection and analysis methodology were adapted from current standards related to the development of hearing standards, considering the issues and environments experienced in CCG seagoing operations. The report's interpretation is subject to a number of limitations, including some related to field data collection. Other limitations are related to the unique, ground-breaking research that was completed to develop BFORs in this type of environment. They include:

- issues related to field data collection on board CCG vessels, including vessel and region scheduling availability, meteorological conditions, and the logistical and safe use of electronic equipment in a marine environment;
- the data were based on predictive engineering analysis methodology and require psychoacoustic normative data for further validation and development of testing methodology;
- some clinical testing methods recommended for subsequent testing have not yet been developed (i.e., French speech discrimination tests, localization tests); and
- limited information available on the reliability of hearing aids in marine environments, potentially requiring simulation testing and / or field evaluation.

With these limitations in mind, a number of future directions were identified. They include the development of clinical procedures to test speech discrimination, signal detection and localization that reflect the CCG seagoing environment. Validation of the minimum hearing requirement using normative data is recommended to further establish the minimum hearing requirements in these occupations.

Considering the project limitations and requirements for future research, the methodology meets the CHRC requirements for a task-oriented minimum medical standard focused on safety, performance, and fairness.

# SOMMAIRE

La Garde côtière canadienne, une division du ministère des Pêches et des Océans (MPO), assure un certain nombre de services essentiels dans les eaux canadiennes, y compris les services de déglaçage et d'assistance aux navires qui se trouvent dans des eaux couvertes de glace, d'entretien d'un système d'aides à la navigation, de conservation des ressources et de protection de l'environnement, d'intervention en cas d'événements ou de catastrophes de nature environnementale, de recherche en matière de pêches, d'hydrographie et de recherche et de sauvetage maritimes. Ces tâches sont habituellement effectuées dans des conditions météorologiques difficiles ou encore dans des régions éloignées, et elles se déroulent généralement sur une longue période. Pour des raisons de sécurité et de performance liées aux conditions précitées, les officiers de bord et les membres de l'équipage des navires en mission doivent satisfaire à certaines exigences médicales.

La Garde côtière a décidé d'examiner ses normes médicales. Cet exercice avait pour but de mieux définir les aptitudes physiques et mentales nécessaires à l'exécution d'opérations sûres et efficaces en mer. La Commission canadienne des droits de la personne (CCDP) a imposé des restrictions quant à la politique de la Garde côtière d'exclure certaines personnes parce qu'elles ne satisfont pas aux exigences d'ordre médical en matière d'audition. La CCDP précise que les exigences professionnelles justifiées (EPJ) doivent être basées sur les aptitudes nécessaires à l'exécution des tâches réelles liées à l'emploi plutôt que sur des précédents historiques ou sur l'opinion d'experts du domaine médical ou du domaine opérationnel. Elle précise également que l'élaboration des normes médicales et des épreuves destinées à vérifier la conformité à ces normes doit être basée sur ce qui suit :

- les principales tâches réelles liées à l'emploi;
- les aptitudes requises pour exécuter ces tâches;
- des méthodes appropriées d'évaluation de l'aptitude des personnes à effectuer les principales tâches liées à l'emploi dans des limites raisonnables d'adaptation du milieu de travail;
- des exigences ne dépassant pas celles qui sont effectivement liées à l'emploi (CHRR Supplement, 1982, TR/82-3)

Une fois cette étude réalisée, le présent projet avait pour but d'aider la Garde côtière à élaborer des normes justifiables relatives à l'acuité auditive, axées sur les tâches à accomplir et sur la performance, et visant le personnel navigant de cet organisme. De telles normes professionnelles ont pour but :

- d'assurer la sécurité individuelle de chacune des personnes;

- d'assurer la sécurité des autres personnes et du navire;
- de veiller à ce que chaque personne soit en mesure d'effectuer les tâches nécessaires à l'exécution du programme opérationnel du navire.

Pour répondre aux besoins de la Garde côtière, BC Research a mis sur pied une équipe de projet formée d'experts dans les domaines tels l'acoustique, l'audiologie, le traitement des signaux, l'analyse des tâches et l'élaboration de normes professionnelles, puis établi une méthode approfondie d'analyse des tâches. Au cours de la première et de la deuxième étape du projet, on a répertorié les fonctions et les tâches du personnel navigant de la GCC, les plus importantes en ce qui a trait à la sécurité et à l'exécution du programme opérationnel du navire, et cerné les principales caractéristiques en matière d'audition nécessaires à l'exécution de ces fonctions et de ces tâches. À l'étape 3, les données à cet égard ont été recueillies auprès d'un échantillon représentatif de personnes travaillant sur différents navires de la GCC, en mission dans différentes régions et affectées à différentes opérations. À l'étape 4, les données ont été analysées selon des méthodes basées sur une technologie de pointe et sur les normes les plus récentes dans le domaine. Ces méthodes ont par la suite été modifiées pour inclure le nouvel indice d'intelligibilité de la parole (IIP) (ANSI S3.5-1997). L'analyse a porté à la fois sur la capacité de discrimination de la parole et sur la capacité de détection des signaux et des alarmes dans diverses conditions d'exploitation. Enfin, les questions relatives au port de prothèses auditives par des personnes travaillant dans un environnement maritime, en particulier les effets d'une telle situation sur la sécurité et la performance, ont été étudiées à l'étape 5.

D'après les résultats de l'analyse, on a recommandé des exigences minimales en matière d'audition dans le cas de trois services de la Garde côtière, c'est-à-dire la Passerelle, le Génie et la Logistique. Ces recommandations ont été établies en fonction des tâches répertoriées pour chacun des services et de celles reconnues comme étant communes à l'ensemble des services (par exemple les fonctions d'urgence en mer). On a également déterminé le seuil d'audition minimal nécessaire pour satisfaire aux exigences de chaque service à cet égard, et établi à 0,50 (sur une échelle de 0 à 1) le seuil minimal d'intelligibilité de la parole.

Les résultats de l'analyse ont également démontré que la surdité de perception est plus susceptible de diminuer le degré de performance des tâches nécessitant une capacité de discrimination de la parole que de celles nécessitant une capacité de détection des signaux. Les données analysées dans le cadre de cette étude ont été comparées à celles d'une étude précédente portant sur l'apparition d'un déficit auditif relativement à l'intelligibilité vocale en termes de seuil d'audition des sons purs. Cette comparaison a révélé une similitude quant aux exigences minimales en matière d'audition.

Il est important de rappeler que les seuils d'audition recommandés correspondent au seuils minimaux requis pour réussir la première batterie d'épreuves audiologiques. Les personnes dont les audiogrammes tonaux indiquent des seuils auditifs situés dans les limites établies n'ont pas à subir d'épreuves additionnelles et devraient être considérées comme des sujets satisfaisant aux normes médicales en matière d'audition. Dans le cas contraire, toutefois, les personnes devraient subir d'autres épreuves otologiques/audiologiques portant, entre autres, sur la capacité de discrimination de la parole, la capacité de détection des signaux et la capacité de localisation des sons. La présente étude ne comporte pas de recommandations sur les méthodes d'évaluation ni sur les valeurs minimales des différentes caractéristiques analysées; toutefois, on a fourni les renseignements nécessaires sur les épreuves cliniques pertinentes qui ont cours actuellement. On a également recommandé de procéder à des études supplémentaires appuyées par des essais cliniques élaborés, ainsi qu'à l'établissement de valeurs normatives pour chacune des caractéristiques relatives à l'audition.

Cette méthode de collecte et d'analyse des données, qui tient compte des conditions de travail du personnel navigant de la Garde côtière, a été établie à partir d'autres méthodes connues d'élaboration de normes relatives à l'audition. L'interprétation du rapport est assujettie à un certain nombre de restrictions, dont quelques-unes liées à la collecte des données sur place. D'autres restrictions sont liées aux résultats de la seule étude novatrice ayant porté sur l'élaboration de normes professionnelles justifiées pour ce type d'environnement, et elles visent ce qui suit :

- collecte des données sur les navires de la Garde côtière, plutôt difficile en raison du calendrier des différentes missions et des horaires du personnel, des conditions météorologiques, de la logistique et de la fiabilité plutôt précaire du matériel électronique dans un environnement maritime;
- données basées sur une méthode d'analyse technique prédictive et devant par conséquent être appuyées par des données normatives psychoacoustiques pour permettre la validation et la mise au point ultérieures d'une méthode d'évaluation;
- non-disponibilité de certaines méthodes d'évaluation clinique recommandées aux fins d'évaluations subséquentes (p.ex. discrimination de la parole en français, localisation des sons);
- peu de renseignements disponibles sur la fiabilité des prothèses auditives dans un environnement maritime, lesquelles devraient peut-être faire l'objet d'essais de simulation ou d'évaluations sur place.

Ces restrictions prises en compte, d'autres avenues ont été inventoriées, entre autres la mise au point de méthodes cliniques destinées à évaluer la capacité de discrimination de la parole, la capacité de détection des signaux et la capacité de localisation des sons dans des environnements présentant des caractéristiques similaires à celles dans lequel travaille le personnel navigant de la Garde côtière. Une validation des exigences minimales en matière d'audition par comparaison avec des valeurs normatives est recommandée aux fins d'établissement de normes minimales pour ce type d'emploi.

Malgré ses limites et compte tenu de la nécessité de procéder à des études plus poussées, la méthodologie faisant l'objet du présent projet satisfait aux exigences de la CCDP en ce qui a trait à l'établissement de normes médicales minimales orientées sur les tâches à accomplir de même que sur la sécurité, la performance et l'équité.

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# 1 INTRODUCTION

The Canadian Coast Guard (CCG), a division of the Department of Fisheries and Oceans (DFO), provides continuous support for a number of essential services in Canadian waters including icebreaking and ice escort, maintenance of navigational aids, conservation and protection, environmental response, fisheries research, hydrography, and search and rescue. These services are often performed under hostile meteorological conditions, in remote locations, and for extended periods of time. It is essential that Ships' Officers and Ships' Crew meet appropriate minimum medical requirements to ensure safety and performance in a range of operating conditions.

To address minimum medical requirements, CCG investigated its medical standards. The aim is to better define the components of medical fitness essential for safe and effective seagoing operations. The Canadian Human Rights Commission (CHRC) has imposed restrictions regarding the exclusion of individuals from the CCG because they do not meet the medical hearing requirement. The CHRC specifies that *bona fide* occupational requirements (BFORs) must be based on the requirements for tasks performed on the job, rather than only historical precedent and expert operational and clinical opinion. The CHRC further stipulates that medical standards and subsequent testing procedures are based on:

- identification of essential tasks that are the actual requirements of the job;
- identification of relevant skills and capabilities required to perform the essential tasks of the job;
- methods that evaluate the individual's capability to perform the job's essential tasks within reasonable limits of job accommodation; and
- standards that do not exceed the minimum job requirements (Canadian Human Rights Reporter Supplement, 1982).

The project's objective was to support the CCG in the development of defensible, task-oriented, performance-based hearing standards relevant to CCG seagoing occupations in response to their investigation of the medical standards. Hearing standards were developed for this occupational setting for three reasons:

- to ensure the safety of the individual;
- to ensure the safety of others and the vessel; and
- to ensure that an individual can perform the tasks required to complete the vessel's operational program.

There are several classes of hearing requirements specified by Health and Welfare (H&W). The current CCG hearing standard for seagoing occupations is the H&W Class 1 requirement, with uncorrected or corrected (i.e., with a hearing aid) ability (Anon, 1994). The H&W Class 1 requirement uses pure-toned audiometry and specifies that between 500 and 3000 Hertz (Hz), average hearing loss be no greater than 25 decibels (dB) in the better ear and no greater than 30 dB in the poorer ear. In simple terms, a hearing loss can be likened to having an internal noise which masks, or hides, the sound that the listener wishes to hear. The H&W Class 1 standard requires binaural hearing, which is important for sound localization in three-dimensional space and speech perception in noise (Del Dot *et al.*, 1992; Myers *et al.*, 1963).

BC Research completed a preliminary investigation of hearing standards for CCG personnel (Forshaw and Hamilton, 1995, 1997). The project reviewed the literature on clinical tests for hearing loss, psychophysical issues, hearing aids, and hearing standards. The review identified that occupational hearing standards have traditionally had little relationship to the actual job-related auditory requirements. It was noted that the H&W Occupational Health Assessment Guide indicates that "…pure tone audiometry is seldom directly relevant to an occupation and should only be regarded as an indicator of hearing ability" (Anon, 1994). Furthermore, it was noted that the Canadian Human Rights Act (1989) prohibits any discriminatory policies and practices or agreement affecting recruitment, referral, hiring, promotion, training, apprenticeship, transfer, or other employment-related matters if it deprives an individual or class of individuals of any employment opportunities on a prohibited ground of discrimination. Paragraph 14(a) of the Act provides exception to these prohibitions and indicates that it is not a discriminatory practice if the employer can establish that the practice is based on BFORs. To ensure that individuals are assessed equally, the occupational requirement policy attempts to define parameters for the evaluation of an individual's performance or capacity to perform (Laroche, 1994; Hétu, 1993).

To address the CCG's needs, BC Research assembled a project team with expertise in relevant subject areas including acoustics, audiology, signal processing, task analysis, and development of occupational standards. A list of BC Research team members and their role in the project are provided in Appendix A. The team consulted with CCG operational experts to investigate the task requirements in the seagoing environment and to identify the skills and capabilities required to perform these tasks. Based on this information, on-board acoustic assessments were conducted and the data were used to recommend a minimum hearing standard for each of the three CCG departments: Deck, Engineering, and Logistics.

The final deliverable of the project was to recommend a minimum hearing level threshold (HLT) or "fence". The HLT was based on the minimum requirements for hearing in critical tasks in each CCG department (i.e., Deck, Engineering, Logistics) identified through the project methodology. The HLT was intended to represent a preliminary clinical referral threshold, involving a standard clinical test, or audiogram, conducted by an audiologist. If the threshold is passed, the individual requires no additional testing and is considered to meet the medical requirements for hearing. If the threshold is not met, the individual proceeds to a second round of additional audiological clinical tests.

The project comprised the following phases.

### Phase 1: Job/Task Identification

***Purpose:*** To identify key job titles and associated tasks that may require operationally based hearing standards.

### Phase 2: Development of a Task Analysis Methodology for Assessing Operational Hearing Requirements

***Purpose:*** To develop the methodology and conduct a comprehensive task analysis in consultation with CCG operational experts to characterize operational auditory task requirements for CCG seagoing personnel.

### Phase 3: Collection of Field Data

***Purpose:*** To collect and confirm task analysis data and to collect acoustic data in operational scenarios associated with selected critical tasks identified in Phases 1 and 2.

### Phase 4: Recommendations for Hearing Standards and Corresponding Tests

***Purpose:*** To identify operationally-based hearing standards for CCG seagoing personnel that are relevant to task requirements, as well as being sensitive to speech discrimination, signal detection, and sound localization abilities.

### Phase 5: Assessment of the Reliability of Hearing Aids

***Purpose:*** To review specifications and standards to which hearing aids are manufactured in order to determine hearing aid reliability and performance in relation to working and living environments of seagoing personnel.

### Phase 6: Final Report

***Purpose:*** To summarize the project and provide the following deliverables:

- recommendations for an operationally-based minimum hearing standard for CCG seagoing personnel; and
- recommendations for testing procedures to be used for individuals failing to meet the agreed upon minimum hearing standard.

The data collection and analysis methodology used in this project was based on the latest research and standards that are relevant to the development of hearing standards. This project required ground-breaking research in the development of BFORs. The project team responded by being highly diligent in ensuring the methodology and subsequent results meet the requirements of the CHRC to develop a task-oriented minimum medical standard that is focused on safety, performance and fairness.

# 2 METHODS

The methods used to accomplish each phase of this project are detailed in the following sections. The focus of the methodology was to ensure that the recommended minimum criteria and techniques for auditory assessment are directly relevant to actual CCG shipboard hearing requirements. A flowchart outlining the overall project is provided in Figure 1. More details to each step of the process are provided in the following sections.

## 2.1 Phase 1: Job/Task Identification

CCG seagoing job positions are categorized into three departments: Deck, Engineering, and Logistics. Within each of these departments, job positions may be further categorized as Ships' Officers or Ships' Crew. These divisions were used to categorize tasks and formed the basis of subsequent data collection procedures.

The Marine Medical Standards Report (CCG, 1990) identifies tasks in CCG seagoing operations by department, vessel, program, and as performed by Ships' Officers or Ships' Crew. This document was generated by CCG based on a previous project that investigated physiological requirements of CCG personnel. This report includes descriptions of tasks for each of the three departments (i.e., Deck, Engineering and Logistics), generic tasks performed by all officers and crew (e.g., using ship's communication devices), and Marine Emergency Duties (MED) (e.g., first aid, ship evacuation, fire fighting). It was used as a basis of information to develop a task analysis methodology. However, this document did not include tasks that are specific to DFO programs as it was completed prior to the merger of DFO and CCG in 1995.

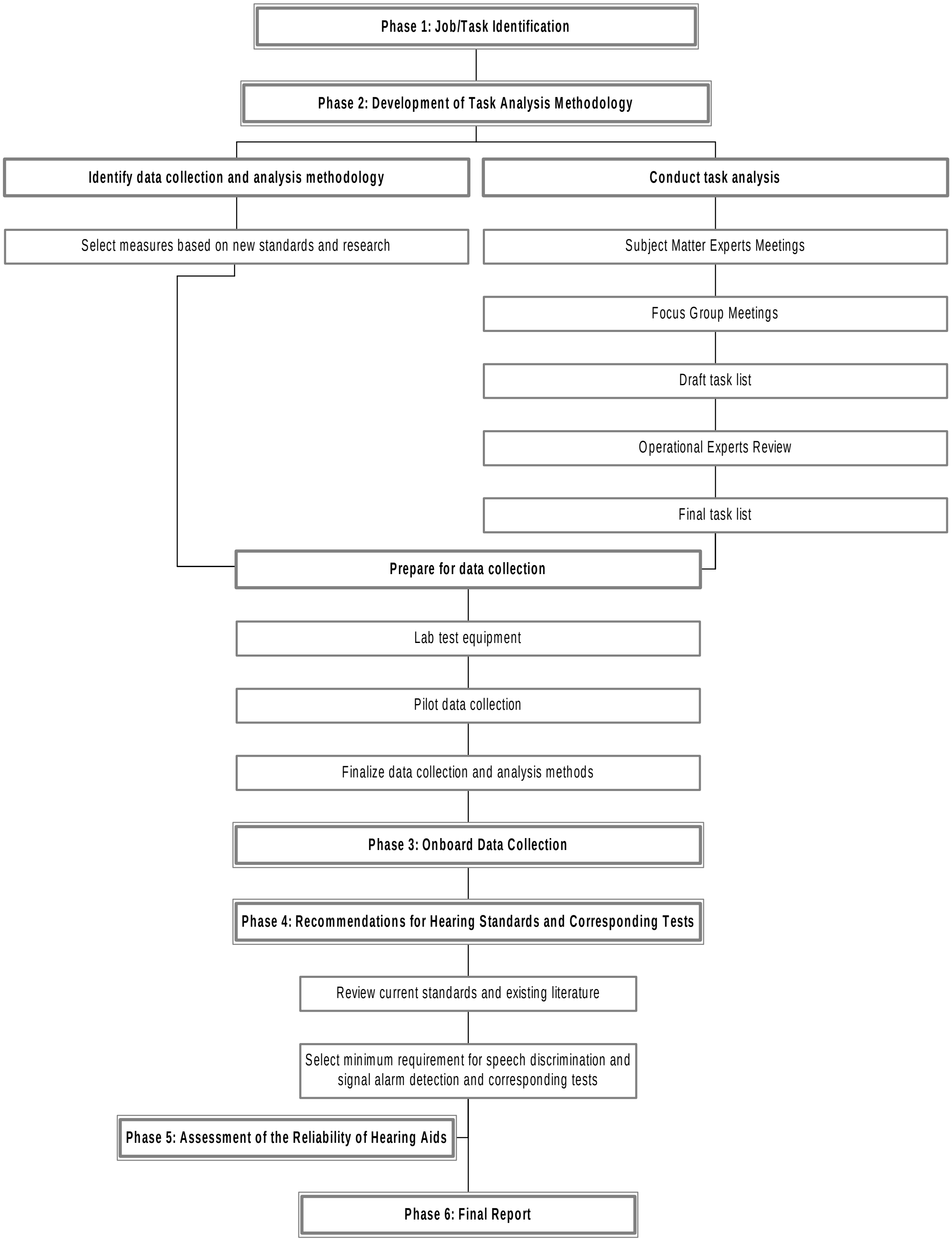



**Figure 1:**
**Flowchart of Overall Project**

## 2.2 Phase 2: Development of a Task Analysis Methodology for Assessing Operational Hearing Requirements

The purpose of the task analysis was to provide a description of CCG seagoing tasks that require a significant auditory component and that were part of the duties of Ships' Officers and Ships' Crew for the Deck, Engineering and Logistics Departments. The task analysis methodology was based on functional job analysis procedures and focused on the hearing requirements of the task. The methodology was designed to capture the auditory components as well as the frequency and criticality of the various tasks. In addition, the analysis characterized the shipboard acoustic environment in which frequent and critical auditory tasks are performed (e.g., wheelhouse, engine control room, deck).

The task analysis was performed through a series of meetings with operational experts (CCG Ships' Officers and Ships' Crews) in each of the three CCG seagoing departments to discuss task and hearing requirements on board CCG vessels. For the purpose of the task analysis, the following four primary job categories were used: Deck Officers; Deck Crew; Engineering Officers and Crew; and Logistics Officers and Crew. In the interest of scheduling, the Deck Department was divided into two groups because it included the largest number and greatest variety of tasks. However, because there is such variability among the division of tasks between Deck Officers and Deck Crew on various CCG vessels and programs, no clear division could be established between tasks that may be performed by a Deck Officer or Deck Crew member. Therefore, although the data were collected separately for the Deck Officer and Deck Crew tasks, a decision was made to combine the task analysis information for the Deck Officers and Deck Crew into one category for subsequent analysis: Deck Department.

Tasks identified as MED were discussed in detail with the Deck Officers group as this was the first department scheduled for the Task Analysis. The MED data were then reviewed by personnel in the other job categories to ensure that the information was valid and representative of all departments.

Two levels of task analysis were conducted in each of the four job categories bringing together two groups of CCG personnel for each job category. These personnel were selected based on their years of experience, and to represent various job categories and programs to provide a good representative of the CCG seagoing environment. The two groups were identified as:

- Subject Matter Experts (SMEs), composed of senior seagoing personnel from the Western Region; and
- Focus Groups, composed of senior seagoing personnel from all five CCG regions (i.e., Pacific, Central and Arctic, Laurentian, Maritime and Newfoundland Regions).

The SMEs provided initial information based on the experiences of CCG personnel in the Pacific Region. The Focus Groups provided a group of seagoing personnel with more experience, as well as establishing regional differences in task requirements.

Due to the location of BC Research in Vancouver, BC, the Pacific Region was chosen as the source of SMEs and these meetings were held at BC Research. Focus Groups were held both at BC Research and at the CCG Headquarters in Ottawa. Table 1 outlines the dates and locations of the SME and Focus Group meetings held during the task analysis. A total of 22 days (e.g., approximately 180 hours) of meetings were involved in the task analysis. The task analysis was conducted by two BC Research team members, with one of these individuals present at all task analysis meetings to provide consistency. The CCG Project Officer attended all task analysis meetings. The TDC Project Authority was present during the first stage of task analysis meetings.

**Table 1:**
**Location and Date of Task Analysis Meetings**

| Job Category | Subject Matter Experts Meetings: Location and Date | Focus Group Meetings: Location and Date |
|---|---|---|
| Deck Officers | Vancouver, BC<br>January 29-31, 1997 | Ottawa, ON<br>February 24-26, 1997<br>April 24, 1997 |
| Engineering Officers and Crew | Vancouver, BC<br>March 17-18, 1997 | Ottawa, ON<br>April 22-23, 1997 |
| Logistics Officers and Crew | Vancouver, BC<br>May 12-14, 1997 | Vancouver, BC<br>July 14-15, 1997 |
| Deck Crew | Vancouver, BC<br>June 2-4, 1997 | Vancouver, BC<br>July 16-18, 1997 |

Six to eight CCG personnel were involved in each meeting. The primary purpose of each meeting was to review and modify task descriptions from the Marine Medical Standards Report (CCG, 1990) and provide information detailing the hearing requirements of each task. Task descriptions were modified to generate a more precise description, or to identify changes to the task since the publication of the Marine Medical Standards Report in 1990. Each group was also asked to generate descriptions for tasks not included in the Marine Medical Standards Report, but which are performed in DFO or CCG programs.

The task analysis procedures were first completed with the SMEs for a particular job category (e.g., Deck Officers). The SMEs confirmed or modified the task description from the Marine Medical Standards Report (CCG, 1990) and provided initial information on the hearing requirements of the tasks. The Focus Group for the same job category confirmed the data, provided regional perspectives (e.g., variability in programs, vessel types, equipment), and completed an overall ranking of the tasks in terms of frequency and criticality.

To ensure that the data were relevant to the broad scope of DFO and CCG programs, additional meetings were held with specialized groups. A meeting was held with the crew at the CCG Kitsilano Base, including the Officer-in-Charge (OIC), to discuss issues related to small vessel operations. This involved discussing the task descriptions and gathering specific information about implications for hearing on small vessels. Complete task analysis procedures were not completed during the meeting at the Kitsilano base due to time and budget restrictions. In addition to the general group discussion, during the Deck Crew Focus Group held at BC Research, two coxswains were interviewed individually regarding small vessel operations to further investigate this specialized job position which is common on a variety of CCG and DFO small vessels.

Because the Marine Medical Standards Report (CCG, 1990) was focused on CCG programs, task descriptions specific to DFO programs had to be developed during the task analysis. This was achieved during the Deck Officers and Deck Crew Focus Groups. During a focus group, personnel assigned to DFO programs were asked to discuss tasks specific to these operations (i.e., Conservation and Protection). Descriptions of additional DFO program tasks were only generated by the Deck Department because tasks completed by the Engineering and Logistics Departments are generally not program dependent. In addition to the task descriptions which were generated, information was gathered to identify similarities to CCG operations in terms of hearing requirements and background noise. These similarities were important to ensure data collected relevant to vessel operations in a CCG program (e.g., icebreaking) could be applied to vessel operations in a DFO program (e.g., fisheries research) and to ensure the recommended hearing requirement could be applied across all CCG and DFO programs. Information collected during the additional meetings was included in the selection of tasks for on-board data collection.

### 2.2.1 Subject Matter Experts (SMEs) Meetings

At the beginning of each SME meeting, the CCG Project Officer briefed the participants on the purpose and background of the project. As required, BC Research provided details regarding technical aspects of the data collection and the task analysis process. The BC Research facilitators led the discussion during the task analysis.

For each job category examined, corresponding tasks from the Marine Medical Standards Report (CCG, 1990) were reviewed and edited to ensure that all task descriptions were accurate. Editing the tasks was based on obtaining consensus from the group. If consensus on the task description could not be reached, differences were noted in the recorded description. The group then provided summary information by answering the following questions for each task description.

- "Is hearing required to carry out this task?" If the answer was "No", the group would proceed to the next task.
- "When carrying out this task, are there other sounds in the ambient environment that you need to be aware of which are not directly related to the task itself?" (e.g., ship alarms, radio communications).
- "On a scale from 1 to 9, how critical or important is hearing to being able to carry out this task successfully?" (where: 1=not at all; 5=somewhat; and 9=a great deal).
- "Under which DFO or CCG programs is this task performed?"
- "On which vessel types is this task performed?"
- "Which job titles are responsible for performing this task?"

This procedure was repeated for all tasks identified for the job category, including any additional tasks whose descriptions were generated during the SMEs meeting.

Due to budget limitations and restrictions in the amount of time which could be spent collecting acoustic data on board the vessels (Phase 3), all the tasks identified as having a critical hearing requirement could not be measured. Therefore, a method to prioritize these tasks and compile a representative sample for on-board data collection was required.

After the summary information was collected for all tasks, the tasks identified as having a criticality of hearing rating of 7 or above (on a 1 to 9 scale) were targeted for a more detailed task analysis. The methodology and questionnaire used to collect this information is provided in Appendix B. The general categories of information collected during the task analysis included:

- general task information;
- task frequency, duration, and sequence;
- task environment (i.e., location, ambient noise, meteorological conditions, hearing protection);
- auditory processing (i.e., speech, signals, localization, machinery, active listening, workload, experience);
- communication characteristics (i.e., repetition, familiarity, feedback, proximity, face-to-face communication, equipment); and
- errors (i.e., type and consequence).

The SMEs were asked to reach consensus on each question. Generally, the group members agreed easily on responses to the questions to reach consensus. Where consensus could not be reached, notations to special circumstances were made to satisfy the opinions and experiences of all participants.

Where possible, SMEs were asked to identify tasks with similar hearing requirements. This procedure was used to streamline the data collection process and highlight similarities between tasks (e.g., types of auditory requirements, ambient noise). On the basis of this information, tasks were then classified and assigned a group number. However, important differences such as task frequency and consequence of error were recorded for individual tasks.

### 2.2.2 Focus Group Meetings

The procedures used for the Focus Group meetings were similar to those used in the SME meetings. The Focus Group was briefed on the project by the CCG Project Officer and then briefed on the task analysis process by BC Research team members. The BC Research facilitators led the task analysis process. Information obtained from the SME meeting for the relevant department was reviewed and the Focus Group was asked to verify the information verified by the SMEs. Based on experience from the various regions, the Focus Group made revisions to the task descriptions and the general summary information.

The Focus Groups were asked to confirm the criticality rating for tasks identified by the SMEs with a criticality rating of 7 or greater (on a 1 to 9 scale). For each of these tasks, the detailed task analysis carried out with the SMEs was reviewed by the Focus Group. The Focus Group confirmed or modified the original responses to ensure representative information from all CCG operating environments and regions. In a few instances, the Focus Group identified a task as having critical hearing requirements (i.e., 7 or greater on a 1 to 9 scale) which had not been identified by the SMEs. This task was then investigated more thoroughly by the Focus Groups using the task analysis questionnaire (Appendix B).

Based on information from the final detailed task analysis, the Focus Groups were instructed to follow an overall ranking procedure which had not been performed by the SMEs (Appendix B, Section 8.0). The Focus Groups produced summary information for each task which re-examined the following details:

- job titles which perform the task;
- task name and description;
- task frequency;
- overall criticality of hearing to the task;
- possible consequences of an error;
- criticality of hearing in terms of personal safety in performing this task; and
- criticality of hearing in terms of the safety of others and the vessel in performing this task.

The Focus Group was then asked to answer the following questions:

- "Overall, how critical is hearing to carrying out this task safely (based on questions regarding safety to self, safety to others and the vessel, and the possible consequences of error)?"; and
- "Overall, how important is this task to vessel operations to this program completion?".

The summary information and the responses to the questions which were focused on the overall ranking were completed for all tasks for which hearing was designated as critical (i.e., 7 or greater on 1 to 9 scale).

### 2.2.3 Final Task List

An initial list of 236 tasks were presented to the CCG SMEs and Focus Groups. Using the task analysis methodology, the operational experts in the SMEs and Focus Groups identified 52 tasks as having critical hearing requirements and being important to operational effectiveness, as well as the safety of the ship, crew and individual. Acknowledging that every potential environment and circumstance could not be reasonably or logistically measured, tasks were selected for on-board data collection to provide a representative sample of hearing requirements in CCG operations.

The 52 tasks were categorized as follows: Deck Department, Engineering Department, Logistics Department, and Universal (i.e., generic tasks and MED). These 52 tasks were then further categorized by the criteria of task frequency and CCG program. These criteria were determined through the task analysis, BC Research team members, the CCG Project Officer and the TDC Project Authority to provide a cross section of the CCG operating environment. From these categories, tasks were randomly selected by BC Research to result in 50% representation of each category for a total of 26 tasks. Two tasks were added (for a total of 28 tasks) to ensure that all vessel operating conditions (e.g., alongside, steaming), vessel types, and location on the vessel in which tasks are performed (e.g., wheelhouse, galley) would be represented during the on-board data collection in Phase 3.

During a subsequent meeting between the CCG and TDC Project Officers, and CCG operational experts, the task list was modified to a final list of 34 tasks. The task list was modified to exclude tasks that could not be realistically simulated on board the vessels (i.e., shoring a breach in the hull) and to ensure a more representative sample of DFO program tasks. This meeting with operational experts also provided an opportunity to gather additional information on DFO program tasks, as the Marine Medical Standards Report (CCG, 1990) was completed prior to the 1995 merger between CCG and DFO. Subsequently, this document did not include descriptions of DFO tasks. Details on the methods used to expand the task list are provided in Appendix C.

Table 2 outlines the final task distribution. The list of the original 28 tasks as well as full task descriptions of the final 34 tasks selected for the on-board data collection are provided in Appendix D. The complete task analysis for the final 34 tasks is provided in a supplementary document (“Summary of Task Analysis”).

**Table 2:**
**Task List from Final Task Analysis**

| Department | Total number of tasks | Tasks with Critical Hearing Component | | Tasks Chosen for Data Collection (BC Research/CCG/TDC)) | | | Tasks Chosen for Data Collection (CCG/TDC) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | % of total tasks | Total | % of total tasks | % of hearing critical tasks | Total | % of total tasks | % of hearing critical tasks |
| Deck (officers and crew) | 135 | 28 | 21% | 15 | 11% | 50% | 21 | 16% | 75% |
| Engineering (officers and crew) | 26 | 8 | 31% | 4 | 15% | 50% | 4 | 15% | 50% |
| Logistics (officers and crew) | 50 | 4 | 8% | 2 | 4% | 50% | 2 | 4% | 50% |
| Universal (inc. MED) | 25 | 12 | 48% | 7 | 28% | 58% | 7 | 28% | 58% |
| Total | 236 | 52 | | 28 | | | 34 | | |

### 2.2.4 Summary

The task analysis methodology allowed for three stages of information generation and verification by CCG operational personnel. These three stages include:

- SMEs verification of the Marine Medical Standards report (CCG, 1990);
- Focus Group confirmation of SMEs task analysis data; and
- the meeting between the CCG Project Officer and TDC Project Authority with CCG and DFO operational experts to identify the final task list.

The task analysis was based on scientific methods common in ergonomics and human factors. The tasks generated in the final task list were selected to ensure a fair representation across the CCG seagoing environment.

## 2.3 Phase 3: Collection of Field Data

The purpose of Phase 3 was to confirm the task analysis data and to collect acoustic data characterizing the auditory requirements of Ships' Officers and Ships' Crew in relation to task requirements, department, vessel type and program. The selection of data collected during Phase 3 was based on information from the task analysis and final task list generated in Phases 1 and 2.

### 2.3.1 Participating Vessels and Regions

Eleven CCG vessels were selected as sites for on-board data collection. Prospective vessels were chosen to provide a representative sample of program, vessel type, size, and region. However, the vessel's assigned schedule and availability were also considered in the final selection. Therefore all five CCG regions could not be represented in the on-board data collection. Arctic icebreaking was not included due to time and budget constraints, as well as the fact that the Arctic ice season during the data collection period did not yield significant ice. However, data were collected on a CCG icebreaker which performs Arctic icebreaking (i.e., the CCGC *Des Groseillier*) while it was breaking ice in the St. Lawrence River. The participating vessel name, program, region, and dates of data collection are provided in Table 3.

A pilot study was conducted on two vessels in the Pacific Region. The pilot study allowed field testing of on-board data collection methods and subsequent data analysis. Additional details about the pilot study are provided in following sections.

**Table 3:**
**On-board Data Collection Schedule**

| CCG Vessel | Program | Region | Date |
|---|---|---|---|
| *CCGS *Sir Wilfrid Laurier* | Major NavAids Tender | Pacific | Feb. 1998 |
| *CCGS *Osprey* | Small Multi Task Utility Craft | Pacific | Feb. 1998 |
| CCGS CG-039 | SAR: Air Cushioned Vehicle | Pacific | Mar. 1998 |
| CCGS *Sir Wilfrid Grenfell* | Offshore Ice Strengthened Multi Task (Patrol) Cutter | Newfoundland | Sept. 1998 |
| CCGC *W. Jackman* | Multi Task High Endurance Lifeboat | Newfoundland | Sept. 1998 |
| CCGS *Revisor* | Hydrographics | Pacific | Oct. 1998 |
| CCGS *John P. Tully/ Surge* | Offshore Research / Survey | Pacific | Oct. 1998 |
| CCGS *W.E. Ricker* | Offshore Fisheries Research | Pacific | Nov. 1998 |
| CCGS *Atlin Post* | Small Multi Task (Patrol) Cutter | Pacific | Nov. 1998 |
| CCGS *Des Groseillier* | Medium Gulf / River Icebreaker | Laurentian | Jan. 1999 |

* denotes vessels involved in the pilot study

### 2.3.2 Dependent Measures

A number of methods were considered during the development of the project methodology. The first option was to use psychophysical procedures requiring speech discrimination and signal detection measures during the on-board data collection using crew members as subjects. Three major problems were identified with this method:

- subjects' hearing thresholds (i.e., audiograms) would be required;
- a large number of subjects representing a wide range of hearing losses would be required to address the large between- and within-subject variability commonly observed in this type of testing; and
- each subject would require training in the speech discrimination and signal detection tests used in the study.

It was concluded that the limited availability of CCG subjects with appropriate hearing losses, and the time that would be required to complete such testing made psychophysical procedures impractical.

As an alternative to psychophysical procedures, the on-board testing methodology was based on the following three predictive engineering/psychoacoustic procedures resulting in physical measures which have been shown to correlate with average human performance. These methods are supported by experimental data, the first of which (i.e., Speech Intelligibility Index) is the basis for the current American national standard for speech intelligibility:

- Speech Intelligibility Index (SII) (ANSI S3.5-1997);
- Speech Transmission Index (STI) (Houtgast *et al.*, 1980) and;
- Detectsound™ to analyze acoustic alarms and signals (Laroche *et al.*, 1991).

These standards and methods were chosen because they provided the most current and comprehensive procedures to collect and analyze acoustic data, specifically speech intelligibility, and signal and alarm detection. The underlying assumptions of these procedures are approximations of the speech-recognition and signal detection processes they describe.

A series of typical HTL profiles were derived from ISO Standards 7029 and 1999 (ISO 1982, 1988). These standards provide population data as to the expected hearing losses associated with age and years of noise exposure. These standards were used in conjunction with the SII and Detectsound™ procedures to predict speech recognition and signal detection performance in ambient noise experienced during CCG operations. The STI procedures was used to provide input variables into the SII analysis.

Descriptions of the dependent measures collected during the on-board phase are provided below. These measures were initially collected during the pilot study. Based on the results of the pilot study, modifications were made to the on-board data collection procedures and data analysis methodology. Where appropriate, reference to the modifications is provided in the following sections. Prior to data collection for any of these measures, equipment was properly calibrated using standardized procedures.

### *Direct Speech Transmission*

Direct speech transmission is defined as speech communication between a speaker and listener without any type of electro-acoustic device (e.g., telephone, broadcasting system). This type of speech transmission was measured using a system which simulates a speaker-to-listener scenario, termed the Maximum Length Sequence System Analyzer (MLSSA). The MLSSA system generates an artificial speech signal which is random noise spectrally shaped to match the long-term root-mean-square spectrum of running speech, and 100 per cent modulated (sinusoidally) at rates comparable to that of real speech (Houtgast *et al.*, 1980). A typical young adult with no hearing pathology can hear a frequency range of 16 to 13000 Hz, with some individuals having a range up to 30,000 Hz (Myers *et al.*, 1963).

The MLSSA system speaker was housed in a mannequin called SSARAH (Speech Source for Acoustical Research in Architecture and Hearing). SSARAH has the directivity of a human speaker and emitted an artificial speech signal controlled by a computerized software system. The signal produced by the computer was processed through an equalizer in order to modulate the signal to frequencies simulating human speech, and through an amplifier to boost the signal. The artificial speech signal plus interfering noise and temporal distortions were collected at the "listener's" location using a free-field measurement device (i.e., sound level meter (SLM)). These data were recorded digitally in the MLSSA system for subsequent processing. Figure 2 represents a schematic of the MLSSA system. Photographs from the on-board data collection showing the MLSSA system are provided in Figure 3.

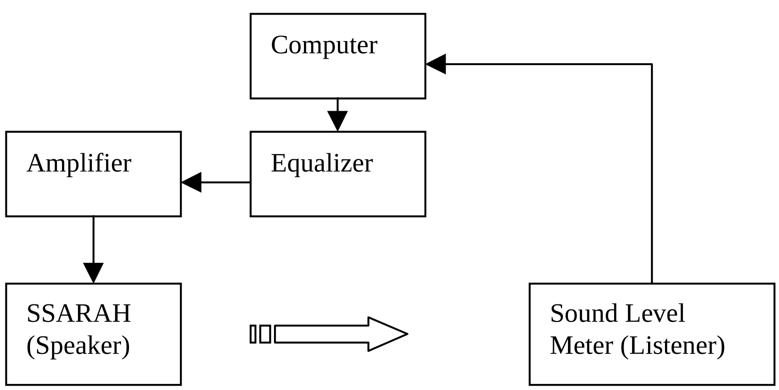



**Figure 2:**
**Schematic of MLSSA System for Direct Speech Transmission**

**Figure 3:**
**Photographs of MLSSA System During On-board Data Collection**
**CCGS *Sir Wilfrid Grenfell*: Engine Control Room (top);**
**CCGS *Sir Wilfrid Laurier*: Engine Space and Galley (bottom)**

For each of the 34 tasks selected from the task analysis, relevant “scenarios” were identified on each vessel included in the on-board data collection. First, the task information was confirmed by on-board personnel. Then, the speaker-listener positions were identified, as well as the expected voice levels and whether the listener was facing the speaker (i.e., could the listener see the speaker’s lips during communication). The MLSSA system was oriented to simulate this scenario and the appropriate data were collected. If the task could be performed through a different scenario (e.g., the navigating officer may give commands to the helm from different positions and distances on the bridge), these data were also collected.

In some situations during the on-board data collection direct speech transmission could not be measured using the MLSSA system due to meteorological conditions, risk to equipment, or absence of a reliable power source. In these situations ambient noise measures at the "listener" position were collected using a free-field measurement device (i.e., sound level meter) and digitally recorded in its memory for subsequent downloading and processing. The distance between the "listener" and an assumed "speaker" location was noted for calculation of the inverse-square-law attenuation of a speech signal over the distance. Calculation of SIIs were then determined using the measured noise-spectrum level at the "listener" position, the speech-spectrum level derived from the assumed vocal output at the "speaker" location and the attenuation over the listener-speaker distance. Although using the MLSSA system for all data collection would have been preferable, the SII calculated from the data collected on the sound level meter offered a scientifically and methodologically acceptable alternative.

The MLSSA system was capable of producing an artificial speech signal at various voice levels (e.g., normal, raised, loud, shout). The equalizer in the MLSSA system shaped the output spectrums to simulate an octave-band sound pressure level (SPL) distribution accurately reflecting the human voice at different levels (ANSI S3.5-1997). This distribution is provided in Table 4.

**Table 4:**
**Speech Octave-Band Sound Pressure Levels (SPLs) for Voice Levels**

| Octave-Band Centre Frequency (Hz) | Voice Level (dB) | | | |
|---|---|---|---|---|
| | **Normal** | **Raised** | **Loud** | **Shout** |
| 250 | 34.8 | 39.0 | 41.6 | 42.5 |
| 500 | 34.3 | 40.2 | 44.9 | 49.2 |
| 1000 | 25.0 | 33.9 | 42.2 | 51.3 |
| 2000 | 17.3 | 25.3 | 34.4 | 44.3 |
| 4000 | 9.3 | 16.8 | 25.4 | 34.4 |
| 8000 | 1.1 | 5.1 | 11.4 | 20.7 |
| Overall SPL | 62.4 | 68.3 | 74.6 | 82.3 |

NB: Octave-band and overall voice-level SPLs are measured 1 metre in front of the talker (ANSI Standard S3.5-1997)

During the pilot study, data collected for a particular scenario were repeated using a range of voice levels. After analysis of these data, the protocol was modified so that the artificial speech signal used during direct speech transmission was set at the "shout" level for all direct speech communication measurements. Using the "shout" level ensured an acceptable speech-to-noise ratio (S/N) required for data analysis procedures. During the analysis, if the voice level of the talker in that particular scenario was expected to be different from "shout", the average apparent speech level produced by the MLSSA system was adjusted accordingly using an appropriate mathematical procedure, based on the values in Table 4. Generally, voice levels are naturally raised by the talker as the communication task becomes more demanding (e.g., in higher ambient noise) (Webster, 1984).

People naturally raise their voice level to be heard above high ambient, or background, noise. In high ambient noise, the increase in voice level (or “loudness”) varies considerably between individuals. Values as low as a 3 dB increase in response to a 10 dB elevation in ambient noise have been reported (van Heusden *et al.*, 1979; Webster and Klump, 1962). In other cases voice level increases between 5 and 10 dB in response to 10 dB ambient noise elevations have been observed (Lane *et al.*, 1961; Pearson *et al.*, 1977).

How loudly an individual speaks will also vary with the distance to the listener. Harris (1979) published graphical data showing the effects of distance, background noise, and voice level on communication effectiveness. These relationships are shown in Figure 4. The data assume a 10 dB increase in voice level for a 10 dB noise increase, in accordance with the trading relation adopted by the Environmental Protection Agency (EPA) for its equal intelligibility values (EPA, 1974). As an example of using the chart in Figure 4, in an ambient noise of 80 dB, where the speaker to listener distance is 1 metre, the speaker would be expected to use a “SHOUT” voice level. The frequency distribution of the “SHOUT” would match those frequencies in the “shout” column of Table 4.

The data in Figure 4 were used as a guide to draw conclusions regarding appropriate voice levels for each measurement condition (i.e., ambient noise level (dBA) and speaker-listener separation (metres)). It is noted that the “VERY LOUD” voice level shown in the Figure 4 is equivalent to the “LOUD” voice level specified in the ANSI Standard S3.5-1997 (see Table 4).

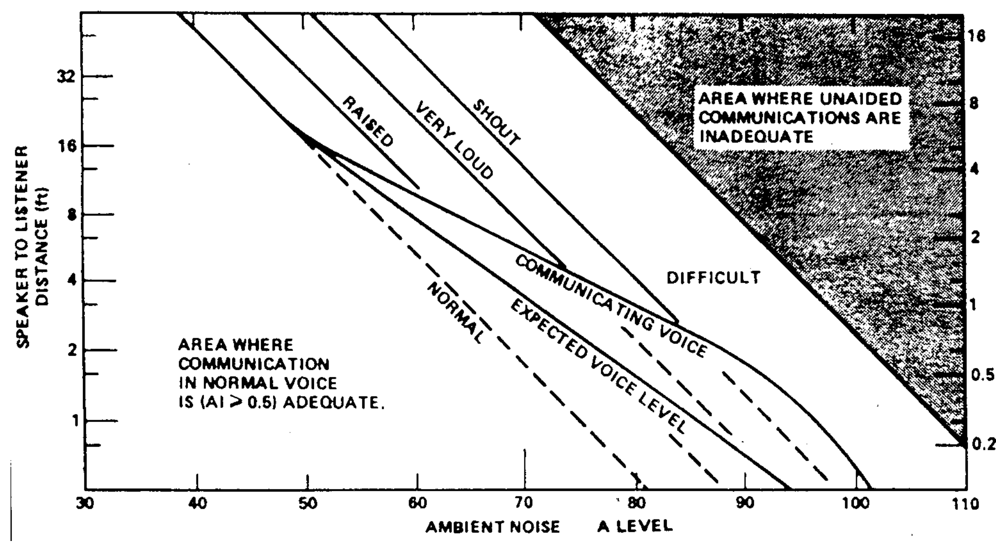



**Figure 4:**
**Voice Levels and Speaker-Listener Distances (EPA, 1974)**

### *Speech Transmission Over Electro-acoustic Communications Devices*

Some tasks required the use of communication devices, such as telephones, handsets and headsets. For these tasks, speech transmission over electro-acoustic communication equipment was collected using the SSARAH and MLSSA systems. The voice level produced by SSARAH over the communication devices was maintained at different voice levels (e.g., normal, raised, loud, shout). Because electro-acoustic communication devices are typically non-linear systems, the mathematical procedure to calculate S/N ratios from a "shout" level during data collection could not be performed with confidence.

During data collection, the equipment input device (e.g., handset or headset-mounted microphone) was placed at a normal position (close to the mouth) of the SSARAH mannequin. The "listener" (i.e., receiving SLM) was placed at an appropriate location close to the output of the communication link (e.g., VHF radio). If the output device was intended to be held against the "listener's" ear (e.g., telephone handset or headset), the SLM microphone was installed in a Kunov mannequin head (Kunov *et al.*, 1986; Kunov and Giguère, 1989).

The pinnea and ear canal of the Kunov head are made from a "rubberized" material which simulates the mechanical characteristics of the skin of the human external ear. The dimensions of the ear canal and the volume of the microphone coupler terminating the ear canal provide the acoustic impedance observed at the average human tympanic membrane. An example of this system is provided in Figure 5.

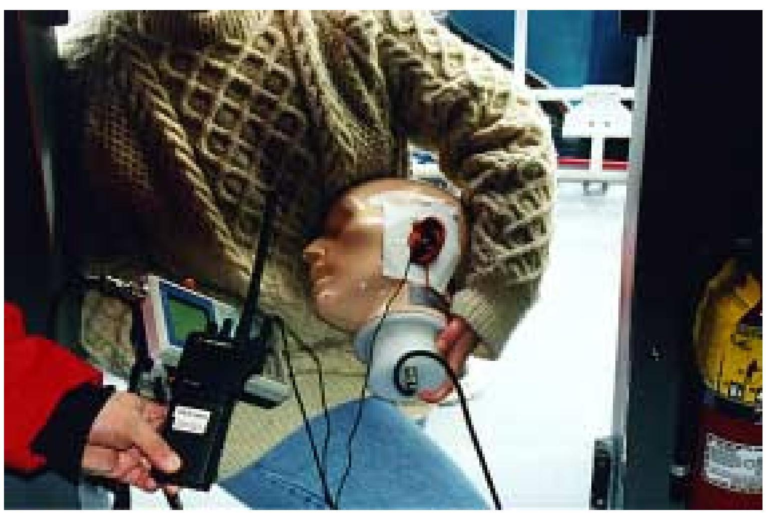


**Figure 5:**
**Data Collection with Electro-acoustic Communications Devices using Kunov Head on the CCGC *W. Jackman***

### *Alarms and Signals*

Various alarms and signals (i.e., sound of telephone ringing) were collected during the on-board procedure. The data were collected using the SLM and computer. To allow further analysis by a specialized software system (i.e., Detectsound™), data for the alarms and signals were also collected using a digital tape recorder.

Detectsound™ allows users to determine the characteristics of warning sounds to be used in a specific environment or to evaluate the effectiveness of the warning sounds currently used in an environment (Laroche *et al.*, 1991; Tran Quoc *et al.*, 1992). Detectsound™ considers the following information:

- the background noise at each workstation (one-third octave-band levels from 25 to 12,500 Hz);
- the hearing protectors worn by a standard individual or by actual individuals in the work environment (attenuation in dB from 63 to 8,000 Hz);
- the audiogram of a standard individual or the actual individuals assigned to a workstation (hearing thresholds from 125 to 8,000 Hz); and
- all warning sounds that can be heard at the station (one-third octave-band levels from 25 to 12,500 Hz).

The loss of frequency selectivity (i.e., the ability of the ear to extract a sound signal in a background noise) is also taken into account in the software. It is statistically related to the loss of sensitivity.

These factors are analyzed together and the results are displayed in a graphic or a table form. Figure 6 is an example of a graphic display. In Figure 6, the frequency content is presented on the x axis and the level of each one-third octave band of the noise or the warning sound is on the y axis. The full horizontal line corresponds to the background noise level at the workstation. The thin vertical lines correspond to the spectral content of the signal heard at this workstation. The dark hatched zone represents the “hearing window” (i.e., the spectral and level region in which at least three spectral lines of a well-designed warning sound should be in order to attract attention and be recognized among different warning sounds). This zone is based on the masked threshold (i.e., hearing threshold in noise) computed for each third octave band to which 13 to 25 dB is added (ISO, 1986; Laroche *et al.*, 1991; Patterson, 1982). Dark vertical lines represent frequencies of the alarm which reach the design window. The frequencies which do not fall within the design window are spectral components of the alarm, but do not contribute to its audibility to a human listener. In Figure 6, six dark vertical lines meet the design window, representing six frequencies of the alarm which contribute to its audibility to a human listener.

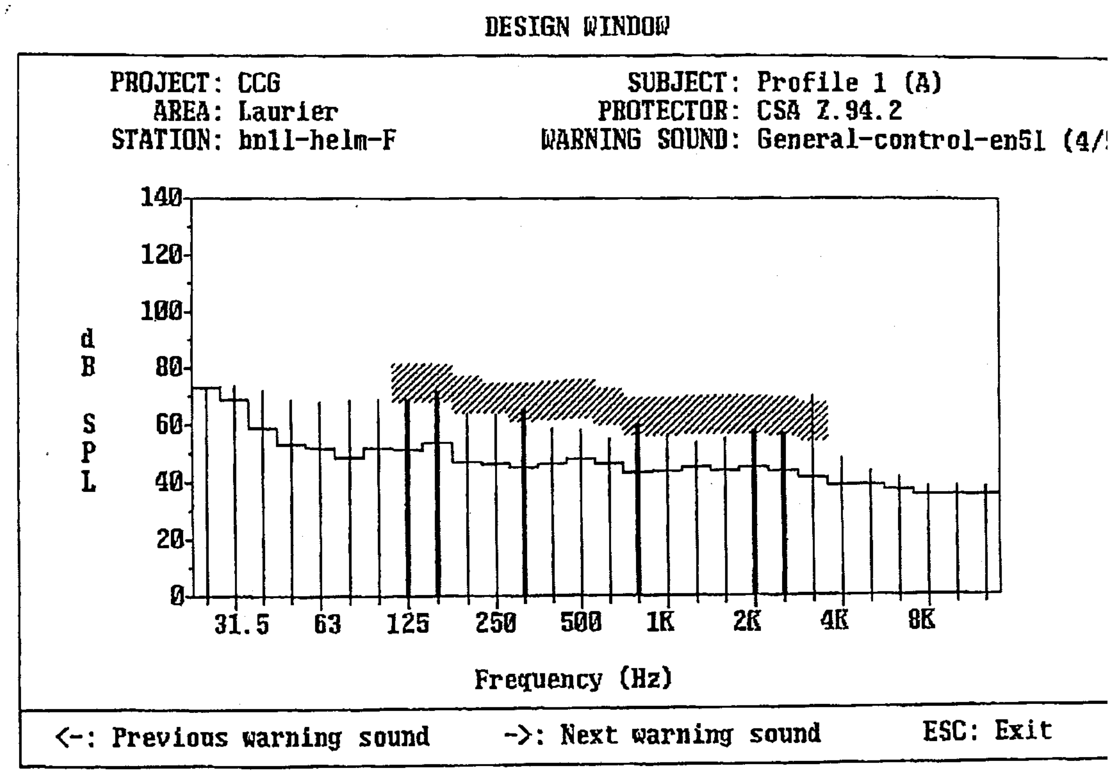



**Figure 6:**
**Graphical display of the "hearing window" for a particular workstation and a particular sound signal**

According to ISO Standard 7731 (1986), at least one spectral component should reach the "hearing window" to be considered to provide minimum audibility. In order to address fluctuations in background noise common in work environments, it is preferable that more than one component reach the "hearing window". This ensures that if one component is temporarily masked by the background noise other components would then be available. In Figure 6, the alarm should be well perceived and recognized by people with normal hearing because six spectral lines are inside or at the borders of the "hearing window". If all the spectral lines would have been below the design window, this alarm would not be considered to be audible. If the lines would have been above the design window, the warning sound level would have been too high and could have caused hearing damage, interfered with communication or resulted in a startle reaction.

## *Localization*

The ability to identify a sound source in three dimensional space, termed localization, was identified during the task analysis in Phase 2 as a critical hearing requirement in all of the 34 tasks included in the on-board data collection. However, given the field study methodology, localization could not be reliably measured in an on-board environment. To provide useful data, localization data must be collected under controlled conditions which could not be established in a maritime environment. However, based on the task analysis and literature review, localization was determined to be a significant requirement in the CCG seagoing environment.

### *Ambient Noise*

Background noise was collected in various locations under typical operating conditions on board the vessels (e.g., alongside, steaming). The vessel operating conditions were representative of the vessel, program and task as determined by the Commanding Officer (CO) or OIC, and the task analysis data. Ambient noise was collected in the same locations in which speech transmission data or signal and alarm data were collected, as well as additional locations where speech transmission data could not be collected logistically (i.e., steering gear space). Ambient noise was collected using the computer and sound level meter, or sound level meter only where an external power supply was not available (i.e., in a 733-Fast Response Craft).

Table 5 provides examples of ambient noise levels experienced in daily life, including the minimum human hearing threshold (at 1000Hz).

**Table 5:**
**Examples of Typical Ambient Noise Levels**

| Noise Source | Decibels (dB) |
|---|---|
| Human hearing threshold (at 1000Hz) | 5 dB |
| Normal conversation | 65 dB |
| Town traffic | 80 dB |
| Workshop | 100 dB |
| Jet at take off (60m away) | 125 dB |
| Pain threshold | 140 dB |

### *Verbal Verification*

Although the use of psychophysical procedures for speech testing on board ship was not a practical method of developing a hearing standard (due to limitations outlined in Section 2.3.2), a restricted study (termed herein "verbal verification") was conducted to obtain a rough comparison between the calculated predictions of speech intelligibility and on-site speech discrimination performance. The results were not intended to contribute quantifiably to the development of the hearing standard, but to differentiate qualitatively between very good and not-so-good communications.

Furthermore, a number of factors precluded using CCG crews as subjects for the verbal verification procedure: lack of ethics approval; lengthy preliminary subject testing, including an audiogram, prior to testing; extended and dedicated crew time while on board; additional scheduled ship-board time; and characterization of the DFO/CCG operating environment. Accordingly, a within-subjects design using BC Research team members was used to ensure that the test was performed consistently across operating conditions and that hearing loss, if any, was kept constant so as not to confound the results.

To conduct the verbal verification, a scenario for the speech communication was established (e.g., between the chart table and helm on the bridge, over a VHF radio), including both direct speech and the use of electro-acoustic communications devices. Audiograms for the two BC Research team members performing the verbal verification testing were obtained prior to on-board testing to permit the calculation of the SII, based on their hearing loss profiles, the ambient noise in the talker/listener environment, and the distance between the two individuals.

During the pilot study, one BC Research team member read a randomized list of five-digit numbers. The reader was instructed to use a natural voice level, based on the ambient noise. A second BC Research team member recorded (via pen and paper) what was heard. When the list of numbers had been read and recorded, the roles of the two BC Research personnel were reversed and a different list of randomized five-digit numbers was used (to eliminate learning effects). When the second listener had completed the task, the per cent correct for each individual was calculated. The results showed that the five-digit test was insensitive to the varying acoustic conditions encountered during the pilot study, as all scores equalled or exceeded 94 per cent correct discrimination. As a result, lists of phonetically balanced (PB) monosyllabic words from ANSI Standard S3.2 (1960) were used as the test stimuli for the remainder of the project. This was done to overcome the effects of over-learned speech-test stimuli.

The protocol for the remaining verbal verification was the same as in the pilot study, including the same pair of BC Research team members who performed the verification process throughout the on-board data collection. To address concerns that a series of word lists drawn from a finite set would soon become over-learned stimuli with a restricted number of listeners, a large number of the PB items contained in the ANSI Standard word lists was used. The verification process was limited in the number of on-board situations, and the PB words were randomized for each trial.

### 2.3.3 On-board Procedures

Prior to the on-board data collection, the following procedures were followed.

- A letter outlining the project and the needs of the team while on board was sent to the CO or OIC by the CCG Project Officer at least one week in advance on the scheduled data collection.
- The CCG Project Officer followed up with the vessel or appropriate Regional Office to solicit comments, encourage the availability of a crew member and ensure that requests for data collection (i.e., locations, use of communications equipment) were acceptable to the CO or OIC.
- Upon arrival at the vessel, BC Research and the CCG and TDC Project Officers met with the CO or OIC and crew to discuss the project and requirements while on board.

- Ships' Officers and Ships' Crew were interviewed as to the detailed requirements of the tasks selected for data collection, to convey the procedures and to confirm the task requirements.
- Baseline data were collected while the vessel was alongside, in a manner which met the schedule and requirements of the vessel and crew.
- Acoustic and verbal verification data were collected during a range of vessel operations.

Data which were collected on board the vessels listed in Table 3 represented the final list of 34 tasks identified as characterizing the operational environment and tasks of CCG seagoing personnel. For each task, specific variables considered during the on-board data collection included:

- positions of the speaker and listener to represent speech transmission in the task;
- distance between speaker and listener;
- orientation of speaker and listener (i.e., facing or not facing each other);
- voice level used (i.e., normal, raised, loud, shout);
- use of hearing protection;
- use of communications equipment;
- distance between listener and signals or alarms; and
- various ambient noise levels based on vessel operations and program.

For each task, the information gathered during Phase 2 was confirmed with appropriate personnel on board each vessel during the data collection to determine specific locations and distances between the speaker and listeners, as this varied with the individual vessel design and operations.

## 2.4 Phase 4: Recommendations for Hearing Standards and Corresponding Tests

The overall focus of Phase 4 was to identify operationally-based hearing standards for CCG seagoing personnel which are relevant to task requirements and sensitive to speech discrimination and signal detection abilities. In this phase, acoustic data from the on-board data collection were analyzed. These data were reduced to equivalent speech and noise spectrum levels. In conjunction with a series of HTL profiles, a series of SIIs were calculated. The HTL profiles were also used in the analysis of signals and alarms. Specific auditory tests to be used for screening seagoing personnel were suggested.

To achieve these objectives, Phase 4 was divided into the following two sub-tasks:

- assessment of speech communication requirements; and
- assessment of alarm detection and signal discrimination requirements.

### 2.4.1 Data Analysis: Assessment of Speech Communication Requirements

Current methods of analyzing the speech discrimination characteristics of communication environments were used to predict speech intelligibility. The methods included:

- Speech Intelligibility Index (SII) (ANSI S3.5-1997), which is the revised version of the Articulation Index (AI) (ANSI S3.5-1969); and
- Speech Transmission Index (STI) (Houtgast *et al.*, 1980).

These methods were quantitatively and objectively adapted and linked to provide a thorough analysis of general speech intelligibility requirements in CCG operations.

#### *Articulation Index (AI)*

To appreciate the SII, an explanation of the AI is provided below.

The ability to predict the speech transmission quality of a communication system in the presence of noise was introduced by Collard (1930). The original method involved dividing the speech spectrum into 20 bands that contribute equally to overall intelligibility. The S/N in a given band determines the degree to which the speech signal in the band contributes to speech intelligibility. The resulting measure, the Articulation Index (AI), ranges from 0 to 1, and is related monotonically to the speech-recognition score.

French and Steinberg (1947) published a detailed procedure for calculating the AI, and Kryter (1962a) carried out the work that led to the standardization of the procedure (ANSI S3.5-1969, “Methods for the Calculation of the Articulation Index”). The standard allowed the AI to be calculated using octave or one-third octave-band spectra together with frequency-importance functions which characterize the importance of each octave or one-third octave-band to intelligibility. In addition, a weighting function was prescribed which indicated the proportion of the speech dynamic range within a frequency band that contributes to intelligibility.

Kryter (1962b) noted that no single value of AI could be specified as a criterion for “acceptable” communications because speech intelligibility is highly dependent, for example, upon the constraints placed on the message being communicated. Typical constraints may consist of grammatical structure and context as found in sentences, limitations in vocabulary size, or in the syllabic length of the words used. For contextually rich speech material, 100 per cent correct intelligibility can be achieved in listening situations in which only a small proportion of the speech spectrum is audible (i.e., at an AI much less than 1.0). The relationship between the AI and speech intelligibility for various types of word and sentence characteristics is illustrated in Figure 7 (ANSI S3.5-1969). As an example from Figure 7, at an AI of 0.5, 70 per cent correct intelligibility of a list of 1000 nonsense syllables, 75 per cent correct intelligibility of 1000 PB words, and 95 to 100 per cent correct intelligibility of known sentences, and vocabularies of 32 and 100 words could be achieved by the listener.

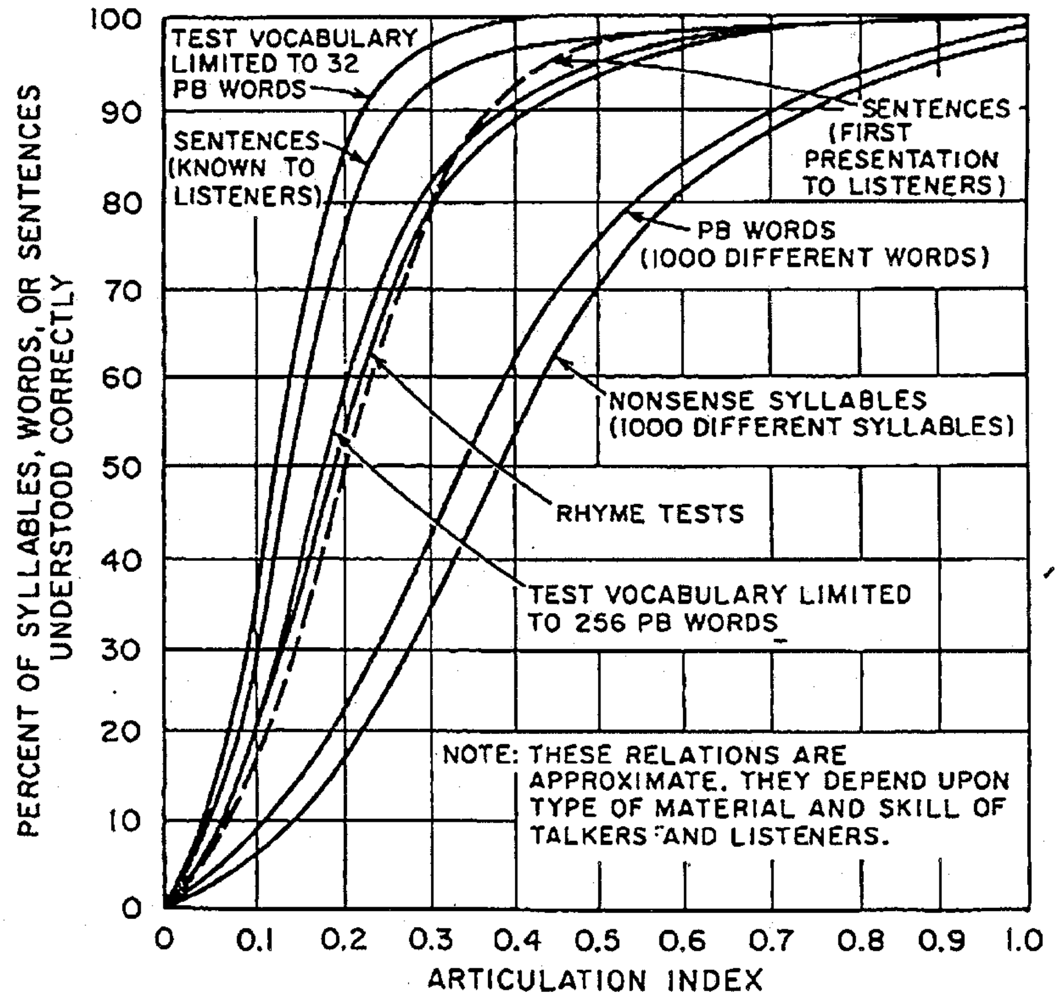



**Figure 7:**
**Relation between AI and Measures of Speech Intelligibility (ANSI S3.5-1969)**

### *Speech Intelligibility Index (SII)*

In 1997, the American National Standards Institute published a major revision of the AI (ANSI S3.5-1997). To identify the revised standard, its name was changed from "Articulation Index (AI)" to "Speech Intelligibility Index (SII)". Changes to the standard were made to provide a general framework into which various methods for determining the required input variables could be incorporated (e.g., equivalent speech spectrum level, equivalent noise spectrum level, equivalent hearing threshold level). The revised standard was extended to include various measurement points (e.g., free-field for architectural acoustics or eardrum for telephony). In addition, changes were made to take into account new data which have accumulated since 1969 (e.g., spread of masking, standard speech spectrum level, and relative importance of various frequencies to speech intelligibility). The measure of the SII is also expressed from 0 to 1, just as the AI.

The standard draws attention to the fact that the intelligibility of received speech depends not only on the SII but also on other factors such as the nature of the message being communicated (e.g., syntactic, semantic, linguistic, and contextual constraints) and the proficiency of the listeners and talkers. An annex to the standard gives the importance functions of a variety of speech materials. These include PB nonsense syllable tests of consonant-vowel-consonant (CVC), consonant-vowel (CV) or vowel-consonant (VC) type (Fletcher and Steinberg, 1929), the CID-W22 PB words (Hirsh *et al.*, 1952), the Speech Perception in Noise (SPIN) monosyllables (Kalikow *et al.*, 1977), and short passages of easy reading material (Cox and McDaniel, 1984).

For communication systems where the nature of the message and proficiency of the listeners and talkers may vary greatly, the intelligibility of speech also varies greatly. The new standard recommends that for such conditions, the SII, calculated with the importance function given for average speech (Pavlovic, 1987), is a better descriptor of the quality of the communication system with respect to intelligibility than an SII calculated with any of the other importance functions (ANSI S3.5-1997). Accordingly, the importance function for average speech was used in this study to calculate SII values.

Additional details regarding the calculation of the SII are provided in Appendix E.

*The Effects of Hearing Loss on Speech Discrimination*

There are two major consequences of hearing loss on the perception of sound. The first consequence is attenuation, which results in a loss in pure-tone sensitivity, as exhibited by the HTL outlined on an audiogram (clinical method to test hearing ability). Sound energy that falls below threshold is not detected and cannot contribute to perception because the listener cannot differentiate the sound from the ambient noise level. The second consequence is distortion which results from abnormal suprathreshold processing and is observed in sensorineural pathologies (e.g., dysfunction of the sensory system of the inner ear and/or of the neural pathways from the inner ear through the auditory nervous system to the cerebral cortex). Clinical speech discrimination testing is conducted at suprathreshold levels, typically 25 to 40 dB above the speech reception threshold (i.e., the lowest speech level at which an individual responds correctly to 50 per cent of two-syllable test words having equal stress on both syllables).

In general, normal hearing speech discrimination is observed in cases of conductive hearing loss (i.e., an interference with the normal mechanical transmission of sound energy from the external ear to the inner ear) or relatively poor speech discrimination in cases of sensorineural hearing loss (Berger, 1971). In addition, the speech discrimination of listeners with sensorineural hearing loss does not always improve with increased speech intensity (e.g., increased volume) (Plomp, 1978; Hannley and Dorman, 1983; Dubno *et al.*, 1984; Pavlovic, 1984; Kamm *et al.*, 1985).

*The Effects of Sensorineural Impairment on the Prediction of Speech Discrimination*

Although the AI procedure provides good predictions of speech intelligibility under various conditions of filtering, noise distortion, and low speech level (French and Steinberg, 1947; Kryter, 1962a, 1962b), the investigations of Pavlovic (1984), Studebaker *et al.* (1987) and Kamm *et al.* (1985) suggest that the AI overpredicts speech-discrimination performance in individuals with severe sensorineural impairment. Further, poorer discrimination was often found to be more pronounced in those frequency regions where the hearing loss was greatest.

Pavlovic (1984) concluded that the poorer predictions could not be accounted for by a single global adjustment to the AI calculation, but required frequency-dependent corrections. Accordingly, a desensitization factor applied to the frequency-importance function improves the predictions of speech intelligibility for individuals with sensorineural impairment. The desensitization factor (termed herein the "Pavlovic Correction") is given by:

$$C = 1.19 - 0.0127\,L \qquad \text{for } 15 < L < 94,$$

where L is the hearing loss in dB HL (see Appendix E). Two constraints are placed on C: its value cannot exceed 1 and cannot become negative (Pavlovic *et al.*, 1986).

The Pavlovic Correction provides a better prediction of speech intelligibility for individuals with sensorineural impairment compared to the SII without the correction factor. To ensure a robust approach to the SII, the Pavlovic Correction was accepted and integrated into the analysis procedures for this project.

#### *Speech Transmission Index (STI)*

The Speech Transmission Index (STI) employs an artificial speech signal which is random noise spectrally shaped to match the long-term root-mean-square spectrum of running speech, and 100 per cent modulated (sinusoidally) at rates comparable to that of real speech (Houtgast *et al.*, 1980). The signal is used to measure the impulse responses in each of the seven octave bands centred at 125 to 8000 Hz. Changes in the modulated signal (due to interfering noise and or temporal distortion) in each octave band and at each modulation frequency determines the modulation transfer function (MTF) for each of the seven octave bands. Each MTF is then converted to an average apparent S / N from which the STI is calculated.

The concept of the MTF has resulted in the development of calculation procedures and specific measuring devices that are used by acousticians in determining speech intelligibility for auditoria and halls. In this project, the MTF was employed to determine the apparent speech spectrum and noise spectrum levels which are input variables required for the calculation of the SII (Appendix E).

### 2.4.2 Derivation of the Hearing Threshold Level Profiles

Hearing threshold level (HTL) is one of the input variables for the SII calculations to in order to obtain predictions of speech perception in listener environments which are degraded by noise, filtering, and reverberation.

One of the purposes of the CCG study was to estimate the effect of various levels of sensorineural hearing loss on the SII. Accordingly, a range of HTL profiles were defined and are provided in Appendix F. The HTL profiles were arranged in two types: profiles 1 to 20 and profiles 21 to 32.

HTL profiles from 1 to 20 represent the typical manifestation of the combination of noise-induced permanent threshold shift (NIPTS) plus age-related threshold shift (ARTS) (i.e., presbycusis) as determined from ISO Standard 7029 (1982) and ISO Standard 1999 (1988). The eight HTL profiles marked with asterisks in Appendix F (Nos. 1, 3, 6, 9, 12, 15, 19, and 20), termed herein the “breakpoint profiles”, were computed directly from these two ISO reference standards.

Table 6 provides the population percentiles, ages, and noise exposures that yielded these profiles through clinical audiometric testing. Noise exposure refers to the number of years that an individual has been exposed to a working noise environment, at the levels specified in the table. The profiles that lie between the breakpoint profiles were determined for each audiometric test frequency by adding a constant increment to the HTL profiles between the two breakpoints. From breakpoint to breakpoint, the slope of the onset of hearing loss may change as dictated by the difference between successive breakpoint values.

**Table 6:**
**Derivation of "Breakpoint" Hearing Threshold Level (HTL) Profiles**

| Profile | Age of Population | Years of Noise Exposure | Noise Exposure (Leq in dBA) | Population Percentile within Profile |
|---|---|---|---|---|
| 01 | 29 | 9 | 79 | $10^{th}$ |
| 03 | 34 | 14 | 84 | $10^{th}$ |
| 06 | 37 | 17 | 87 | $10^{th}$ |
| 09 | 40 | 20 | 90 | $10^{th}$ |
| 12 | 43 | 23 | 93 | $10^{th}$ |
| 15 | 45 | 25 | 95 | $10^{th}$ |
| 19 | 47 | 27 | 97 | $10^{th}$ |
| 20 | 48 | 28 | 98 | $10^{th}$ |

Because of the lack of sufficient epidemiological data at 250 and 8000 Hz, ISO Standard 1999 (ISO, 1988) does not provide values of NIPTS at these frequencies. As a result, estimates of the NIPTS were made and added to the ARTS values derived from the ISO 7029 standard to give the HTL profiles appearing in the HTL profiles 1 to 20 (Appendix F). At 250 Hz, the NIPTS was made equal to the value at 500 Hz. The NIPTS component at 8000 Hz was derived using the slope of the HTL profiles between 4000 and 6000 Hz. Since the contribution of the octave bands at 250 and 8000 Hz to speech intelligibility is only 11.7 per cent, any error arising from the estimates of NIPTS at these frequencies may be considered minimal.

HTL profiles 21 to 32 represent atypical sensorineural losses that are more or less constant across the audiometric test frequencies. The 12 profiles are arranged in 5 dB increases of HTL between 0 and 55 dB. These types of sensorineural losses represent a small percentage of hearing loss in the general population. Including the atypical HTL profiles in the analysis served as a means of determining if the two types of sensorineural profiles produced similar profile cut-offs.

### 2.4.3 Data Analysis: Assessment of Alarm and Signal Discrimination Requirements

The acoustic signatures (pressure-time histories) of the alarms and signals underwent spectrum analysis and were transformed into one-third octave-band pressure levels for use in a computerized signal detection model (Detectsound™). The alarm spectra and the background noise in which the alarms were presented were used to compute masked thresholds for normal-hearing listeners and individuals with hearing level profiles who may be capable of meeting task requirements.

An array of hearing losses was prepared to encompass the range within which the low fence was likely to occur. As explained in Section 2.4.2, twenty hearing threshold level (HTL) profiles were defined, based on the epidemiological data published in ISO Standards 7029 (1982) and 1999 (1988), and represent typical manifestations of noise-induced and age-related hearing losses.

The one-third octave-band levels of each signal or alarm and each background noise (for the same position in space) were entered into the Detectsound™ program. The attenuation values of a Type A protector (CSA Z94.2 Standard, 1994) were used for data files representing scenarios in which hearing protectors are worn by CCG personnel (e.g., engine room). The CSA Z94.2 Standard was used as a conservative method because of the variability in the type of hearing protectors used on CCG vessels.

To determine the low fence for signal perception, each alarm or signal was analyzed according to the following decision matrix (Table 7).

**Table 7:**
**Decision Matrix for Signal and Alarm Perception using the Detectsound™ Model**

| | |
|---|---|
| (++) | 3 or more components in the "hearing window" |
| (+) | 1 or 2 components in the "hearing window" and some under, but above noise level |
| (+-) | 1 or 2 components in the "hearing window" |
| (-) | All components under the "hearing window" but above noise level |
| (--) | All components under noise level |

The low fence was set at the lowest HTL profile for which the (+-) label was met, for each alarm and signal. This decision represents a compromise and was motivated by the ISO 7731 standard (1986) which states that one component should at least be well over the background noise, and the fact that the (++) label would be the ideal situation. In fact, due to the high levels of background noise on the CCG vessels, low signal levels or a limited number of spectral alarm components, the (++) label was not achieved for much of the on-board data.

### 2.4.4 Summary

The main project objective was to recommend a minimum hearing requirement based on seagoing operating requirements by using an empirical scientific methodology. To meet this objective, current methods of analyzing speech discrimination characteristics of communication environments were used to predict speech intelligibility. The AI (ANSI S3.5-1969) was the original standardized method to determine intelligibility. The AI was replaced by the SII (ANSI S3.5-1997) as the standardized method to determine intelligibility. The SII included a number of additional considerations which were taken into account, including the effects of interfering noise and reverberation and the effects of hearing loss on speech intelligibility. The Pavlovic Correction Factor (Pavlovic *et al.*, 1986) was integrated into the SII process to provide a better prediction of speech intelligibility for individuals with sensorineural hearing impairment. The STI process (Houtgast *et al.*, 1980) provided modulation transfer functions for background noise and speech required by the SII calculation. These methods are accepted empirical methods. The STI is an internationally accepted method of measuring the effects of a listening environment on speech intelligibility. The SII is the current ANSI standardized method for measuring speech intelligibility (ANSI S3.5-1997).

A flow chart outlining the overall data analysis procedures is provided in Figure 8. The flow chart outlines various types of acoustic data that were collected during the on-board data collection (i.e., direct speech communication, indirect speech communications using an electro-acoustic device, and signals or alarms). Using a mathematical procedure, ambient noise from various relevant operating conditions was added to the acoustic data, and these data (ambient noise plus direct speech, indirect speech or signals and alarms) were then analyzed. The speech communications data (both direct and using an electro-acoustic device) were analyzed using the STI procedure. The MTFs from the STI were then input into the SII, as well as the HTL profiles (simulating a hearing loss in the individual), and the attenuation from the use of hearing protectors (if relevant to the task). The signal and alarm data were analyzed by Detectsound™, including the HTL profiles and hearing protector characteristics, if relevant. In both the SII procedure (speech communication) and Detectsound™ analysis (signals and alarms), a limiting HTL profile could then be identified for each data file. However, choosing the limiting, or the minimum hearing ability profile, had yet to be determined.

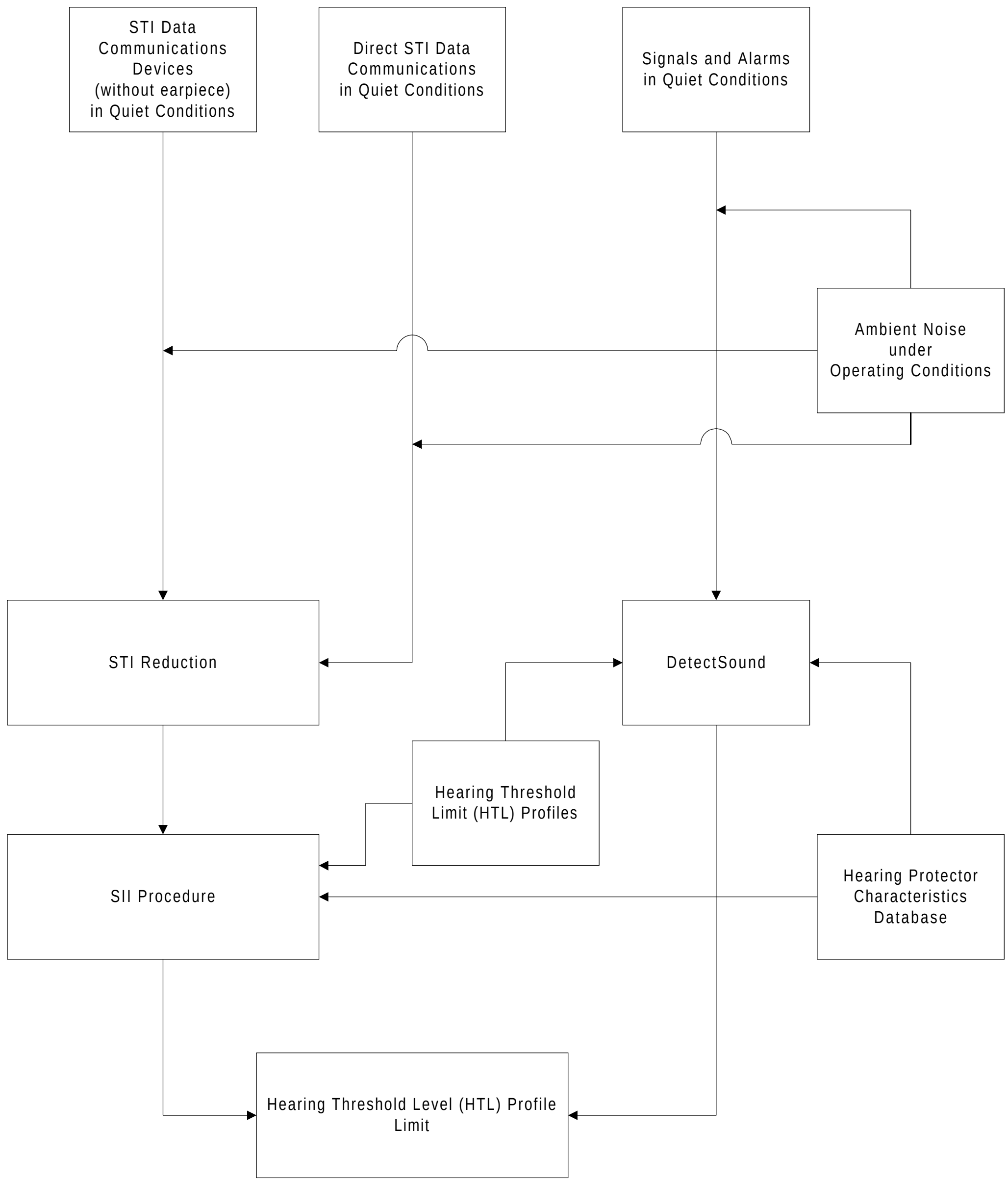



**Figure 8:**
**Overall Data Analysis Procedures**

### 2.4.5 Determining the Minimum Hearing Requirement

A limiting, or "cut-off" HTL profile was required to determine the minimum hearing requirement in CCG seagoing operations. A review of current standards and previous research in this area was conducted to determine an appropriate cut-off value.

As outlined in Section 2.4.1, the SII results in a measure ranging from 0 to 1. The current SII standard states that "good communication systems have an SII in excess of 0.75, while poor communication systems have an SII below 0.45" (ANSI S3.5-1997). The issue in this project was to determine an appropriate SII value between these two limits that is relevant to CCG hearing requirements for seagoing occupations.

A number of studies have been conducted to investigate the question of what is the threshold, or "fence" that may be considered to represent an unacceptable level of hearing (Robinson, *et al.*, 1984; Acton, 1970; Suter, 1978, 1985; Smoorenburg, 1986, 1992). The implications of setting the cut-off value with respect to CCG operations were also carefully considered. It was imperative that the minimum hearing level must be based on real job tasks and associated hearing requirements. This minimum hearing level must represent a minimum acceptable level of performance without compromising safety. The requirement could not be so high as to only allow those with supranormal hearing ability. An SII cut-off value which is set too high (i.e., too restrictive) may result in regulations which are unnecessarily stringent and expensive (e.g., more individuals will be sent for clinical testing), and employees would be required to undergo additional audiological assessment that would not otherwise be required. However, the requirement could not be so lenient as to compromise safety of the individual, other crew, vessel or public. An SII cut-off value that is set too low (i.e., too permissive) may result in persons performing critical communication tasks who might not be able to adequately perceive speech. Therefore, precedent and guidance from relevant research and existing hearing standards were investigated.

#### *Estimates of Hearing Impairment in terms of Pure-Tone Thresholds*

The World Health Organization (1980) provide a number of definitions to categorize a hearing loss. They define "impairment" as a pathological condition that affects an individual's ability, compared to non-impaired or normal abilities. A "disability" denotes an actual or presumed reduction in ability. "Handicap" describes the disadvantage in everyday circumstances resulting from a disability or impairment. Generally, the clinical manifestation of hearing impairment is the beginning point for evaluating auditory handicap and disability. The analysis of hearing threshold levels is really a determination of where hearing impairment begins. For the purposes of this report, the term "hearing impairment" will be used (World Health Organization, 1980; Stephens and Hétu, 1991).

Early procedures for estimating hearing impairment were based on pure-tone thresholds, typically the three-frequency average of hearing level (HLs) at 500, 1000 and 2000 Hz (AAOO, 1959). Subsequent research for impaired speech-perception-in-noise led to the inclusion of the HL at 3000 Hz, with the minimum fence set at 25 dB (AAO, 1979). The British Association of Otolaryngologists and the British Society of Audiology recommended a low fence of 20 dB for the mean HLs at 1000, 2000, and 4000 Hz (BAOL/BSA, 1983).

Acton (1970) and Suter (1978, 1985) attempted to pinpoint the HL at which persons with mild hearing losses begin to lose speech perception. They estimated that hearing impairment begins at an average HL of 19 dB at 1000, 2000, and 3000 Hz. This value translates to approximately 9 dB at 500, 1000, and 2000 Hz, and 22 dB at 1000, 2000, and 4000 Hz, since most individuals with mild sensorineural impairments have threshold profiles that slope toward the high frequencies. Suter (1978, 1985) noted that the selection of a fence depends on the definition of hearing impairment and the conditions under which the impairment is assessed. Smoorenburg defined the onset of hearing impairment as the point at which an individual begins to notice a impairment in somewhat noisy everyday situations (Smoorenburg, 1986, 1992). This level was identified as an average HL of 30 dB at 2000 and 4000 Hz.

In an extensive investigation of speech-perception impairment, Robinson *et al.* (1984) tested normal-hearing and hearing-impaired subjects in a variety of listening tasks. The tasks covered a number of situations and included a simulated social gathering, a set of public address announcements recorded at the Waterloo Railway Station, and a telephone listening situation involving speech and noise. The listeners were also tested for speech discrimination with CVC monosyllables at several S/Ns. It was concluded that a threshold of impairment could not be identified because the threshold is dependent on the difficulty of the test. Therefore, the selection of any one set of conditions for the definition of "beginning-of-impairment" is necessarily arbitrary. As the threshold data were in the range 27 to 34 dB HL (averaged over the frequencies at 1000, 2000, and 3000 Hz), a low fence of 30 dB at these three frequencies was established.

A summary of the above estimates of hearing impairment is provided in Table 8, along with the equivalent HTL profiles for typical sensorineural losses.

Although speech energy is found in the 3000, 4000 and 5000 Hz frequency bands, most of the energy in speech occurs at frequencies below 3000 Hz where the vowel sounds are produced. The consonant sounds require far less energy than the vowels, but they are very important for understanding speech. To illustrate, the SII calculations treat the speech energy in the various octave bands in accordance to their contribution to intelligibility. They are weighted as follows: for the octave bands at 250, 500, 1000, 2000, 4000 and 8000 Hz, the percentage contribution to intelligibility of the bands are 6.2, 16.7, 23.7, 26.5, 21.4 and 5.5 per cent respectively. Therefore, according to the SII, the three most important frequency bands are 1000, 2000, and 4000 Hz, further demonstrated by the heavy reliance on these frequency bands in determining the onset of impairment (Table 8).

**Table 8:**
**Estimates of the Onset of Hearing Impairment in terms of Average HTL across Specified Test Frequencies and the Equivalent HTL Profiles for Typical Sensorineural Losses**

| Onset of Impairment | Frequency Range | Source | Equivalent Typical Loss HTL Profile |
|---|---|---|---|
| 19 dB HL | 1000, 2000, 3000 Hz | Acton (1970), Suter (1978, 1985) | Profile 6 |
| 25 dB HL | 500, 1000, 2000, 3000 Hz | AAO (1979) | Profile 11 |
| 20 dB HL | 1000, 2000, 4000 Hz | BAOL / BSA (1983) | Profile 6 |
| 27 to 34 dB; Mean: 30 dB | 1000, 2000, 3000 Hz | Robinson *et al.* (1984) | Profiles 10 to 13 (Mean Profile 11) |
| 30 dB HL | 2000, 4000 Hz | Smoorenburg (1992) | Profile 8 |

## *Operational Communications Requirements*

The task analysis procedures completed during Phase 2 identified critical hearing requirements in each department (e.g., Deck, Engineering and Logistics), as well as those requirements of all departments (e.g., MED tasks). The most commonly identified hearing requirement was verbal communication, whether direct or indirect (e.g., over an electro-acoustic communication device). The participants in the Focus Groups and Subject Matter Expert meetings emphasized that verbal communication in a variety of vessel locations (e.g., bridge, engine control room, deck, galley) and working conditions (e.g., wind, engine noise) was very important both to completing the task efficiently, but more importantly completing the task safely. Selecting minimum criteria for hearing performance with voice communications was to be extremely important in recommending an overall minimum standard.

Beranek (1947) conducted an early investigation to test the validity of the AI concept by comparing its predictions with measured discrimination scores. Using aircraft variable-gain intercommunication systems and speech-spectrum shaped white-noise masking, listeners' responses to single-word CVC, CV and VC word stimuli (Fletcher and Steinberg, 1929) were compared with calculated AIs for each system and S / N condition. In general, Beranek (1947) concluded that an entirely satisfactory system would have an AI greater than 0.5, while the AI of an unsatisfactory system would be less than 0.3.

The jurisdictions responsible for military and civil operations place great importance on the effectiveness of communication systems. This interest stems not solely from speech communication reliability *per se*, but from the impact of poor speech intelligibility on operator stress and system efficiency. In this context, Cole (1983) stated that an AI of at least 0.6 is required to provide adequate intelligibility with reasonable listening effort. The US Army intelligibility criteria for voice communication systems, contained in MIL-STD-1472 (Anon, 1981), is summarized in Table 9 as a function of AI and PB-word scores.

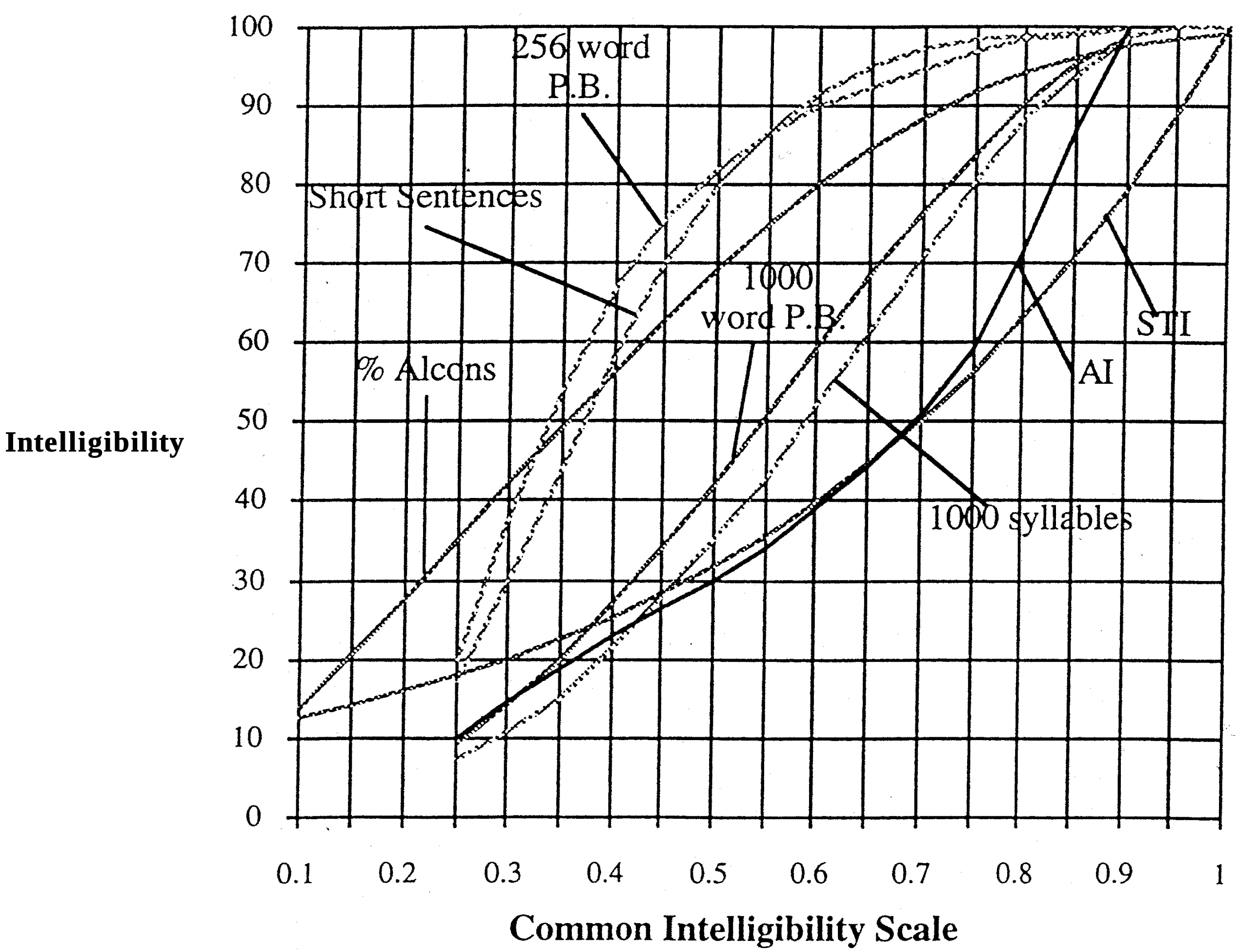
**Table 9:**
**US Army Intelligibility Requirements in terms of PB-Word Scores and the Articulation Index (Anon, 1981)**

| Communication Requirement | PB-Words Correct | Articulation Index |
|---|---|---|
| Exceptionally high intelligibility (separate syllables understood) | 90% | 0.7 |
| Normally acceptable intelligibility (separate syllables understood, about 98% of sentences heard correctly, single digits understood ) | 75% | 0.5 |
| Minimally acceptable intelligibility (limited standardised phrases understood, about 90% of sentences heard correctly; not acceptable for operational equipment) | 43% | 0.3 |

### *Common Intelligibility Scale (CIS)*

In 1992, the UK Institute of Acoustics set up a working group to review various methods of assessing speech intelligibility and to propose a scale from which the measures of intelligibility produced by these methods could be compared. The result was the Common Intelligibility Scale (CIS) (Barnett and Knight, 1995). Included in the CIS were standard intelligibility evaluation methods, including PB 1000-word tests, and the AI and STI (Figure 9). The CIS was used to compare similarities between the STI and AI intelligibility scores. Table 10 provides data samples from the CIS presented in Figure 9 to demonstrate that for CIS values up to approximately 0.70, the STI and AI values are identical. However, above 0.70, AI values begin to exceed STI values.

SII data were not yet available for inclusion in the CIS concept as the new ANSI standard had not yet been developed (ANSI S3.5-1997). In this project, the SII calculations were calculated from apparent speech-spectrum and noise-spectrum levels which were derived from MTFs. Therefore, an investigation was conducted to determine if the SII and STI values calculated from the same MTF were equivalent. A random sample of the MTF data obtained during the pilot study was used to calculate SII and STI pairs. MTF octave-band importance functions for the SII calculations were those for average speech, and the MTF octave-band importance functions for the STI calculations were those used in ANSI S3.5 (1969). The results suggest a near linear relationship (Figure 10). Therefore, for the purpose of this investigation and for the frequency weightings specified above and the speech and noise spectra encountered during the pilot study, the SII and STI pairs were considered to be equivalent, as outlined in Table 9.




NB: The vertical axis is scaled from 0 to 100 to accommodate per cent intelligibility or AI and SII values as is appropriate.

**Figure 9:**
**Relationships between Various Speech Intelligibility Scales and the Common Intelligibility Scale (CIS) (Barnett and Knight, 1995)**

**Table 10:**
**Relationship between Percentage of Correct PB 1000 Word Scores and STI and AI Values as a Function of the Common Intelligibility Scale (after Barnett and Knight, 1995)**

| PB 1000 Word Score | STI/SII* | AI | CIS |
|---|---|---|---|
| 90 | 0.63 | 0.71 | 0.80 |
| 85 | 0.57 | 0.60 | 0.76 |
| 80 | 0.53 | 0.55 | 0.73 |
| 75 | 0.50 | 0.50 | 0.69 |
| 70 | 0.45 | 0.45 | 0.66 |
| 60 | 0.40 | 0.40 | 0.61 |
| 50 | 0.35 | 0.34 | 0.54 |

* SII as derived from pilot study

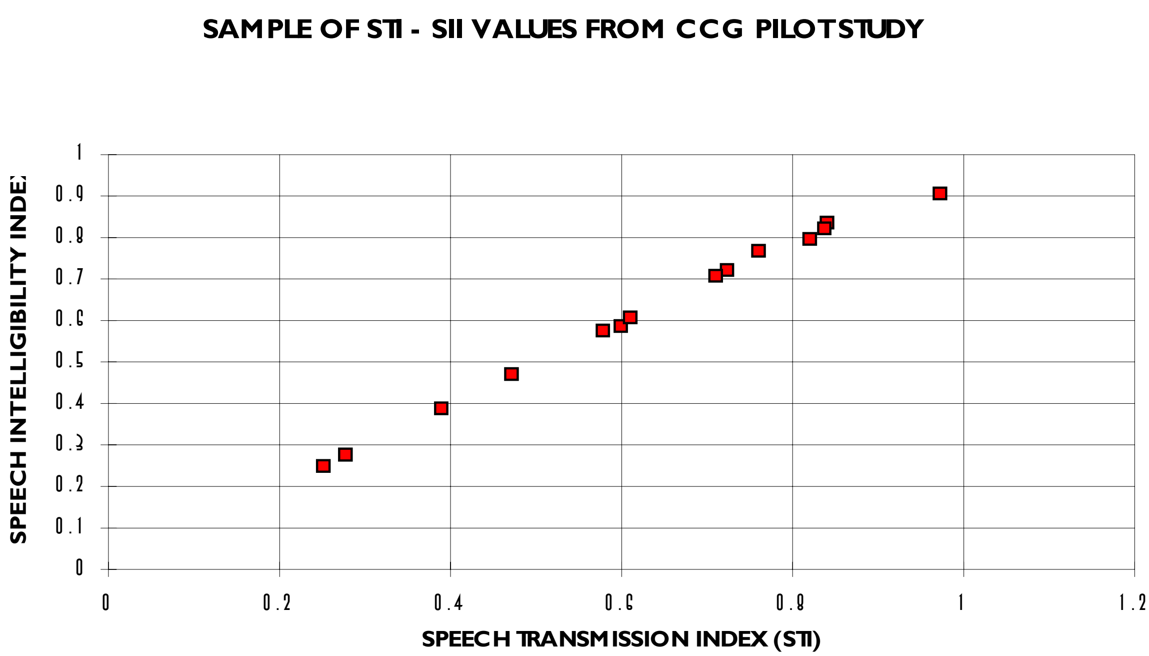



**Figure 10:**
**Calculated STI - SII Pairs from Pilot Study Data Sample**

Given the derivations and information presented above, the US Army communication requirements (Table 9) become: SII = 0.63 for exceptionally high intelligibility; SII = 0.50 for normally acceptable intelligibility; and SII = 0.3 for minimally acceptable intelligibility. Cole's (1983) requirement for adequate intelligibility with reasonable listening effort becomes SII = 0.57.

If one accepts that the communication criteria presented by the military operational sources is applicable to CCG requirements, a limiting SII value may be set at 0.50 or 0.55. On the other hand, if one decides that communication characterised as "normally acceptable intelligibility" (US MIL-STD-1472) is not acceptable, then a limiting SII value may be set at 0.60 or higher to yield "exceptionally high intelligibility. However, this has implications on the number of individuals who would be required to undergo additional audiological testing. Accordingly, for the initial data reduction phase, four SII cut-off values were used: 0.70, 0.60, 0.55, and 0.50.

### *Summary*

Based on the investigation of existing standards and research to determine minimum acceptable hearing impairment, the minimum hearing threshold level was developed. This cut-off, or fence, was developed to act as a clinical indicator to identify personnel requiring additional testing (e.g., speech discrimination, signal detection). A frequency average at 500, 1000, 2000 and 3000 Hz were used to conform with well-accepted and standardized methods used by the American Academy of Otoloaryngology (AAO, 1979), the US Occupational and Safety Health Administration (OSHA) and H&W Canada (Anon, 1994). This frequency average is also in the range used by other researchers (Acton, 1970; Suter, 1978, 1985; Smoorenburg, 1992; Robinson, *et al.* 1984).

In determining the SII cut-off value, a number of existing studies and definitions of hearing ability were considered. The recommended minimum acceptable values of these studies were very similar to each other, as outlined in Table 8. It was important to determine the cut-off based on the importance of hearing contribution to the safety and performance of seagoing personnel to CCG operations. Defined for a civilian / military operational environment, the US-MIL-STD-1472 recommended a minimum SII cut-off value for an environment similar to that experienced by seagoing personnel (Anon, 1981). For this reason, the SII value of 0.50 was considered to be a relevant minimum requirement (Table 9). To complete a thorough analysis, each data file were also analyzed for the HTL profile at SII cut-off values of 0.55, 0.60 and 0.70. These four SII values represented the range of minimum acceptable hearing thresholds suggested by existing literature.

## 2.5 Phase 5: Assessment of Reliability of Hearing Aids

National, international, and industrial standards were reviewed to identify specifications pertaining to hearing aid design, construction, performance, and testing in relation to the exposure of hearing aids to environments such as moisture, salt water, extremes of temperature, mechanical shock, and vibration. Major hearing aid manufacturers were surveyed as to the availability of water / moisture resistant devices, performance data (noise reduction technology, electro-magnetic shielding) and other important features identified in the task analysis conducted in Phase 2.

# 3 RESULTS

In this report, the results of the measures used to determine the minimum level of hearing required for CCG operations are presented by department (i.e., Deck, Engineering, and Logistics). The tasks which were selected for evaluation are listed in Appendix D. The measures include cut-off values for hearing threshold levels, speech transmission, and audibility characteristics of signals and alarms.

## 3.1 Interfacing Task Analysis with Hearing Threshold Levels

The HTL profiles were developed based on expected hearing losses described in ISO Standards 7029 and 1999 (ISO, 1982, 1988). These were used as a guideline to set the cut-off value of the HTL profile required for CCG personnel to perform their duties in an operational environment.

For each data file collected on board the CCG vessels in Phase 3, the cut-off HTL profile corresponding to the SII value of 0.50, 0.55, 0.60 and 0.70 was calculated. From this initial analysis, it became apparent that the SII value limits of 0.60 and 0.70 were extremely restrictive. In a number of data files, a value of 0.70 could not be calculated for that given environment. This was often due to the high levels of ambient noise present in these operating conditions. It was determined that selecting a minimum cut-off of 0.60 or 0.70 would present an unreasonably high initial benchmark, resulting in a very high number of personnel recommended for additional clinical testing. In some operating environments, these SII values could not be achieved, therefore presenting an unreasonable requirement of a human listener with normal hearing. In addition, the SII values of 0.60 and 0.70 represented the more stringent limits suggested by the literature, with many studies suggesting acceptable performance at less restrictive SII values (e.g., 0.50). Therefore, the remainder of the data analysis focused on calculating the mean HTL profile at an SII cut-off at 0.50 and 0.55.

The cut-off HTL profile calculated from each data file representing one operational scenario was categorized by task and by department which performed the task (i.e., Deck, Engineering, Logistics). A cut-off HTL profile was applied to one or more departments if the speech transmission, or signal or alarm was relevant to different tasks completed by different departments. A HTL profile for any task designed as “universal” (e.g., MED task) was applied to each of the three CCG departments.

As the data collected to calculate the minimum hearing requirement were representative of critical tasks which were, in turn, representative of CCG seagoing tasks, the mean HTL was considered to be appropriate method of statistical analysis. Previous research in this area has also used the mean in calculating limiting hearing levels (Acton, 1970; Suter, 1978, 1985; Smoorenburg, 1986, 1992; Robinson *et al.*, 1984; AAO, 1979). Although a relatively small number of data samples were used to calculate the mean, the data plots showed a tight grouping with a consistent fall-off of data to either side of the mean, suggesting selection of the mean was an acceptable statistical method and that the data were reliable.

For each department, a list of all cut-off HTL profiles at an SII value of 0.50 and 0.55 was generated. In the following sections, graphed data summarizing the analysis at only the 0.50 SII cut-off are provided for each department. As expected, the analysis at the 0.55 SII cut-off value moves the distribution of data to be more restrictive, requiring a higher (or better) HTL minimum profile. The implication of these results will be discussed in more detail in Section 4.0.

### *Speech Discrimination*

For each task, data were collected to evaluate direct speech transmission and speech transmission over electro-acoustic communications devices (as described in Section 2.3 and Section 3.1).

The mean and standard deviation of the cut-off HTL profiles for each department was calculated for the typical and atypical hearing loss. As described in Section 2.4.4, the atypical HTL profiles were evaluated to ensure that all types of hearing loss would be addressed by the SII and Detectsound™ analysis. For each department, the typical and atypical HTL profiles were very similar. For this reason, and because typical HTL profiles represent the most common of sensorineural hearing loss, only results for the typical HTL profiles are provided.

To illustrate the results of the data analysis, a sample of the SII analysis for one data file is provided in Appendix H.

### *Signals and Alarms*

The sound pressure signatures for various signals and alarms were collected as described in Section 2.3 and the data were analyzed using the methodology described in Section 2.4.3.

The mean and standard deviation of the cut-off HTL profiles for each department was calculated for the Detectsound™ data. These cut-off profiles were determined by whether or not the sound pressure signatures of signals and alarms were within a normal hearing window. The typical and atypical hearing loss profiles were considered in this analysis. However, as with the speech discrimination data, only the results of the typical HTL profiles are provided.

## 3.2 Deck Department

From the final task list generated during Phase 2, 21 tasks were designated for the Deck Department. In addition, 7 universal tasks were included in this department. As discussed in Section 2.2, the task analysis for the Deck Department was completed with two groups (i.e., Deck Officers and Deck Crew). This department was divided into two groups for the task analysis process because of the large number and variety of the tasks. However, based on the results of Phases 1 and 2, and information gathered during the on-board data collection, it is apparent that depending on the vessel, region and program, tasks in the Deck Department may be performed by either Officers or Crew. Therefore, all data for the Deck Department was combined into one single minimum hearing requirement.

### 3.2.1 Speech Discrimination

Based on the data collected, 105 HTL profiles were calculated for speech discrimination requirements identified for the Deck Department. A histogram representing the distribution of these data is presented in Figure 11, where the HTL profile which is required to satisfy a particular task is plotted as a function of the number of observations for that HTL. As an example, one data file representing one scenario identified by the Deck Department task analysis required a HTL profile of 3, or better. In addition, three of these deck Department scenarios required a HTL profile of 4, or better. At the SII criteria of 0.50, the mean cut-off HTL profile for typical hearing loss was 11.6 with a standard deviation of 3.8.

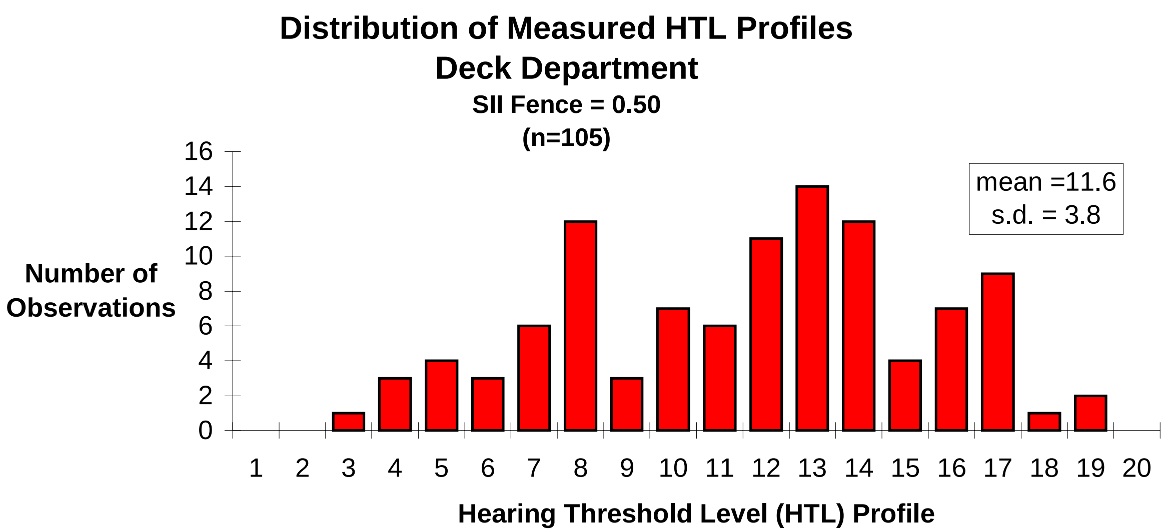



**Figure 11:**
**Distribution of HTL Profiles for Speech Discrimination in the Deck Department**

### 3.2.2 Signal and Alarm Detection

Based on the data designated for the Deck Department, 18 HTL profiles were calculated for signal/alarm detection tasks. The mean cut-off HTL profile was 19.1 with a standard deviation of 4.7.

## 3.3 Engineering Department

From the final task list generated during Phase 2, 4 tasks were identified for the Engineering Department. In addition, 7 universal tasks were assigned to this department.

### 3.3.1 Speech Discrimination

Based on the data collected for the Engineering Department, 56 HTL profiles were calculated for speech discrimination tasks. A histogram representing the distribution of these data are presented in Figure 12. At the SII criteria of 0.50, the mean cut-off HTL profile for a typical hearing loss was 10.5 with a standard deviation of 4.0.

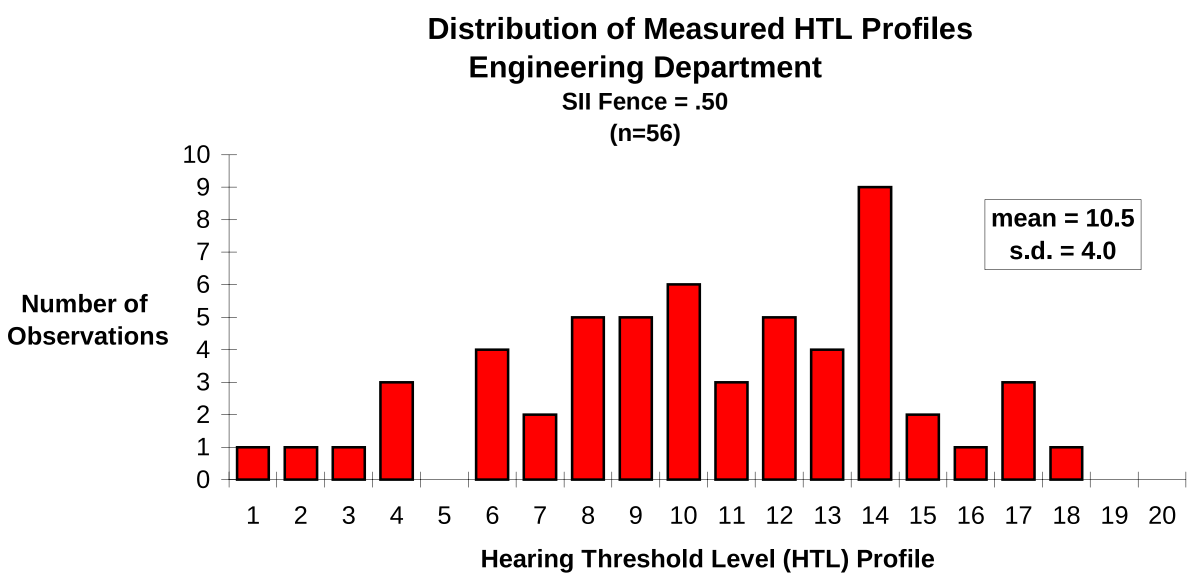



**Figure 12:**
**Distribution of HTL Profiles for Speech Discrimination in the Engineering Department**

### 3.3.2 Signal and Alarm Detection

From the sound pressure signatures collected for signals and alarms related to the duties of the Engineering Department, 8 HTL profiles were calculated for signal/alarm detection tasks in this department. The mean cut-off HTL profile was 13.0 with a standard deviation of 8.8.

## 3.4 Logistics Department

Data collected for the Logistics Department represented 2 tasks from the final task list generated during Phase 2. In addition, 7 universal tasks were included in this department.

### 3.4.1 Speech Discrimination

Based on the tasks which were designated for the Logistics Department, 46 HTL profiles were calculated for speech discrimination tasks identified for this department. A histogram representing the distribution of these data are presented in Figure 13. At the SII criteria of 0.50, the mean cut-off HTL profile for typical hearing loss was 10.6 with a standard deviation of 3.9.

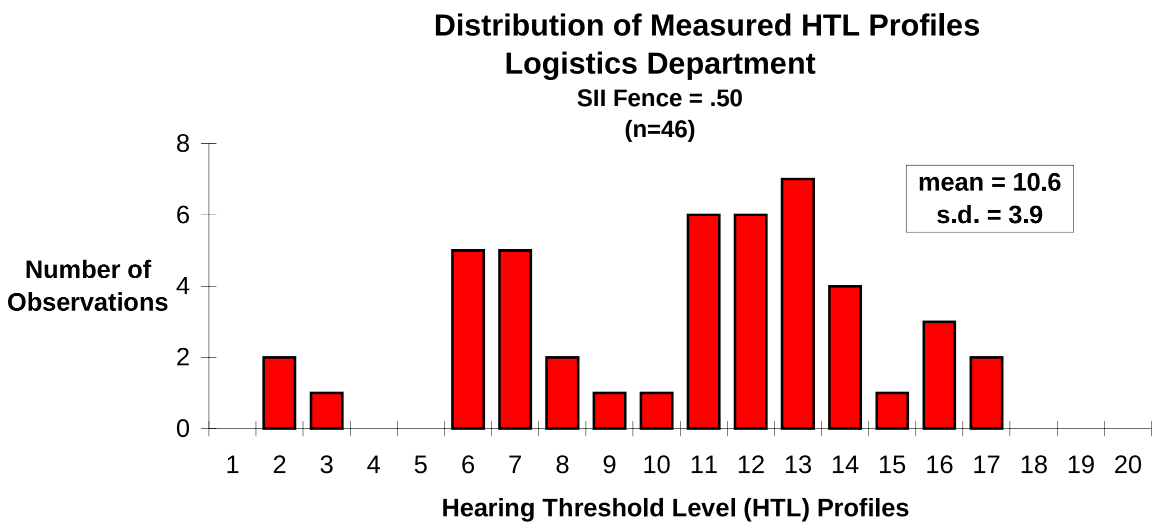



**Figure 13:**
**Distribution of HTL Profiles for Speech Discrimination in the Logistics Department**

### 3.4.2 Signal and Alarm Detection

From the sound pressure signatures collected for signals and alarms related to the duties of the Logistics Department, 6 HTL profiles were calculated for signal/alarm detection tasks in this department. The mean cut-off HTL profile was 17.3 with a standard deviation of 6.5.

## 3.5 Verbal Verification

The results of the verbal verification procedures completed by BC Research personnel during the on-board data collection were inconclusive. The data were intended to provide a performance-based method to compare qualitatively with the engineering acoustical predictions. However, the results suggested factors other than pure speech discrimination had affected the verbal verification data. Overall, the subjects performed very well (with an average SII greater than 0.9). When errors were committed, short-term memory rather than an inability to discriminate words appeared to play a significant role. Given the limitations in the role of the verbal verification, its methodology and the results, the data were not analyzed more thoroughly.

# 4 RECOMMENDATIONS

The objective of the project was to develop recommendations for a preliminary hearing requirement in CCG seagoing operations based on *bona-fide* occupational requirements. The task analysis methodology (Phases 1 and 2) identified the CCG seagoing occupations and operational tasks which are most important to safety and program completion, as well as the critical aspects of hearing to perform these tasks. Acoustic characteristics of the critical tasks were collected in Phase 3 with a representative sample of CCG vessels, regions, and operations. In Phase 4, analysis methods applied to the acoustic data were based on the latest available technology and standards. The analysis methods were modified during the project to include the newly established SII (ANSI S3.5-1997). Issues relative to the use of hearing aids in a marine environment, specifically the impact of reliability on safety and performance were reviewed in Phase 5. Therefore, the recommendations for hearing requirements in CCG seagoing operations are empirically based and directed by the actual requirements of this environment and the latest scientific methodology.

## 4.1 Recommendations for the Hearing Requirement

Based on the results of the speech discrimination and signal and alarm detection analysis presented in Section 3, the recommended minimum HTL profile for each of the three departments (i.e., Deck, Engineering and Logistics) was determined. These recommended minimum HTL profiles are based on SII cut-off values at 0.50. The data on which these recommendations are based include the tasks identified for each specific department, as well as the tasks identified as a requirement of all departments (i.e., generic and MED tasks). The recommended minimum HTL profiles are provided in Table 11.

**Table 11:**
**Recommended Minimum HTL Profiles by Department**

| Department | # Tasks | Minimum Speech Discrimination HTL Profile | | Minimum Signal Detection HTL Profile | | Recommended Overall Minimum HTL Profile |
|---|---|---|---|---|---|---|
| Deck | 21 | HTL 11.6 (sd=3.8) | n=105 | HTL 19.1 (sd=4.7) | n=18 | HTL 11.6 |
| Engineering | 11 | HTL 10.5 (sd=4.0) | n=56 | HTL 13.0 (sd=8.8) | n=8 | HTL 10.5 |
| Logistics | 9 | HTL 10.6 (sd=3.9) | n=46 | HTL 17.3 (sd=6.5) | n=6 | HTL 10.6 |

The minimum HTL profile for the minimum requirement for speech discrimination was identified for each department. As discussed in Section 2.2, data were collapsed in the three departments (e.g., Deck, Engineering and Logistics), with the same hearing requirement identified for both Officers and Crew members within each department. Therefore, one HTL mean profile was calculated for each department. Due to the conformity of the data and the calculated mean and standard deviations, these three department profiles were not found to be significantly different from each other.

Because the analysis methods for the speech discrimination and signal detection data were different, these two types of data were not grouped to calculate an overall minimum HTL profile. The speech discrimination data were chosen to drive the standard for two reasons:

- because most vessels use a few selected audible alarms to alert the user to an alarm panel, the number of files analyzed for the signal detection data was very few compared to the number of files analyzed for the speech intelligibility data which was more variable on board the vessels; and
- the minimum HTL profiles suggested by the signal detection data were less restrictive than those suggested by the speech discrimination data, and were not considered to represent the complete range of hearing requirements required in a CCG seagoing environment. For example, an individual who only satisfied the minimum HTL profile for signals and alarms would not be able to satisfy the minimum HTL for speech discrimination.

In addition, an alarm may be engineered to be more audible to a human listener. This is not as simple an option with human speech. Therefore, speech intelligibility was considered to be the limiting requirement.

## 4.2 Discussion of Results and Recommendations

It was noted in Section 2.3.2 that the derived estimates of auditory task performance with hearing loss in CCG acoustical environments were based on three predictive engineering/psychophysical procedures, each of which was supported by the experimental data. The underlying assumptions of the procedures are approximations of the processes they describe. In addition, as discussed in Section 2.4.5, a review of current standards and previous research in this area was conducted. Estimates of hearing impairments in terms of pure-tone thresholds and operational communications were considered. Based on this review a limiting SII value of 0.50 was selected in recommending a minimum hearing standard criteria.

The results presented in Table 11 indicate that speech discrimination tasks are more susceptible to degraded performance due to sensorineural hearing loss than the signal detection tasks. The recommended overall minimum HTL profiles are determined by the speech discrimination limits (Table 11). Using a limiting SII value of 0.50, the minimum HTL profiles for CCG personnel to complete their tasks in an operational environment are HTL Profile 10 (i.e., Engineering and Logistics Departments) and Profile 11 (i.e., Deck Department). The resulting question is whether the derived estimates of speech discrimination are reasonable.

The estimates of onset of hearing impairment for speech reception in terms of pure-tone HTL profiles reviewed in Section 2.4.5 are provided in Figure 14 (Acton, 1970; Suter, 1978; AAO, 1979; BAOL/BSA, 1983; Robinson *et al.*, 1984; Smoorenburg, 1992). This figure also includes the HTL profiles of the current H&W Class 1 standard (i.e., current CCG hearing standard) (Anon, 1994) and the Canadian Forces H1 Standard (i.e., directed to air crew) (CAF, 1995). The range of hearing impairment onsets of Robinson *et al.* (1984), between profiles 10.5 and 13.5, are denoted by the small stars.

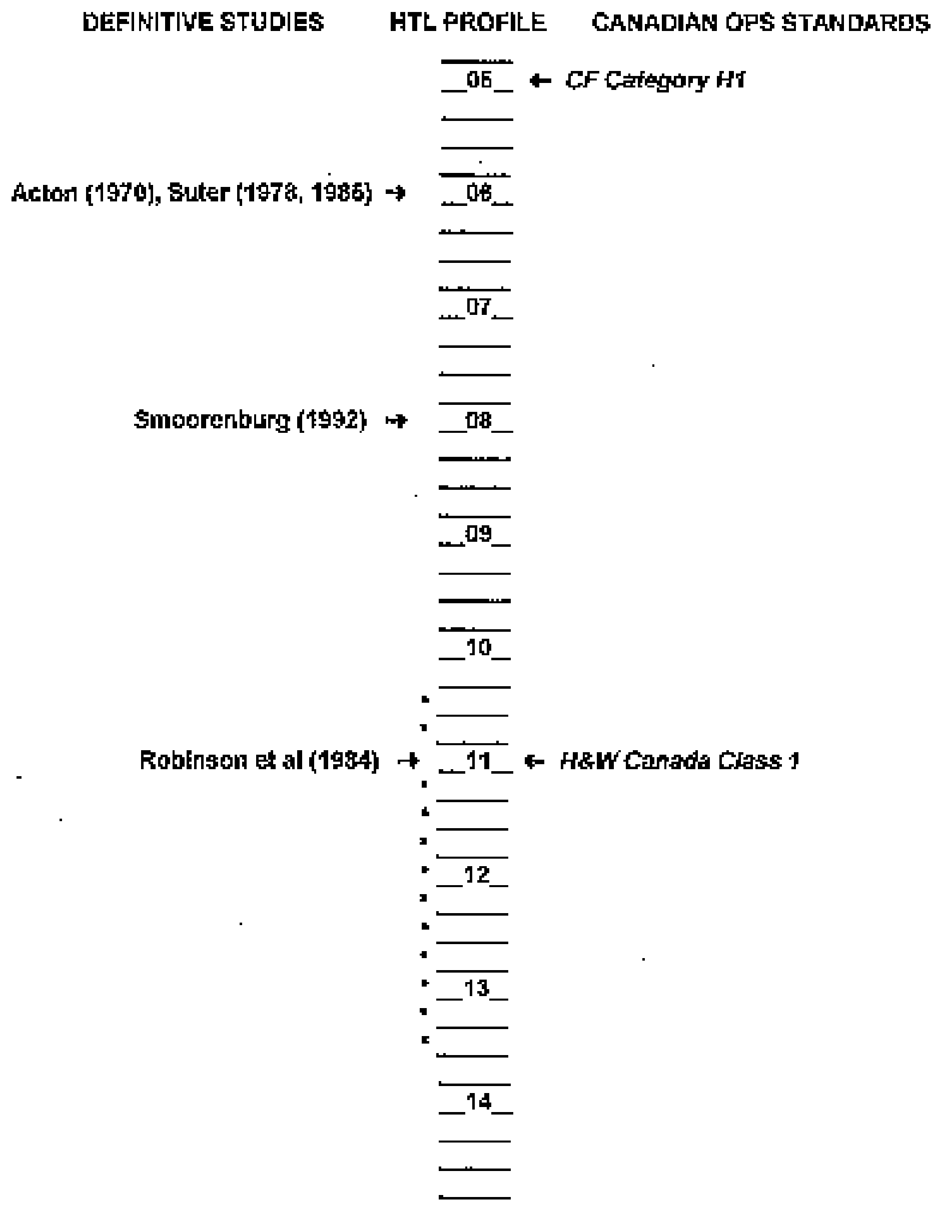



**Figure 14:**
**Onset of Hearing Impairment for Speech Reception in Terms of Hearing Threshold Levels (HTL) Profiles**

Figure 14 suggests that Robinson *et al.* (1984), the current H&W Class 1 standard, and the requirements based on the empirical methods in the current study recommend a similar minimum HTL profile. The three minimum HTL profiles for the Deck, Engineering, and Logistics Departments (11.6, 10.5, and 10.6 respectively) fit on the HTL profile scale within the range (e.g., HTL profiles 10 to 13) of the Robinson *et al.* (1984) estimates for the onset of hearing impairment for speech reception, and are close to the H&W Class 1 Standard (e.g., HTL profile 11.0). When the more stringent SII cut-off value of 0.55 was applied to the data, the minimum HTL profiles for the Deck, Engineering, and Logistics Departments became 8.2, 6.8, and 7.4 respectively. These fit on the profile scale from below the Acton (1970) and Suter (1978, 1985) estimates for the onset of hearing impairment for speech reception to above the estimate of Smoorenburg (1992).

The minimum HTL profiles for the three departments, including Universal tasks, are transformed to HTL threshold low fences as a function of SII cut-off values in Table 12. These values were determined by using the HTL provides in Appendix F, for the average loss of the frequency bands of 500, 1000, 2000, and 3000 Hz. This threshold of 25dB is recommended for all three departments (e.g., Deck, Engineering, Logistics).

**Table 12:**
**Estimate of the Onset of Hearing Impairment for Speech Discrimination in Terms of Hearing Levels (averaged at 500, 1000, 2000, and 3000 Hz)**

| Department | SII = 0.50 | SII = 0.55 |
|---|---|---|
| Deck | 25 dB | 21 dB |
| Engineering | 24 dB | 17 dB |
| Logistics | 24 dB | 19 dB |

The 25 dB low fence threshold is recommended for both ears. This was determined to be a reasonable methodology as this is a recommendation for first stage testing and additional second round testing will require further development. In addition, recognizing localization abilities to be an important requirement, asymmetry may further complicate the preliminary standard. Finally, a number of existing hearing requirements, including the Canadian Forces, US Air Force, US Navy, US Army and US Coast Guard, allow only the same loss in both ears (Hamilton and Forshaw, 1997). Therefore, a level of 25 dB is the recommended limit for both ears.

### 4.2.1 Summary

The SII cut-off value of 0.50 is the recommended minimum hearing level. It was selected over the SII value 0.55 as the statistical analysis did not suggest a significant difference in hearing requirement between the two cut-off values. In addition, the cut-off value of 0.50 has been recommended and standardized in a similar operating environment in which performance at this level can be expected to represent “normally acceptable intelligibility with syllables understood, about 98% of sentences heard correctly and single digits understood” (Anon, 1981). It is emphasized that the SII values only suggest the availability of auditory cues to a human listener. With experience and other non-auditory cues (e.g., hand signals, flashing alarm lights) which are commonly observed during the on-board data collection, performance would be expected to improve. Based on the reviewed literature, the conformity of the data, the variability of the seagoing environment and the fact that this is a preliminary standard to be followed by additional clinical testing if required , the selection of an SII cut-off value of 0.50 and its results are considered to be a reasonable and appropriate methodology.

## 4.3 Recommendations for Tests and Testing Procedures

It must be emphasized that the HTL profiles recommended by this research are intended to represent the minimum HTL profile required to pass a first round of audiological testing. Those individuals whose pure-tone audiograms meet this profile require no additional testing and should be considered to meet the medical requirement for hearing. However, those individuals who do not meet this requirement should be directed to additional otological/audiological assessment. The assessment should include the following:

- speech discrimination (e.g., for direct and indirect verbal communication);
- signal detection (e.g., for signals and alarms); and
- localization abilities (e.g., for locating a sound source).

The results of this additional testing may result in the following:

- the individual passes each dimension and is considered to meet the medical requirement for hearing; or
- the individual fails to meet the requirement on one or more dimensions, and the potential for job accommodation is considered on a case-by-case basis.

Recommendations for further testing methods (e.g., speech, alarms and localization) and the minimum requirement for each of the specific hearing dimensions were not included in the scope of the current research. Additional research involving extensive clinical testing and the development of normative data for each hearing requirement are recommended.

A brief summary of the available testing methods for each of the three main hearing abilities are provided below and should be considered by CCG for subsequent testing in the event that an individual produces an audiogram that does not meet the minimum recommended hearing requirement. At the time of this report appropriate clinical testing procedures have not yet been fully developed.

### 4.3.1 Speech Discrimination

A number of speech discrimination testing methods have been developed which may be relevant to the CCG seagoing environment. It is recommended that the clinical test that is selected includes a component of speech discrimination in noise, as this is a consistent requirement of CCG operations. Potential testing methods include:

- Speech Perception in Noise (SPIN) (Bilger *et al.*, 1984; Kalikow *et al.*, 1977);
- Four Alternative Auditory Feature Test (FAAF) (Foster and Haggard, 1979); and

- Hearing in Noise Test (HINT) (Nilsson *et al.*, 1996, 1994).

An issue related to speech discrimination testing is that the testing procedures have not yet been developed in French. To truly represent the CCG seagoing population, an equivalent speech testing procedure in French should be developed.

### 4.3.2 Signal Detection

Additional tests specific to signal detection may involve using recorded alarms and signals used on CCG vessels in a variety of background noise conditions. This type of testing differs from the pure-tone audiometric methods currently used as the signals would include multiple frequencies and would be presented in background noise conditions, similar to the speech discrimination.

### 4.3.3 Localization

During the Phase 2 Task Analysis, CCG operational experts identified a need for localization in all of the 34 tasks identified for on-board data collection. However, at the time of this research, a clinical localization testing method has not been developed for commercial use. A new testing method is currently being developed by the House Ear Institute in the US (Drs. Michael Nilsson and Sigfrid Soli). The Source Azimuth Identification in Noise Test (SAINT) is a computerized system under development and is intended to measure functional hearing ability. It is expected that this test will be available within a one-year period.

## 4.4 Recommendations for Hearing Aids

The reliability of hearing aids in a marine environment was considered in Phase 5 of the current study. The interim report from Phase 5 is included in Appendix I. Overall conclusions from this assessment of hearing aids are outlined below.

Sensorineural pathologies involve reduced sensitivity or resolving power of the neural receptor mechanisms themselves and are not amenable to medical intervention. Hence, hearing aids are prescribed primarily for individuals with sensorineural loss. Occasionally, hearing aids are useful for persons with conductive loss for whom surgery may not be appropriate.

Based on the limited information available in the open literature on the reliability of hearing aids, it appears that malfunctions begin to occur in a significant proportion of hearing aids within the first two years of use. Furthermore, the risk of malfunction is likely to increase if a hearing aid that does not have some degree of water protection is exposed to moisture. Hearing aids used in harsh environmental conditions which can be expected to occur with CCG operations should be tested more often than the standard two year limit to malfunction.

Notwithstanding the fact that water-resistant hearing aids improve hearing reliability, ***CCG should ensure that employees who require hearing aids to meet the hearing criteria undergo testing in a clinical setting while using their hearing aids*** (Forshaw and Hamilton, 1997). This would ensure that individuals meet the speech discrimination, signal detection, and sound localization criteria required for operational effectiveness when using their hearing aid.

From the available literature, it is not possible to know the effect of the ship's environment on the reliability and effectiveness of a hearing aid. For example, unless the electromagnetic radiation (EMR) environment of each vessel is determined, in combination with the sensitivity of each type of hearing aid to EMR, a firm recommendation on hearing aid use is not possible. As well, the moisture environments to which CCG employees are exposed is variable, and this will also affect hearing aid reliability in an undetermined way. Before making a final recommendation on the degree of moisture resistance or moisture repellency, a hearing aid should be subjected to a longitudinal field study.

Finally, the lack of standards to regulate the manufacture and performance of hearing aids with respect to water protection, as well as the uncertainty about the reliability of the hearing aid in the types of environments to which CCG employees are exposed, leaves the decision of which hearing aid to select to the preference of an individual for a particular hearing aid design.

## 4.5 Limitations and Future Directions

The data collection and analysis methodology were adaptations of the latest research and standards relevant to the development of hearing standards, considering the issues and environments experienced in CCG seagoing operations. Each decision point in the project was carefully considered to ensure operational relevance, based on a strong theoretical, technological and research expertise. The interpretation of this report is subject to a number of limitations, including some related to data collection conducted in the field. Other limitations are related to the unique, ground-breaking research that was completed to develop BFORs in this type of environment. The limitations include the following:

- the number of tasks that could be evaluated during the on-board data collection was limited due to issues of time, cost, and feasibility;
- due to vessel and crew scheduling and availability , the number and type of CCG vessels and regions, and DFO / CCG programs were limited;
- acoustic data in some environments could not be collected due to logistical constraints (i.e., meteorological conditions, lack of power supply);
- the data are based on predictive engineering analysis methodology and require psychoacoustic normative data for further validation and development of testing methodology;
- some clinical testing methods that were recommended for subsequent testing have not been developed at the time of this report (i.e., French speech discrimination tests, localization tests); and
- the information available on the reliability of hearing aids in marine environments was limited and may require simulation testing and / or field evaluation as a further investigation.

## 4.6 Conclusions

The minimum recommended HTL is profile 11, or a 25 dB hearing loss in both ears. This value was the result of a SII cut-off of 0.50. It must be emphasized that this is a preliminary standard for first stage pure-tone audiological testing. If the individual does not meet this first stage HTL, it is recommended they proceed to a second stage of specialized testing involving speech discrimination, signal detection and localization tests.

From the limitations, a number of future directions were identified. These include: the development of clinical testing procedures to investigate speech discrimination, signal detection and localization that reflect the CCG seagoing environment; and validation of the recommended standard using normative data to further establish the minimum hearing requirements in these occupations.

Considering the project limitations and requirements for future research, the project methodology that was developed met the requirements of the CHRC that medical standards and subsequent testing procedures are based on the following:

- identification of essential tasks that are the requirements of the job;
- identification of relevant skills and capabilities required to perform the essential tasks of the job;
- methods that evaluate the ability of the individual to perform essential tasks of the job with regard to reasonable accommodation; and
- standards that do not exceed the minimum requirements of the job (CHRRS, 1982, TR/82-3).

The comprehensive task analysis methodology and ground-breaking analysis procedures used during this project met the requirement to develop a task-oriented minimum medical standard focused on safety, performance, and fairness.

# GLOSSARY

***A-Weighted Sound Pressure Level:*** See ***Weighting Network***.

***AI:*** See ***Articulation Index.***

***Air Conduction:*** The transmission of sound through the outer ear and middle ear to the inner ear, as opposed to ***Bone Conduction***, whereby sound vibrations are transmitted through the temporal bone directly to the middle ear and inner ear.

***ANSI:*** American National Standards Institute.

***Apparent Speech Spectrum Level:*** The level for speech where physical measurement of the actual speech level is not feasible because of otherwise disturbing conditions (e.g., reverberation).

***Apparent Speech-to-Noise Ratio:*** At a specified frequency, the difference in dB between the apparent speech-spectrum level and the apparent noise-spectrum level.

***Articulation Index (AI):*** The weighted fraction representing the effective proportion of the normal speech signal that is available for conveying speech intelligibility for a given speech channel, and noise condition. The AI has been applied for predicting the speech-recognition performance of hearing-impaired listeners.

***ARTS:*** Age-Related Threshold Shift (i.e., presbycusis).

***Audiogram:*** A graph for showing hearing loss or hearing level as a function of frequency.

***Auditory Filter:*** See ***Psychophysical Tuning Curve.***

***Bandwidth:*** The range of frequencies contained in a signal or in a filter pass band.

***Behind-the-ear (BTE) Hearing Aid:*** A relatively small instrument whose electronic components are housed in a small elliptical case that fits behind the ear. The acoustical signals generated by the receiver are delivered to the ear canal by means of a flexible tube (termed a “hook”) terminating in an earmold.

***BFORs:*** *Bona fide* Occupational Requirements.

***Binaural:*** Hearing with both ears.

***Bone Conduction:*** See ***Air Conduction***.

***C-Weighted Sound Pressure Level:*** See ***Weighting Network***.

***CCG:*** Canadian Coast Guard.

***CHRC:*** Canadian Human Rights Commission.

***CIS:*** Common Intelligibility Scale.

***CO:*** Commanding Officer.

***Cochlea:*** That part of the inner ear in which sound-pressure variations are transformed into neural impulses.

***Completely-in-the-Canal (CIC) Hearing Aid:*** A micro-technology aid that fits deep inside the ear canal.

***Conductive Hearing Loss:*** An interference with the normal mechanical transmission of sound energy from the external ear to the inner ear.

***CV:*** Consonant-vowel.

***CVC:*** Consonant-vowel-consonant.

***dB:*** Decibels.

***Detectsound™:*** A computerized model for predicting the detectability of signals in noisy environments.

***DFO:*** Department of Fisheries and Oceans.

***Dynamic Range:*** The intensity range of a signal, usually expressed in decibels (dB).

***EPA:*** Environmental Protection Agency.

***FAAF:*** Four Alternative Auditory Feature Test.

***Fence:*** A hearing threshold level above which degrees of hearing impairment (or disability) are deemed to exist.

***Filter:*** An electronic device for suppressing electrical or sound waves of frequencies not required. A bandpass filter passes frequencies between the lower and the upper cut-off frequencies.

***Focus Group:*** During Phase 2, a group of CCG/DFO representatives from all five CCG regions to confirm seagoing tasks with a critical hearing requirement.

***Frequency Selectivity:*** The ability of the auditory system to separate the frequency components of a complex sound and to detect differences in spectrum shape between sounds.

***H&W:*** Health and Welfare Canada.

***Hearing Level (HL)/Hearing Threshold Level (HTL):*** The intensity of a sound in decibels (dB) relative to the average threshold of hearing of young normal adults.

***HINT:*** Hearing In Noise Test.

***Hertz (Hz):*** A unit of frequency.

***In-the-Canal (ITC) Hearing Aid:*** A hearing aid that fits entirely in the ear canal.

***In-the-Ear (ITE) Hearing Aid:*** All the components are contained in a small plastic case that is moulded to fit into the wearer's ear. It occupies the outer portion of the external ear canal and the innermost part of the external ear.

***ISO:*** International Organization for Standardization.

***Leq:*** Equivalent sound level (Leq) equals the continuous sound level which, integrated over a specific time, would result in the same energy as a variable sound level integrated over the same time.

***Localization***: The ability to locate a sound source in three-dimensional space.

***Masking:*** The process of raising the threshold for a given stimulus by the introduction of a second stimulus.

***MED:*** Marine Emergency Duties.

***MLSSA:*** Maximum Length Sequence System Analyzer**.**

***Modulation Transfer Function (MTF):*** The extent to which sinusoidal intensity modulations in a given frequency band, produced at a speaker's position, have been affected by reverberation and ambient noise as they reach a listener's position.

***Monaural:*** Hearing with one ear.

***Neural Hearing Loss:*** A dysfunction in the orderly transmission of electrical energy from the inner ear through the acoustic nervous system to the cerebral cortex.

***NIPTS: N***oise-Induced Permanent Threshold Shift.

***Octave:*** The interval between two tones that are separated by a frequency ratio of 2:1.

***OIC:*** Officer-in-Charge.

***Operational Experts:*** During Phase 2, a group of CCG / DFO senior representatives to finalize a list of seagoing tasks with a critical hearing requirement to be measured during Phase 3: On-board Data Collection.

***PB Words:*** See ***Phonetically Balanced (PB) Words***.

***Peak Clipping:*** The elimination of all portions of a sound at the output of an amplifier that exceed some specified level.

***Phonetically Balanced (PB) Words:*** Monosyllabic words arranged in lists of 50, 200, or 1000, representative of commonly used English speech. The lists are used in hearing-test clinics to test the speech discrimination abilities of hard-of-hearing patients, and in communication laboratories to evaluate the speech-transmission characteristics of equipment.

***Presbycusis:*** A defect of hearing incident to advancing age.

***Psychophysical Tuning Curve:*** The action of auditory signal processing whereby a signal-tone and all noise in a narrow band about it, termed a critical band, is allowed to pass. Noise outside the band is attenuated. The region just outside the critical band where the attenuation changes to or from its band-pass to its band-rejection value is often termed the "skirt" of the filter.

***Pure Tone:*** A sound wave whose instantaneous sound pressure is a sinusoidal function of time.

***Reverberation:*** The persistence of sound in an enclosure after a sound source has been stopped.

***S/N:*** Speech-to-Noise Ratio.

***SAINT:*** Source Azimuth Identification in Noise Test.

***Sensorineural Hearing Loss:*** Generally, hearing losses that are not conductive.

***Sensory Hearing Loss:*** A dysfunction of the sensory system of the inner ear.

***SII:*** See ***Speech Intelligibility Index***.

***SLM:*** Sound Level Meter.

***SMEs:*** See ***Subject Matter Experts***.

***Sound Pressure:*** The dynamic variation in atmospheric pressure produced by a sound wave.

***Sound Pressure Level (SPL):*** The fundamental measure of sound pressure. Defined as 20 times the logarithmic ratio of a given sound pressure to a reference sound pressure, in decibels (dB). The reference sound pressure is 20 micropascals.

***Spectrum Level:*** Spectrum Level of a speech signal or noise is the ratio of the speech-signal or noise SPL, to the bandwidth of the speech-signal or noise, in decibels (dB).

***Speech Intelligibility Index (SII):*** Speech Intelligibility Index is a method of computing a physical measure that is highly correlated with the intelligibility of speech under a variety of adverse listening condition, such as noise, filtering, and reverberation. It is a major revision of the ***Articulation Index (AI)*** method.

***Speech Reception Threshold (SRT):*** The Hearing Level (dB) at which a listener can identify 50 per cent of two-syllable test words having equal stress on both syllables, or the Hearing Level at which the listener can just barely follow continuous discourse with concentrated listening.

***Speech Transmission Index (STI):*** A frequency-weighted mean of the apparent signal-to-noise ratios in the seven octave bands between 125 and 8000 Hz. The latter are derived from the respective octave-band modulation transfer functions (MTFs).

***SPIN Test:*** Speech Perception in Noise Test.

***SSARAH:*** Speech Source for Acoustical Research in Architecture and Hearing.

***Subject Matter Experts:*** During Phase 2, a group of CCG / DFO representatives from the CCG Pacific region to identify seagoing tasks with a critical hearing requirement.

***Suprathreshold:*** Above threshold.

***TDC:*** Transportation Development Centre.

***VC:*** Vowel-consonant.

***Weighting Network:*** An electrical filter incorporated in the amplifying circuits of measuring instruments (e.g., sound level meters) to produce a specific electro-acoustic frequency response. The "A" weighting network of the sound level meter, for example, approximates the human loudness-response to sound by de-emphasizing the low-frequency components of the sound. The "C" weighting network approximates a uniform response of the frequency range between about 100 Hz and 5000 Hz. Sound pressure levels with A-weightings are expressed as dBA. The sound pressure level of a sound, expressed in dB, is assumed to be C-weighted unless specified otherwise.

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# APPENDIX A

## BC Research Team Members

## *BC Research Inc.*
## *Ergonomics and Human Factors Group*

| | |
|---|---|
| Barbara Cameron, Ph.D. | Project management |
| Laurel Ritmiller, M.Sc. | Project management, methodology, coordination of technical team, task analysis, on-board data collection, data analysis, report writing |
| Joanna Zander, B.Sc. | Task analysis, on-board data collection |

## *Project Consultants*

| | |
|---|---|
| Stanley Forshaw, P.Eng. | Methodology, data analysis, data interpretation, report writing |
| Kevin Hamilton, Ph.D. | Project management (when as a BC Research employee), task analysis, methodology, report writing |
| Murray Hodgson, Ph.D., C.Eng | Methodology, data analysis, data interpretation, report writing |
| Chantal Laroche, Ph.D. | Methodology, data analysis, data interpretation, report writing |
| Victor Leung, B.Sc. | Data analysis |

# APPENDIX B

## Task Analysis Methodology

# CCG HEARING STANDARDS: TASK ANALYSIS

## 1.0 General Information (group: )

**1.1 Task Name and Program:**

**1.2 General Task Description:**

**1.3 What type of cues are there for initiating this task?**
**(Signals, verbal or written instructions, etc.)**

**1.4 What is the purpose, goal or objective of this task?**

**1.5 If this is a routine task, on average, how frequently is it carried out? If this is not a routine task, go to question 1.6.**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= ≥ once per 30 min.**
**5= once per day**
**9= ≤ once per 28 day crewing period**

**1.6 If this is not a routine task, what does it's frequency depend upon?**

**Under these conditions, on average, how often is the task carried out? (use a range if necessary)**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= ≥ once per 30 min.**
**5= once per day**
**9= ≤ once per 28 day crewing period**

**1.7 On average, how long does it usually take to carry out this task?**

**1.8 Is this task part of a sequence of tasks that is important to the successful completion of other tasks? (Y/N)**

**1.9 Are other tasks generally carried out at the same time as this task? (Y/N)**

**If yes, what are examples of some of these tasks?**

## 2.0 Task Environment

**2.1 Where on or off the vessel is this task usually carried out?**

**2.2 In carrying out this task, what percentage of the time is spent in an open environment?**

**2.3 In carrying out this task, what percentage of the time is spent in a closed environment?**

**2.4 In carrying out this task, to what level of ambient noise are you generally exposed? Please use the scale provided below.**

**If necessary, use a range to describe the level of ambient noise and provide information on factors that may influence this range (e.g., programs, time of year, vessel type, etc.).**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= quiet enough for relaxed conversation while along side with engines off (light traffic, refrigerator: 40-50 dB)**
**5= Type 300 wheelhouse when engines are running (loud home stereo: 80 dB)**
**9= engine room with all engines running (threshold of pain: 110-130 dB)**

**2.5 In carrying out this task, is hearing protection or head gear generally worn ? (Y/N)**

**2.6 In carrying out this task, are you exposed to meteorological conditions (wind, rain, reduced visibility)? (Y/N)**

**If Yes, can clothing such as hooded rain gear affect hearing on this task? (Y/N)**

**2.7 In carrying out this task, are you exposed to sea conditions (e.g., noise of wind, spray, rough seas)? (Y/N)**

**2.8 In carrying out this task, do you work close to electrical or electronic equipment such as radar scanners, radios, antenna, wireless phones, etc.? (Y/N)**

**2.9 In carrying out this task are you exposed to any other environmental factors that may influence your performance?**

## 3.0 Auditory Processing

**3.1 In carrying out this task, is speech communication generally used? (Y/N)**

**3.2 In carrying out this task, do you need to hear warning signals or alarms? (Y/N)**

**3.3 In carrying out this task, do you need to be able to localize where sounds or speech are coming from? (Y/N)**

**3.4 In carrying out this task, are there other sounds such as machinery or equipment noises that are important to hear? (Y/N)**

**If yes, what are they?**

**3.5 In carrying out this task, what percentage of time is active listening involved?**

**3.6 In carrying out this task, what percentage of time is passive hearing actually involved?**

**3.7 How much auditory effort is required to perform this task? For example, if you have to attend to specific sounds when there is background noise or if you have to selectively attend to one radio when others are operating at the same time.**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**3.8 How important is experience with the task to being able to carry out this task successfully?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**3.9 How important is experience in the work environment (e.g. noise, ship motion, cold, poor visibility) in being able to carry out this task successfully?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

## 4.0 Communication Characteristics

**4.1 With whom do you normally interact to perform this task?**

**4.2 To what extent are a restricted number of familiar terms or commands generally used when performing this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**4.3 Is information usually repeated in performing this task? (Y/N)**

**If Yes, how often and what are some examples of what is repeated?**

**4.4 Is there feedback that the communications in this task has been received? (Y/N)**

**If Yes, is it auditory or other?**

**4.5 What type of voice is generally used when communicating for this task (relaxed, normal voice, raised voice, very loud voice, shouting)?**

**4.6 In carrying out this task, do you usually interact directly with other people? (Y/N)**

**If yes, what is your usual proximity to these people (0-3m, 3-6m, >6m)?**

**Is this communication usually face to face? Y/N**

**4.7 In carrying out this task, are hand or other types of signals generally used ? (Y/N)**

**4.8 In carrying out this task, do you interact with others using communications equipment (e.g., radio, telephone, etc.)? (Y/N)**

**If yes, list the communications equipment used:**

**4.9 What is your usual physical proximity to the communications equipment? (0-3m, 3-6m, >6m)**

## 5.0 Possible Errors

**5.1 Is there a potential for missed communications in performing this task (signals, sounds, incorrect localization)? (Y/N)**

**If Yes, can this result from equipment failure, background noise, competing voices or other sounds, being occupied with too many tasks at the same time, (other)? (Y/N)**

**5.2 Are there any mechanical or electrical error detection mechanisms for this task? (Y/N)**

**If Yes, what are they?**

**5.3 Are other crew likely to observe that an error has occurred on this task? (Y/N)**

**5.4 Are you ever alone when carrying out this task? (Y/N)**

**If Yes, under what conditions are you likely to be alone?**

**5.5 How difficult is it to determine that an error has occurred on this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**5.6 What are the possible consequences of an error on this task (Potential Risks)?**

## 6.0 Criticality of Hearing

**6.1 How critical or important is hearing to being able to successfully complete this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**6.2 How critical or important is hearing to your own safety in performing this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**6.3 How critical or important is hearing to the safety of others and the vessel in performing this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

## 7.0 Vessel Types and Vessel Activity

**7.1 To what extent do the hearing requirements of the task differ on different vessels?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**If the difference between vessels is above 5, what would you consider to be the most difficult vessels for carrying out this task and why?**

**What would you consider to be an average or typical vessel for carrying out this task?**

**7.2 To what extent do the hearing requirements of this task differ with different types of vessel activity (i.e., at anchor, steaming, alongside)?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**If the difference between types of vessel activity is above 5, what would you consider the most difficult type of vessel activity for carrying out this task and why?**

**What would you consider to be an average type of vessel activity for carrying out this task?**

## 8.0 Task Ranking: Summary

**Job Titles:**

**8.1 Task Name:**

**8.2 Task Frequency:**

**Low Medium High**

**8.3 Overall criticality of hearing to the task:**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**8.4 Possible consequences of an error:**

**8.5 How critical or important is hearing to your own safety in performing this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**8.6 How critical or important is hearing to the safety of others and the vessel in performing this task?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**8.7 Overall, how critical is hearing to carrying out <u>this task</u> safely (based on Questions 8.4 to 8.6)?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

**8.8 Overall, how important is <u>this task</u> to vessel operations to this program completion?**

**1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9**

**1= not at all**
**5= somewhat**
**9= a great deal**

# APPENDIX C

## CCG/TDC Operational Review

# Operational Experts Review of the Task Analysis and Program Tasks Selected for Data Collection

## Process and Outcome Overview

A meeting of DFO / CCG Operational Experts was held on May 27, 1998 to review the draft list of 52 program tasks previously selected for data collection. The purpose of this review was to confirm that the list of 52 program tasks was accurate in terms of:

- How the program task was performed
- The environment in which it was performed
- Level of criticality
- Level of frequency

The Operational Experts were also asked to select pre-merger DFO program tasks, based on the previously developed program task selection criteria used by the Subject Matter Experts (SME) to select the 52 program tasks (Appendix A), as this selection was not possible during the earlier focus group meetings. The DFO program tasks would also be included in the final program task list.

The meeting was attended by:

- DFO / CCG Project Manager, Joanne Jankun;
- DFO / CCG Project Assistant, Sharon Robertson;
- TDC, TC Project Officer (consultant to TDC), Betty Ann Turpin; and
- Four DFO / CCG Operational Experts (Drew Edey, Chief Engineer, Western; Shaun Potter, A / Chief Mate, Western; John Stewart, Commanding Officer, Maritimes and Randy Hayes, Logistics Officer, Nfld.).

The agenda for the day was as follows:

- Introduction
- Explanation of the task analysis process
- Debriefing on the process to review the task analysis methodology and tasks selected for data collection
- Discussion and questions
- Confirmation of information gathered on DFO Program tasks (Science & Trawling)
- Confirmation and revision of the draft list of program tasks selected for data collection purposes.

Details of the agenda are provided below.

### *Introduction*

Ms. J. Jankun outlined the purpose of the meeting and the process that would be followed to address the agenda items. Ms. Jankun provided an update on the Hearing Standards Project to the Operational Experts focusing on the following:

- overall project focus;
- the current status of the project;
- the vessel types, programs and departments on board vessels that data collection would pertain to;
- the need to select a limited number of program tasks from the approximately 310 program tasks, which were deemed critical and/or which have a high level of frequency and which are representative of all departments; and
- the procedures that would be utilized on board the vessels during data collection relating to the selected number of program tasks.

### *Explanation of the Task Analysis Process*

A critical stage in the meeting pertained to the debriefing of the Operational Experts on the Task Analysis Methodology employed. This stage was essential to convey to the Operational Experts how the number of program tasks (N=52 out of 310) were arrived at.[1]

The Operational Experts were advised that from 52 program tasks, 28 program tasks[2] were selected as the first 'cut' of program tasks. It was intended that these 28 program tasks be the focus during data collection on board the vessels. It was explained that BC Research, TDC and CCG executed the selection[3] of these 28 program tasks at a meeting in February 1998. DFO/CCG provided this overview with supporting comments from TDC. The outcome of this explanation revealed a good understanding and questions were few, at this point.

Debriefing on the Process to Review the Task Analysis Methodology and Tasks Selected for Data Collection

All participants were presented with a package of 52 completed [completed by SME] program task questionnaires, as well as 8 Trawling and 6 Science program tasks [as

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1 Based on the overall ranking of program tasks which was determined by their high level of frequency and/or high criticality.

2 It was necessary to reduce the list of 52 to a manageable and cost-effective number for data collection, and that this final manageable number was approximately 28 program tasks.

3 This selection adhered to a task selection methodology identified at the February 28, 1998 meeting [described in Chapter – of this final report].

completed by trawling and science seagoing personnel]. They were also provided with a methodology legend, a short form listing of the 52 and 28 program tasks.

The Operational Experts were required to review the list of 52 program tasks to confirm how appropriate / accurate each of the (28 program) tasks were in terms of the criteria of criticality, frequency and representation of departments and programs. This review was guided by the following questions:

- Were there any program tasks on the 52 program task list that were not, but should have been included in the draft 28 program task list, if so why?
- Were there any program tasks on the draft 28 program task list that should not have been on that list, if so why?
- "Any comments on the draft list of 28 program tasks; what strikes you?" This question was deliberately left 'open' to ensure non-bias and to solicit any and all types of comments, questions and concerns. It proved to be a useful technique. The comments were recorded and listed in Table C1, and all were accepted.

**Table C1:**
**General Comments on Original List of 28 Tasks**

| Group/Task # | Comment |
|---|---|
| General | Tasks description in general adequately reflect the duties of the program task named |
| General | Have to keep remembering that we are dealing with auditory issues, not job description, etc. |
| General | These program tasks are divided into all dept. on board ship, armed boarding has no specific dept., and it includes all depts. - this issue will be addressed, only difference is issue of safety of handling guns etc. (much of this is covered under the generic program tasks). |
| 156 | First Aid, CPR - program tasks does not identify galley as being included. |
| 130 | Does not see from the write up that this is something that requires definition of a hearing standard. This is basically the operation of the controls and maneuvering the vessel. They have drawn so much else into it that it is probably covered somewhere else. |
| 42, 44, 41<br>*edit | The description also includes deck and engineering operations, so these should be included as locations that hearing standards should be included, not only ashore. Transfer of fuel is done on deck and through the engine room. Deck and engine room should be indicated with a “Y”. “Dept. column” should include engine as well as deck. |
| 94 | Questioning the hearing req. for flaking chain. Do not see much point in it. If people have been briefed before hand there should be no need for any communication when flaking chain. (Talking about taking nips and lifting chain). Short description does not indicate the program task.<br>To have one set program task for flaking chain, seems to be excessive (redundant) should be included with something to do with buoy operations. (Derek Ops – Task 166) this does fall into the 28 program tasks. Flaking chain is part of the process. 94 maybe should be combined with 166. Agreed to keep as separate program task for the BT program. |
| 161 | This is a better one to have in there than “flaking the chain”. Feels that this includes “flaking the chain”. If you were to rewrite one of these job program tasks, you could include them all in one. (see 94) - But this is the “Bosun’s” program task - not the seaman actually doing the manual labour of flaking the chain. |
| 149 | Seems to be added just to get a percentage for logistics program tasks. Do we want to sacrifice something that may be more important to measure just to ensure all departments are represented? |
| 110 | Should also include work boats, barge, flight deck, diesel forklift and other vessels if we are called on to do them. Should be identified in all locations. |
| 156 | Poor wording, should say, “is required to provide detailed medical information and receive specific medical instructions and advice”. |
| 166 | Should read “direct derrick operations”. |
| 259 | Change program task name to read - launch and populate lifeboat/raft |

**Table C1 (Cont'd):**
**General Comments on Original List of 28 Tasks**

| Group/Task # | Comment |
| --- | --- |
| 188 | Section for engine room watch-keeping but not for Bridge. (This is due to the bridge watch-keeping program task being broken down into specific section). We have covered engine room watch-keeping but not the maintenance yet. |

The following table identifies those program tasks that the Operational Experts selected for omission and/or revision from the draft list of 28 program tasks; which could only be drawn from the list of 52 program tasks and that were recommended for inclusion to the final draft list. This selection was made using the program task selection criteria.

At this point in the process, it was critical that CCG/TDC project authorities not influence the selection decision. This was achieved by recording the Operational Experts choices and not offering any opinions on the program tasks selected. Once all program tasks were reviewed it was necessary to determine if any of these program tasks could not be used in the data collection, based on any of the following reasons. In the event that a program task could not be used, it was replaced with another from the list of 52 program tasks:

- the program task would not be possible to execute due to safety concerns for crew;
- the program task would not be possible to simulate for refitting of the vessel, as this was a very infrequent occurrence and difficult and costly to simulate;
- the program task would not be possible to simulate for critical medical situations.
- the program task would not be possible to simulate due to the high cost involved; and
- the program task could not realistically be simulated.
- The list of program tasks for edit, omission or inclusion is listed in Table C2.

**Table C2:**
**List of Programs of Edit, Omission, or Inclusion in Final Task List**

| No. | A/O | Descriptor | Reason |
|---|---|---|---|
| MED1 | O | damage control | too difficult to simulate onboard. You can’t be knocking holes in the boat. |
| 193 | edit | climb into work boats | change wording to something like “small boat operations”. |
| 126 | O | monitor towline | more difficult to simulate. Have to do your own towline. Leave in list as a backup program task to be measured. |
| 124 | O | tow vessel | more difficult to simulate. Have to do your own towline as in program task 126. Leave in as a backup program task to be measured. |
| 110b | O | refit | maybe should be classified as a vessel type, rather than a program task. Description is of an environment not of a program task. (put as worst op. condition for 110) |
| 110 | edit | inspect machinery | try to test 110 during refit conditions (110b) in a shipyard. Maybe put under title “worst operations”, use contracted dry-docking (sandblasting). |
| 127 | A | lookout duties | lookout is universal to all ships and programs. Already heavily weighted by the collision regulations as a requirement for hearing. Is put there to be the eyes and ears of the ship. (all programs, not just SAR) (DECK TASK) - Done by all crew if necessary and if small vessel |
| 219 | A | operate firefighting and life saving equip. | universal to all programs and vessels. Should be included as a “Yes” in the Galley. High criticality and easily tested. (DECK TASK) - Done by all crew if necessary. |
| 71 | A | steer vessel | common to all programs and vessels. Consequences of not hearing are immediate and dire. (DECK TASK) - Put in “breaking ice” as “worst ops”. |
| 128 | A | use of ship’s comm. equip. | have to be able to hear the ship’s radios and communication equipment, sometimes two or more at the same time. Common to all ship’s and programs. Critical to all operations. Ease of testing. (DECK TASK) - May be some confusion as to understanding of program task) - add locations on ship and shore and boats |
| 190 | A | maintain machinery | watchkeeping (188), inspection (110) already taken care of in different program tasks; third big part of engine dept. is maintaining machinery (so this should be included in program tasks). Ease of testing ,is universal and could be critical. (ENG. TASK) |
| 231 | edit | conduct search | Add “Yes” for FRC / lifeboat. (DECK TASK) |

**Table C2 (Cont'd):**
**List of Programs of Edit, Omission, or Inclusion in Final Task List**

| No. | A/O | Descriptor | Reason |
|---|---|---|---|
| 51 | O | hook cargo sling | You can't hear anything anyway when the helicopter is hovering above you. Most of the time you should have hearing protection on when the helicopter is that close. Test a hearing man and test a deaf man doing this operation and they will test the same. When dealing with aircraft, it is always sight, never sound. "You do not have to hear when you hook cargo sling". (DECK TASK) |
| T3 | A | Trawl coming back on board | Based on criticality, frequency and degree of risk |
| | | | All others T1 - T5 can be captured generically |
| S4 | A | Scientists data collection CTD's etc. | In relation to S1 S4 are more communication activity, more ambient noise and higher overall safety risk. S1 is out and S4 is in. |
| S2 | A | Survey work | It is the only program task of its nature for Hydrographic work. Uses small launches. |

The next step in the review process entailed answering the question – "What rules or decision criteria would you suggest to select the 28 program tasks (or a subset of the 52)?" Table C3 profiles the responses of the Operational Experts.

**Table C3:**
**Criteria for Selecting Final Task List**

| Focus | Comment | Rationale |
|---|---|---|
| Criteria | Should use criticality a bit more | Reason for that is "safety". Consequences of not hearing something can be a very important safety error.<br><br>CCG explained how "criticality" was used. |
| | Risk analysis | Degree of risk we are willing to accept, is that figured into the selection?<br><br>CCG explained about the frequency element |
| Program tasks | 50% selection of program tasks. How was that arrived at, i.e. 50% deck, engineering logistics? Criticality is more important than getting 50% of the 52 program tasks. | Agrees that the number of program tasks per dept. is relative to the no. of personnel per department. Looks like a good effort was made to keep a good balance between departments. |
| Regulate | Existing regulations | Update on what these are was provided. |
| Selection | Random selection is a problem | Thinks that criticality should have been given greater weight.<br><br>Thinks it would have been better to prioritize program tasks.<br><br>Thinks that the only place for random selection is when all things are equal. |

### *Discussion and Questions*

Based on the information and responses in Table 3, discussion ensued. The Operational Experts raised concern that the initial criteria used to select the 28 program tasks may have omitted criteria relating to degree of risk, frequency, and regulations. CCG/TDC pointed out that risk referred to safety to oneself, to others, and to operations in the performance of the program task; selection criteria used by BC RESEARCH during the SME and focus group sessions. However, the Operational Experts proposed alternative definitions of risk, which could logically be applied:

- Regulations – the program task must be officially recognized by the International Convention.
- Frequency – the number of times of occurrence the program task could be performed by an individual, vessel or program.
- Degree of Risk - the impact of an error relative to the safety of life (CCG/DFO person), property and environment ["impact is to maximize positive outcomes and minimize negative ones"], but relative to all program tasks in the marine environment. (Criticality was defined as part of the degree of risk – which was included in the initial selection criteria.)

Differences between the Operational Experts criteria and that initially developed and used by BC Research pertained only to the inclusion of regulations. However, this inclusion really pertained to an indirect, or secondary, impact on program task performance; whereas criticality for example, has a direct impact on program task performance. Nonetheless, the criteria of regulations was tested against each of the final list of program tasks.

Furthermore, outcome of the criteria identified did not conflict or negate those previously used. In fact, it reinforced that the criteria developed by BC RESEARCH and that the initial draft program task selection at the February 1998 meeting was pertinent.

### *Identification of DFO Program Tasks*

The identification of DFO program tasks was not possible during the program task analysis methodology conducted by BC RESEARCH. Consequently, DFO/CCG undertook to compile a list of DFO program tasks, careful to be representative of vessel types. The questionnaires were completed by DFO Program Operational Experts in accordance with the same process, rules and criteria used during the focus groups. This was also completed for the Conservation and Protection tasks, and task selection for data collection on board vessels followed the same process as previously stated.

### *Final Review and Selection*

Once all program tasks, comprised from the initial list of 28 and new DFO program tasks were identified, the Operational Experts were asked to review and score all of these program tasks against the criteria they developed during the meeting, as profiled in Table C4.

**Table C4:**
**Review of Program Tasks by Criteria**

| Task# | Regulation (Y/N) | Frequency (1-9) | Risk (1-9) | Task# | Regulation (Y/N) | Frequency (1-9) | Risk (1-9) |
|---|---|---|---|---|---|---|---|
| 215 | Y | 7 | 2 | 188 | Y | 1 | 9 |
| 259 | Y | 9 | 9 | 190 | Y | 3 | 8 |
| 156 | Y | 9 | 6 | 71 | Y | 1 | 7 |
| 70 | N | 3 | 6 | 127 | Y | 1 | 3 |
| 231 | N | 9 | 6 | 219 | Y | 7 | 9 |
| 130 | N | 3 | 5 | 128 | Y | 2 | 8 |
| 42 | Y | 4 | 7 | 121 | N | 9 | 5 |
| KITS A | N | 6 | 9 | 138 | Y | 4 | 7 |
| KITS B | N | 7 | 5 | S4 | N | 3 | 4 |
| 94 | N | 3 | 8 | T3 | N | 3 | 7 |
| 122 | N | 4 | 7 | S2 | N | 1 | 5 |
| 166 | Y | 3 | 7 | 110 | Y | 9 | 8 |
| 137 | Y | 1 | 1 | 149 | Y | 4 | 5 |
| 185 | N | 9 | 9 | 193 | N | 3 | 5 |
| HOB | N | 9 | 1 | 29 | Y | 2 | 5 |
| | | | | 38 | N | 5 | 8 |

**NB: 2-3 additional program tasks will be added to the list of 31 to include, Conservation and Protection.

Scoring Levels Legend:

| **Risk** | **Frequency** |
|---|---|
| 1 - not at all | 1 - >once per 30 min. |
| 5 - somewhat | 5 - once per day |
| 9 - a great deal | 9 - <once per 28 day crewing period |

### *Summary*

The final selection of program tasks, according to the criteria developed by the Ops Experts, yielded similar results to the initial draft list of 28 program task selection by BC Research/ CCG/TDC in the February 1998 meeting. Four program tasks were dropped from the initial 28. These program tasks were unlikely to be used for data collection due to simulation complexity (e.g., program tasks MED1, 126, 124), or because they could not provide ‘clean’ hearing data (e.g., program task 51).

Five CCG program tasks (taken from the short list of 52) and universal to all vessels, were added to the current list, as well as 3 DFO program tasks which were added to represent Science and Oceans with an anticipated 2-3 program tasks to be added for Conservation & Protection. In a few cases, wording on a program task description required clarification and re-wording (e.g., 156, 193) was required. It was agreed that a final selection of 33-34 program tasks representing all of CCG / DFO programs would be used by the contractor for data collection, analysis and recommendations. The distribution of the initial 28 program tasks by program, department and vessel was considered acceptable and was well maintained in the final list.

# APPENDIX D

## Tasks Selected for On-board Data Collection

**Table D-1:**
**List of Original 28 Tasks**

| Department | Task Number | Task Title |
|---|---|---|
| Universal | 156 | First aid |
| Universal | 193 | Climb into workboats |
| Universal | 137 | Communications on vessel |
| Universal | 259 | Launch liferaft |
| Universal | HOB | Human overboard |
| Deck | 215 | Test alarms |
| Deck | 38 | Move cargo |
| Deck | 42 | Fuel ashore |
| Deck | 51 | Hook cargo sling |
| Deck | 94 | Flake the chain |
| Deck | 122 | Launch the FRC |
| Deck | 121 | Recovery from water |
| Deck | 166 | Direct derrick ops. |
| Deck | KitsA | Boarding vessels |
| Deck | KitsB | Transporting personnel |
| Deck | 124 | Tow vessel |
| Deck | 70 | Buoy repairs |
| Deck | 130 | Manuevering vessel |
| Deck | 231 | Communications with on-scene commander |
| Deck | 126 | Monitor towline |
| Deck | 138 | Break ice in harbour |
| Engineering | 110b | Refit |
| Engineering | 188 | Watchkeeping |
| Engineering | MED | Damage control |
| Engineering | 110 | Inspect machinery |
| Engineering | 185 | Start boiler |
| Logistics | 29 | Prepare food |
| Logistics | 149 | Maintain equipment |

**Table D-2:**
**List of Final 32 Tasks**

| Department | Task Number | Task Title |
|---|---|---|
| Universal | 156 | First Aid |
| Universal | 193 | Small boat operations |
| Universal | 137 | Communications on vessel |
| Universal | 259 | Launch and populate liferaft / boat |
| Universal | HOB | Human overboard |
| Universal | 127 | Lookout duties |
| Universal | 219 | Operate firefighting and life saving equipment |
| Deck | T3 | Trawl coming back on board |
| Deck | S4 | Scientists data collection CTD's etc. |
| Deck | S2 | Survey work - inland waters |
| Deck | CP1 | Conducting equip., net rigging and gear checks |
| Deck | CP2 | Communication related to protection of fishery |
| Deck | CP5 | Gather, give evidence re: charging offenders of Fish. Act |
| Deck | 215 | Test alarms |
| Deck | 38 | Move cargo |
| Deck | 42 | Fuel ashore |
| Deck | 94 | Flake the chain |
| Deck | 122 | Launch the FRC |
| Deck | 121 | Recovery from water |
| Deck | 166 | Direct derrick ops. |
| Deck | KitsA | Boarding vessels |
| Deck | KitsB | Transporting personnel |
| Deck | 70 | Buoy repairs |
| Deck | 130 | Manuevering vessel |
| Deck | 138 | Break ice in harbour |
| Deck | 231 | Communications with on-scene commander |
| Deck | 71 | Steer vessel |
| Deck | 128 | Use of ship's communications equipment |
| Engineering | 188 | Watchkeeping |
| Engineering | 110 | Inspect machinery |
| Engineering | 185 | Start boiler |
| Engineering | 190 | Maintain machinery |
| Logistics | 29 | Prepare food |
| Logistics | 149 | Maintain equipment |

# Descriptions of Final 34 Tasks Selected for On-board Data Collection

## Universal

### *Task HOB: Human over board*

Assist a person overboard by alerting other crew via direct communication or using communications equipment, or responding to a call for help

### *Task 71: Steer vessel*

Continually steer vessel by responding to Officer of the Watch instructions on wheel orders and performing lookout duties by watching for objects such as other ships, rocks, shoreline, navigational aids, fishing boats, fishing nets, and floating debris in the water.

### *Task 127: Lookout*

Stand continuous lookout to locate persons, objects, coloured lights, and other vessels. Use binoculars to confirm visual sitings, listen for various sounds made by persons, horns, bells, etc., and verbally communicate sitings to Officer-in-Charge. This duty is performed during all weather conditions during night and day, with various visibility conditions, e.g., fog, rain, snow, glaring sun and in heavy seas.

### *Task 128: Use ships communication devices*

Listen to and receive simultaneous, continuous communications, from telephones and from numerous different radios, GMDSS, MSAT, etc. e.g. to receive distress messages, mission data from SAR Coordination Centre, Ice Operations Centre etc. and other vessels, receive/confirm receipt of messages relayed, (with variable sound quality). Communicate verbally using same equipment and record relevant information manually and electronically.

### *Task 137: Communications on vessel*

Verbally communicate with all ships personnel e.g. engine room, navigation officers, logistics personnel, helicopter pilot, Commanding Officer, deck crew, program staff, lookout etc. using telephones, portable radios and sound-powered telephone, face to face, over P.A. systems etc.

### *Task 156: First Aid*

Administer first aid, gives verbal or other instruction/directions on the administering of first aid for injured crew and survivors, this can be ashore, in workboats or aboard. May be required to provide general information to medical doctors or experts ashore using ship's radio.

### *Task 193: Small boat operations*

While wearing protective headgear floatation devices embark/disembark workboats or fuel barge, using jacob's ladders. Transit in various sea conditions, while continually observing the workboat machinery while in use during SAR, fisheries enforcement and buoytending operations.

### *Task 215: Test alarms*

Test on a regular basis safety and emergency equipment and sound various alarms that determine if systems and equipment are functioning correctly.

### *Task 219: Operate firefighting and life saving equipment*

During fires direct/operate firefighting and lifesaving equipment such as breathing apparatus, air tank, water hoses, axes, portable pumps and tanks, and related hose hardware such as nozzles, etc. Communicate within fire team as required. This task would expose persons to extinguishing agents such as by-products of the combustion process, e.g., smoke from rubber insulation materials, paint gases, diesel and bunker fuel, plastics, wood, etc.

Immediately proceed to fire station and don protective clothing such as fire suits, boots, breathing apparatus and hat, and strap breathing apparatus (weighing up to 18 kg) to back. Select fire fighting equipment e.g., axe portable tanks, pumps etc., for particular emergency and immediately proceed to fire site climbing up/down steep stairs, hurrying down alleyways, over coamings, through manholes, etc., to engine, boiler or control rooms, or elsewhere as required, while dragging/carrying hoses and equipment.

### *Task 259: Launch lifeboat and FRC*

Upon verbal direction from the Officer-in-Charge abandon ship by climbing into lifeboat before lowered into water, climbing down swinging jacob's ladder or jumping from deck (1 meter to 12 meters high) into water, locate, using visual or audio means, swim to and climb into liferaft, which may first require righting manually, perform lookout for other persons in the water using visual and audio means, assist others by throwing liferings, etc. and those climbing into liferaft/boat by pulling them into boat.

## Deck Department

### *Task CP1: Gear checks*

Conducting equipment, net rigging and gear checks, for compliance with regulations related to size, tags, biodegradible products, quotas, bait, lengths and depths of nets, licences, etc. Manually haul the traps. Equipment used to haul traps/nets, longlines and grappler are a hydraulic hauler and a crane.

### *Task CP2: Verbal communications*

Communicate verbally on boat and in the office, face to face, by telephone and VHF, and DFO radio, to receive and transmit information to/from the public, fishers, fish managers, Coast Guard, Police and Fisheries Officers for information, for tasking and related to the protection of the fishery.

### *Task CP5: Gather/give evidence*

Charter of Rights / Police Warning / Duty Council
a) Compile evidence for the purpose of charging offenders of the Fisheries Act Regulations, by cautioning them and posing questions of their rights;
b) Gather evidence by explaining your actions to the offender and posing questions.
c) Give evidence as Officer of the Court and as Officer of the Crown and act as an expert witness.

### *Task KitsA: Boarding vessels*

Board other vessels which are in distress and in need of help. May be required to fight fires, launch life boats, perform first aid and CPR. May be more difficult unfamiliar vessel because Coast Guard personnel are not familiar with the geography of the ship.

### *Task KitsB: Transporting personnel*

Transporting personnel. Crew will be required to get passengers on and off the bow of the vessel. Will be required to handle lines and maneuver the ship to decrease risk of injury to the passenger. Verbal communication is vital.

### *Task S2: Survey work*

Survey work - the seaman or scientists while operating scientific launches, communicates with the Officer of the Watch on the ship by VHF radio, visually and auditorally monitors scientific and navigational equipment and to prevent grounding of launch monitors audio alarm on echo sounder. Voice communication between scientists and seaman during bottom sampling operations. During launch and recovery of workboats, scientists and deck communicate by voice and hand signals.

### *Task S4: Scientists CTDs*

While carrying out scientific operations, ie setting CTD’s, the winch operator, located in the winchroom or on deck, communicates with scientists in their laboratory by talk-back or other means and with the seaman during release of CTD’s, by voice communication and hand signals. Visually and aurally monitors electronic systems on equipment which indicate depth, angle of wire etc. to determine accuracy of the deployment of the scientific equipment.

### *Task T3: Trawl on board*

Deck crew on standby in dog house for associated machinery sounds, verbal communication by talk-back, P.A or phone to prepare for trawl coming back on board.

After trawl is hauled back on deck, boatswain communicates verbally with deck crew concerning repairs to trawl, etc. in preparation for next trawl. Directs the crew verbally when to open ramp doors for dumping the codend, pulling up wave flap and other associated duties concerning end of tow.

### Task 38: Move cargo

Using mechanical (cranes, winches, etc.) or manual means, lift carry, roll, and push various types or cargo, (e.g., barrels, lumber, supplies) into cargo landing gear such as nets, slings, pallets, etc. Load / unload onto / off ship into barges and surfboats. (Seasonal)

### Task 42: Fuel ashore

Pump fuel, for transferring to lightstation, into ship's barge or tanks using hoses and mechanical or manual pumps. Pump fuel / water into tanks ashore using portable pumps and hoses which are carried, pulled and dragged over beaches, up steep cliffs, through water, etc., to lightstation or dwelling houses ashore. Sound cargo tanks ashore to determine amounts of fuel or water by measuring with sounding (measuring) rods, tapes, and colour pastes. Relay information verbally by radio to pumping stations aboard ship. Guard against spills by maintaining an open line of communication between ship and shore using portable radios or visual means. The pumping is generally done by an engineer, with the deck crew performing other duties. (Seasonal)

### Task 70: Buoy repairs

Perform minor aids / repairs on buoys and beacons. May include relighting buoys or beacons, replacing burnt bulbs, defective sunswitches, worn out batteries and corroded electrical connections working from the barge or by actually climbing onto the buoys which are bobbing with the water's movement. May require climbing steep rock faces to lightstations or beacons while carrying batteries, tools and other equipment while aids are aboard the ship or in the water. Report information back to ship using the radio (Seasonal).

### Task 94: Flake the chain

Flake steel mooring chain to run freely to the mechanical lift without kinks or knots, by physically pushing, pulling and guiding back and forth across the deck and by hooking the steel chain nipper to the mechanical lift.

### Task 121: Recovery from water

Recover living or dead person from the water, using multiple methods. For instance, manually lower stokes litter (basket) into water from the vessel side, maneuver the litter under the body, pull and lift manually using ropes, and leaning over the side, while pulling and lifting the body onto the vessel. Or using a scramble net or a inflatable stairway to vessel.. This job requires at least 2 people.

### *Task 122: Launch FRC/workboats*

Launch the zodiac, boats or barge from the ship using a number of different techniques, depending on the securing method for the vessel. This may include: untying ropes, loosen turnbuckle and lashings, manually or mechanically lift into launch position, climb aboard and release painter to launch boat; manually/mechanically with winch and falls (block, ropes, cables) by cranking davits out over ship's side, release brake to lower boat, tend rope painters to prevent boat from swinging; crank winches manually to lift boat and keep ropes pulled tight when lifting boat clear of water.

### *Task 130: Manuevering vessel*

maneuvering vessel in close proximity to objects and in open water, harbours, berthing, etc.

### *Task 138: Break ice in harbour*

Break ice in harbour while maintaining a continuous plot on ship's position to enable the ice to be broken as close to shore as possible, stopping periodically to confirm depth of water either by electronic depth sounder or using a lead line which is swung over ship’s bow while maneuvering in shallow channels, near the shore, etc., and read markings in order to measure depth of the water. Generally a two person job.

### *Task 166: Direct derrick ops.*

Direct the operation of the derrick (booms) and winches in barge, onboard ship and/or at light stations, to lift or transfer equipment, materials and supplies ashore, or buoys and moorings into/out of water.

### *Task 231: Coordinate search*

Following instructions received from on-scene commander, verbally advise of changes to search action plan, post lookout and maintain radar watch, follow assigned search pattern, adjust track spacing according to visibility, plot vessel's progress on charts and report to on-scene commander using radio and telephone.

## Engineering Department

### *Task 110: Inspect machinery*

Inspect machinery, and electrical equipment and structure after major maintenance for specification and regulatory compliance by visually observing, touching, smelling, measuring, tasting and listening. Performance of this task would expose the individual to a range of conditions which may or may not include: entering of tanks, machinery housings/enclosures and climbing under and over the ships structure, (requiring the use of safety equipment), through very hazardous conditions, e.g., safety guards/rails are removed for access to equipment, airborne contaminants are at a maximum due to cleaning, welding, burning, painting, sandblasting, etc., wires and cables impede movement, electrical panels are open, deck plates and hatches are lifted and removed.

Record and report all findings, observations, measurements and times in a log book and/or on computer.

### *Task 185: Start boiler*

Start up and run the boiler after maintenance or change-over routine.

### *Task 188: Watchkeeping*

Perform watchkeeping duties by operating, cleaning, maintaining and monitoring all systems such as propulsion, bilge, ballast, sewage, fuel, water, electrical generation and distribution and record all significant events in log books. Perform fire rounds by inspecting all machinery spaces for fire, flooding and abnormalities. Perform pre-start checks, e.g., read oil, water and power levels, gauges, etc., start and stop machinery, record each action in log book, adjust to bring into operating mode by manually turning levers, valves, etc. and continually observe and adjust to maintain proper operating conditions. Continually monitor to detect abnormalities of vibration, flow, temperature, pressure, noises, leaks, loose parts, smoke, fire, and coloured indicators. May require climbing over and under machinery, in engine control, propulsion rooms and throughout the ship. Examples of machinery are: main engines, purifiers, turbines, pumps, compressors, work boat and life boat engines, deck machinery, alarms and monitoring systems, boilers and generators. Must be available for other operations as required by the bridge or engine room.

### Task 190: Maintain equipment

Maintain machinery and electrical equipment by arranging tools and equipment required and carry to work site, prepare work site, dismantle machinery including trawling machinery, clean and/or replace filters and parts, grease and oil parts, add or remove fluids such as oils, water, lubricants, chemicals etc. tighten, adjust and measure using hand and power tools, such as screw drivers, shims/spacers, torque wrenches, multi-meters, chart recorders, precision measuring instruments, etc. irregular or abnormal odours such as burnt materials, bacterial/contaminated materials and record observations in log book and/or on computer. Clean, carry and return all equipment and tools to stores.

## Logistics Department

### *Task 29: Prepare food*

Prepare food and baked goods by cutting, chopping, frying, kneading, etc. Use heavy pots, hot ovens, steam, hot grease, or boiling water, and sharp knives. Must maintain constant watch for spills and burning grease, using timers to avoid fire and accidents and guarding against cuts, burns, etc. Prepare hot and cold beverages (i.e., tea coffee, milk).

### *Task 149: Maintain equipment*

Ensure that equipment used in conjunction with food serving and preparation is operated safely and maintained in a safe serviceable condition (e.g., ovens, meat slicers, knives, coffee maker, kettle, toaster, milk and juice dispenser) by observing operations and instructing / demonstrating corrective instructions on their handling. Informs others of necessary repairs, and approves repairs or replacement when required.

# APPENDIX E

## Data Reduction Methodology

The overall data reduction and analysis procedures are outlined in Figure E-1. Additional detail regarding each step is provided below.

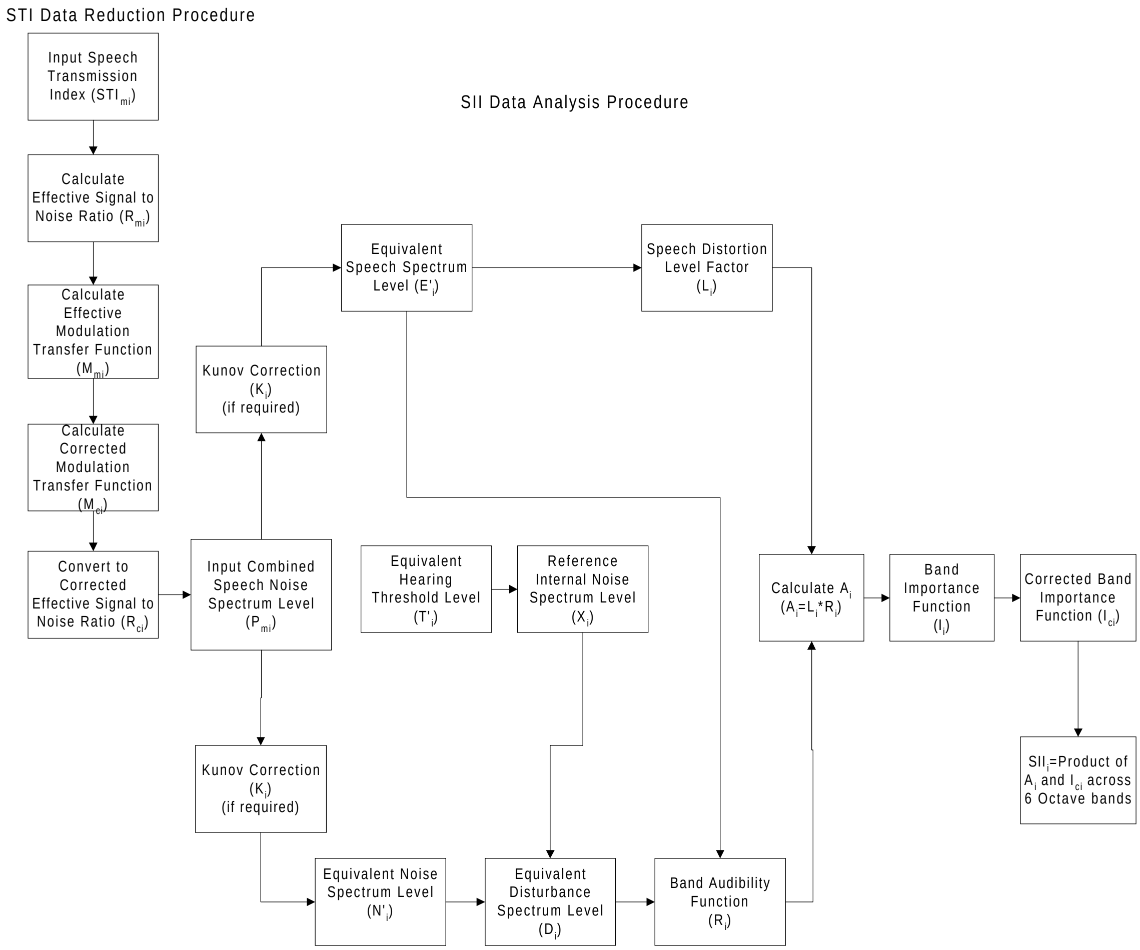


**Figure E-1:**
**Data Reduction and Analysis Procedures**

## *STI Data Reduction*

STI data reduction procedures were used for direct communications and electro-acoustic device communications data collected using SSARAH and the MLSSA system.

Prior to data reduction, a pre-calibration procedure to characterise the data collection system was completed. This was used to correct measurement data for potential imperfections in the measurement system. The pre-calibration was conducted in an anechoic chamber with low background noise. The sound level meter was placed adjacent to the speaker to minimise the effect of distance. Modulation transfer functions ($M_0$) for the 250-8000 Hz octave bands were calculated for each vocal effort.

### *STI Analysis*

The STI was calculated for each direct communication and electro-acoustic communications device file. Ambient noise files were calculated in conjunction with baseline speech transmission to characterise speech transmission under operating conditions. The speech and noise spectrum files ($P_m$) and STI values ($STI_m$) were analyzed at each 250-8000Hz octave band using the following procedures:

- correct $P_m$ for RION calibration and weighting networks;
- convert $STI_m$ to effective signal to noise ratio ($R_m$);

$$R_m = 30 \cdot STI_m - 15$$

- converts $R_m$ to effective modulation transfer function ($M_m$);

$$M_m = \frac{1}{1 + 10^{-Rm/10}}$$

- calculates the corrected modulation transfer function using the baseline data for the vocal effort used in the measurement,

$$Mc = \frac{M_m}{M_o}$$

- converts $M_c$ to corrected effective signal to noise ratio $R_c$; and

$$R_c = 10 \cdot \log\left[M_c / 1 - M_c\right]$$

- calculates the equivalent speech spectrum level ($E'_i$) and the equivalent noise spectrum level ($N'_i$).

$$E_i^{'} = R + 10\log\left[10^{P/10} / (1 + 10^{R/10})\right] \text{ and}$$

$$N_i^{'} = E_i^{'} - R$$

The $E'_i$ and $N'_i$ values are direct inputs for the SII calculation.

### *Data Reduction for Ambient Noise*

Ambient noise data were used to correct STI file under specific operating conditions. Ambient noise collected using the MLSSA system was analyzed in octave bands and one-third octave bands for the frequency range 25 to 10,000 Hz. Ambient noise data collected using only the sound level meter was recalled from the sound level meter memory or data collection sheets at each octave level (31.5 to 8000Hz)

#### Calculation of the SII

Three input functions or values are required by the SII, including:

- Equivalent Speech Spectrum Level ($E'_i$);
- Equivalent Hearing Threshold Level (the amount that a tone must be increased to be "just heard" relative to normal hearing) ($T'_i$); and

- Equivalent Noise Spectrum Level ($N'_i$).

The following calculations are performed to achieve the SII:

1. Correct the Equivalent Speech Spectrum Level ($E'_i$) and the Equivalent Noise Spectrum Level ($N'_i$) for the Kunov free field to ear drum transfer function ($K_i$)

$$E'_i = E'_i - K_i$$

$$N'_i = N'_i - K_i$$

2. Calculate the Reference Internal Noise Spectrum Level ($X'_i$): This is the spectrum level of a fictitious internal noise in the ear of the listener which, if it were an external masker, would give rise to the reference threshold level. This is calculated by adding the normal hearing threshold ($X_i$) and the equivalent hearing threshold level ($T_i$)

$$X'_i = X_i + T'_i$$

3. Determine the Equivalent Disturbance Spectrum Level ($D_i$): The equivalent disturbance spectrum level is used to calculate the signal to noise ratio. The signal to noise ratio is equal to the larger of the external noise (i.e., ambient noise) or internal noise (i.e., reference internal noise spectrum level, $X'_i$ ). This is determined by:

if $N'_i > X_i$ , $D_i = N'_i$

if $X_i > N'_i$ , $D_i = X_i$

4. Calculate the Standard Speech Spectrum Level for normal vocal efforts. The speech level distortion factor ($L_i$) is calculated using the standard speech spectrum level ($U_i$, the speech spectrum level for the normal vocal effort) and the Equivalent Speech Spectrum Level ($E'_i$). The speech level distortion factor accounts for the fact that the intelligibility of speech decreases at higher vocal efforts.

$$L_i = 1 - \frac{(E'_i - U_i - 10)}{160}$$

where $L_i$ is limited to a maximum of 1.0.

5. Calculate the Signal to Noise Ratio ($R_i$): This is the signal to noise ratio on a logarithmic scale. This is calculated by subtracting the Equivalent Disturbance Level ($D_i$)

$$R_i = \frac{(E'_i - D_i + 15)}{30}$$

where $R_i$ is limited between 0 to 1

6. Calculate the Band Audibility Function ($A_i$): This is calculated by multiplying the Speech Level Distortion ($L_i$) by the Signal to Noise Ratio ($R_i$). This includes the effect of distortion on the signal to noise ratio.

$$A_i = L_i \cdot R_i$$

7. Calculate the corrected frequency importance function $Ic_i$ using the band "Pavlovic Correction", $C_i$.

$$Ic_i = I_i \cdot C_i$$

8. Calculate the Speech Intelligibility Index for the (i)th frequency band.

$$A_i \cdot Ic_i$$

9. The above calculations are performed for each of the 6 octave bands. The final calculation is to sum across the 6 octave bands to yield the SII.

$$SII = \Sigma\ A_i \cdot I_i$$

# APPENDIX F

## Hearing Threshold Level Profiles

| | Hearing Threshold Levels (dB) | | | | | | |
|---|---|---|---|---|---|---|---|
| **HTL PROFILE** | **250 Hz** | **500 Hz** | **1000 Hz** | **2000 Hz** | **3000 Hz** | **4000 Hz** | **8000 Hz** |
| 1* | 9 | 9 | 9 | 11 | 13 | 14 | 18 |
| 2 | 9.5 | 9 | 9 | 13.5 | 17 | 17.5 | 20.5 |
| 3* | 10 | 9 | 9 | 16 | 21 | 21 | 23 |
| 4 | 10 | 9 | 9 | 18 | 23 | 23 | 24.7 |
| 5 | 10 | 10 | 10 | 20 | 25 | 25 | 26.4 |
| 6* | 10 | 10 | 10 | 22 | 27 | 28 | 28 |
| 7 | 10 | 10 | 10 | 25 | 30 | 30.7 | 30.7 |
| 8 | 11 | 11 | 11 | 28 | 33 | 33.3 | 33.3 |
| 9* | 11 | 11 | 11 | 31 | 36 | 36 | 36 |
| 10 | 11 | 11 | 11.6 | 33.3 | 38.3 | 38.3 | 37 |
| 11 | 11 | 11 | 12.2 | 35.6 | 40.6 | 40.6 | 38 |
| 12* | 11 | 11 | 13 | 38 | 43 | 43 | 39 |
| 13 | 11.6 | 11.6 | 14 | 40.3 | 45.3 | 45.3 | 45.6 |
| 14 | 12.2 | 12.2 | 15 | 42.6 | 47.6 | 47.6 | 52.3 |
| 15* | 13 | 13 | 16 | 45 | 50 | 50 | 59 |
| 16 | 13.7 | 13.7 | 17 | 47 | 51.7 | 51.7 | 61.2 |
| 17 | 14.4 | 14.4 | 18 | 49 | 53.4 | 53.4 | 63.5 |
| 18 | 15.2 | 15.2 | 19 | 51 | 55.2 | 55.2 | 65.7 |
| 19* | 16 | 15 | 20 | 53 | 57 | 57 | 68 |
| 20* | 18 | 17 | 22 | 58 | 61 | 60 | 75 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 23 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 24 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 25 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 26 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 27 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 28 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| 29 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 30 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| 31 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| 32 | 55 | 55 | 55 | 55 | 55 | 55 | 55 |

# APPENDIX G

## SII Data Analysis at a 0.55 Cut-off

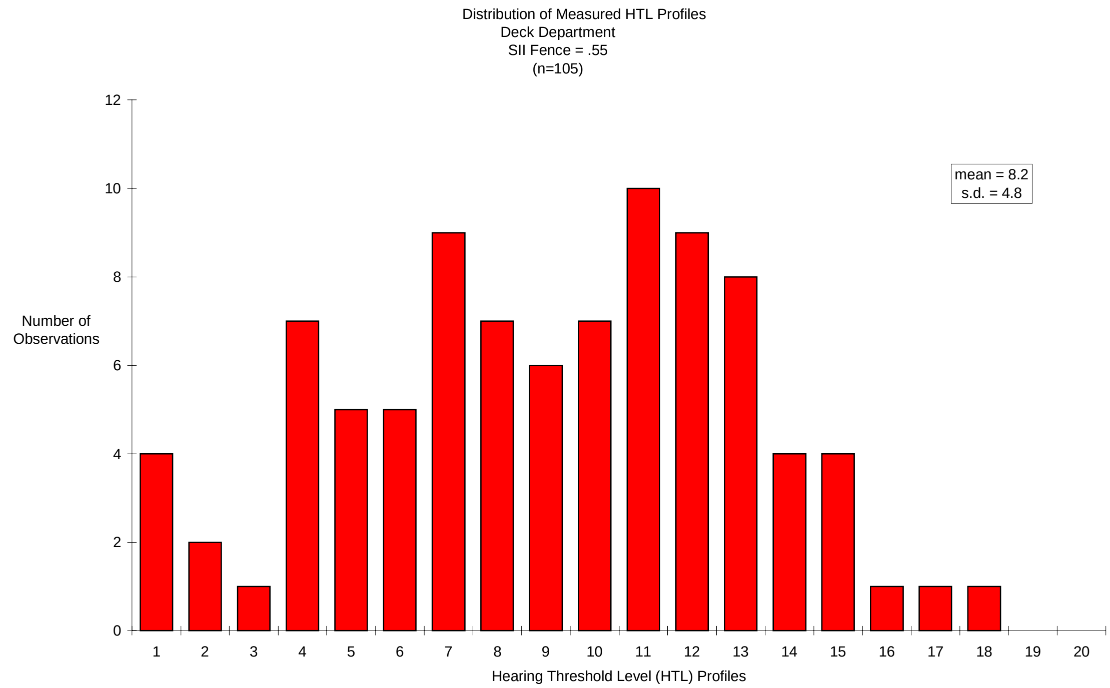


**Figure G2: Distribution of HTL Profiles for Speech Discrimination in the Engine Room Department (SII=0.55)**

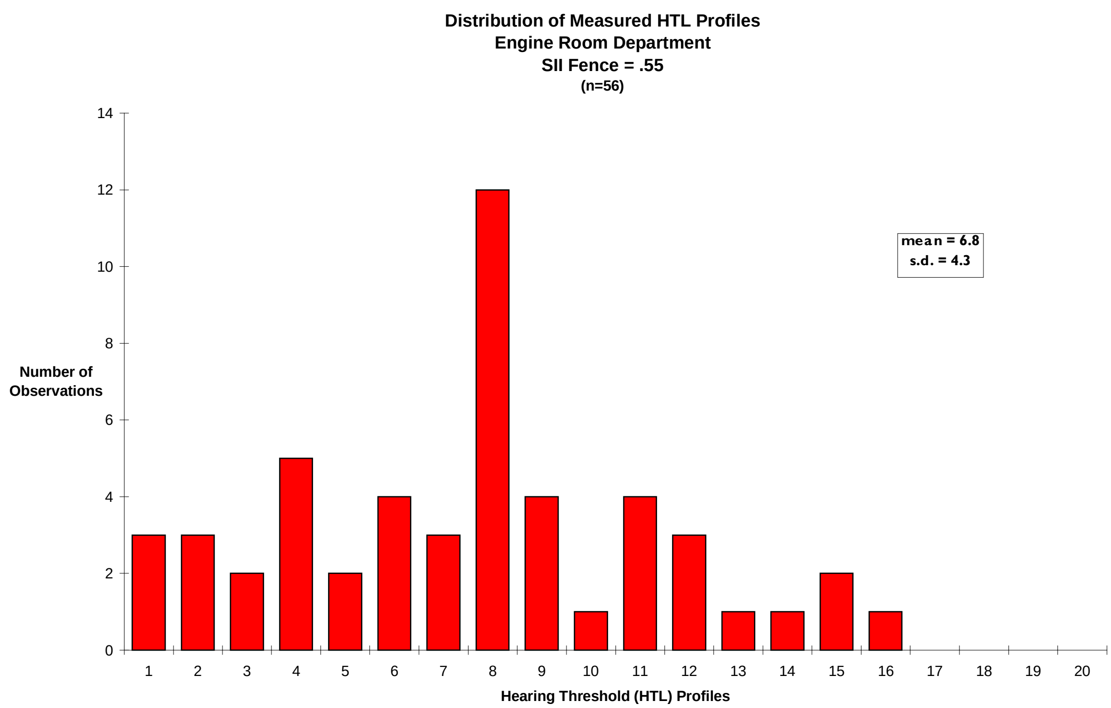


**Figure G2: Distribution of HTL Profiles for Speech Discrimination in the Engine Room Department (SII=0.55)**

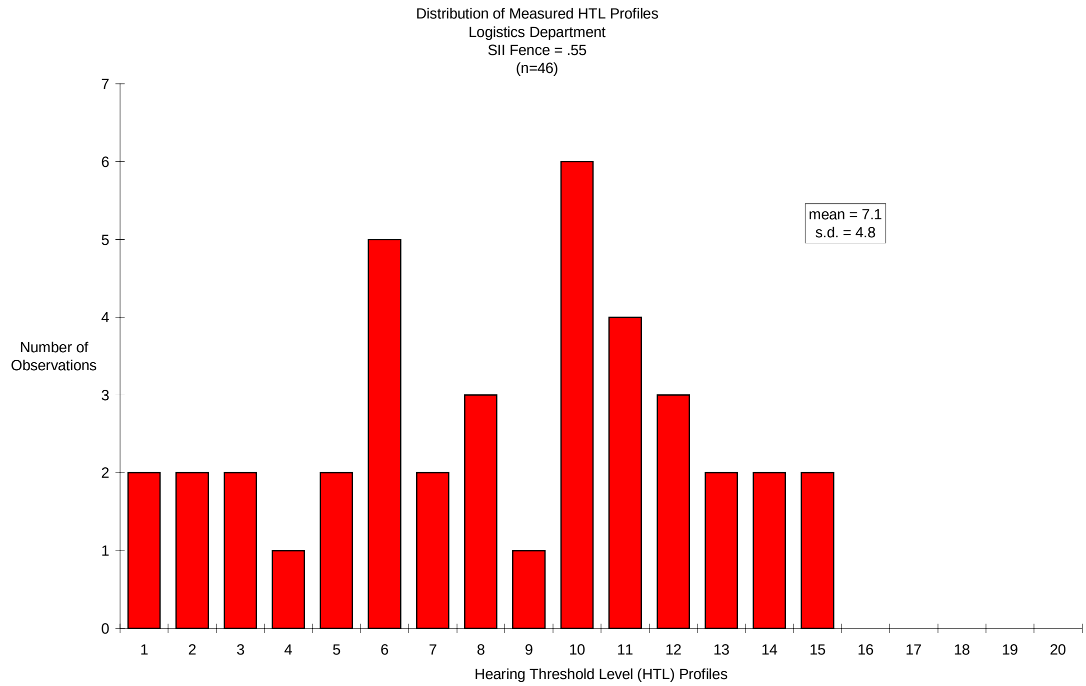


**Figure G3: Distribution of HTL Profiles for Speech Discrimination in the Logistics Department (SII=0.55)**

# APPENDIX H

## Sample SII Data Analysis

Estimates of speech intelligibility for a data record were listed as an array of SII values for each of the 32 HTL profiles. Tables H1 shows the results for data collected on board the Sir Wilfred Grenfell (record G-B5(S)). The bracketed letter following the record identifier denotes the vocal effort that applies to the results: (S) Shout, (L) Loud. Each table consists of a header outlining the measurement conditions, equivalent noise and speech spectrum levels, and the vocal effort (output) of the SSARAH mannequin.

For the G-B5(S) data, the SII values range from 0.775 ( profile 1) to 0.494 (profile 20) for the typical sensorineural losses, and from 0.777 (profile 21) to 0.351 (profile 32) for the atypical sensorineural losses. For the typical losses, the profiles occurring at the SII cut-off values of 0.70, 0.60, 0.55 and 0.50 are 7, 14, 18, and 19 respectively (rounded to one decimal place).

When the vocal output is reduced to LOUD, the resulting SII values are shown in Table H2. For the typical sensorineural losses, the SII cut-off values for 0.55 and 0.50 are 3 and 8 respectively. Note that with the reduced voice level, the SII values for HTL profiles 1 and 21 are 0.57. What this means is that the predicted intelligibility values for the given acoustical conditions (ambient noise = 76 dBA; “talker”-“listener” distance =3 metres ) do not meet the SII cut-off values of 0.70 or 0.60.

This is due, at least in part, to the limited range of the hearing thresholds levels covered by the profiles. The HTL profiles for typical sensorineural losses (profiles 1 to 20) do not cover the HTL range from -10 to +8 dB HTL; the profiles for atypical sensorineural impairment (profiles 21 to 32) do not cover HTLs in the range -10 to 0 dB HTL. These ranges were not included in the analysis because they were clearly below the HTLs that would be considered reasonable for a threshold fence.

The above cut-off HTL profiles for Grenfell records G-B5(S) and G-B5(L) are summarized in Table H3.

**TABLE H1**

**GRENFELL**

**Record Number = G-B5(S)**

**NOISE OCTAVE BAND SPECTRUM LEVELS**

**40.7 45.0 43.5 39.7 29.6 14.9**

**SPEECH OCTAVE BAND SPECTRUM LEVELS**

**44.8 57.9 55.5 51.7 41.7 24.4**

**BINAURAL LISTENING**

**MEASUREMENTS ARE FREE FIELD**

**PER CENT CONDUCTIVE LOSS = 0 %**

**SHOUTED VOCAL EFFORT**

| HEARING PROFILE | SII(C) | HEARING PROFILE | SII(C) |
|---|---|---|---|
| HTL PROFILE 01 | 0.775 | HTL PROFILE 21 | 0.777 |
| HTL PROFILE 02 | 0.769 | HTL PROFILE 22 | 0.777 |
| HTL PROFILE 03 | 0.756 | HTL PROFILE 23 | 0.777 |
| HTL PROFILE 04 | 0.743 | HTL PROFILE 24 | 0.777 |
| HTL PROFILE 05 | 0.731 | HTL PROFILE 25 | 0.727 |
| HTL PROFILE 06 | 0.716 | HTL PROFILE 26 | 0.674 |
| HTL PROFILE 07 | 0.698 | HTL PROFILE 27 | 0.618 |
| HTL PROFILE 08 | 0.681 | HTL PROFILE 28 | 0.563 |
| HTL PROFILE 09 | 0.663 | HTL PROFILE 29 | 0.509 |
| HTL PROFILE 10 | 0.651 | HTL PROFILE 30 | 0.456 |
| HTL PROFILE 11 | 0.639 | HTL PROFILE 31 | 0.402 |
| HTL PROFILE 12 | 0.626 | HTL PROFILE 32 | 0.351 |
| HTL PROFILE 13 | 0.608 | | |
| HTL PROFILE 14 | 0.596 | | |
| HTL PROFILE 15 | 0.583 | | |
| HTL PROFILE 16 | 0.571 | | |
| HTL PROFILE 17 | 0.560 | | |
| HTL PROFILE 18 | 0.549 | | |
| HTL PROFILE 19 | 0.533 | | |
| HTL PROFILE 20 | 0.494 | | |

**TABLE H2**

**GRENFELL**

**Record Number = G-B5(L)**

**NOISE OCTAVE BAND SPECTRUM LEVELS**

**40.7 45.0 43.5 39.7 29.6 14.9**

**SPEECH OCTAVE BAND SPECTRUM LEVELS**

**44.8 57.9 55.5 51.7 41.7 24.4**

**BINAURAL LISTENING:**

**MEASUREMENTS ARE FREE FIELD**

**PER CENT CONDUCTIVE LOSS = 0 %**

**Vocal Effort Changed from SHOUT to LOUD**

| HEARING PROFILE | SII(C) | HEARING PROFILE | SII(C) |
|---|---|---|---|
| HTL PROFILE 01 | 0.568 | HTL PROFILE 21 | 0.569 |
| HTL PROFILE 02 | 0.563 | HTL PROFILE 22 | 0.569 |
| HTL PROFILE 03 | 0.554 | HTL PROFILE 23 | 0.569 |
| HTL PROFILE 04 | 0.544 | HTL PROFILE 24 | 0.568 |
| HTL PROFILE 05 | 0.535 | HTL PROFILE 25 | 0.532 |
| HTL PROFILE 06 | 0.524 | HTL PROFILE 26 | 0.492 |
| HTL PROFILE 07 | 0.511 | HTL PROFILE 27 | 0.449 |
| HTL PROFILE 08 | 0.498 | HTL PROFILE 28 | 0.407 |
| HTL PROFILE 09 | 0.485 | HTL PROFILE 29 | 0.369 |
| HTL PROFILE 10 | 0.476 | HTL PROFILE 30 | 0.334 |
| HTL PROFILE 11 | 0.468 | HTL PROFILE 31 | 0.294 |
| HTL PROFILE 12 | 0.461 | HTL PROFILE 32 | 0.255 |
| HTL PROFILE 13 | 0.453 | | |
| HTL PROFILE 14 | 0.446 | | |
| HTL PROFILE 15 | 0.437 | | |
| HTL PROFILE 16 | 0.429 | | |
| HTL PROFILE 17 | 0.421 | | |
| HTL PROFILE 18 | 0.413 | | |
| HTL PROFILE 19 | 0.401 | | |
| HTL PROFILE 20 | 0.370 | | |

**TABLE H3**

GRENFELL LIST OF RECORDS IN THIS FILE

| | SII CUT-OFF VALUES | | | |
|---|---|---|---|---|
| | **.70** | **.60** | **.55** | **.50** |
| G-B5(S) | | | | |
| SII Corrected | 7 : 25 | 14 : 27 | 18 : 28 | 19 : 29 |
| G-B5(L) | | | | |
| SII Corrected | xx : xx | xx : xx | 3 : 24 | 8 : 25 |

Explanatory Notes

The bracketed letter following the record identifier denotes the vocal effort that applies to the results: (S) Shout, (L) Loud.

A double "x" indicates that a specified SII level cannot be met for the given vocal effort, noise and reverberation conditions, and range of HTL profiles that apply. The profiles for typical of sensorineural impairment (profiles 1 to 20), for example, do not cover the hearing threshold range from -10 to +8 dB; the profiles for atypical of sensorineural impairment (profiles 21 to 32) do not cover HTLs in the range -10 to 0 dB.

# APPENDIX I

## Interim Report: Assessment of the Reliability of Hearing Aids

# HEARING STANDARDS FOR SEAGOING PERSONNEL

**(SSC. FILE NO. T8200-5-5567/A)**

## PHASE 5 REPORT:
## ASSESSMENT OF THE RELIABILITY OF HEARING AIDS

*Prepared for:*
Transport Canada
Transportation Development Centre
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800 Rene Levesque Blvd. West
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*Prepared by:*
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*Project No* : 6-08-0657
December, 1997

# 1 INTRODUCTION

The current Canadian Coast Guard (CCG) hearing requirements for seagoing personnel are listed in the Occupational Health Assessment Guide, issued by the Occupational and Environmental Health Services Directorate of Health and Welfare Canada (1994). A footnote to the requirements states that the necessary hearing threshold levels may be met with the use of a hearing aid.

In a previous study (Forshaw and Hamilton, 1997), the hearing standards of a number of defence and transportation were summarized. This review noted the following:

- many existing occupational standards permit the use of hearing aids; and
- persons whose losses are primarily conductive and use a well fitted and properly adjusted conventional hearing aid can understand speech almost as well as persons with normal hearing, at least in the absence of high levels of extraneous sound.

Because it is essential in Coast Guard operations that what needs to be heard is heard, it follows that the hearing aids must be reliable if auditory tasks are to be carried out effectively by personnel who wear them. In the marine environment, the hearing aid may be exposed to salt water/moisture, electromagnetic radiation, extremes of temperature, and mechanical shock and vibration.

The report presents the following:

- a brief review of hearing pathologies;
- the appropriateness of amplification in overcoming hearing deficits;
- an assessment of the physical conditions encountered in marine environments that may impact on hearing aid reliability;
- a review of any national or international standard that provides design, performance and/or test requirements for a hearing aid with respect to its ability to operate reliably in a wet environment; and
- an assessment of any commercially available hearing aids which are designed to be waterproof or water-resistant.

# 2 HEARING PATHOLOGIES AND HEARING AIDS

Hearing loss is categorized according to the location of the abnormality or pathology causing the loss. The following are three major sites where this can occur:

- at the external or middle ear;
- at the inner ear (cochlea); and
- along the neural pathways from the inner ear to the brain.

The first is the external or middle ear where an abnormality can interfere with the conduction of sound pressure variations to the inner ear. This form of hearing loss is termed conductive deafness. The second site of hearing loss is the inner ear (cochlea) where the sensory transformation of the pressure variations to neural impulses can be affected. Structures of the inner ear can be damaged by high-intensity noises, resulting in a form of hearing loss called sensory deafness. The third source of hearing loss is any location in the neural pathways between the cochlea and the auditory association area of the brain (the region that processes auditory information, and interprets the meaning of speech by translating words into thoughts), the resulting impairment being called neural deafness.

Since routine hearing tests do not normally differentiate between sensory and neural impairments, hearing losses that are not of the conductive type are generally termed sensorineural losses. Most conductive pathologies are successfully treated through medical intervention. Sensorineural pathologies involve reduced sensitivity or resolving power of the neural receptor mechanisms themselves and are not amenable to medical intervention. Hence, hearing aids are prescribed primarily for individuals with sensorineural loss. Occasionally, hearing aids are useful for persons with conductive loss for whom surgery may not be appropriate.

## 2.1 Components of Hearing Aids

Amplification is the primary method employed to enhance the reception of speech and other information bearing signals for hearing impaired persons. The typical hearing aid consists of the following components:

- microphone;
- electronic filter;

- controls and circuitry for adjusting the amplification and overall shape of the frequency response;
- circuits for limiting the amplified signals to a comfortable level and for reducing noise;
- telephone induction circuitry (telecoil or T-coil);
- an earphone (receiver);
- a battery; and
- for hearing aids not worn in the ear canal, acoustic components such as flexible tubing and an earmold for coupling the output of the receiver to the external ear canal (CHABA, 1991).

## 2.2 Types of Hearing Aids

One method of classifying conventional hearing aids is according to their relative size and how they are worn. The three most common classifications are behind-the-ear (BTE), in-the-ear (ITE), and in-the-canal (ITC) models. Diagrams of these three types of hearing aids are presented in Figure 1.

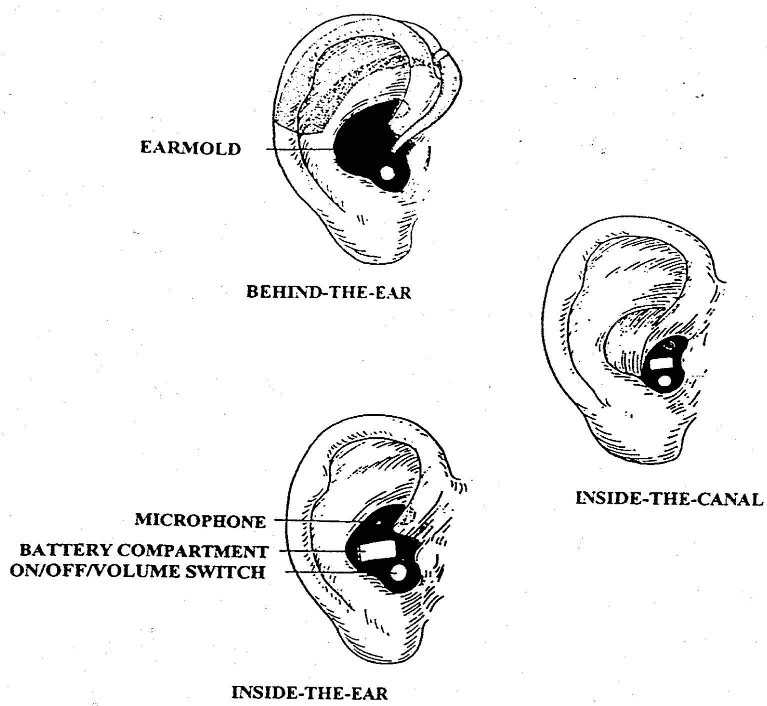


**Figure 1:**
**Three types of hearing aids: behind-the-ear, inside-the-ear, and inside-the-canal.**

- The BTE hearing aid is a relatively small instrument. Its electronic components are housed in a small elliptical case that fits behind the ear. The acoustical signals generated by the receiver are delivered to the ear canal by means of a flexible tube (termed a ‘hook’) terminating in an earmold.

- The ITE hearing aid is a smaller instrument. All of its components are contained in a small plastic case that is molded to fit into the wearer's ear. It occupies the outer portion of the external ear canal and the innermost part of the external ear.
- The smallest hearing aid is the ITC hearing aid which fits entirely in the ear canal. A recently developed micro-technology hearing aid, the completely-in-the-canal (CIC) model, fits deep inside the ear canal making it almost invisible. The volume control is either preset or controlled by infra-red (IR) control, eliminating adjustments that are almost impossible while in the wearer's ear.

Because the available power decreases with size, due primarily to the very small batteries that these instruments can accommodate, ITC and CIC aids are generally restricted to those individuals with only mild hearing losses.

In the United Kingdom, individuals who are judged to be in need of amplification, are provided with National Health Service hearing aids free of cost. Due to budget limitations, the aids which are most often provided are the BTE type rather than the more expensive ITE or ITC types (Brooks, 1994). In the United States, where there is no public provision of hearing aids, 78 per cent of hearing aid users purchase either an ITE or ITC instrument in preference to a BTE type (Kirkwood, 1990). It is not clear whether the decision to purchase the ITE or ITC aids is based on assumed superior acoustical performance and ease of handling or because of greater perceived cosmetic acceptability. ITC hearing aids are less visible than BTE instruments, but it is questionable whether ITE aids are more or less obvious than BTE aids, especially for individuals with long hair.

In a controlled study, Jerlvall et al. (1983) offered ITE hearing aids to experienced BTE users and assessed the outcome after a 6-month trial period. Of the 211 participants, 72 per cent preferred the ITE aid, but the reasons for that preference were not stated. Cosmetic appearance was rated as superior by 62 per cent of the subjects. Directional ability with the ITE aid was rated better by 30 per cent, and worse by 5 per cent. Sound quality was also rated as superior with the ITE instruments.

# 3 HEARING AID PERFORMANCE

## 3.1 Performance Standards

The most recently published standard that deals with hearing aids is the revised American National Standard S3.22 (1996), *Specification of Hearing Aid Characteristics* (ANSI, 1996). The standard describes hearing aid measurement methods that are appropriate for specification and tolerance purposes. These include output sound pressure level, frequency response, harmonic distortion, equivalent input noise, current drain, induction-coil sensitivity, and the static and dynamic characteristics of automatic gain control. The standard does not address design, performance, and/or test requirements for a hearing aid with respect to its ability to operate reliably in a diverse physical environments.

The International Electrotechnical Commission (IEC) Standard 529, *Degrees of Protection Provided by Enclosures*, addresses the water protection performance of electrical enclosures (IEC, 1989). The parts of this standard that apply to hearing aid water protection are discussed in the report section entitled "Performance Requirements".

Published information on the quality and stability of hearing aids is scarce. In one of the few investigations relating to the relatively current generation of hearing aids, Dawson (1987) studied 82 BTE hearing aids worn by hearing impaired children. Dead batteries were the major cause of defective operation. The component requiring the most frequent repair was the flexible tube (hook) that delivers sound from the receiver to the earmold, due to the tendency of the tubing to harden and discolour over time. Components requiring less frequent repair included the battery hatch, the on/off switch, the trimmer cover and the hearing aid case.

Sibelle and Parving (1994) carried out a longitudinal study of 2,377 hearing aids dispensed by the Danish National Hearing Health Service (ITC = 830, ITE = 455, BTE = 1092). Their data show that 34 per cent of the BTE models, 44 per cent of the ITE models, and 57 per cent of the ITC models became defective within the first year of use. After two years of use, 72, 62 and 76 per cent of the respective models became defective. Sixty-three per cent of the defects occurred in an external component of the hearing aids. The most common defects involved the housing, the controls, and the battery compartment. Thirty per cent of the defects involved internal components, including the circuitry, the microphone, the receiver, and the T-coil. The proportion of internal- to external-component defects was about the same in the ITC and ITE hearing aids. In the BTE hearing aids, defects in the external components were more frequent.

## 3.2 Performance in Adverse Physical Conditions

### 3.2.1 Electromagnetic Radiation

Hearing aids (mainly BTE models) can be equipped with a telecoil (T-coil) for direct telephone receiving. When the T-coil is switched ‘ON’, the input to the hearing aid amplifier is switched from the microphone to a coil of wire for pickup of the varying magnetic field at the earpiece of a telephone handset.

The T-coil does not alter a listener’s ability to discriminate in background noise. What the T-coil does is remove the noise in the listener’s environment that would otherwise be picked up by the handset microphone. It does nothing to the noise in the listener’s environment that reaches the person’s inner ear by air or bone-conduction, or noise being transmitted through the intercom from the talker’s microphone. Thus in the T-coil mode of operation, the speech signal is not degraded by noise or reverberation in the listener’s surroundings that otherwise would be amplified by the hearing aid amplifier.

Because the T-coil is intended to pick up a varying magnetic field, it is vulnerable to noise produced by electromagnetic interference (EMI). In buildings, sources of EMI include fluorescent-light ballasts, transformers, motorized valves and appliances, computers and other electronic equipment, magnetic fields around improperly shielded wires and ground-loop currents passing through conducting service pipes (Champagne, 1994; McKinnon, 1994).

This review did not find published or anecdotal information on the effect of ship electromagnetic radiation on hearing aid performance. However, given the multitude of electromagnetic sources onboard ships it is not unreasonable to assume that the telecoil mode of hearing aid operation may be adversely affected.

### 3.2.2 Extremes of Temperature

Manufacturers of hearing aids warn that the devices should not be exposed to extreme heat (e.g., the heat produced by hair dryers, heaters, stoves etc., or experienced in a closed car on a hot day) (Vernick and Grzelka, 1993). In cold environments, hearing aid performance can degrade significantly (Skinner, 1988). The limiting temperature for effective operation is usually determined by the low-temperature characteristics of the battery of the device. The two most common hearing aid power sources are the zinc-air and the silver-oxide batteries, having low temperature ratings of 0°C and -20°C respectively.

### 3.2.3 Mechanical Shock and Vibration

Dropping or knocking a hearing aid on a hard surface can result in damage to the housing, circuitry, and electroacoustic transducers of the device (Skinner, 1988). In rough weather, sea-induced ship motion is characteristically large-amplitude low-frequency roll, pitch and heave. There is the potential in rough seas for damage to a hearing aid, particularly models that are not seated securely in the ear canal.

### 3.2.4 Exposure to Moisture

Users of conventional hearing aids are cautioned against exposing the devices to water while bathing or showering, to bathroom steam, or to perspiration during manual labour or exercise (Vernick and Grzelka, 1993). This raises concern regarding the reliability of a hearing aid in the marine environment when the device is not designed to withstand moisture and sea spray.

## 3.3 Waterproof and Water-resistant Hearing Aids

### 3.3.1 Performance Requirements

The International Electrotechnical Commission (IEC) Standard 529, *Degrees of Protection Provided by Enclosures* (IEC, 1989), defines the degrees of protection provided to electrical equipment by an enclosure against the ingress of water. Included in the standard are designated degrees of protection and the tests to be performed to verify that the enclosure meets the designated level of protection.

The degree of protection is designated by an IP (International Protection) code. For example, the code IPX4 indicates acceptable protection of an enclosure against the ingress of water splashed against the enclosure from any direction. The code IPX7 indicates that the protection applies to temporary immersion in water to a depth between 0.15 and 1.0 metres.

The test protocol for code IPX4 requires that the enclosure be sprayed from a oscillating nozzle, through an angle of 180 degrees on either side of the vertical, the time for one complete oscillation (cycle) being about 12 seconds. The flow rate is specified in the standard as a function of the arrangement and number of the nozzle holes. The duration of the test is 10 minutes, resulting in a total of about 50 spray cycles.

The test protocol for code IPX7 requires the enclosure to be immersed in water in its service position so that the following conditions apply:

(1) the lowest point of an enclosure with a height less than 850 mm is located 1 metre below the surface of the water;

(2) the highest point of an enclosure with a height equal to or greater than 850 mm is located 150 mm below the surface of the water;

(3) the duration of the test is 30 minutes.

In general, an enclosure is considered to meet the standard if any of the water that may have entered the enclosure does not interfere with the correct operation of the electrical components contained within the enclosure. If the enclosure is provided with drain holes, it should be confirmed by inspection that any water which enters does not accumulate and that it drains out of the device without doing damage to the components contained therein.

### 3.3.2 Design Requirements

The BTE type hearing aid lends itself most readily to the water protection required to make it resistant to moisture damage. Because of their small size, ITC and ITE hearing aids do not lend themselves to practical moisture protection. The following are three critical parts of a BTE hearing aid which require moisture protection: the elliptical case containing the microphone, receiver and electronic components; the control block containing the on/off switch, volume control, amplifier, and receiver; and the battery compartment.

In 1988, Narisawa described the development of such a hearing aid (HB-35PT) by the Rion Company Ltd., of Japan. The contact portion between the case and the control block of the hearing aid was shielded with rubber packing which provided a watertight pressure seal. The moving parts of the battery holder and the volume control covers were designed so that the watertight seal protecting the case was maintained when the covers were opened. The two components of the hearing aid which are constantly used by a wearer (i.e., the on/off switch and volume control) were completely encased. The connecting control shafts were exposed, and waterproofing was maintained by means of two sets of large and small O-rings (Narisawa, 1988).

In the development of the waterproof hearing aid, protection of the microphone proved to be the critical challenge. The protection needs to provide resistance to water with a minimal loss of sound transmission. A water protection net of polytetrafluoroethylene was developed which resulted in less than 2 dB of sound attenuation at 5000 Hz, and a minimum of 0.5 $kg/cm^2$ of water pressure resistance.

Although the performance of the waterproof hearing aid met the requirements of IEC Standard 529 water protection code IPX4, the modified test that was used employed 60 cycles of spraying, each cycle lasting for 7 seconds once every one hour. The water resistance protection of the hearing aid was also verified using a modified IPX7 protocol. The hearing aid was immersed in water at a depth of 1.0 metres, for a total duration of 10 minutes rather than 30 minutes (Narisawa, 1988).

### 3.3.3 Availability of Water-resistant and Waterproof Hearing Aids

As far as can be determined, the only supplier of water protected hearing aids in Canada is the Rion Company Ltd. of Japan. Until recently, Philips Hearing Instruments marketed a "water-resistant" BTE instrument (P54-0). Philips Canada advise that the hearing aid is no longer available. Rion Company Ltd. carries a line of water-resistant and waterproof hearing aids that employs the technology that was developed for the original HB-35PT model. The approximate cost of a number of standard hearing aids, including the Rion instruments and two programmable units, are listed in Table 1.

**TABLE 1:**
**Approximate prices for commercially available hearing aids**

| | BTE | ITE | ITC | CIC |
|---|---|---|---|---|
| RION HB-37 (Water-resistant) | $870 | | | |
| RION HB-54 (Waterproof) | $1170 | | | |
| BELTONE | $700 | $1300 | $2000 | |
| STARKEY | $750 | $800 | $900 | |
| SIEMENS | $780 | $750 | $950 | |
| PHONAK | $900 | $750 | $750 | $1200 |
| UNITRON | $1000 | $1100 | $1200 | $1600 |
| SENSO Computer Programmable | $1000 | $1100 | $1200 | $1600 |
| RESOUND Computer Programmable | $1300 | $1600 | $2000 | $2600 |

Notes:

(1) Prices are in effect November 1997 and include the dispenser's charges for hearing assessment and hearing aid fitting and adjustments. The charges may vary across dispensers.

(2) Price additions may apply on some models for circuit options not included in standard models.

(3) RION hearing aids are complete with low-frequency noise suppression, a telecoil, gain and frequency-response trimmers, tone control, output limiter and wind screen.

(4) The RION company is represented in Canada by:

Assistive Listening Device Systems (ALDS) Incorporated
Richmond, BC,
Telephone: (604) 270-7751

Sentech Hearing Systems
Mississauga, Ont.
Telephone: (905) 564-7411;

(5) Servicing of the Rion hearing aids is carried out in Mississauga by factory-trained technicians.

The Rion water-resistant hearing aid meets the IEC Standard 529 IPX4 water protection requirements. It is intended for individuals who perspire excessively during work or athletic activities. Its electronics are not harmed by ordinary water spray or high humidity, but it is not intended to be worn underwater or subjected to excessive submersion. Drainage ports to drain moisture that may find its way inside the hearing aid are located on the lower part of the casing.

The Rion waterproof hearing aid exceeds the IEC Standard 529 IPX7 water protection requirements. The hearing aid case is completely waterproof and is rated for submersion in 10 metres of water for 7 days. The hearing aid is recommended for individuals employed in occupations such as life guards, boat operators, and all-weather outdoors maintenance and repair persons.

# 4 DISCUSSION

Although improvements in the design of hearing aids have increased their reliability, even the most robust hearing aid may not guarantee effective speech communications when used by persons with significant sensorineural discrimination losses in noisy or reverberant surroundings (Van Tasell, 1993; Poland et al., 1994). The problem of hearing aid performance in noise is not one of reliability *per se*; the hearing aid performs remarkably well in noise, and the new technology is able to reduce ambient noise effects to some degree. The problem with hearing aid performance is often a question of physiological impairment rather than hardware reliability (i.e., the broadening of the auditory filters that accompanies sensorineural pathology). More detailed information is provided in a previous report (BC Research, 1995).

Advances in signal processing and noise reduction techniques suggest that the new generation of hearing aids will be able to overcome, in part at least, the degradation of the acoustical signal between the speaker and the listener (CHABA, 1991). However, it is not clear how well the new hearing aid technologies can ameliorate the speech perception in noise and discrimination problems that accompany severe sensorineural pathology. Accordingly, pre-employment and periodic speech-discrimination tests conducted in a clinical setting have been recommended for these individuals, using their hearing aids, in realistic work-environment noise (Forshaw and Hamilton, 1997). This would ensure that the individual meets the speech discrimination, signal-detection, and sound-localization fences and also ensures that the listener/hearing-aid combination meets CCG requirements.

The use of water protection technology can increase the reliability of hearing aids which might otherwise be rendered inoperative in the moist environments encountered during CCG marine operations. However, the use of such hearing aids by persons with significant sensorineural hearing impairment will not guarantee effective speech communications.

With respect to the moisture environment encountered in marine operations, the question is what level of water/moisture protection is required for the hearing aids worn by seagoing personnel. This cannot be answered definitively in the absence of *in situ* experience with the devices. The waterproof aids certainly provide the most effective protection against moisture producing malfunctions. However, their cost is considerably higher than the less expensive conventional BTE aids (see Table 1). This could be of concern to prospective CCG employees who need amplification to meet the Health and Welfare hearing requirements but do not receive disability entitlement. If the moisture exposure of the hearing aid is restricted to perspiration and high humidity, the water-resistant aid may suffice. The cost of the water-resistant aid is competitive with conventional BTE hearing aids.

The use of hearing aid telecoils on CCG ships may be limited to the degree that electromagnetic interference is experienced. However, the electromagnetic leakage emitted from ships' communication handsets may not be sufficiently intense for usable pickup by the hearing aid.

# 5 CONCLUSIONS

Although there is limited information in the open literature on the reliability of hearing aids, it appears that malfunctions begin to occur in a significant proportion of hearing aids within the first two years of use. Further, the risk of malfunction is likely to increase if a hearing aid that does not have some degree of water protection is exposed to moisture.

The International Electrotechnical Commission Standard 529 defines the degree of protection provided by an enclosure against the ingress of water. The IPX4 code indicates acceptable protection against water splashing; the IPX7 code applies to enclosures that provide protection from immersion in water.

Two classes of water-protected hearing aids are available in Canada. Both are manufactured by the Rion Company of Japan. A water-resistant hearing aid that meets the IEC IPX4 standard is intended for individuals who perspire excessively during work or athletic activities. Its electronics are not harmed by ordinary water spray or high humidity. It is not intended to be worn underwater or to be subjected to excessive submersion. A waterproof hearing aid that exceeds the IEC IPX7 standard is recommended for individuals who work as life guards, boat operators, and all-weather outdoors maintenance and repair persons.

It is not possible to specify the level of water or moisture protection required for the hearing aids worn by seagoing personnel without *in situ* experience with the devices. The waterproof aids certainly provide the most effective protection from moisture producing defects. However, their cost is significantly higher than conventional aids with equivalent electro-acoustic capabilities. This could be of concern to prospective CCG employees who need amplification to meet the Health and Welfare Canada hearing requirements but do not receive disability entitlement.

Notwithstanding the fact that water-resistant hearing aids improve hearing reliability, CCG should ensure that employees who require hearing aids to meet the H&W Class 1 hearing criteria undergo speech-discrimination tests in a clinical setting while using their hearing aids (Forshaw and Hamilton, 1997). This would ensure that individuals meet the speech discrimination, signal-detection, and sound-localization fences when using their hearing aid.

From the available literature, it is not possible to know the effect of the ship's environment on the reliability and effectiveness of a hearing aid. For example, unless the electromagnetic radiation environment of each vessel is determined, in combination with the sensitivity of each type of hearing aid to this radiation, a firm recommendation on hearing aid use is not possible. As well, the moisture environment to which CCG employees are exposed is variable, and this will also affect hearing aid reliability in an undetermined way. Before making a final recommendation on the degree of moisture resistance or moisture repellency a hearing aid should be subject to a longitudinal field study.

Finally, the lack of standards to regulate the manufacture and performance of hearing aids with respect to water protection and reliability in the types of environments to which Coast Guard employees are exposed leaves the decision of which hearing aid to select to the preference of an individual for a particular hearing aid design.

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