**Performance/Design Criteria Review
Advanced Worker Protection Systems**

**Topical Report
August 1994**

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Work Performed Under Contract No.: DE-AC21-93MC30178

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Oceaneering Space Systems
16665 Space Center Blvd.
Houston, Texas 77058-2268

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Table of Contents

Change Log	i
List of Figures	v
List of Tables	vi
Acronym List	vii
1.0 Introduction	1
1.1 Approach	2
1.1.1 Methods of Acquiring Information	2
2.0 Performance Requirements	3
2.1 Overview of Current Technologies and Applications	3
2.1.1 Potential hazards and related requirements	5
2.1.2 Anticipated Work Tasks and Related Requirements	6
2.1.3 Deficiencies/Inadequacies of Existing Systems	7
2.1.4 Potential System Enhancements and Definition of Performance Goals	7
2.2 AWPS Performance Objectives	8
3.0 Regulatory and Certification Requirements	10
3.1 Performance	10
3.2 Testing	12
3.3 Certification	13
3.4 Production	13
3.5 Use	14
3.6 Existing DOE Personnel Protection Regulations and Guidelines	15
3.6.1 DOE Acceptance Testing of Hazardous Materials Fully Encapsulating and Splash Suits	15
3.6.2 DOE Site Contractor Standard Operating Procedures (SOPs)	16
3.7 OSHA And Other Government Regulations	16
3.7.1 Hazardous Chemical Worker Protection Standard (29 CFR 1910.120)	16
3.7.2 29 CFR 1910.134	17
3.7.3 NIOSH, Other CFR, Other Government Regulations	18
3.8 Non- Government Regulations	18
3.8.1 National Fire Protection Association (NFPA) Standards	18
3.8.2 ANSI/ISEA Coverall Sizing Standard	20

Table of Contents, continued

4.0	Test Protocols	21
4.1	Certification Testing	21
4.2	Other AWPS Testing	21
4.2.1	AWPS Suit Tests	21
4.2.2	AWPS Ensemble Tests	22
5.0	Preliminary AWPS Hardware Descriptions	24
5.1	Hazardous Materials PLSS	24
5.2	Face-Piece, Regulator, Helmet, Communications	24
5.3	High Performance LCG	24
5.4	Protective Clothing	25
5.4.1	Vapor-Protective Suit	25
5.4.2	Liquid Splash-Protective Suit	26
5.5	Sub Scale Recharge Station	29
6.0	Life Cycle Cost/Benefit Analysis	30
6.1	Development of Model	30
6.2	Model Variables	31
6.2.1	Purchase Costs	33
6.2.2	Operating Costs	33
6.2.3	Cleaning or Decontamination Costs	34
6.2.4	Maintenance Costs	35
6.2.5	Storage Costs	36
6.2.6	Disposal Costs	36
6.3	Determination of Specific Benefits	36
6.3.1	Worker Productivity	37
6.3.2	Worker Protection	38
6.4	Basis for Comparing Different Ensembles	39
6.4.1	Methods of Estimating Costs	40
6.4.2	Assumptions	41
6.5	Life Cycle Cost Calculations (Base Case)	43
6.6	Sensitivity Analysis	46
6.7	LCC Summary	49

Table of Contents, continued

7.0	Analysis Of Prior Performance Data	50
7.1	Manned Testing	50
7.1.1	Test Matrix	50
7.1.2	Apparatus	51
7.1.3	Results/Analysis	52
7.2	Backpack Testing	53
7.2.1	Test Matrix	54
7.2.2	Apparatus	54
7.2.3	Test Protocol	55
7.2.4	Results/Analysis	55
7.3	Duration Predictions	56
7.4	Oxygen Variability	58
7.5	Multi-Orientation Operation	58
8.0	Conclusions	59
	Appendix A - Questionnaire	1
	Appendix B - EPA Levels of Protection	1
	Appendix C - List Of Test Plans	1
	Appendix D - Life Cycle Cost Analysis Charts (Section 6)	1

Table of Contents, continued

List of Figures

Figure 6-1: Proportion of Costs for LCC	44
Figure 6-2 LCC Sensitivity to Use Time	48
Figure 7-1: Q_{need} vs. Environmental (suit/temp)	53
Figure 7-2: $Q_{backpack}$ vs. Flow	56
Figure 7-3: AWPS Backpack Duration	57

Table of Contents, continued

List of Tables

Table 2-1: PPE Open Use at Fernald DOE Site	4
Table 3-1: Protective Suit Types and Characteristics	19
Table 4-1: Prospective Criteria for Selection of Clothing Materials	22
Table 5-1: Comparison of Design Features for Levels A and B/C PPE	27
Table 6-1: Model Variables for Each Cost Area	32
Table 6-2: Time Required in Ensemble Operations	42
Table 6-3: Cost Model Variable Values	43
Table 6-4: Calculation of Life Cycle Costs (Simple Model - Best Case)	45
Table 6-5: Range of Key Variables Investigated	46
Table 6-6: Sensitivity of Life Cycle Costs to Key Variables	47
Table 7-1: Heat Exchange (BTU/Hr)	54
Table 7-2: Vaporizer T _{out} (°F)	54

Acronym List

AAPD	Advanced All Positioning Dewar
AWPE	Advanced Worker Protection Ensemble
AWPS	Advanced Worker Protection System
CFR	Code of Federal Regulations
D&D	Decontamination & Decommissioning
DFMA	Design for Manufacturing and Assembly
DOE	Department of Energy
EPA	Environmental Protection Agency
HAZWOPER	Hazardous Waste Operations and Emergency Response Standard
IDLH	Immediately Dangerous to Life and Health
KSU	Kansas State University
LCC	Life Cycle Cost
LCG	Liquid Cooling Garment
NB PLSS	Neutral Buoyancy Portable Life Support System
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
OSS	Oceaneering Space Systems
PLSS	Portable Life Support System
PPE	Personal Protective Equipment
PRDA	Program Research and Development Announcement
RAC	Respiratory Advisory Committee
RCTC	Refrigerated Controlled Temperature Circulator
SAR	Supplied Air Respirators
SCBA	Self Contained Breathing Apparatus
SOP	Standard Operating Procedures

1.0 Introduction

The Department of Energy (DOE) is in the process of defining the magnitude and diversity of Decontamination and Decommissioning (D&D) obligations at its numerous sites. The DOE believes that existing technologies are inadequate to solve many challenging problems such as how to decontaminate structures and equipment cost effectively, what to do with materials and wastes generated, and how to adequately protect workers and the environment. Preliminary estimates show a tremendous need for effective use of resources over a relatively long period (over 30 years).

Several technologies are being investigated which can potentially reduce D&D costs while providing appropriate protection to DOE workers. The DOE recognizes that traditional methods used by the EPA in hazardous waste site clean up activities are insufficient to provide the needed protection and worker productivity demanded by DOE D&D programs. As a consequence, new clothing and equipment which can adequately protect workers while providing increases in worker productivity are being sought for implementation at DOE sites.

This project will result in the development of an Advanced Worker Protection System (AWPS). The AWPS will be built around a life support backpack that uses liquid air to provide cooling as well as breathing gas to the worker. The backpack will be combined with advanced protective garments, advanced liquid cooling garment, respirator, communications, and support equipment to provide improved worker protection, simplified system maintenance, and dramatically improve worker productivity through longer duration work cycles.

Phase I of the project will result in a full scale prototype Advanced Worker Protection Ensemble (AWPE, everything the worker will wear), with sub-scale support equipment, suitable for integrated testing and preliminary evaluation. Phase II, if the project continues, will culminate in a full scale, certified, pre-production AWPS and a site demonstration.

This topical report is intended to detail the findings of the visits to DOE sites and the results of the first two tasks in Phase I - Operational, Regulatory, and Performance Requirement Definitions; and the Life Cycle Cost/Benefit Analysis. It also provides preliminary recommendations on the design of AWPE clothing and equipment. Data compiled previously will also be compared with the established requirements.

1.1 Approach

1.1.1 Methods of Acquiring Information

The methods of gathering the information necessary for the development of the AWPS were based on several factors that will inevitably govern its use at DOE and other sites. The most important of these factors are:

- The regulatory requirements of ensemble components;
- Performance criteria of the ensemble;
- Specific requirements for DOE use; and
- User acceptance of the ensemble based on equipment in use today.

Regulatory documents that affect the development, production and use on site of the AWPS were compiled. Regulations included those that control key features and components of the AWPS as well as testing and final certification of the entire ensemble. Also, referenced in this document are the regulations that control the use of this type of personnel protective equipment in hazardous materials situations (such as Occupational Safety and Health Administration (OSHA) 29 CFR 1910.120).

In order to better understand the requirements of the end user at DOE sites, a questionnaire was constructed. This questionnaire was used as a tool to determine the performance requirements at DOE sites and as a method of gathering data for the cost benefit analysis. A sample of the questionnaire is provided in Appendix A.

The final method used to compile information was the experience and knowledge of the personnel involved in the development of the AWPS. Some of this experience is related to similar clean up activities such as practices employed at the U.S. Environmental Protection Agency (EPA) Superfund sites. Additional experience in respirator and protective equipment development help to guide AWPS development. Also, personnel involved in AWPS development have hands on Haz Mat and Firefighting experience which significantly enhances the AWPS design effort.

2.0 Performance Requirements

2.1 Overview of Current Technologies and Applications

The AWPS will establish a revolutionary and distinctive category of Personal Protective Equipment (PPE). The respiratory protection system will provide as a by-product an effective form of cooling to relieve heat stress. The AWPS will also include protective clothing which provides consistent protection to the worker commensurate with different types of chemical and radiological hazards. This will be the first such unit to provide respiratory protection, full body skin protection, and full body cooling in one package.

Current systems for respiratory protection offer limited duration and provide little to no relief from heat stress for extended work periods or in hot environments. When cooling is provided, it must be provided separately and often adds significant weight to the overall worker protective ensemble.

Most protective clothing in use at DOE sites today is does not completely protect the worker from all hazards. Some clothing involves the improper selection of base materials. For example, Tyvek, a porous spunbond polyethylene product is used in many operations where liquid contact is probable. Yet, the manufacturer of Tyvek warns against the use of their product in these applications. Since few protective clothing manufacturers address appropriate components and interfaces, many DOE end users rely on "duct tape" to overcome these deficiencies while still risking potential exposure.

There is no uniform system of protective clothing and equipment use throughout the DOE D&D programs. Each site selects, uses, and maintains its own personnel protective equipment inventory. Since there is little communication between sites, these inventories vary greatly and different protective systems are used by different sites for the same type of operations. Moreover, each site now uses a large variety of protective clothing and equipment. These practices lead to inappropriate selections, overextensive procurement requirements, and difficulty in DOE workers realizing the applications and limitations for each item. Table 2-1 provide a list of protective clothing and respirators showing the diversity of this equipment used at one site.

Table 2-1: PPE Open Use at Fernald DOE Site

Clothing or Equipment Item	Manufacturer
Gloves Knit cotton inner liner Vinyl plastic Latex surgical Thin nitrile rubber Thick latex rubber Unsupported Neoprene Unsupported Viton Leather Cotton High temperature Knit Kevlar	Disposables Becton-Dickson Ansell Best Manufacturing Ansell Edmont North Unknown Unknown Unknown Golden Needles
Protective Suits Cotton coveralls FR cotton coveralls Cotton/polyester coveralls Cotton washable "Anti-C's" Kleenguard coveralls Sontara coveralls Comfortgard II coveralls Tyvek (uncoated) coveralls Saranex/Tyvek coveralls CPF II coveralls Vinyl plastic suits Chemrel encapsulating suits Nitrile splash suits Trelchem Level A suits	Unknown TOPPS manufacturing Unknown Unknown Kimberly-Clark Mar-Mac Durafab Kappler Kappler Kappler Defense Apparel Chemron Edmont Trelleborg
Air-Purifying Respirators 7700 series half mask Comfo II half mask Comfo II belt-mounted mask Ultratwin full face mask Ultravue full face mask Optimum air 6 PAPR full Optimum air MM PAPR full	North MSA MSA MSA MSA MSA MSA

Clothing or Equipment Item	Manufacturer
Air-Supplying Respirators	
Continuous flow airline	MSA
PD Duoflow full face airline	MSA
Pressure demand hip air full	MSA
Continuous welders full face	MSA
Type CE abrasive blasting	MSA
Continuous flow airline	Nuclear Power Outfitters
PD 60 minute SCBA	Survivair
ISI 5 minute EBA	ISI

2.1.1 Potential hazards and related requirements

DOE D&D workers face a multitude of hazards at each of the sites. These hazards include:

- Contamination (radiological or chemical);
- Physical (punctures, cuts, tears, and abrasions);
- Thermal (contact with molten metal from welding operations, flame impingement, chemical flash fires); and
- Thermal stress (heat or cold-related exposures).

Contamination hazards exist at different levels of severity. Based on site visits, the principal contamination hazard to DOE workers is contact with radionuclides or other radioactive contaminants, principally particles. In addition, several sites also involve mixed wastes primarily metals, anions, chlorinated hydrocarbons, fuel hydrocarbons, ketones, phthlates, PCB's, explosives, pesticides, alkyl phosphates, complexing agents, and organic acids. While most of the time these contaminants are encountered at relatively low concentrations, some substances have extreme toxic effects at these levels. Much of this contamination is found in specific areas at each site, particularly storage tanks, and former processing facilities.

The nature of D&D work produces severe physical hazards to DOE workers. Much of the dismantling of structures and removal of waste involves different forms of machinery. Therefore, worker PPE and other equipment must protect workers from the excessive vibration, sharp edges, and rough surfaces found in these environments.

As determined in site visits, the potential for flame contact and hot surfaces is expected to be at a minimum. Nevertheless, certain operations will involve extensive welding or cutting. These

operations provide the potential for worker contact with flame or small amounts of molten metal. To meet these specialized protection needs, additional external protective items may be required.

DOE D&D will be undertaken in a variety of environmental conditions with a wide range of temperature and relative humidity. The high work loads required for many operations will produce large metabolic energy consumption causing workers to overheat even in low temperature, low humidity conditions. Most protective clothing and equipment by its very nature contributes to worker heat stress. Thus, it is important that clothing ensembles used at DOE sites must be designed to minimize the impact of heat stress. In addition, worker mobility must not be impaired as limitations in worker function also affect increases in heat stress and overall energy expenditures.

Hazards associated with the AWPS will be no greater than those associated with breathing apparatus used today. The AWPS is a low pressure (60 psi) system that has passive safeguards to protect against failure of the system and injury to the wearer.

The prospective design of the cooling garment represents a well established technology which has been optimized to be used at a lower weight without any risk to the end user. Likewise, protective clothing systems will be based on existing, demonstrated materials used in current commercial products. Protective clothing improvements will encompass design enhancements, attention to interfaces, and complete integration with other equipment, all of which contribute to improved worker safety over existing systems.

2.1.2 Anticipated Work Tasks and Related Requirements

Work activity at DOE sites will vary from relatively low metabolic energy costs at 100 watts (standing) to well over 500 watts (heavy two handed work). The variability of work tasks have a large bearing on the design of the AWPS cooling system. The cooling can be adjusted independently of the breathing system. However, the more that is understood about the anticipated work loads, the more accurate the design of the AWPS.

The DOE also expects a large variety of contamination hazards at the different D&D sites. Different contamination hazards will dictate different levels of protection. In those cases involving the most severe hazards, totally encapsulating protective ensembles must be used. More routine work involving self-contained respiratory protection will require protection against well-defined or incidental contamination hazards and a lower level of skin protection. For this reason, the AWPS will encompass two different forms of protective clothing: a vapor-protective totally encapsulating fully-integrated clothing system (EPA Level A); and a liquid splash-protective multi piece protective clothing system (Level B).

2.1.3 Deficiencies/Inadequacies of Existing Systems

Systems now used in hazardous materials applications have many deficiencies. A Self Contained Breathing Apparatus (SCBA) does not provide sufficient duration for efficient and cost effective hazardous materials operations and does not supply cooling to the subject. Supplied Air Respirators (SAR) have an indefinite duration, but do not supply cooling. They also limit wear mobility due to the tethered breathing line required for these systems. Some users are employing an air supplied cooling vest. However this system consumes large quantities of compressed air usually requiring an umbilical, and has limited comfort because of the air flow into the suit and the hot air ejected by the vortex mechanism. When in a fully encapsulating or splash suit, without cooling the wearer is not capable of working safely or comfortably for more than forty five minutes even in a relatively cold environment. The worker typically requires a minimum of an hour rest to cool down after each forty-five minute work period. In many environments this work period is reduced to twenty minutes.

Many outer protective garments worn today are either uncomfortable and bulky, or they are too expensive for large scale operations. Fully encapsulating suits rarely fit the wearer correctly, creating a more stressful and inefficient work environment. A more form fitting suit that is also less expensive would be more efficient to use in operations the size of DOE D&D work.

In addition, nearly all protective clothing in use today does not provide effective interfaces with other clothing or equipment. End users must use duct tape to seal gloves and boots to garments and to ensure that hoods stay over respirators. This practice defeats the purpose of wearing protective clothing constructed of barrier materials since particulates, liquid, and other contamination can easily penetrate these poorly constructed interfaces.

2.1.4 Potential System Enhancements and Definition of Performance Goals

A number of system enhancements have been identified through three different site visits (Fernald, Hanford, and Oak Ridge). It has become clear that current protective clothing and equipment systems within the DOE:

1. Are not sufficient in providing complete protection commensurate with the types of hazards found at DOE sites;
2. Do not address proper integration of clothing and equipment nor allow for the effective implementation of internal or external cooling systems; and

3. Are inefficient since they encompass a large range of protective clothing and respirators for which there are few or poorly prepared specifications, no understanding of limitations, or few warnings and instructions provided for their use.

Goals for the proposed AWPS address each of these areas by:

- Providing a high level of respiratory protection consistent with DOE site hazards combined with a cooling garment (to eliminate heat stress and provide for increased worker comfort, productivity, and safety) and protective clothing against both physical and contamination hazards;
- Integrating all clothing and equipment items such that they fit together, provide complete protection to the wearer, and allow ease of donning/doffing, decontamination, and maintenance;
- Replacing several existing protective clothing and equipment systems with two different systems which can be configured in several fashions to accommodate a wide range of operations while minimizing procurement needs, system maintenance, and training; and
- Improving cost efficiency of D&D operations.

2.2 AWPS Performance Objectives

The unique features of the AWPS objectives should dictate design for proper apparatus development. The primary source of this information has come from the potential end users of the AWPS, specifically the personnel involved in cleanup at the DOE sites. Site visits have been completed to Fernald, Hanford, and Oak Ridge. Information compiled from the visits is being used to guide the development of the respirator, cooling garment, and outer garment portions of the AWPS, and it's associated support equipment.

Based on this information, the Portable Life Support System (PLSS), Liquid Cooling Garment (LCG), and protective clothing used as part of the Advanced Worker Protection System will have the following characteristics:

1. The PLSS will provide at least 2.0 hours of breathing air at an average respiratory consumption rate of 40 liters per minute per National Institute of Occupational Safety and Health (NIOSH) certification standards. This is discussed further in Section 3.0;
2. The PLSS will operate in any orientation;

3. The PLSS will operate in the pressure demand mode only and provide positive pressure operation at breathing rates up to 120 liters per minute;
4. The PLSS will provide a clear indication of remaining air supply and provide a low air warning;
5. The overall PLSS weight will be no more than 40 pounds fully charged. However, 30 pounds will be used as a design goal;
6. The PLSS outer shell will provide for ease of decontamination;
7. The PLSS will be refillable in a time similar to that of an SCBA high pressure (4500 psig) bottle;
8. The LCG will weigh less than 6 pounds when fully filled with water;
9. The LCG will provide effective cooling for work rates ranging from 100 to 500 watts for a period of up to 2 hours at the highest work levels;
10. The garments in conjunction with the PLSS will form a complete protective envelope around the wearer. Interfaces between clothing items and the PLSS will maintain protective qualities commensurate with the clothing and PLSS systems separately;
11. The clothing will provide barrier protection consistent with the actual or potential hazards at DOE remediation sites;
12. The clothing will possess adequate strength and durability to prevent loss of suit or system integrity from the physical hazards of the DOE remediation site through the intended number of clothing use cycles;
13. The clothing will afford the wearer less than a 20 percent decrease in mobility, tactility, and time necessary to complete task functions when compared to the same activity without the protective clothing; and
14. The clothing, LCG, and PLSS in combination will extend working times compared to existing Personal Protective Equipment (PPE) ensembles by at least 100%.

3.0 Regulatory and Certification Requirements

All PPE must meet specific federal regulatory requirements. There are individual requirements for the respirator, container, protective suits, helmet, and support equipment. Use of PPE is controlled by these regulations, and the suits and respirator must complete certification testing as part of additional regulatory requirements. The design, testing, certification, production, and use requirements of the AWPS are described below.

Regulatory requirements for the AWPS include requirements for the backpack (SCBA), pressure vessels, suits, recharge station, operations on site, and breathing air quality. EPA regulations will also govern the amount of secondary waste, and the impact of the system as a whole on the environment. A better description of these requirements is provided in sections 3.6 through 3.8. The regulations are described below.

3.1 Performance

Respirators for use in Immediately Dangerous to Life and Health (IDLH) atmospheres must be designed to meet certain criteria. The primary driver for respirators is the National Institute for Occupational Safety and Health (NIOSH 31 CFR Part II) certification process. The major design requirements that are specific to the AWPS include:

1. The respirator must maintain a positive pressure within the face mask, throughout the entire range of breathing cycles at a maximum breathing rate of 40 liters per minute. This prevents any contaminated gases from entering the mask during breathing;
2. The apparatus must supply breathing gas in any orientation. This is not a concern with compressed air, however, for a liquid air respirator to work in any orientation, the intake portion of the container must always be submerged. This has been a major design consideration in development of the AWPS;
3. High flow rates of air delivered to the wearer are required in emergency situations. Normally an SCBA is equipped with a by-pass switch for this purpose. However, newer versions fail into a free flow delivery;
4. The respirator must be equipped with a gauge showing the remaining amount of air and alarm which sounds when 20-25 % of the total air supply remains;
5. The overall weight of the respirator and cooling system must not exceed 40 pounds including mask, when fully charged (with liquid air);

6. The support frame should evenly distribute weight to the wearer's back and hips. The apparatus should not ride up on the wearer's back while bending;
7. The respirator should have a suspension system which provides a waist belt and shoulder straps which are constructed of durable, materials of sufficient strength; and
8. The apparatus should be designed such that it is easily donned, used, decontaminated, refilled, and maintained.

Protective clothing used for worker protection during hazardous waste management and handling activities (such as site characterization, removal actions, remediation, decontamination, and decommissioning) should effectively isolate the worker from substances harmful by skin contact. Specific design requirements include:

1. Protective clothing materials should adequately prevent the penetration or permeation, as appropriate, of hazardous substances at DOE sites (primarily metals, anions, radionuclides, chlorinated hydrocarbons, fuel hydrocarbons, ketones, pthtlates, PCB's, explosives, pesticides, alkyl phosphates, complexing agents, and organic acids);
2. Protective clothing materials should combine durability and physical hazard resistance with light weight, flexibility, breathability, and related comfort properties;
3. Seaming technologies and clothing interfaces (such as closures, sleeve to glove attachments, pant cuff to boot attachments, and hood to respirator attachments) should offer garment integrity consistent with either liquid or vapor hazards, as needed;
4. Garment design should accommodate other clothing items or equipment to be worn for additional protection;
5. Garment design should provide a minimum impact on worker comfort, mobility, and functionality to complete assigned tasks;
6. Garments sizing should provide a good fit for the majority of the worker population;
7. Garments should be designed to affect ease of donning, doffing, and decontamination; and
8. Garment labelling should clearly identify the use and warnings appropriate to the protective clothing item.

3.2 Testing

The AWPS will be evaluated at OSS to complete preliminary assessments on its capability to qualify for certification. At the end of Phase I, the AWPS will be tested at Kansas State University (KSU). This testing will be third party verification of the operation of the respirator, but more importantly KSU will evaluate the cooling performance of the apparatus in various environments and working scenarios. The test subjects will critique the fit and comfort of the AWPS.

The primary objectives for testing include:

- Operational Testing of the AWPS for:
  - Duration
  - Cooling performance
- Comfort/load distribution of backpack (ability of system to operate in different orientations);
- Orientation testing;
- Fit, form, and function of AWPS;
- Human factors assessment; and
- Failure mode testing.

Protective clothing should be evaluated for various properties to demonstrate that stated design objectives have been met. Testing is to be performed to recognized consensus standards with available or other test protocols relative to DOE needs. Testing areas include:

- Verification of material chemical resistance and key physical properties;
- Determination of seam/closure chemical resistance;
- Evaluation of overall clothing integrity (gas-tight or liquid-tight); and
- Assessment of overall clothing comfort, fit, and function.

3.3 Certification

Protective clothing design will follow the existing NFPA standards for hazardous chemical emergencies and operations described below and meet the acceptance protocols established by the DOE and the NFPA protection equivalent to Level A and B protective suits, as appropriate.

The regulation with the most impact on the development of the respiratory portion of the AWPS is 30 CFR Part 11. This regulation is for the Certification of Respiratory Protective Devices. The NIOSH is the primary controlling organization for this CFR (Code of Federal Regulations). Certification of the AWPS to Title 30 is essential for the unit to be used in a hazardous environment. The AWPS will be certified as a pressure demand, open circuit Self Contained Breathing Apparatus. A matrix was constructed to guide the design effort of the AWPS toward the NIOSH certification. This matrix can be found in Appendix E of this document. NFPA requirements for SCBA are similar to NIOSH but more restrictive in materials and environmental testing. Many tests simulate vigorous activity and environmental extremes.

There are many other regulations that are specified in Title 30 certification. These certify the pressure vessels, lenses, hoses, connections, and air (consumables).

NFPA Regulations 1991, 1992 and 1993 as well as the Los Alamos LA-10156-MS dictate the requirements for the suit portions of the AWPS. Preliminary evaluation to these regulations will be at the Los Alamos National Laboratory.

The regulation that controls the general use of respirators is 29 CFR Part 1910.134 which is controlled by OSHA. OSHA also controls Safety and Health for hazardous materials handling with 29 CFR 1910.120 which is the Hazardous Waste Operations and Emergency Response Standard (HAZWOPER).

3.4 Production

The respirator portion of the AWPS that completes NIOSH certification will be a production grade unit. All methods used to manufacture the certification units will be used in production of the commercial grade respirators. Design For Manufacturing practices will be followed throughout the development of the AWPS. Methods to create a more efficient manufacturing process and ease of maintenance of the apparatus will be followed at all times. OSS has on staff Quality Engineers to monitor the manufacturing of all AWPS components and to ensure that proper operations are being followed. Detailed specifications and patterns of protective clothing should be provided to ensure consistent quality of manufacture.

Protective clothing production costs should be minimized to provide products at the lowest

possible manufacturing cost without sacrifice of quality. Clothing materials, components, and manufacturing methods will be chosen to provide the most economical and efficient means of production.

Protective clothing certified to the NFPA standards is listed by the certification organization. The NFPA standards establish requirements for manufacturer quality assurance for ensuring continuing clothing compliance to the relevant standard. Specific guidelines for production quality control will be established for this program at OSS.

3.5 Use

Simple, easily understood instructions will be provided for informing DOE workers of the proper use of PLSS, LCG, and protective clothing as part of the AWPS. All instruction will be according to the proper regulatory requirements. These instructions will cover the following areas that are specific to the AWPS:

- Safety;
- Donning procedures;
- Doffing procedures;
- Safety considerations while using protective clothing and equipment;
- Optimum storage conditions;
- Recommended shelf life;
- Decontamination recommendations and considerations;
- Maintenance criteria;
- Methods of repair, if recommended;
- Recharge procedures;
- Respirator cleaning and reconditioning;
- Cooling garment cleaning and reconditioning; and
- Retirement considerations.

3.6 Existing DOE Personnel Protection Regulations and Guidelines

3.6.1 DOE Acceptance Testing of Hazardous Materials Fully Encapsulating and Splash Suits

The Respiratory Advisory Committee (RAC) and the Department of Energy require that all Level A and B suits used in Hazardous Materials operations at DOE facilities are to be evaluated for construction and performance in several areas. Testing is conducted by the Industrial Hygiene Group, Research and Development Section of the Health and Safety Division at Los Alamos National Laboratory. The evaluation is completed according to the Los Alamos document LA-10156-MS Acceptance-Testing Procedures for Air-Line Supplied-Air Suits. Testing areas include:

1. Fit Factor Testing. This testing involves the measurement of inward leakage of contaminants during both standards exercises and simulated work tasks.
2. Inducement of Heat Stress. This test examines physiological changes in the wearer while wearing the protective suit.
3. Temperature. The effects of temperature variations on the performance of the suit and the level of protection provided are assessed.
4. Aging. Suit deterioration is investigated as related to storage and reuse.
5. Communications and Manipulation Tests. These tests include reading, writing, dexterity, and performance of a cylinder repair operation to evaluate how the suit impacts basic worker functions.
6. Noise Generation. The level of noise generated inside the suit is measured.
7. Air-Supplied Hose Performance. Air-supplied hoses, provided with some protective suits, are evaluated for: (a) the strength of the connection to the suit covering, (b) crush resistance, (c) non-kinkability, and (d) strength of hose and couplings by means of rapid pulling test.

Los Alamos National Laboratory will also evaluate any other areas of the protective clothing considered to be deficient during the above testing.

Requests for this testing are made using special request form (EH-412) to be forwarded to the DOE Industrial Hygiene Programs Division accompanied by a statement regarding the need for

the suit, Standard Operating Procedures entailing donning, doffing, decontamination, storage, and reuse protocols, and a statement describing the conditions under which the suit is to be used.

Results from testing are forwarded to the DOE RAC for review. This group also sets a schedule for future periodic testing of the suit.

3.6.2 DOE Site Contractor Standard Operating Procedures (SOPs)

Standard Operating Procedures (SOP) were obtained for each of the sites visited. The SOP's were published by the site prime contractor for operations specific to the site. These SOP's will be used as a guide in order to develop the AWPS to be suitable to the user.

3.7 OSHA And Other Government Regulations

3.7.1 Hazardous Chemical Worker Protection Standard (29 CFR 1910.120)

OSHA 29 CFR 1910.120 covers the responsibilities of employers engaged in hazardous waste operations or emergency response. These regulations include clean-up operations involving hazardous substances that are conducted at hazardous waste sites as required by a Federal government body. Specific provisions within the regulations address:

- Development of a written safety and health program for hazardous waste clean-up workers;
- Establishment of a chain of command for supervisors and employees;
- Development of a comprehensive work plan which addresses the tasks and objectives of all site operations; and
- Development of a site-specific safety and health plan that provides a hazard analysis for each task, training assignments, personnel protective equipment use, medical surveillance, air monitoring requirements, site control measures, decontamination procedures, an emergency response plan, confined space entry procedures, and a spill containment program.

Requirements relating to selection of personal protective equipment are covered in paragraph (g) (3). These rather general requirements specify that:

1. Selected PPE must adequately protect employees from actual and potential hazards as identified in site characterization and analysis.
2. PPE selection must be based on performance factors characteristic of the site, task specific conditions, task length, and actual/potential hazards.
3. Positive pressure SCBA or air-line respirators equipped with escape SCBA must be used when chemical exposure levels create a substantial possibility of immediate death or serious injury.
4. Totally encapsulating protective suits must be used when death or serious injury from skin absorption is a potential hazard.
5. The level of protection provided by the PPE must be increased when additional information is gained to show additional hazards to employees. Appendix B provides the EPA's Levels of Protection. Levels A through D are appropriate for hazardous waste site clean-up. The level chosen must reflect both the actual and potential hazards of the site. Table 3-1 provides a synopsis of each level.
6. PPE must meet the requirements of 29 CFR Part 1910, Subpart I. This requirement essentially indicates that the protection offered by the clothing and equipment must be commensurate with the actual or potential hazards that may be encountered.
7. Totally encapsulating protective suits must pass a pressure test or prevent inward leakage using the procedures specified in Appendix A of the regulation. The pressure test is equivalent to ASTM F 1052, Standard Practices for Pressure Testing of Totally Encapsulating Chemical Protective Suits.

3.7.2   29 CFR 1910.134

In addition to the HAZWOPER regulation, which is an overall regulation for working in a hazardous environment, another portion of the same regulation governs the general use of respirators. This regulation is 29 CFR 1910.134. This portion of 29 CFR describes respirator selection, use, and maintenance for use in any industry.

3.7.3 NIOSH, Other CFR, Other Government Regulations

NIOSH - 30 CFR Part 11 Respiratory Protective Apparatus is the certification regulation for all types of respirators. Certification of SCBA, which is covered in Subpart H - Self-Contained Breathing Apparatus is applicable to the AWPS. Title 30 certifies that the apparatus has met the appropriate form and function, and it has passed several manned and unmanned tests. The cooling portion of the AWPS is not required as part of this testing, as it is not essential for operation of the apparatus. The certification testing which is all completed at the NIOSH facility includes several respirator tests on a mechanical breathing machine. These tests determine proper operation and performance of the apparatus and tests for required failure modes. Manned tests are also performed using two test subjects wearing the apparatus. The main objective of the manned tests are to evaluate the performance of the apparatus during specific tasks while being critiqued by the wearer for donning and doffing ease, fit, comfort, operation in various orientations, and general user friendliness.

3.8 Non- Government Regulations

3.8.1 National Fire Protection Association (NFPA) Standards

While not mandatory, Appendix B of 29 CFR 1910.120 recommends that protective suits meet one of the following standards:

- NFPA 1991, Standard on Vapor-Protective Suits for Hazardous Chemical Emergencies;
- NFPA 1992, Standard on Liquid Splash-Protective Suits for Hazardous Chemical Emergencies; and
- NFPA 1993, Standard on Support Function Protective Garments for Hazardous Chemical Operations.

At the time 29 CFR 1910.120 was promulgated, these standards were still undergoing development. Since then, each of the standards were adopted in 1990 and future revisions are planned for the middle of 1994. Table 3-1 provides the equivalence of these standards with the EPA levels of protection.

Table 3-1: Protective Suit Types and Characteristics

Suit Design Type	EPA Level	Suit Integrity	Material Performance
Encapsulating suit with AWPS backpack worn internally, attached or detachable gloves and boots (NFPA 1991 compliant)	A	Gas-tight	Resists permeation to chemicals with hazardous vapors
One or two piece 'splash' suit with PLSS worn either internally or externally, integrated with separate gloves and boots (NFPA 1992 or 1993 compliant)	B or C	Liquid-tight	Resists penetration to chemicals which are hazardous as liquids

Standards by the National Fire Protection Association represent consensus standards. However, compliance to each of the standards is demonstrated through independent, third-party certification. Compliant products must meet all of the minimum documentation, design, and performance criteria in order to be labelled as compliant with the respective standard.

In this program, two types of suit design will be considered based on the prevalence of different chemical hazards at DOE sites. These will include:

1. An encapsulating chemical protective suit that includes attached or detachable gloves and boots providing gas-tight integrity with respect to the outside environment and having materials resisting permeation by priority DOE site chemical vapor hazards. In this suit design, the PLSS would be worn internally. This suit type is consistent with EPA Level A as described in OSHA 1910.120, Standard for Protection of Workers during Emergency Response and Hazardous Waste Site Cleanup. It is intended for emergency response operations at DOE sites.
2. A splash suit with means of integrating PLSS mask, gloves, and boots providing liquid splash-integrity with respect to the outside environment and having materials resisting penetration by priority chemical liquid hazards. This suit type is consistent with EPA Level B as described in OSHA 1910.120, Standard for Protection of Workers during Emergency Response and Hazardous Waste Site Cleanup. It is intended that this suit be used for the majority of D&D operations at DOE sites.

- Level A encapsulating chemical protective suits will be designed to meet NFPA 1991
- Level B and C splash protective suits will be designed to meet NFPA 1993.

The suits will be designed to meet the proposed changes to the upcoming 1994 editions of these NFPA standards.

SCBA or airline breathing systems equipped with emergency escape breathing apparatus are to be used for both EPA Levels A and B when high or moderate respiratory hazards exist.

NFPA 1981 Open-Circuit Self Contained Breathing Apparatus for Fire Fighters, is the regulation that certifies SCBA's for use in the fire service. This standard will be used as a guide for AWPS development, primarily because it is a more descriptive and up to date document that can be readily referenced. However, NFPA 1981 will not alter the development of the AWPS as it is not a legally required certification for SCBA use in the hazardous materials industry.

3.8.2 ANSI/ISEA Coverall Sizing Standard

Coveralls and similar garments will be designed to meet ANSI/ISEA 101-1993, Size and Labelling Requirements for Limited-Use and Disposable Coveralls. This standard sets minimum dimensions for key size-related areas of coverall and coverall-like garments. It also addresses coverall labelling and packaging.

4.0 Test Protocols

4.1 Certification Testing

Subassemblies of the optimized prototypes developed in Phase II will be submitted for certification to respective organizations for clothing and equipment. The respirator portion of the PLSS will be submitted to the National Institute for Occupational Safety and Health (NIOSH) for certification under 30 CFR Part 11. These regulations require strict adherence to several specifications involving air flow, wearer comfort, and the basic safety of the device. A total of two units will be submitted for evaluation by NIOSH. Prior to undertaking PLSS certification, OSS personnel will visit with NIOSH personnel to gain a better understanding of system requirements for avoiding resubmittals in the event of a deficiency.

Protective suits developed as part of the AWPS will be submitted to Los Alamos National Laboratory for evaluation. Los Alamos National Laboratory has the responsibility for evaluating all chemical protective clothing used in DOE applications. Their evaluation of the protective suits involves principally inward leakage and related overall performance tests of the ensemble. In some cases, OSS will suggest that the entire AWPS be evaluated as a single ensemble to determine compliance with DOE requirements.

4.2 Other AWPS Testing

4.2.1 AWPS Suit Tests

A series of tests will be performed as described under testing requirements above for evaluating protective suits developed under this program. While already qualified materials will be used for protective clothing, the criteria in Table 4-1 will be used to determine if additional material tests are necessary.

The effectiveness of selected or designed interfaces will be determined by evaluation of the subcomponent assembly. In the case of seams and closure systems, this will include chemical permeation/penetration resistance and strength tests. Glove and boot interfaces will be evaluated in strength tests and further evaluated in overall suit integrity tests to be performed after initial prototypes are fabricated. Test plans for the proposed barrier and physical tests are provided in Appendix C. Interfaces not demonstrating acceptable performance consistent with system requirements will be redesigned and further optimized until project goals are met.

Table 4-1. Prospective Criteria for Selection of Clothing Materials

Characteristic or Property	Test Method	Recommended Criteria
Permeation resistance	ASTM F 739	Breakthrough time > 8 hrs. for selected chemicals
Penetration resistance	ASTM F 903	No penetration in 8 hrs. for selected chemicals
Tensile strength	ASTM D 751	Strength > 30 lbs.
Burst strength	ASTM D 751	Strength > 50 psi
Tear resistance	NFPA 1971, Section 5-4	Tear force > 8 lbs.
Puncture/tear propagation	ASTM D 2582	Puncture force > 5.5 lbs.
Abrasion resistance	ASTM D 4157	To be determined ^A
Flexural fatigue resistance	ASTM F 392	To be determined ^A
Flame resistance	NFPA 702	Class I
Flame impingement	ASTM F 1358	Burn time < 10 seconds; Burn distance < 4 inches
Cold temperature flexibility	ASTM D 747	Bending moment < 60 in.-lbs.
Static charge resistance	AATCC 76	Resistivity < 10 ¹⁰ ohms

^A Recommended criteria will depend on whether disposable, limited use, or reusable suit materials are chosen.

4.2.2 AWPS Ensemble Tests

A series of tests will be performed to evaluate the characteristics of the initial prototype suits and PLSS/cooling systems, including:

- Integrity tests performed on the protective suits to determine if suits offer gas-tight or liquid-tight integrity as appropriate;
- Qualitative comfort, fit, and function tests to determine user mobility, sizing requirements, and ability to perform DOE related clean up tasks while wearing protective suits and PLSS; and

- Quantitative human factors testing to demonstrate longer duration capabilities of the AWPS and needed design changes.

Integrity tests will be performed on the suits by themselves. Qualitative and quantitative human factors tests will be performed on the AWPS including suit, LCG, and PLSS. The latter tests will encompass an assessment of perceived comfort and cooling on the part of the AWPS as it related to increased wearer endurance. Test plans for each area are provided in Appendix C. Findings from each test will be used to optimize the design of the suits, LCG, PLSS, and method for interfacing clothing and equipment to achieve system requirements.

5.0 Preliminary AWPS Hardware Descriptions

For the cost benefit analysis described in this report, a preliminary configuration for the AWPS hardware was assumed. This section briefly describes the hardware configurations and some possible alternatives.

5.1 Hazardous Materials PLSS

The design of the AWPS backpack utilizes Design for Manufacturing and Assembly (DFMA) techniques to minimize production costs and many of the components will be plastic injection molded to reduce weight, simplify maintenance, and ease decontamination procedures. The Advanced All Position Dewar (AAPD) consists of an inner vessel, outer vessel, and pivot components. The pivot components will be placed in the inner vessel which will be bonded closed. The half of the outer vessel against the user's back is to be integrated into the frame of the backpack so as to be a single component. The pump, electronics, plumbing, and other components will be installed into mounting points molded into the frame wherever possible. A cover will clip over the system to protect the interior components from impact loads. The supply lines to the mask will come over the shoulder from the top of the backpack. The metering valve control will be designed and situated in such a manner as to allow the user to easily control it through a Level A or B suit.

5.2 Face-Piece, Regulator, Helmet, Communications

A Cairns face-piece and regulator will be modified to incorporate backpack status displays and optional communications. It will also have a quick connection to the backpack for simpler donning and doffing. The Cairns regulator and face-piece system has already completed NIOSH certification, although it will need to be slightly modified to meet AWPS needs and will require recertification.

The requirements for head protection and integrated communication system are being explored at this time. It may become more efficient to use off the shelf products for the helmet and communications systems, rather than designing an integrated system for the AWPS apparatus.

5.3 High Performance LCG

The three primary methods the body uses to reject heat (radiation, convection, and evaporation) are all severely impaired in the environment of protective clothing. The result of this heat build-up is heat stress and impaired mental awareness. The High Performance LCG eliminates heat stress by assisting the body in rejecting heat.

The High Performance LCG consists of a body-suit type garment constructed of stretchable material with tubing and patches attached to the inside. Heat is conducted away from the subject by circulating chilled water from the vaporizer through the tubing and patches that lie against the surface of the skin. The patches provide a large surface area for heat conduction, and are located in various locations such as on the upper torso, thighs, and upper arms. The large area of contact between the patches and the subject's skin will allow a comfortable temperature cooling water to be used.

Many of the cooling suits available on the market today are constructed of small water carrying tubes which are either sewn or woven into a snug fitting suit. The process of attaching and routing the tubes within the suit is time consuming and expensive. The tubing itself is also expensive when compared to the raw materials used in the patch garments. The patch manufacturing process is also much less expensive and less time consuming. Because the patch system requires less flow, and warmer (or less temperature difference) temperature water, it is inherently a more efficient system to be integrated with the AWPS. It also reduces the systems pressure drop allowing for a smaller pump compared to tube based systems.

5.4 Protective Clothing

Based on the three site visits, conceptual designs are proposed for both Level A (vapor-protective) and Level B (liquid splash-protective) suits. Preliminary descriptions of these designs are offered in the sections below. The selection of appropriate materials is currently being undertaken. Material candidates are presented in Table 5-1. The current philosophy supports the selection of a durable/reusable material for the vapor protective suit, due to the high initial purchase cost for this relatively complex item of protective clothing, while a disposable material is recommended for liquid splash protection. The possibility for a lower cost, disposable material-based vapor-protective suit is also being investigated.

5.4.1 Vapor-Protective Suit.

The design of the vapor protective suit will have the following characteristics:

1. It will be designed with an integral visor, detachable gloves, and sock-like booties and will be worn over the worker and the PLSS.
2. The hood area of the suit will provide ample room for a worker to wear a hard hat, respiratory face mask, and communications set.
3. The back area of the suit will have an expanded pouch-like protrusion to accommodate wearing of the PLSS backpack.

The High Performance LCG consists of a body-suit type garment constructed of stretchable material with tubing and patches attached to the inside. Heat is conducted away from the subject by circulating chilled water from the vaporizer through the tubing and patches that lie against the surface of the skin. The patches provide a large surface area for heat conduction, and are located in various locations such as on the upper torso, thighs, and upper arms. The large area of contact between the patches and the subject's skin will allow a comfortable temperature cooling water to be used.

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2. The hood area of the suit will provide ample room for a worker to wear a hard hat, respiratory face mask, and communications set.
3. The back area of the suit will have an expanded pouch-like protrusion to accommodate wearing of the PLSS backpack.

4. Brunswick Guardian 37 mil Neoprene gloves will be used with the suit. Gloves will be mounted to a hard ring adhesively bonded to the end of the suit arm sleeve. Glove mounting will be accomplished by using a low profile polyethylene "hose" clamp. The glove interface area will be covered by a splash shield consisting of the garment material and extending three inches down over the interface area from the forearm area.
5. Booties will be fully integrated into the termination of the suit leg. Splash guards consisting of the garment material will be provided to prevent liquid accumulation into the outer boots. Bata Shoe HazMax boots will be used as the outer boots.
6. Garment seams will be heat sealed and taped on both sides. The garment to visor interface will include sewing of the visor material into the garment with heavy duty taping on both sides of the seam.
7. A minimum four foot gas-sealing zipper will be used as the suit closure. This closure will be placed on the front of the garment on the wearer's right side beginning at the head region and extending to the upper right thigh region of the suit.
8. One to three flapper-style, screw-mounted exhaust valves will be used. One exhaust valve will be positioned at the back of the hood. The other two exhaust valves will be placed on the upper rear thigh on each side of the suit. Each exhaust valve will be protected by an inverted pocket.
9. Suit sleeves will be designed with Dohlman sleeves to allow the wearer to withdraw his or her hand into the suit interior.
10. The visor will consist of a 30 mil PVC material with a 5 mil Teflon FEP overlay and will be sized to provide 180 degree side-to-side vision, and 120 degree top-to-bottom vision.
11. The suit will have an exhaust port for a short hose segment from the PLSS face piece to vent exhaled breathing air.

5.4.2 Liquid Splash-Protective Suit

The design of the liquid splash-protective suit will have the following characteristics:

1. It will be designed as a two piece garment with coverall and hooded shroud with visor and partial arms. It will be worn with the PLSS outside the coverall but inside the hooded shroud.

2. The suit hood will have a 20 mil PVC visor.
3. Brunswick Guardian 37 mil Neoprene gloves will be used with the suit. Gloves will be mounted to a light-weight, plastic hard ring adhesively bonded to the end of the suit arm sleeve. Glove mounting will be accomplished by using a elasticized band. The glove interface area will be covered by a splash shield consisting of the garment material and extending three inches down over the interface area from the forearm area.
4. Booties will be fully integrated into the termination of the suit leg. Splash guards consisting of the garment material will be provided to prevent liquid accumulation into the outer boots. Bata Shoe HazMax boots will be used as the outer boots.
5. Garment seams will be heat sealed and taped on the outside only.
6. A minimum four foot liquid-proof zipper will be used as the suit closure. This closure will be placed on the front of the garment down the middle from the neck to above the crotch area.
7. The garment hooded shroud will have an exhaust port for a short hose segment from the PLSS face piece to vent exhaled breathing air.

Table 5-1 provides and compares a complete list of proposed suit features for both types of suits.

Table 5-1 Comparison of Design Features for Levels A and B/C PPE

Design Feature	Level A Suit	Level B/C Clothing
Overall protection goal	Vapor protection	Liquid splash and particulate protection
Expected application	Emergency response	D&D activities requiring Level B or C protection
Certification standard	NFPA 1991	NFPA 1993
General configuration	Single piece with gloves and boots, totally encapsulates wearer and PLSS	Two piece, coverall and hooded shroud with short arms and visors, attached gloves and boots, totally covers wearer and PLSS
Design approach	Modify or retrofit existing NFPA 1991 compliant suit	Conceive new two piece design with attention to glove, boot interfaces, closure design, and overall form and fit
Preferred base material	Challenge 6400	Tychem 7500

Design Feature	Level A Suit	Level B/C Clothing
Chemical resistance of base materials	> 480 minutes ASTM F 1001 chemical battery	Offers 75% efficiency against ASTM F 1001 liquid chemical battery; no penetration to most chemicals
Durability of base materials	Resists repeated flexing and abrasion; may be reused if properly decontaminated and not damaged	Intended for single wearing use (single shift)
Flame resistance of base materials	No ignition or burn time per ASTM F 1358	Not rated for flame resistance
Seam construction	Sewn, heat sealed, taped both sides	Sewn, heat sealed, taped one side
Visor	10 mil FEP overlay onto 30 mil PVC (modification to commercial suit)	20 mil PVC
Gloves	Heavy gauge (35 mil) Neoprene over 4 mil Silvershield	Base recommendation - Heavy gauge (35 mil) Neoprene; other gloves may be used
Glove attachment	Hard plastic glove ring adhesively bonded to inner suit sleeve; both gloves attached with steel hose clamp and rubber band; sleeve splash guard provided	Lightweight, thin plastic glove ring with thin plastic retaining strap; sleeve splash guard provided
Footwear design	Soft bootie (extension of suit leg); Bata Shoe PVC blend outer boot, cuff splash guard provided	Soft bootie (extension of suit leg); Bata Shoe PVC blend outer boot, cuff splash guard provided
Closure	PVC/brass pressure-sealing zipper; outer flap with velcro tape	Inner cloth/nylon zipper with two track, splash resistant outer closure
Closure location	Rear of suit	Front of coverall part
Exhaust valves and PLSS interface	Valves (3) at top of the suit and on both side of suit hips; additional valve provided for direct exhaust of PLSS	Valve provided for direct exhaust of PLSS
LCG interface	None required	Hose connection through coverall portion
Wearing configuration	Suit donned as a single unit over PLSS and LCG, but requires adding outer boots	Coverall portion donned first over LCG, followed by PLSS, and then hood shroud
Donning assistance	Requires helper	Can be donned without assistance

Design Feature	Level A Suit	Level B/C Clothing
Sizes	Two sizes (large and extra large); incorporates internal straps to shorten torso length	Minimum of five sizes; coverall conforms to ANSI/ ISEA 101-85
Projected cost		
Anticipated prototypes for Phase I	One (size large)	Five (all sized large)

B

5.5 Sub Scale Recharge Station

The sub scale recharge station will be a "bench-top" type system that uses liquid nitrogen to convert compressed breathing air into subcritical liquid air. The recharge system will consist of a heat exchanger with all the necessary monitoring instrumentation to ensure that the system is operating properly. The consumables, breathing air and industrial grade LN₂, are standard items and will be purchased from outside gas suppliers as required for use.

6.0 Life Cycle Cost/Benefit Analysis

Visits to the three DOE remediation sites yielded the information necessary for determining the life cycle costs for Personal Protective clothing and Equipment (PPE) used in the existing ensembles. This information has been applied in the form of a model which can also determine the equivalent life cycle costs for proposed AWPS configurations.

Specific life cycle cost information was gathered at each of the sites using an elaborate survey and interview process. This information included:

- The number of missions (sorties) involving PPE;
- The number of individual PPE uses;
- The expected number of uses for each PPE item (service life);
- The number of PPE uses for each maintenance cycle;
- The proportion of PPE use activity involving high, moderate, or low work rates;
- The proportion of PPE use involving Level A or B protection;
- The specific PPE items in use and their purchase costs or sources;
- Consumables and their costs associated with each of the PPE items; and
- Labor costs associated with each of the PPE items.

In some cases exact data was not available for an item, and estimates were used.

6.1 Development of Model

The life cycle cost of PPE is based on costs associated with:

- Purchase;
- Operations;
- Cleaning or decontamination;

- Maintenance and repair;
- Storage; and
- Disposal

Incumbent in these costs are both labor and material costs. For example, the purchase price for the PPE includes not only the price paid for the item, but the time spent ordering the item, receiving the item, and putting the item into service. Operating costs include both labor and supplies needed to replenish the system. The same is true for maintenance (repair), storage, and disposal costs.

In its simplest form, the total support cost (T) is the sum of each of these costs:

$$T = P + O + C + M + S + D$$

Equation 1

where:

T =	Total support cost
P =	Purchasing costs
O =	Operating costs
C =	Cleaning and decontamination costs
M =	Maintenance and repair costs
S =	Storage costs
D =	Disposal costs

For the complex PPE ensembles used in DOE remediation operations, these costs are calculated for each major item of the ensemble--respirator, protective clothing, cooling system, communications device, and any other equipment. In comparing ensembles, only those items which are different need be considered. However, each item must be placed on the same time basis to allow a comparison of the total support cost. For the purposes of this study, the total PPE support costs for a specific job (with a defined amount of actual work) has been chosen as the basis for providing estimates.

6.2 Model Variables

Different variables affect each of the individual cost areas in Equation 1. Some costs are based on the number of uses, while others are based on the number of missions involving PPE use or the total number of items in use. In addition, since tasks and consequent PPE item selection vary, the model must account for differences in work activity. For example, heavy work activity will more rapidly consume breathing air supply (for SCBA), increase clothing wear, and create the need for maintenance or disposal. Costs also vary based on the type of worker protection

needed, i.e., EPA Level A versus Level B protection. Table 6-1 below lists the different variables involved in determining the costs in each PPE cost area.

Cost Area	Item Specific?	Model Variables
Purchase	Yes	Number of PPE uses per year Number of uses per PPE item PPE item purchase price PPE purchasing hours Purchasing hourly labor rate
Operations	Yes	Number of PPE uses per year Ratios of low, moderate, and high work level activity Consumable costs Worker labor hours Worker hourly labor rate Indirect labor hours Indirect hourly labor rate
Cleaning and Decontamination	No	Number of PPE uses per year Number of missions per year Consumable costs Proportion of Level A/B use Decontamination labor hours Decontamination hourly labor rate
Maintenance and Repair	Yes	Number of PPE uses per year No. uses per maintenance cycle Ratios of low, moderate, and high work level activity Consumable costs Maintenance labor hours Maintenance hourly labor rate
Storage	Yes	Number of PPE uses per year PPE item purchase cost
Disposal	Yes	Number of PPE uses per year Number of uses per PPE item PPE item purchase cost

Table 6-1: Model Variables for Each Cost Area

6.2.1 Purchase Costs

The purchase costs of PPE is equal to the number of items per year times the sum of the total purchase price for each the PPE items, plus labor consumed in ordering the PPE, plus labor consumed in placing the PPE in service as shown in Equation 2.

$$P = \left(\frac{AU}{IU}\right)[I\$ + (HRS_p)(L\$_p)]$$

Equation 2

where:

AU	=	Number of PPE uses per year
IU	=	Number of uses per PPE item
I\$	=	PPE item purchase price
HRS _p	=	Number of hours involved in PPE purchasing
L\$ _p	=	Hourly labor rate for PPE purchasing

6.2.2 Operating Costs

PPE operating costs are based on the number of uses of PPE per year. However, these uses are qualified in terms of low, medium, and high level activities. The reasoning behind these distinctions are to account for different rates of consumption both in supplies and worker energies. For example, high level activities require more supplies (such as breathing air) and result in more rapid worker fatigue. As a result, the latter incurs longer or more frequent rest periods. The number of PPE uses per year are thus qualified as being one of these three categories by applying a ratio. The individual costs for use involve three components:

1. Labor associated with worker activity;
2. Support labor for worker activity; and
3. Resources consumed in PPE use.

Since the level of work alters each of these components, different individual costs are associated with the respective level. The relationship between these variables is shown in Equation 3.

$$O = (AU * HRS_o * L\$_o) + AU * ([R_{hw} (C_{hw} + HRS_{hw} * L\$_{hw})] + [R_{mw} (C_{mw} + HRS_{mw} * L\$_{mw})] + [R_{lw} (C_{lw} + HRS_{lw} * L\$_{lw})])$$

Equation 3

where:	HRS _o	=	Number of labor hours for operations support personnel
	L\$_o	=	Hourly labor rate for operations support personnel
	R _h	=	Ratio of PPE uses at high work level
	C _h	=	Cost of consumables for high work level PPE use
	HRS _{hw}	=	Number of labor hours for workers at high work level
	L\$_hw	=	Hour labor rate for workers at high work level
	R _{mw}	=	Ratio of PPE uses at high work level
	C _{mw}	=	Cost of consumables for moderate work level PPE use
	HRS _{mw}	=	Number of labor hours for workers at moderate work level
	L\$_mw	=	Hour labor rate for workers at moderate work level
	R _{lw}	=	Ratio of PPE uses at low work level
	C _{lw}	=	Cost of consumables for low work level PPE use
	HRS _{lw}	=	Number of labor hours for workers at low work level
	L\$_lw	=	Hour labor rate for workers at low work level

6.2.3 Cleaning or Decontamination Costs

The major portion of decontamination cost is assumed to be based on the number of missions (or sorties) instead of the individual PPE uses since the processes associated with PPE cleaning and decontamination are usually mission specific. These costs also reflect the type of PPE use--EPA Level A or Level B since more severe decontamination requirements apply to Level A PPE use as compared to Level B PPE use. The total cleaning or decontamination cost is therefore related to both the number and the type of mission encompassing the labor costs of decontamination personnel and consumables used. A factor has also been added to account for the magnitude of the cleaning/decontamination effort as shown in Equation 4. In other words, while both large and small missions may use some of the same resources, some costs are also proportional to the number of PPE uses within a given mission.

$$C = AM * (R_a * [C_{ca} + (\frac{AU}{AM}) * (HRS_{ca}) * (L\$_{ca})] + R_b * [C_{cb} + (\frac{AU}{AM}) * (HRS_{cb}) * (L\$_{cb})])$$

Equation 4

where:

AM	=	Number of missions per year
R _a	=	Ratio of Level A PPE missions
C _{ca}	=	Cost of consumables for Level A PPE decontamination
HRS _{ca}	=	Number of labor hours for Level A decontamination personnel
L\$ _{ca}	=	Hourly labor rate for Level A decontamination personnel
R _b	=	Ratio of Level B PPE missions
C _{cb}	=	Cost of consumables for Level B PPE decontamination
HRS _{cb}	=	Number of labor hours for Level B decontamination personnel
L\$ _{cb}	=	Hourly labor rate for Level B decontamination personnel

6.2.4 Maintenance Costs

The overall maintenance costs are based on the number of PPE uses per maintenance cycle. It is recognized that some maintenance may be performed each time PPE is used to return the PPE to a useable condition. Such costs are considered part of the cleaning or decontamination costs. Here, the maintenance costs represent routine or unscheduled maintenance of an item. For example, periodic replacement of an exhaust valve in a mask or exchange of a glove on an encapsulating suit. These costs involve not only the cost of the replacement items but the labor required in affecting repair or maintenance of the PPE item. Since the need for maintenance or repair may be based the "wear and tear" on PPE, the ratios of work level activities have been factored into the model. Equation 5 shows how these costs are calculated.

$$M = \left(\frac{AU}{UMC_{hw} + UMC_{mw} + UMC_{lw}} \right) * [C_m + HRS_m * L\$_m]$$

Equation 5

where:

UMC _{hw}	=	Number of PPE items uses per maintenance cycle (high level of work activity)
UMC _{mw}	=	Number of PPE items uses per maintenance cycle (moderate level of work activity)
UMC _{lw}	=	Number of PPE items uses per maintenance cycle (low level of work activity)
C _m	=	Cost of consumables for PPE maintenance
HRS _m	=	Number of labor hours for PPE maintenance personnel
L\$ _m	=	Hourly labor rate for PPE maintenance personnel

6.2.5 Storage Costs

As in operating costs, storage costs are directly proportional to the number of PPE uses per year. It is further assumed that there are no material or consumable costs for storage of PPE. In considering the space needed for storage as the principal cost (in combination with labor), the storage cost is based on both number of PPE uses and a fraction of the initial purchase cost of the item (Equation 6). This is based on the fact that more expensive items are likely to be more complex and require more carefully controlled storage.

$$S = AU * 0.03 * I\$$$

Equation 6

6.2.6 Disposal Costs

The disposal costs are related to the number of items used per year as are the purchase costs. As above, the assumption is made that these costs are based on a fraction of the initial purchase cost as shown in Equation 7.

$$D = \left(\frac{AM}{IU}\right) * 0.01 * I\$$$

Equation 7

6.3 Determination of Specific Benefits

After the total support costs for the ensemble are calculated, these costs can be factored with benefits achieved from the improved system. Benefits are quantitatively determined in two areas:

1. Improvements in worker productivity allowing employees to spend more time actively performing tasks, and
2. Improvements in worker protection and thus lower costs in medical care and long term liability costs.

6.3.1 Worker Productivity

Improvements in worker productivity can be directly determined by comparing the number of additional work hours afforded by the AWPS. The operational life cycle costs show the average number of hours for each level of work activity. These hours are based on the combination of both rest and actual work time. The proportion of actual work to rest time can be determined for each ensemble. This ratio can then be used to calculate the amount of additional actual work that may be accomplished with the AWPS from measures of the total work time required to complete specific tasks at the different work levels. It is important that the level of work activity be considered since the provision of cooling from the AWPS is expected to have somewhat different impacts on increasing actual work time.

Equations 8 through 10 show the relationships used for determining increases in worker productivity.

$$(HRS_T)_{pres} = (HRS_{hw})_{pres} + (HRS_{mw})_{pres} + (HRS_{lw})_{pres}$$

Equation 8

$$\begin{aligned} (HRS_T)_{AWPS} = & (HRS_{hw})_{pres} * \left[\frac{(PR_{hw})_{AWPS}}{(PR_{hw})_{pres}} \right] + \\ & (HRS_{mw})_{pres} * \left[\frac{(PR_{mw})_{AWPS}}{(PR_{mw})_{pres}} \right] + \\ & (HRS_{lw})_{pres} * \left[\frac{(PR_{lw})_{AWPS}}{(PR_{lw})_{pres}} \right] \end{aligned}$$

Equation 9

$$SAVINGS = [(HRS_T)_{pres} - (HRS_T)_{AWPS}] * (L\$)_w_{avg}$$

Equation 10

where:

HRS_T	=	Total worker hours (rest and actual productive time)
pres	=	present ensemble(s)
AWPS	=	advanced worker protection system
PR_{hw}	=	worker productivity at high work activity level (proportion of actual work time to total time on site)
PR_{mw}	=	worker productivity at high work activity level
PR_{lw}	=	worker productivity at high work activity level

6.3.2 Worker Protection

The benefits of increased worker protection require several assumptions, specifically:

- Prediction of the proportion of workers who will receive various exposure-related injuries;
- An estimate of the average costs associated with treatment for exposure-related injuries; and
- Determination of probable liability costs for exposure-related injuries.

The relationship for these values in equating a benefit is shown in Equation 11:

$$Benefit = W_{exp} * (Treat\$ + W_{liab} * Liab\$)$$

Equation 11

where:	Benefit	=	Total amount saved through greater protection of AWPS
	W_{exp}	=	Number of workers who are exposed to hazardous chemicals while engaged in D&D worker and who later develop chronic illnesses resulting in disability or death
	Treat\$	=	Average cost of medical treatments for affected workers
	W_{liab}	=	Number of affected workers (or their estates) who file law suits against contractors or government for recovery of damages
	Liab\$	=	Average liability costs for affected workers

Calculation of this benefit was determined independent of the life cycle cost due to less defined basis. For the purposes of this study, values were assumed for each of the above three areas based on historical chemical process industry statistics.

- It is estimated that between 500,000 and 1,000,000 workers will be engaged at one time or another in D&D activities at DOE sites. Of this number, only 5 percent are expected to come in contact with hazardous materials which are capable of causing long term health hazards. Of this latter number, only 0.2 percent are expected to develop long term medical disorders such as cancer which may be attributed to site exposures. Using the higher end of estimated DOE worker population ($1,000,000 \times 0.05 \times 0.002$), a total of 100 workers are expected to have long term disabilities or medical disorders as the result of clothing and equipment which fails to provide adequate protection (based on existing technologies).

- Insurance industry statistics show that the average cancer case cost \$250,000 in medical bills. This amount varies with the severity of the cancer and the methods of treatment available for the specific disorder.
- Of cases where long term illnesses are suspected to be the result of work place exposure, the American Bar Association estimates that 20 percent of these will be brought into the court system with settlements made in half of the cases. The average settlement is \$1,000,000.

Based on these estimates, the total benefit becomes:

$$\begin{aligned} &= 100 \text{ workers} \times (\$250\text{k in medical costs} + 0.1 \times \$1,000\text{k in liability costs}) \\ &= \$35 \text{ million} \end{aligned}$$

6.4 Basis for Comparing Different Ensembles

Since the principle utility of the AWPS is for worker protection during Level A and B operations, life cycle costs have been computed for these operations only. Initial visits to both the Fernald Environmental Management Project, Hanford, and Oak Ridge DOE sites show an increase in both Level A and B clothing ensemble uses as decontamination and decommissioning processes fully begin.

For the purposes of this study, a total of 5,000 man hours are assumed to require self-contained breathing air for a specific remediation function. Ninety five percent of this time is assumed to require Level B protection (4,750 man hours), while 5% of that total--250 man hours are assumed to require Level A protection. Both of these figures are based on the actual number of man hours required to complete the work and not time spent in non-work activities such as donning, doffing, decontamination, and rest periods.

The analysis of life cycle costs is therefore based on the costs needed to affect the indicated number of work hours. A comparison is made between conventional Level A and B systems and the AWPS Level A and B systems.

The current Level A ensemble includes:

- A limited use totally encapsulating suit constructed of a light weight plastic laminate-based material;
- Attached gloves; and

- A 30 minute or 60 minute Self Contained Breathing Apparatus (SCBA).

While other items may be worn with the ensemble such as a over boots, cooling system, communications device, and hard hat, none of these items were considered in estimating total ensemble purchase costs. The suit in this scenario is used only once before requiring disposal. SCBAs have a 5 year service life under heavy use conditions (approximately 1000 uses). The encapsulating suit purchase price is approximately \$400, while the SCBA costs \$2200.

The AWPS Level ensemble includes:

- A reusable totally encapsulating suit constructed of a durable material;
- Attached gloves;
- An inner cooling garment; and
- The modified PLSS.

The suit in this scenario is expected to provide five uses before requiring disposal and costs . The PLSS also is estimated to have a 5 year service life (1000 uses) with a purchase price of .

The Level B scenario includes the same ensembles but a liquid splash protective suit is substituted for the totally encapsulating suit. For the existing ensemble, this clothing costs \$25 and is disposable after a single use. In the AWPS Level B ensemble, the purchase price for the splash suit is and is designed for only one use.

Since each ensemble consists of two separate parts having different service lives, the individual life cycle costs must be calculated for each.

6.4.1 Methods of Estimating Costs

While some information was obtained during the site visits, the majority of costs have been estimated using related data for EPA remediation activities. Specifically, a series of equations have been developed by Schwope and Renard, "Estimation of the Cost of Using Chemical Protective Clothing,"¹ which define the individual costs and labor requirements of protective

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¹ Schwope, A.D. and Renard, E.P., "Estimation of the Cost of Using Chemical Protective Clothing," Performance of Protective Clothing: Fourth Volume, ASTM STP 1133, James P. McBriarity and Norman W. Henry, Eds., American Society for Testing and Materials, Philadelphia, 1992. 972-981.

clothing as a function of its purchase price. These relationships were used for determining labor requirements for both existing and AWPS ensembles.

Decontamination Labor

$$L\$_c = 0.3 * I\$^{0.38}$$

Inspection and Maintenance Labor (considered in total as maintenance)

$$L\$_m = 0.026 * I\$^{0.43} + 0.1 * I\$^{0.51}$$

6.4.2 Assumptions

Despite information gathered on site visits and methods of estimation provided above, a number of assumptions were necessary to calculate life cycle costs. In the first set of calculations, several simplifications of the model were used. These included:

1. All work is conducted at a moderate work load;
2. All operational labor is at a rate of \$40/hour (includes overhead);
3. All other labor is at a rate of \$25/hour (includes overhead);
4. Decontamination costs are the same for Level A as they are for Level B; and
5. Decontamination labor costs are based on the protective suit only.

Under a moderate work load, the SCBA offers a maximum of 20 minutes useful work time, while the PLSS is assumed to provide 120 minutes useful work time. Table 6-2 below shows the individual times associated with operational used of each ensemble (applies to both Level A and B):

Activity	Amount of Time Each Activity (minutes)	
	Current Ensemble	AWPS
PPE donning	15	25
Pre-entry inspection	0	10
Working time	20	120
Decontamination	10	10
Rest time	30	30
TOTAL TIME REQUIRED	75	195
Ratio actual work to total time required	0.27	0.62

Table 6-2: Time Required in Ensemble Operations

Other specific assumptions were required for other costs, particularly purchasing labor consumables for different activities. The following estimates were used:

- Purchasing labor for the existing ensemble is considered to be twice as much for the AWPS due to myriad of choices affecting current clothing purchases. The AWPS purchase labor requirement is 20 hours per year.
- Operation consumables vary between ensembles primarily due to the difference between compressed and liquefying air. The AWPS uses 270 cubic feet of compressed air at \$0.05/scf and 12 lbs of liquid nitrogen at \$0.38/lb for a total consumable cost of \$16.65. In comparison, the SCBA uses 30 scf of compressed air for a total cost of \$1.35.
- Cleaning/decontamination consumables have been previously estimated (by Schwope and Renard) at \$50/entry for disposable supplies and \$25/entry for reusable supplies.

- Maintenance costs are assumed to be the same for AWPS PLSS and the existing ensemble SCBA at \$25 with a total of 10 uses per maintenance cycle for each item. Likewise, the principal maintenance for protective clothing is replacement of gloves at \$25/pair with a total of 20 uses.

6.5 Life Cycle Cost Calculations (Base Case)

Table 6-3 shows the values used for each variable in the model based on the estimates and assumptions above. The AWPS shows a significantly smaller life cycle cost for both Level A and B operations for the 5000 work hours.

Variable	Existing Ensemble	AWPS
Level A suit purchase cost	\$400	
Level B suit purchase cost	\$25	
SCBA purchase cost	\$2200	
Labor rate (except operations)	\$25/hour	same
Purchasing hours	20/year	same
Actual work time/use	20 minutes	120 minutes
Support time/use	15 minutes	35 minutes
Total time/use	75 minutes	195 minutes
Ratio actual to total time	0.27	0.62
Operations labor rate	\$40/hour	same
Consumables/use	\$1.25	
Decon consumables/mission	\$25	

Table 6-3: Cost Model Variable Values

Results using the life cycle cost model are presented in Table 6-4. The overall Life Cycle Cost (LCC) for the existing ensemble was calculated as \$1,676,851. For the AWPS, a LCC of \$980,886 was obtained. This represents a difference or savings of nearly \$700,000. Note that

while the acquisition (purchase) costs of the AWPS hardware are significantly higher than for the existing ensemble, much lower costs were demonstrated for the other expense areas. The majority of the AWPS LCC was the purchase cost which had roughly the same contribution as the operational cost. Over 50% of the LCC for the existing ensemble was due to operational costs. Figure 6-1 shows the relative proportion of costs for each the LCC. Note that while the acquisition (purchase) costs of the AWPS hardware is significantly higher than for the existing ensemble, significantly lower costs are demonstrated for the other expense areas.

Existing Ensemble

AWPS

Figure 6-1: Proportion of Costs for LCC

Table 6-4 also provides estimates that show the increase in productivity for the AWPS. Since the assumption has been made that PLSS can provide at least 120 minutes of air and cooling, the actual time on site is six times higher than achieved with a conventional SCBA. Nevertheless, use of the AWPS is considered to require more support time. As a consequence, the best way to examine increases in productivity (separately from the life cycle costs) is to compare actual work times. On that basis the AWPS provides more than a two fold increase in worker productivity. Use of the AWPS allows completion of the 5,000 hour job in 156 days as opposed to 625 days for the existing protection technology.

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 280

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	IS	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	LS(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$88,738		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	LS(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	LS(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	LS(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	LS(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$117,103		\$1,305,972		\$863,782

Table 6-4 Calculation of Life Cycle Costs (Simple Model - Best Case)

6.6 Sensitivity Analysis

Key variables were selected for ascertaining their effect on the life cycle costs, including:

- AWPS purchase costs;
- the number of reuses for the Level A garments;
- the relative amount of support labor time;
- the expected lifetime of the PLSS; and
- actual work time provided by the AWPS.

With the exception of the AWPS actual work time, a relatively low and high value was chosen as compared to the base case assumption or estimate. Several different actual work times were evaluated ranging from 40 minutes to 160 minutes. The values of these variables are shown in Table 6-5. Calculation worksheets for each of these cases are provided in Tables 6-4A through 6-4P (included in Appendix D). A summary of LCC calculations are provided in Table 6-6.

Table 6-5: Range of Key Variables Investigated

Variable	Base	Low	High
Level A suit cost			
Level B suit cost			
PLSS Cost			
Level A suit reuse	5X	Once	10X
Support labor time	35 minutes	15 minutes	55 minutes
PLSS service life	1000 uses	500 uses	1500 uses
Actual work time	120 minutes	40 minutes	160 minutes

Table 6-6 Sensitivity of Life Cycle Costs to Key Variables

Variable	Range	Level A		Level B		Total	
		Existing	AWPS	Existing	AWPS	Existing	AWPS
Base	None	\$370,879	\$117,103	\$1,305,972	\$863,782	\$1,676,851	\$980,886
Purchase Cost	Low		\$103,394		\$724,968		\$828,362
	High		\$130,801		\$1,002,219		\$1,133,020
Level A Use	Single		\$467,103		\$863,782		\$1,330,886
	Multiple		\$73,353		\$863,782		\$937,136
Support Time	Low		\$115,072		\$825,188		\$940,261
	High		\$119,812		\$915,240		\$1,035,052
PLSS Service Life	Low		\$118,041		\$881,595		\$999,636
	High		\$116,791		\$857,845		\$974,636
Actual Work Time	40 min		\$331,310		\$2,211,346		\$2,542,657
	60 min		\$224,207		\$1,537,564		\$1,761,771
	80 min		\$170,655		\$1,200,673		\$1,371,328
	100 min		\$138,524		\$998,538		\$1,137,063
	140 min		\$101,803		\$767,527		\$869,330
	160 min		\$90,328		\$695,337		\$785,664
Single Use Level A	N/A		\$278,735		\$863,782		\$1,142,517
Level B Only	N/A	\$0	\$0	\$1,374,644	\$909,228	\$1,374,644	\$909,228

The largest effects on the AWPS LCC were demonstrated by the reusability of the Level A suit and the actual work time provided by the PLSS. Since the AWPS purchase cost is relatively high, the largest benefit is seen from longer stay times for conducting actual work. This increase in productivity is the single largest factor contributing to the more favorable LCC for the AWPS. Figure 6-2 shows how LCC varies with actual work time. The PLSS and AWPS must provide approximately one hour of actual work time (3 times that of the existing ensemble) in order to match the LCC cost of the existing ensemble. A relatively high LCC was shown for the case when a expensive Level A suit is used only once. Repeated use of this suit, even in its limited applications has a profound effect on the overall AWPS LCC.

Figure 6-2 LCC Sensitivity to Use Time

While varying purchase cost had some effect on the AWPS LCC, increasing Level A and B suit costs to \$4000 and \$200, respectively, in combination with raising the PLSS cost to \$10,000 still provided a lower LCC than the existing ensemble.

Requirements for less or more support time for AWPS operations had little effect on the LCC. The LCC was still lower than the existing ensemble when the support time increased to 55 minutes (donning and preentry inspection).

Varying the service life of the PLSS by fifty percent either up or down has the least effect on the LCC for the AWPS.

Two other areas were investigated. The first situation compared the LCC of the expensive, reusable suit with a single use product of similar performance. Both suits considered are compliant with NFPA 1991. The lower cost products generally run forty to sixty percent of the cost for reusable suit purchase prices. The LCC in case showed a dramatic increase (sixteen percent) over the base case (more expensive, reusable suit). The situation of Level A only was investigated for both the existing ensemble and the AWPS. In this scenario, the LCC for the AWPS dropped over seven percent while the LCC for the existing ensemble increased over five percent. Therefore, this exclusive Level B use provided a more favorable difference for the AWPS.

6.7 LCC Summary

The most efficient way to define the feasibility of producing a new system is to determine if the initial cost of the system will benefit the user/industry in the long run. That is to say, the system being developed must give the end user a more productive system that will save time and money. Based on the LCC analysis, we feel the AWPS will provide significant cost benefits to the industry. The sensitivity analysis performed on the key variables shows continued cost benefits, even with the least favorable assumptions.

7.0 Analysis Of Prior Performance Data

The most effective approach to a design effort is to determine the validity of a concept prior to commencing with full scale build up. Typically this can be completed in a bench-top manner, testing components, or full systems. Information gathered from this testing can then be applied to the next phase of development. Because OSS had previously developed the Hazardous Materials (Haz Mat) PLSS system, it was used as a test bed to determine new design concepts for the upcoming AWPS.

Many decisions were required regarding specific components of the system, as well as more general requirements such as liquid air capacity, sizing, weight distribution, and overall comfort. The Haz Mat PLSS backpack was tested to determine system functionality, backpack cooling capacity, worker cooling requirements in various environments and protective garments, current backpack duration, and predicted duration for future systems. This information will be used to more accurately design specific system components. To determine durations, cooling requirements and backpack performance data were analyzed and compared.

Testing was broken down into two types, manned testing to determine "human" requirements, and unmanned testing to determine backpack capabilities. The testing was completed using the OSS Haz Mat PLSS with the subject wearing a total encapsulating suit (Level A) and a splash suit (Level B). The tests were conducted in varying environments, and work activities. This information was analyzed and is described in this section.

7.1 Manned Testing

7.1.1 Test Matrix

Testing was done under the conditions listed in the following table to determine cooling requirements with different garments in various environments. Data from testing conducted by other groups such as the NB PLSS project for NASA, Navy standard work tables, and the Bioastronautics Data Book has also been examined.

Manned tests were conducted in the Level A ensemble in ambient environments of 69°F and 78°F. Similar tests were conducted in the Level B ensemble at 69°F, 78°F, and 100°F.

Parameters that were controlled or measured during manned testing include: breathing rate, cooling requirements (LCG flow and inlet temperature), environmental temperature, and protective garment type. It was found that cooling garment type, work rate, environmental conditions and type of protective garment (insulation) all affect the amount of cooling required by the test subject.

7.1.2 Apparatus

7.1.2.1 Garments

For this testing, the test subject wore a LCG, cotton coveralls, and either a Level B or Level A protective garment. With both suits, breathing air was supplied to a Cairns regulator and mask via a pressurized supply line. The Level B suit was a reusable coated tyvek type with elastic at the wrists and hood, and attached booties. The latex gloves were taped to the sleeves. The hood was not taped to the mask as is the usual operating procedure. In addition, the LCG tubes, breathing air supply line, gas analysis capillary and telemetry cables exited the suit at the neck opening.

The Level A suit was a LifeGuard Training suit with integral hood, gloves, and booties. As in the Level B suit, the umbilical (LCG tubes, breathing air, gas analysis and telemetry lines) exited the suit at the top of the zipper.

7.1.2.2 Instrumentation

Data was collected using a Macintosh computer with Strawberry Tree data acquisition hardware and software (Analog Connection Workbench). Data collected by the computer was pre-processed to calculate parameters such as metabolic rate, LCG cooling, and breathing rate. This data was displayed to the operator as numeric values and scrolling graphs of parameter vs. time. These values were also logged to disk for later graphing and analysis.

Temperatures (LCG water in and out) were measured with Analog Devices AC2626L semiconductor temperature probes. LCG flow was measured with a turbine type water flow meter. Gas flow was measured with an Omega fast response gas flow meter. Metabolic rate was calculated based on change in average oxygen percentage. The gas composition of the exhaled gas was sampled through a 0.125" OD capillary tube, sample pump, Sorbead(TM) desiccant bed, and Servomex paramagnetic oxygen analyzer.

Water was circulated through the LCG with a positive displacement pump. The water temperature was controlled with a Refrigerated Controlled Temperature Circulator (RCTC). The RCTC can provide up to 2150 W of cooling and is controllable to within $\pm 1.0^{\circ}\text{F}$. A heat exchanger is attached across the inlet and outlet of the RCTC and the LCG water was pumped through the other side of the heat exchanger. This was done to better control the pressure and flow of water through the LCG. Cooling was controlled by one of two methods, adjusting temperature or adjusting flow rates. In the first method, water temperature was adjusted with the RCTC (hotter or colder) until the test subject indicated that he was comfortable doing exercise. Using this method, water temperatures ranged from 43°F to 80°F with a flow rate of

~0.5 gpm. In the second method the temperature was set at a predetermined level (to simulate an umbilical system) and flow was varied by adjusting pump current until the test subject indicated that he was comfortable. Using this method, flow was varied from 0 to 0.5 gpm with a water temperature of 41 °F.

7.1.2.3 Exercise Protocol

A standard test protocol was established to provide consistency between tests. This protocol consisted of suiting up and connecting the LCG to the water source. The temperature or flow of LCG water was then adjusted to establish cooling requirements at rest, and to allow the gas analyzer to stabilize. Once the instrumentation readings were stable and the test subject had become accustomed to the apparatus, the exercise was started. Work performed during tests was kept as constant as possible. The test subject operated a Nordic Trak ski machine at 4-5 kph at a resistance setting of ~2.5. This work rate was continued for approximately 1 hour until 5 kilometers had been traveled as indicated by the ski machine electronics. During the work cycle, the test subject would indicate to the test conductor when more or less cooling was desired. The test conductor would adjust the temperature or flow of the LCG water until the test subject indicated that he was comfortable. After 5 kilometers had been completed, the test subject stopped exercising and rested until breathing rates had returned to pre-work levels. During the cool down period, cooling continued to be adjusted to maintain comfort.

7.1.3 Results/Analysis

Analysis of our data and evaluation of the data from other sources provided the information needed to construct Figure 7-1. This graph shows probable cooling needs for people working as specified by each bar. The bars are arranged in order of increasing cooling needs. As can be seen, work rate, environment temperature, and garment type all contribute to cooling requirements. It would be possible to produce a 3-D surface with cooling, work rate and environmental temperature as the three axes for each garment type, however to establish duration predictions, only minimum and maximum cooling requirements are needed to establish flow rate extremes and thus determine duration.

Breathing rates were also measured to compare with the flow rates determined to be needed to provide cooling to ensure that the worker would not be overcooled.

Figure 7-1: Q_{need} vs. Environmental (suit/temp)

7.2 Backpack Testing

Testing of the AWPS Breadboard was conducted to establish several aspects of operation such as level of cooling provided, oxygen percentage variability, and operability in all orientations. Determination of cryogen flow rates needed to provide various cooling levels in the LCG was used to determine backpack efficiencies as well as being combined with cooling requirements to determine backpack duration in various environments at different work rates with different protective garments.

7.2.1 Test Matrix

Tables 7-2 and 7-3 show tests conducted to determine thermal performance of the AWPS breadboard.

Table 7-1: Heat Exchange (BTU/Hr)

		Vaporizer T _{in}	
		75	65
gas flow (scfm)	0.5	400	200
	1.0	600	
	2.0	1100	1100
	4.0	2300	2300

Table 7-2: Vaporizer T_{out} (°F)

		Vaporizer T _{in}	
		75	65
gas flow (scfm)	0.5	73	62
	1.0	72	
	2.0	70	60
	4.0	65	53

As can be seen, changing the vaporizer inlet temperature in this range does not significantly affect heat exchange capability.

Parameters measured or controlled during this testing are similar to those for manned testing and include: vaporizer water flow rate, vaporizer inlet temperature, vaporizer outlet temperature, gas flow rate, gas temperature, and dewar pressure.

7.2.2 Apparatus

Test equipment used in this testing included: the AWPS breadboard, the adjustable temperature water source as described for manned testing, liquid air mixing apparatus (scale and mixing dewar), a vacuum pump to dynamically evacuate the dewar insulation space, and a multi-orientation test stand.

7.2.2.1 Liquid Air Mixing Apparatus

The Liquid Air used for testing was mixed by weight in a 35 liter dewar using mixing procedures developed and tested as part of the NB PLSS work done for NASA. The 35 liter mixing dewar is placed on a scale and filled with predetermined amounts of liquid oxygen and liquid nitrogen. The resulting mix is then checked to verify the proper oxygen percentage and if correct, the AWPS is filled from the mixing dewar. Cryogen transfers between systems were through a 6 foot vacuum-jacketed transfer line.

7.2.2.2 Orientation Test Stand

The AWPS breadboard was mounted on a 3 axis test stand for unmanned testing. The test stand allowed the system to be manually rotated through a range of motion that would simulate a user wearing the AWPS system. The position could be locked in place in 15° increments so that the system could be tested for an extended period in a set orientation. The range of motion tested is covered in Section 7.5.

7.2.3 Test Protocol

The test protocol was based on obtaining thermal performance and orientation data of the AWPS breadboard. The system was mounted on the orientation test stand for all of the testing. Data was collected to fill in the matrix in Section 7.2.1. The LCG out temperature was set using the RCTC to simulate the added body heat from a person wearing a cooling garment. A sample flow rate was set using the metering valve and the backpack was allowed to achieve thermal equilibrium. Once that had happened, the system was moved into one of the orientations described later in Section 7.5 and again allowed to equilibrate. However, no changes occurred in the thermal performance with reorientation. During the test, the same instrumentation was used from the manned testing, except in a different configuration. The oxygen percentage of the gas was also monitored throughout the test for any unexpected changes, though none occurred. The range of gas flow rates and LCG temps used are described in the test matrix.

7.2.4 Results/Analysis

The backpack testing results were analyzed to provide a linear regression of the LCG cooling rate vs. liquid air flow rate data. This gives an indication of how efficiently heat is being transferred from the LCG water to the cryogen. The analysis showed that the breadboard system is approximately 62% efficient. Figure 7-2 also shows the theoretical maximum cooling rate available for a given flow calculated from the heat capacity of liquid air. Based on an analysis of the vaporizer design, it is expected that a thermal efficiency of approximately 85% could be achieved by better insulation. For the AWPS breadboard, the vaporizer is covered with insulative foam. The prototype AWPS design will have the vaporizer located in the evacuated area of the AAPD. Considering that there is a 400 °F temperature difference between the cryogen and ambient, the additional 23% efficiency should be achievable by removal of convective and conductive heat leak into the vaporizer by insulating it in a vacuum jacket.

The horizontal lines on the graph show the minimum and maximum expected cooling rates required based on the manned testing results. The vertical lines show the flows required to achieve those cooling rates. It can be seen how an increase in the thermal efficiency can save cryogen at the higher cooling rates. The expected and average testing efficiency lines are used in the next section to predict durations that should be achievable with the prototype AWPS.

Figure 7-2: Qbackpack vs. Flow

7.3 Duration Predictions

The durations shown in Figure 7-3 are calculated from the average flow rates in the previous chart and assuming an AWPS with approximately 15 lbs (200 SCF) of liquid air. The shorter durations show what has been achieved with the current breadboard. The longer durations predict what will be achievable by better insulating the prototype system. Several factors must be considered to project an expected duration, including metabolic work rate, breathing rate, type of protective garment worn, environment, and perceived comfort level. Perceived comfort level accounts for personal preferences in the amount of cooling used.

The breathing rate of a person while he works will determine the base cooling rate received as this determines the minimum flow rate of cryogen through the vaporizer. Additional cooling will then be made up by opening the metering valve. Testing has shown consistently that the cooling rate achieved with just breathing flow is about $\frac{2}{3}$ of the cooling desired at a given work rate. Effectively, the breathing air is a byproduct of obtaining the required cooling.

Figure 7-3 shows that the backpack duration could be approximately 1 to 6 hours depending on the combination of aforementioned factors. A person using the AWPS at a low work rate in a cooler environment (i.e. below 70°F) could be given a six hour duration with the predicted efficiency. Conversely, a person working consistently at a high work rate in a hot environment may only have a one hour duration. Moderate work rates should result in a duration of approximately two hours.

Figure 7-3: AWPS Backpack Duration

7.4 Oxygen Variability

In liquid air systems, the cryogen mix tends to become more oxygen-rich over time. Liquid nitrogen has a lower boiling point than liquid oxygen, 77K as opposed to 90K, and as heat leaks into the AAPD, the nitrogen boils off faster than oxygen. This means that the change in oxygen percentage is a function of the heat leak to the cryogen and therefore the design of the AAPD.

During unmanned and manned testing of the AWPS breadboard, the O₂% was continuously monitored. The liquid air for the testing was mixed by weight to begin testing with an approximately 20% O₂ mix. Typically, the O₂% would increase to around 25% by the end of a two hour test. However, the pre-prototype AAPD being used for this testing has a much higher heat leak rate than is expected in the final version. Improvements in the design of the suspension system in the AAPD will minimize changes in the O₂% over a period of use.

Another consideration on oxygen variability was that the ullage, the gaseous phase in the dewar, might be mostly nitrogen. The concern was that if a user consumed all the cryogen, an amount of nitrogen gas would be delivered to the mask. However, testing has definitively shown that this is not the case. In all the tests, as the cryogen ran out, there was no noticeable change in the O₂ composition of the gas being delivered to the user. It should be noted however, that to use up all of the cryogen in the system is about as safe as breathing an SCBA bottle down to ambient pressure and is not acceptable standard operating procedure.

7.5 Multi-Orientation Operation

The AWPS breadboard was mounted on a 3 axis stand for unmanned testing to verify that the Advanced All-Position Dewar (AAPD) design would allow the AWPS to work in any orientation. Orientations tested simulated combinations of a user leaning 45° to the left or right, bending over forward horizontal or 30° below horizontal. The test stand was rotated through the positions every few minutes during the course of unmanned testing.

The rotational mechanism in the AAPD was designed to move with the cryogen and maintain the intake submerged in liquid. If the cryogen intake were to become exposed, it would be immediately obvious due to a decrease in gas pressure and LCG cooling because gas rather than liquid would be delivered to the vaporizer. During the test, a flow rate was set using the metering valve and once steady state was reached, the system was rotated to a new orientation. A small pressure spike would occur each time the AWPS breadboard was rotated because the cryogen would come in contact with parts of the vessel that had warmed up slightly. If it was indicated that the intake had become exposed, the dewar was rotated through the positions to determine if there was any more cryogen left or if the pickup had just become stuck in one position. In each of the tests, the intake became exposed only after all the cryogen had been consumed, therefore the AAPD design will meet the orientational requirements for use in the AWPS.

8.0 Conclusions

OSS is committed to the proper development of the AWPS and has begun the PRDA program at Maturity Level III. Because of our commitment to the development of the technology, we acknowledge that it is very important to completely identify all aspects of the AWPS development prior to manufacturing any hardware.

The performance criteria for the AWPS have been developed. These criteria were developed with both an understanding of the AWPS capabilities combined with the identification of DOE Decontamination and Decommissioning activities protection needs. The unique features of the AWPS will allow it to be used in environments and situations beyond the capability of current systems. Furthermore, a review of current DOE practices has identified several areas of concern which will be rectified with the introduction of the AWPS. The AWPS will reduce DOE inventory needs, reduce selection problems, enhance personnel protection, safety, and provide significant gains in worker productivity.

We have identified, and feel we can meet, all applicable regulatory requirements with regards to the respirator, pressure vessel, protective suits, helmet, and support equipment. Regulatory requirements for DOE use, as well as those which will govern the use of the AWPS once in production, have had a bearing on the design of the AWPS. Compliance with these regulatory and similar requirements will be demonstrated through an extensive battery of testing, and certification of individual components by the appropriate authorities.

Visits to three key DOE remediation sites have yielded the information necessary to perform a cost benefit analysis, with positive results. A model was developed to determine the equivalent life cycle costs of various configurations of the AWPS. This information was used to compare the AWPS with systems currently in use. Using a specific scenario deemed representative of DOE D&D activities, the determination of life cycle costs has shown the AWPS will provide a savings of over \$700K (based on a total life cycle cost of \$1.7 Million) for a 5000 man hour job when compared to similar costs for existing protective clothing and equipment. This type of scenario is likely to be repeated many times over the 30 year period as the DOE undertakes specific D&D tasks at its various sites which require self-contained breathing air. Through a similar analysis, productivity gains of 100% or better were shown as well as lower potential medical and liability costs through better worker protection. Calculations of life cycle cost also demonstrated the preferred configuration for Level A clothing as being a more durable, reusable product.

Testing of the AWPS backpack has been performed in-house at OSS to verify its functionality, cooling capacity, worker cooling requirements, current backpack duration, and predicted duration for future systems. Indications are that the system works as planned, and will provide

a desirable level of performance for hazardous materials worker protection. Because of the testing performed at OSS and the testing that will be done at Kansas State University there will be reduced technical risks.

Document N° 19801-70001B
Release Date Mar 30, 1994
Page A-1

Appendix A - Questionnaire

Personal Protective Equipment and Hazardous Operations Questionnaire

1 Operational Information

1.1 How many employees are directly involved in the clean up of hazardous materials? How is this number expected to change in the future?

1.2 How many employees, such as supervisors and technicians, support hazardous materials clean up operations? How is this number expected to change in the future?

1.3 What percentage of the workers who wear PPE are male? Female? How are these numbers expected to change in the future?

1.4 What are the ranges of build and heights for the workers who wear PPE? How are these ranges expected to change in the future?

1.5 What suit sizes do you currently purchase? How do you expect this to change in the future? Are these sizes suitable?

PPE Questionnaire

1.6 What are the restrictions on and the requirements for suit sizes?

1.7 Please fill out *Worksheet 1: Personal Protective Equipment*, concerning the type of PPE used for various operations or provide copies of brochures on the equipment you use.

1.8 Please fill out *Worksheet 2: PPE Utilization*.

1.9 Summarize donning, doffing, and decontamination procedures for the three classifications of hazardous operations on Worksheets 3 and 4, or provide copies of procedures.

1.10 What are the range of ambient conditions in which workers wearing PPE operate? (i.e. outdoors in 90 °F summer heat)

1.11 How do the ambient conditions impact scheduling and length of operations?

1.12 Do you presently have a productivity or human factors assessment for personnel engaged in on-site (hazardous) activities? If so, please elaborate or provide a copy of the assessment.

1.13 What are the average and maximum durations for operations in Level A, Level B, and Level C PPE? (Fill in chart below)

	Maximum	Average
Level A		
Level B		
Level C		

1.14 Please fill out *Worksheet 5: HazMat Tasks*. The purpose of this worksheet is to identify the physical exertion required to perform the necessary tasks so that the cooling requirements for different regions of the body can be estimated.

1.15 Based upon light, moderate, and heavy work load tasks, how long do workers wear PPE, on the average? (Fill in matrix below)

	Light	Moderate	Heavy
Level A			
Level B			
Level C			

1.16 What type of work cycles do workers have based upon task work load?

PPE Questionnaire

1.17 Under what conditions are workers told to stop?

1.18 What type of medical monitoring is performed?

1.19 Who performs the monitoring and how much time is spent monitoring workers in PPE?

1.20 See Section 4 on the labor costs associated with using and monitoring workers in PPE.

1.21 See Section 5 on the consumables used in operations involving PPE.

2 Maintenance and Storage

2.1 What forms of maintenance and repair are performed on PPE?

PPE Questionnaire

2.2 Who is responsible for the maintenance and repair and how much time do they spend weekly or monthly?

2.3 How and where is PPE stored?

2.4 Who is responsible for PPE storage and how much time do they spend weekly or monthly on the task?

2.5 See Section 4 on hourly rates of personnel involved in maintenance, repair, and storage of PPE.

2.6 See Section 5 on consumables used in maintaining, repairing, and storing PPE.

3 PPE Selection

3.1 How is PPE currently selected? What factors are considered?

3.2 What personnel are currently involved in reviewing, selecting, and purchasing worker PPE and how much time do they spend on the task per week or month?

3.3 How is new PPE received, inspected, and stored?

3.4 What personnel are currently involved in receiving, inspecting, and storing new PPE and how much time do they spend on the task per week or month?

3.5 See Section 4 on hourly rates of personnel involved in reviewing, selecting, and purchasing worker PPE.

4 Cost Information

4.1 What are the average hourly rates for workers who wear PPE?

4.2 In *Worksheet 6: Labor Costs*, please provide the job titles and average hourly rates for those people involved in the specified tasks.

4.3 Please list any additional operating costs associated with activities utilizing PPE. See Section 5 for costs of consumables.

5 Consumables

5.1 In *Worksheet 7: Consumables*, please list the consumables utilized in the specified activities, along with the quantity used, the suppliers of the consumables, and the associated costs..

5.2 List any other consumables not indicated in Worksheet 6.

6 Requirements and Regulations

6.1 What regulations and requirements for PPE, other than NIOSH and OSHA, are followed?

6.2 What are the weight limitation requirements for PPE?

7 Miscellaneous

7.1 Who are the principal points of contact at each site for personnel protection and site safety? If possible, provide an organizational chart highlighting the various groups and divisions involved with personnel protection and site safety.

7.2 What are the potential uses for umbilicals during operation, standby, and/or decontamination?

7.3 What are the mobility requirements for support equipment? How often, to where, and why is support equipment moved or would need to be moved?

PPE Questionnaire

7.4 What type of injuries have been reported on site? Are any of these due to inadequate or improperly used PPE?

7.5 What special hazards exist that could damage the suit?

7.6 What are typical failure modes for various PPE?

PPE Questionnaire

7.5 What are common complaints about PPE?

7.6 In Worksheet 8, please indicate the advantages and disadvantages of the systems currently used and identified in Worksheet 1.

7.7 Please list any systems you have used in the past but no longer use. Also indicate the reason for discontinuing system.

7.8 What suggestions have workers made concerning the selection or the use of PPE?

Worksheet 1: Personal Protective Equipment

	Equipment	Supplier	Model #	Cost	Quantity In Use	Estimated Life
Level A						
Level B						
Level C						

Worksheet 2: PPE Utilization

	Average work load *	Average number of workers donning PPE per day	Average number of suit ups per worker per day	Average rest time	Average length of operation
Level A - Currently					
Level A - Projected					
Level B - Currently					
Level B - Projected					
Level C - Currently					
Level C - Projected					

• **Work load definitions:**

light - movements into and out of site, use of monitoring equipment, and supervision of workers

moderate - moving light supplies into and out of site, operating machinery, and driving vehicles

heavy - tearing down structures and lifting and moving heavy objects

Worksheet 3: Donning and Doffing Procedures

	Personnel Involved	Time Required
Level A Donning Procedure		
Doffing Procedure		
Level B Donning Procedure		
Doffing Procedure		
Level C Donning Procedure		
Doffing Procedure		

Worksheet 4: Decontamination Procedures

		Personnel Involved	Time Required
Level A Decontamination Procedures			
Level B Decontamination Procedures			
Level C Decontamination Procedures			

Worksheet 5: HazMat Tasks

[illegible]

Note:

exertion required to perform the necessary tasks so that the cooling requirements for different regions of the body can be estimated.

Several tasks have already been identified. Use blank space to identify additional tasks

* Exertion specified as either none, light, moderate, or heavy

Worksheet 6: Labor Costs

PPE Selection		PPE Receiving and Inspection		Donning/Doffing of PPE	
Job Title	Hourly Rate	Job Title	Hourly Rate	Job Title	Hourly Rate

Medical Monitoring		Decontamination		PPE Disposal	
Job Title	Hourly Rate	Job Title	Hourly Rate	Job Title	Hourly Rate

PPE Maintenance and Repair		PPE Storage	
Job Title	Hourly Rate	Job Title	Hourly Rate

Worksheet 7: Consumables

[illegible][illegible][illegible]

Worksheet 8: Current PPE Evaluation

[illegible]

Appendix B - EPA Levels of Protection

Table B1: EPA Levels of Protection

Level	Equipment	Protection Provided	Should Be Used When	Limiting Criteria
A	RECOMMENDED: ● Pressure-demand, full-facepiece SCBA or pressure-demand supplied-air respirator with escape SCBA. ● Fully-encapsulating, chemical resistant suit. ● Inner chemical-resistant gloves. ● Chemical-resistant safety boot/shoes. ● Two-way radio communications. OPTIONAL: ● Cooling unit. ● Coveralls. ● Long cotton underwear. ● Hard hat. ● Disposable gloves and boot covers.	The highest available level of respiratory, skin, and eye protection.	● The chemical substance has been identified and requires the highest level of protection for skin, eyes, and the respiratory system based on either: - measured (or potential for) high concentration of atmospheric vapors, gases, or particulates; or - site operations and work functions involving a high potential for splash, immersion, or exposure to unexpected vapors, gases, or particulates of materials that are harmful to skin or capable of being absorbed through intact skin. ● Substances with a high degree of hazard to the skin are known or suspected to be present, and skin contact is possible. ● Operations must be conducted in confined, poorly ventilated areas until the absence of conditions requiring Level A protection is determined.	● Fully-encapsulating suit material must be compatible with the substances involved.
B	RECOMMENDED: ● Pressure-demand, full-facepiece SCBA or pressure-demand supplied-air respirator with escape SCBA. ● Chemical resistant clothing (coveralls and long-sleeved jacket; hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit.	The same level of respiratory protection but less skin protection than Level A. It is the minimum level recommended for initial site entries until the hazards have been further identified	● The type and atmospheric concentration of substances have been identified and require a high level of respiratory protection, but less skin protection. This involves atmospheres: - with IDLH concentrations of specific substances that do not represent a severe skin hazard; or - that do not meet the criteria for use of air-purifying respirators.	● Use only when the vapor or gases present are not suspected of containing high concentrations of chemical that are harmful to skin or capable of being absorbed through intact skin.

Table 1. EPA Levels of Protection (Continued)

Level	Equipment	Protection Provided	Should Be Used When	Limiting Criteria
B	● Inner and outer chemical-resistant gloves. ● Chemical-resistant safety boot/shoes. ● Hard hat. ● Two-way radio communications. OPTIONAL: ● Coveralls. ● Disposable boot covers. ● Face shield. ● Long cotton underwear.		● Atmosphere contains less than 19.5 percent oxygen. ● Presence of incompletely identified vapors or gases is indicated by direct-reading organic vapor detection instrument, but vapors and gases are not suspected of containing high levels of chemicals harmful to skin or capable of being absorbed through intact skin.	● Use only when it is highly unlikely that the work being done will generate either high concentrations of vapors, gases, or particulates, or splashes material that will affect exposed skin.
C	RECOMMENDED: ● Full-facepiece, air-purifying canister-equipped respirator. ● Chemical resistant clothing (coveralls and long-sleeved jacket; hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit. ● Inner and outer chemical-resistant gloves. ● Chemical-resistant safety boot/shoes. ● Hard hat. ● Two-way radio communications. OPTIONAL: ● Coveralls. ● Disposable boot covers. ● Face shield. ● Escape mask ● Long cotton underwear.	The same level of skin protection as Level B, but a lower level of respiratory protection.	● The atmospheric contaminants, liquid splashes, or other direct contact will not adversely affect any exposed skin. ● The types of air contaminants have been identified, concentrations have been measured, and a canister is available that can remove the contaminant. ● All criteria for the use of air-purifying respirators are met.	● Atmospheric concentration of chemicals must not exceed IDLH levels. ● The atmosphere must contain at least 19.5 percent oxygen.
D	RECOMMENDED: ● Coveralls. ● Safety boots/shoes. ● Safety glasses or chemical splash goggles. ● Hard hat. OPTIONAL: ● Gloves. ● Escape mask. ● Face shield	No respiratory protection. Minimal skin protection.	● The atmosphere contains no known hazard. ● Work functions preclude splashes, immersion, or the potential for unexpected inhalation of or contact with hazardous levels of any chemicals.	● This level should not be worn in the Exclusion Zone. ● The atmosphere must contain at least 19.5 percent oxygen.

Document N^o 19801-70001B
Release Date Mar 30, 1994
Page C-1

Appendix C - List Of Test Plans

Test Plan - Evaluation of Seam or Closure Permeation Resistance	
Objective	To determine the barrier characteristics of selected seams and closure designs intended for Level A encapsulating suits.
Test Equipment	Permeation test cells; Permeation test system with automated actuators for controlling flow of collection medium into test cells and sampling by photoionization detector.
Test Procedures	Conduct tests per ASTM F 739, Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids and Gases.
Test Conditions	1. Ambient temperature ($25 \pm 2^{\circ}\text{C}$); 2. Three chemical battery (to be selected); 3. Minimum test apparatus sensitivity of $0.1 \mu\text{g}/\text{cm}^2\text{min}$; 4. Eight hour test duration.
Number of Tests	3 replicates per seam or closure type
Data Collected	Breakthrough time Steady state or maximum permeation rate Observation of material damage
Method of Data Collection	Databus linking photoionization detector to portable computer
"Success" Criteria	Breakthrough time greater than 8 hours for three selected test chemicals

Test Plan - Evaluation of Seam or Closure Permeation Resistance	
Objective	To determine the barrier characteristics of selected seams and closure designs intended for Level B splash suits.
Test Equipment	Penetration test cells; Permeation test apparatus with means for pressurizing test cells to 2 psig; Source of compressed air.
Test Procedures	Conduct tests per ASTM F 903, Test Method for Resistance of Protective Clothing Materials to Penetration by Liquids.
Test Conditions	1. Ambient temperature ($25 \pm 2^{\circ}\text{C}$); 2. Three chemical battery (to be selected); 3. Eight hour test duration.
Number of Tests	3 replicates per seam or closure type
Data Collected	Time of penetration "Pass" or "fail" determination Observations of visible damage to material
Method of Data Collection	Visual observations
"Success" Criteria	No penetration of three selected test chemicals with 8 hours.

Test Plan - Evaluation of Seam and Closure Strength	
Objective	To evaluate the crosswise strength of selected seams and closure systems for both Level A and Level B chemical protective suits.
Test Equipment	Tensile testing machine with a constant rate of travel; 4 inch wide grips; Tension cell rated to 100 lbs.
Test Procedures	Conduct test per ASTM D 751, Method of Testing Coated Fabrics (Seam Strength).
Test Conditions	1. Ambient temperature ($25 \pm 2^{\circ}\text{C}$) 2. Two inch wide samples 3. closure samples must include seam joining closure with garment material
Number of Tests	3 replicates per seam and closure type
Data Collected	Tensile strength versus load; Observation for failure mode (material or seam)
Method of Data Collection	Connection with strip chart recorder or portable computer
"Success" Criteria	Average tensile strength > 15 lbs (force) for two inch wide specimen; seam as strong as material

Test Plan - Evaluation of Gas-Tight Integrity for Encapsulating Chemical Protective Suit	
Objective	To evaluate the gas-tight integrity of prototype Level A encapsulating suits and interfaces.
Test Equipment	Pressure test kit including Magnehelic gauge, valves, and plugs for suit exhaust valve openings; Source of compressed air.
Test Procedures	Conduct tests per ASTM F 1052, Practice for Pressure Testing of Totally Encapsulating Chemical Protective Suits. When integrity conditions are not met, identify leak locations by inflating suit and brushing lightly with soapy water solution.
Test Conditions	1. Use initial inflation pressure of 3 inches water gauge. 2. Use starting test pressure of 2 inches water gauge. 3. Conduct tests at ambient temperature ($25 \pm 2^{\circ}\text{C}$) in environment free of air currents or changes in temperature.
Number of Tests	Test each suit three times.
Data Collected	Ending internal suit pressure. Identified areas of leakage.
Method of Data Collection	Visual observation of magnahelic gauge.
"Success" Criteria	Pressure drop in suit is less than 20% (to 1.6 inches water gauge or greater) in period of 3 minutes.

Test Plan - Evaluation of Liquid-Tight Integrity for Level B Splash Suits

Objective	To evaluate the liquid-tight integrity of prototype Level B splash suits and interfaces.
Test Equipment	Shower stall conforming to ASTM F 1359; Recirculating pump rated at 5 gallons per minute; 55 gallon water supply; Surfonyl 104H surfactant; Human form mannequin; Water-absorptive garment fitting mannequin.
Test Procedures	Conduct tests per ASTM F 1359, Practices for Evaluating the Liquid-Tight Integrity of Chemical Protective Suits and Suit Ensembles.
Test Conditions	1. Use surfactant at 0.1% w/w concentration to achieve liquid surface tension at 33 ± 4 dynes/cm. 2. Use dummy breathing apparatus on mannequin with cover made of same material as water-absorptive garment. 3. Conduct tests in temperature range of 18-30°C.
Number of Tests	Evaluate each ensemble once
Data Collected	Observations of liquid penetration onto water absorptive garment.
Method of Data Collection	Visual observations
"Success" Criteria	No observations of liquid penetration inside ensemble.

Test Plan - Qualitative Evaluation of Ensemble Integrity, Fit, Function and Comfort	
Objectives	To rate human factors aspects of Level A and Level B ensembles following an exercise routine designed to stress suits and simulate DOE worker tasks; To determine the change in suit integrity before and after use.
Test Equipment	Pressure testing equipment per ASTM F 1052: Liquid integrity testing equipment per ASTM F 1359 55 gallon drum Handtruck 10 foot hose 6 foot step ladder Screw driver Wrench Large wheel valves
Test Procedures	Conduct tests per ASTM F 1154, Practices for Qualitative Evaluating the Comfort, Fit, Function, and Integrity of Chemical Protective Suit Ensembles; Conduct both exercise protocols; Measure suit integrity for Level A ensembles before and after test subject use using ASTM F 1052 (see gas-tight integrity test plan); Measure suit integrity for Level B ensembles before and after test subject use using ASTM F 1359 (see liquid-tight integrity test plan).
Test Conditions	1. Conduct tests at 18-30°C and relative humidity of 30-80%. 2. Use 3 human test subjects who are physically fit and monitored for heart rate, weight, and oral temperature before and after tests. 3. Have each human subject rate each area of performance. 4. Have each human subject perform tests without protective clothing and with current clothing ensemble for comparison.
Number of Tests	One test for each ensemble (3 types) for each human subject.
Data Collected	1. Integrity observations before and after trial. 2. Human subject ratings on ensemble comfort, fit, and function.
Method of Data Collection	Visual observations from human subjects and integrity measurements
"Success" Criteria	Prototype ensemble provides greater overall ratings compared to existing ensemble. Decrease in wearer mobility less than 20% when compared to tests without protective clothing.

Test Plan - Quantitative Evaluation of Ensemble Human Factors

Objective	To assess the physiological impact of the new ensemble on human subjects as compared to the existing protective clothing/equipment ensemble.
Test Equipment	Environmental controlled chamber; Treadmill; Heart rate monitoring equipment; Respiration rate monitoring equipment; Core and skin temperature monitoring equipment; Weight scales.
Test Procedures	Human subjects will perform treadmill tests at rate of 3 miles/hour wearing (a) no protective clothing, (b) existing protective clothing/ equipment ensemble, and (c) prototype clothing/equipment. During treadmill tests, human subject physiological parameters (heart rate, respiration rate, core temperature, and skin temperature) will be measured remotely. Test subjects will also be periodically asked to rate ensemble comfort, function, and fit. Human subject weights will be taken before and after tests.
Test Conditions	1. Test will be conducted at two separate conditions (25°C at 50% relative humidity, and 30°C at 90% relative humidity). 2. A minimum of three human subjects will be used.
Number of Tests	Each subject will wear each ensemble twice for each environmental condition.
Data Collected	Heart rate versus time; Respiration rate versus time; Core and skin temperature versus time; Subject weight before and after test; Subject qualitative ratings of each ensemble.
Method of Data Collection	Strip chart recorder for physiological data; Written responses for human subject ratings.
"Success" Criteria	Prototype ensemble shows slower rise in heart rate, core temperature, and skin temperature compared with existing ensemble. Prototype ensemble shows longer endurance for human subjects compared to existing ensemble.

Document N^o 19801-70001B

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Page D-1

Appendix D - Life Cycle Cost Analysis Charts (Section 6)

Table 6-4A. Calculation of Life Cycle Costs (Low PPE Cost)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 280

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$75,925		\$98,102		\$249,675
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		583.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.629		0.102		0.173
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,308		\$303,503		\$54,781
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.219		0.131		0.250
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,006		\$20,154		\$13,357
Total Storage Cost	S		\$2,925		\$1,500		\$47,559		\$18,169
Total Disposal Cost	D		\$975		\$500		\$15,853		\$6,056
LIFE CYCLE COST	T		\$370,879		\$103,394		\$1,305,972		\$724,968

Table 6-4B. Calculation of Life Cycle Costs (High PPE Cost)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$101,550		\$98,102		\$499,050
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.701		0.102		0.225
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,535		\$303,503		\$57,870
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.395		0.131		0.344
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,061		\$20,154		\$13,919
Total Storage Cost	S		\$2,925		\$2,625		\$47,559		\$36,338
Total Disposal Cost	D		\$975		\$875		\$15,853		\$12,113
LIFE CYCLE COST	T		\$370,879		\$130,801		\$1,305,972		\$1,002,219

Table 6-4C. Calculation of Life Cycle Costs (Single Use Level A Suit)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act/Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing Suit	SCBA	AWPS Suit	PLSS	Existing Suit	SCBA	AWPS Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	1	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$438,738		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,684
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$467,103		\$1,305,972		\$863,782

Table 6-4D. Calculation of Life Cycle Costs (Reusable Level A Suit)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	IS	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	10	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	LS(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$44,988		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	LS(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$18.65		\$1.35		\$18.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	LS(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	LS(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	LS(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,684
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$73,353		\$1,305,972		\$863,782

Table 6-4E. Calculation of Life Cycle Costs (Low Support Labor Requirement)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	180	120	20	0.67	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing	SCBA	AWPS	PLSS	Existing	SCBA	AWPS	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$88,738		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.33		0.25		0.33
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.00		1.25		3.00
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$18,123		\$820,800		\$344,335
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$115,072		\$1,305,972		\$825,188

Table 6-4F. Calculation of Life Cycle Costs (High Support Labor Requirement)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act/Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	215	120	55	0.56	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing	SCBA	AWPS	PLSS	Existing	SCBA	AWPS	PLSS
Purchase Price	IS	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	LS(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$88,738		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.92		0.25		0.92
Support Labor Rate	LS(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.58		1.25		3.58
Operation Labor Rate	LS(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$22,863		\$820,800		\$434,388
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	LS(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	LS(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$119,812		\$1,305,972		\$915,240

Table 6-4G. Calculation of Life Cycle Costs (Short PLSS Service Life)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year

260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	500	1	1000	1	500
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$89,675		\$98,102		\$392,175
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$362,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$118,041		\$1,305,972		\$881,595

Table 6-4H. Calculation of Life Cycle Costs (Long PLSS Service Life)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1500	1	1000	1	1500
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$88,425		\$98,102		\$368,425
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,427		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,034		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$2,063		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$688		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$116,791		\$1,305,972		\$857,845

Table 6-41. Calculation of Life Cycle Costs (40 Minutes Actual Time)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	115	40	35	0.35	7500	1875	469

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$901		\$1,202		\$901
Total Purchasing Cost	P		\$302,852		\$266,214		\$98,102		\$1,123,089
PPE Uses	AU		750		375		14250		7125
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		1.92		1.25		1.92
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$40,463		\$820,800		\$768,788
No. Missions	AM		187.5		93.75		3562.5		1781.25
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$13,281		\$303,503		\$169,466
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$3,103		\$20,154		\$40,991
Total Storage Cost	S		\$2,925		\$6,188		\$47,559		\$81,759
Total Disposal Cost	D		\$975		\$2,063		\$15,853		\$27,253
LIFE CYCLE COST	T		\$370,879		\$331,310		\$1,305,972		\$2,211,346

Table 6-4J. Calculation of Life Cycle Costs (60 Minutes Actual Time)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act/Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	135	60	35	0.44	5000	1250	313

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$601		\$1,202		\$601
Total Purchasing Cost	P		\$302,852		\$177,476		\$98,102		\$748,726
PPE Uses	AU		750		250		14250		4750
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$18.65		\$1.35		\$18.65
Operation Hrs	HRS(W)		1.25		2.25		1.25		2.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$30,308		\$820,800		\$575,858
No. Missions	AM		187.5		62.5		3562.5		1187.5
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$8,854		\$303,503		\$112,977
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$2,069		\$20,154		\$27,327
Total Storage Cost	S		\$2,925		\$4,125		\$47,559		\$54,506
Total Disposal Cost	D		\$975		\$1,375		\$15,853		\$18,169
LIFE CYCLE COST	T		\$370,879		\$224,207		\$1,305,972		\$1,537,564

Table 6-4K. Calculation of Life Cycle Costs (80 Minutes Actual Work)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act/Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	155	80	35	0.52	3750	938	234

Working days/year 280

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$451		\$1,202		\$451
Total Purchasing Cost	P		\$302,852		\$133,107		\$98,102		\$561,544
PPE Uses	AU		750		187.5		14250		3562.5
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		2.58		1.25		2.58
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$25,231		\$820,800		\$479,394
No. Missions	AM		187.5		46.875		3562.5		890.625
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$6,640		\$303,503		\$84,733
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,552		\$20,154		\$20,496
Total Storage Cost	S		\$2,925		\$3,094		\$47,559		\$40,880
Total Disposal Cost	D		\$975		\$1,031		\$15,853		\$13,627
LIFE CYCLE COST	T		\$370,879		\$170,655		\$1,305,972		\$1,200,673

Table 6-4L. Calculation of Life Cycle Costs (100 Minutes Actual Work)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act/Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	175	100	35	0.57	3000	750	188

Working days/year 280

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$361		\$1,202		\$361
Total Purchasing Cost	P		\$302,852		\$106,486		\$98,102		\$449,236
PPE Uses	AU		750		150		14250		2850
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		2.92		1.25		2.92
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$22,185		\$820,800		\$421,515
No. Missions	AM		187.5		37.5		3562.5		712.5
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$5,312		\$303,503		\$67,786
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$1,241		\$20,154		\$16,396
Total Storage Cost	S		\$2,925		\$2,475		\$47,559		\$32,704
Total Disposal Cost	D		\$975		\$825		\$15,853		\$10,901
LIFE CYCLE COST	T		\$370,879		\$136,524		\$1,305,972		\$998,538

Table 6-4M. Calculation of Life Cycle Costs (140 Minutes Actual Work)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.85
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	215	140	35	0.65	2143	536	134

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$258		\$1,202		\$258
Total Purchasing Cost	P		\$302,852		\$76,061		\$98,102		\$320,883
PPE Uses	AU		750		107.142857		14250		2035.71428
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.58		1.25		3.58
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$18,704		\$820,800		\$355,368
No. Missions	AM		187.5		26.7857143		3562.5		508.928571
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$3,794		\$303,503		\$48,419
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$887		\$20,154		\$11,712
Total Storage Cost	S		\$2,925		\$1,768		\$47,559		\$23,360
Total Disposal Cost	D		\$975		\$589		\$15,853		\$7,787
LIFE CYCLE COST	T		\$370,879		\$101,803		\$1,305,972		\$767,527

Table 6-4N. Calculation of Life Cycle Costs (160 Minutes Actual Work)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	235	160	35	0.68	1875	469	117

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$225		\$1,202		\$225
Total Purchasing Cost	P		\$302,852		\$86,553		\$98,102		\$280,772
PPE Uses	AU		750		93.75		14250		1781.25
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.92		1.25		3.92
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$17,616		\$820,800		\$334,697
No. Missions	AM		187.5		23.4375		3562.5		445.3125
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$3,320		\$303,503		\$42,367
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$776		\$20,154		\$10,248
Total Storage Cost	S		\$2,925		\$1,547		\$47,559		\$20,440
Total Disposal Cost	D		\$975		\$516		\$15,853		\$6,813
LIFE CYCLE COST	T		\$370,879		\$90,328		\$1,305,972		\$695,337

Table 6-40. Calculation of Life Cycle Costs (Single Use Compliant Level A Suit)

Total no. work hours	5000
Ratio of Level A work	0.05
Ratio of Level B work	0.95
Total hrs. Level A	250
Total hrs. Level B	4750

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	IS	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	1	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	LS(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$1,202		\$300		\$1,202		\$300
Total Purchasing Cost	P		\$302,852		\$251,238		\$98,102		\$374,363
PPE Uses	AU		750		125		14250		2375
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	LS(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	LS(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$43,200		\$20,154		\$820,800		\$382,929
No. Missions	AM		187.5		31.25		3562.5		593.75
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.539		0.102		0.201
Decon Labor Rate	LS(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		\$19,544		\$4,028		\$303,503		\$56,489
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.008		0.131		0.301
Maint. Labor Rate	LS(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$1,383		\$940		\$20,154		\$13,664
Total Storage Cost	S		\$2,925		\$1,781		\$47,559		\$27,253
Total Disposal Cost	D		\$975		\$594		\$15,853		\$9,084
LIFE CYCLE COST	T		\$370,879		\$278,735		\$1,305,972		\$863,782

Table 6-4P. Calculation of Life Cycle Costs (Level B Use Only)

Total no. work hours	5000
Ratio of Level A work	0
Ratio of Level B work	1
Total hrs. Level A	0
Total hrs. Level B	5000

	Total Time	Actual Time	Support Time	Ratio Act./Tot.	Individ. Uses	Missions Required	Days Required
Op. Time - Existing	75	20	15	0.27	15000	3750	625
Op. Time - AWPS	195	120	35	0.62	2500	625	156

Working days/year 260

Cost	Variable	Level A				Level B			
		Existing		AWPS		Existing		AWPS	
		Suit	SCBA	Suit	PLSS	Suit	SCBA	Suit	PLSS
Purchase Price	I\$	400	2200			25	2200		
Uses per PPE Item	IU	1	1000	5	1000	1	1000	1	1000
Purchasing Hrs	HRS(P)		20		20		20		20
Purchasing Labor Rate	L\$(P)		\$25		\$25		\$25		\$25
Purchasing Labor Cost			\$0		\$0		\$1,202		\$300
Total Purchasing Cost	P		\$0		\$0		\$103,202		\$394,050
PPE Uses	AU		0		0		15000		2500
Support Hrs	HRS(O)		0.25		0.58		0.25		0.58
Support Labor Rate	L\$(O)		\$25		\$25		\$25		\$25
Consumables	C(O)		\$1.35		\$16.65		\$1.35		\$16.65
Operation Hrs	HRS(W)		1.25		3.25		1.25		3.25
Operation Labor Rate	L\$(W)		\$40		\$40		\$40		\$40
Total Operation Cost	O		\$0		\$0		\$864,000		\$403,083
No. Missions	AM		0		0		3750		625
Cons. Cost/Mission	C(C)		\$75		\$75		\$75		\$75
Decon Hrs	HRS(C)		0.292		0.667		0.102		0.201
Decon Labor Rate	L\$(C)		\$25		\$25		\$25		\$25
Total Decon Cost	C		ERR		ERR		\$319,477		\$59,462
No. Uses/Maint. Cycle	UMC		20		10		20		10
Consumables	C(M)		\$25		\$50		\$25		\$50
Maintenance Hrs	HRS(M)		0.475		1.310		0.131		0.301
Maint. Labor Rate	L\$(M)		\$25		\$25		\$25		\$25
Total Maint. Cost	M		\$0		\$0		\$21,215		\$14,383
Total Storage Cost	S		\$0		\$0		\$50,063		\$28,688
Total Disposal Cost	D		\$0		\$0		\$16,688		\$9,503
LIFE CYCLE COST	T		ERR		ERR		\$1,374,644		\$908,228

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Page E-1

Appendix E - NIOSH Compliance Matrix

Title 30 CFR Test Methods and Applications for SCBA

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.10 Application procedures	Applicants may visit and/or communicate with the laboratory in order to discuss proposed designs.		We will visit NIOSH with the first generation DOE unit. Also, we can discuss items with them at any time.
11.11 Contents of Application Production Grade Unit	d) Must submit a statement that the apparatus has been pretested, and include data from the testing. e) Submit a statement that the respirator and component parts submitted are either prototypes, or made on regular production tooling. All manufacturing operations must be the same as what will be done for production units.		Depending on the details of the processes, NIOSH may approve some changes made between prototype and production units.
11.12	d) NIOSH may retain one fully assembled respirator for laboratory exhibit.		Need to see how this transaction works and who pays for the unit. DOE may not want a unit they paid for to go to NIOSH.
11.20 Fees	SCBA entry and escape \$3,500 Facepiece 450 Hoses 250 Harnesses 100		All charges will be paid with every certification attempt.
11.22 Unlisted Fees	NIOSH reserves the right to conduct any examination they deem necessary to ensure a quality and effective system is being certified. All fees for these tests will be assessed to the user (OSS).	This is solely based on the Test Engineer's (team) prerogative.	
11.30(c) Certification Approval/Production Methods	Applicants required to resubmit respirators and components parts made on regular production tooling, with no operation included which will not be incorporated in regular production processing, shall be charged fees in accordance with Subpart C of this part.		"No major changes." Major changes classified as i.e. machined part changed to cast part; swaged tube now welded tube fittings.

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.31(c) Certificates of Approval; Contents	Drawings and specifications listed in each certificate of approval shall set forth in detail the design and construction requirements which shall be met by the applicant during commercial production of the respirator.		
11.31(e) Certificates of Approval; Contents	No test data may be submitted with certificate of approval. Test data from certification process may be requested.		Test data will be sent to us if we submit a written request.
11.35(a) Changes to respirator	Each applicant may, if desired, change any feature of an approved respirator, request a modification of the original certificate of approval issued.	The application for modification will be reviewed by NIOSH to determine whether additional testing will be required.	
11.36 Delivery of Modified Respirator	An approved respirator that has been modified, must be delivered to NIOSH for retesting.		If only a specific component of the unit has been modified, it may only be necessary for that component to be tested.
11.41 Quality Control Contents	Failure Characteristics: Critical: A defect resulting in a failure immediately dangerous to life or health for individuals using or depending on the respirator. Major A: A defect, other than critical, that is likely to result in failure to the degree that the respirator does not provide any respiratory protection, or a defect that reduces protection and is detectable by the user.	MIL-STD-105D "Sampling Procedures and Tables for Inspection by Attributes" MIL-STD-414 "Sampling Procedures and Tables for Inspection by Variables for Percent Defective"	

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.41 Quality Control Contents, cont.	Major B: A defect other than Major A, resulting in reduced respiratory protection, and is detectable by the user. Minor A: A defect that is not likely to materially reduce the usability of the respirator for its intended purpose, or a defect that is a departure from established standards and has little bearing on the effective use of operation of the respirator. The Acceptable Quality Level (AQL) for each major or minor defect so classified by the applicant shall be: (1) Major A. 1.0%; (2) Major B. 2.5 %; Minor 4.0%.		
11.43 QC Records	a) Applicant is required to keep QC inspection records to these standards. b) MSHA and NIOSH may request to inspect our facilities and interview employees to ensure proper QC practices, and records.	MSHA and the Institute (NIOSH) reserve the right to have representatives inspect QC test methods, equipment and records, and interview employees in regard to QC methods. <i>MIL-STD-105D, MIL-STD-414, or approved equivalent</i>	
11.50 thru 11.53 Classification of Respirator	The respirator shall be classified to provide respiratory protection for <u>fixed periods of time</u> against the hazards described in such approval (i.e. IDLH).	11.51(a) Entry and escape respirator. 11.53(a) Approval duration times: (1) 4 hours; (2) 3 hours; (3) 2 hours; (4) 1 hour; (5) 45 minutes; ... (10) 3 minutes. (b) Other service times may be prescribed.	AWPS duration needs to be determined prior to certification testing.
11.53 Service time Classification	The prescribed service times are: 4 hr; 3 hr; 2 hr; 1 hr; 45 min; 30 min; 15 min; 10 min; 3 min. Other times may be approved. The unit has to be classified to one of these times.		Service time classification of the unit will be dependent on the testing. Verification of the unit's duration will be made by the Institute.

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.62 Component parts	(1) Designed, constructed, and <u>fitted</u> , to insure against creation of any hazard to the wearer. (2) Assembled to permit easy access for inspection and repair of functional parts (3) Permit easy access to parts which require periodic cleaning and disinfecting.		Common sense, and design for manufacturing, simplicity. No FMEA required.
11.63 (c) Additional Test Requirements	MSHA and NIOSH reserve the right to require, as a further condition of approval, any additional testing they deem necessary.	Based on the NIOSH Test Engineers discretion.	They are especially concerned with the AWPS since it is a cryogenic unit. NIOSH has only certified one other LOX unit.
11.65 Conduct of Examinations	The testing is completed at NIOSH (METC). Only MSHA and NIOSH personnel, and those specifically invited will be present during testing.		NIOSH has stated that there will be no problem with OSS personnel being present during testing. Also, OSS personnel may be requested to be present during assembly/disassembly or testing preparation.
11.70 (a) SCBA Description	Self-contained breathing apparatus including all completely assembled, portable, self-contained devices designed for use as respiratory protection during entry into and escape from or escape only from hazardous atmospheres, are described...11.70(a)(2)(ii).		The AWPS is classified as an <u>Open Circuit Pressure Demand SCBA</u> .
11.70(a)(2) Open circuit apparatus	An apparatus from which exhalation is vented to the atmosphere and not rebreathed.		
11.70(a)(2)(ii) Pressure-demand type apparatus	An apparatus in which the pressure inside the facepiece in relation to the immediate environment is positive during both inhalation and exhalation.		
11.72 Breathing tubes; minimum requirements	Shall be designed and constructed to prevent: restriction of free head movement, disturbance of the fit of facepieces and mouthpieces, interference with the wearer's activities, and shutoff of airflow due to kinking or from chin or arm pressure.		Tested as part of manned testing. Wearer/subjects critique: fit; comfort; donning/doffing; user friendliness; etc.

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.73 Harnesses	Designed to hold all components against wearer's body, permit easy removal and replacement of components, and provide a mechanism for holding a full facepiece in the ready position when not in use.		No load or shock tests will be done on harness. This is an NFPA requirement.
11.74 Apparatus containers	(a) Must bear all appropriate markings which show name, type, commercial designation of the respirator, and approval labels.		The apparatus must be supplied in a carrying and storing container fitted for the system. (11.74 a-c)
	(b) Containers supplied to carry the respirator, will be tested as components of the respirator.		
11.75 Facepieces	(b) Full Facepieces shall provide for the optional use of corrective spectacles or lenses which shall not reduce the respiratory protective qualities of the apparatus.		
	(d) Facepieces shall be designed to prevent eyepiece/lens fogging.		
11.76 Facepieces	(b) Eyepieces shall be designed and constructed to meet Federal Spec.	<i>Federal Specification, Mask, Airline, and Respirator, Air Filtering, Industrial, GGG-M-125d, October 11, 1965.</i>	
11.77 Inhalation and Exhalation valves	(a) Inhalation and exhalation valves shall be provided where necessary and protect against damage and distortion.		
	(b) Exhalation valves shall be protected from damage or distortion, (1) protected against external influence, and (2) prevent inward leakage of contaminated air.		
11.78 Head harnesses	(a) Facepieces shall be equipped with adjustable and replaceable harness to secure facepiece to head and provide even distribution and contact to wearer's face.	Critiqued by subjects in manned testing.	

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.79 Breathing Gas	(a) Breathing Gas shall have an Oxygen percentage between 19.5 and 23.5. Per CGA spec G-7.1 Grade B.	Sensors are in the dummy head, monitoring throughout testing.	
	(b) Oxygen shall meet USP for medical breathing Oxygen		
	(d) Liquified breathing air shall meet Type II CGA G-7.1 Grade B or higher	<i>CGA Commodity Specification for Air, G-7.1</i>	
11.79-1 Interchangeability of Oxygen and Air	Approvals will not be issued for apparatus designed to use Oxygen and Air interchangeably		
11.80 Container requirements	(a) Shall meet DOT requirements for Interstate shipment when fully charged	Container (dewar) must be certified by DOT per our drawings.	
	(b) Shall be legibly marked to identify contents i.e., "Liquified Breathing Air"		
	(c) If the container is removable it shall be equipped with a dial type gage to indicate internal pressure.		NA for AWPS. Inner vessel will be classified as removable for maintenance only.
	(d) Compressed breathing gas contained valves, or a separate charging system, or adapter, shall have threads that meet ANSI standard.	<i>American National Standard for Compressed Gas Cylinder Valve Outlet and Inlet Connections B57.1.</i>	Valves must be clearly distinguishable by both sight and touch.
11.81 (b) Liquid Level Gages	Shall be calibrated in fractions of the total container capacity or in units of liquid volume.	NIOSH Test No. 11	We can take readings during in house testing, and report findings to NIOSH. Gage only need to indicate worst case situation to be acceptable. For instance the capacitance gage reads half full when wearer is on hands and knees, but could actually be three fourths full.
	(f) Gas loss/leaks shall not exceed 70 lpm when liquid level is at one-half.		

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.82 Remaining Service Life Indicator.	(2) Liquid level gages shall be visible to the wearer. Where the liquid cannot be rapidly vented, and service time begins immediately after filling, a timer shall be provided in place of a visible gage.	NIOSH Test No. 24 Sound level determination of alarm NIOSH Test No. 45	<i>Will AWPS be capable of rapid venting? Will service time begin immediately after filling?</i>
	(e) Remaining service life indicator or warning device shall be provided in addition to a pressure gage (f) Each remaining service life indicator shall give an alarm when the remaining service life of the apparatus is reduced within a range of 20-25% of its rated service time.		The warning device must be audible. We can have a visible indicator in combination with the audible device. But an audible device is mandatory.
11.83 Hand Operated Valves	(a) Hand operated valves: designed to prevent removal of stem(knob) from valve during normal use. Mainly guards against release thru the stem/bonnet		
	(b) designed/positioned to prevent accidental opening/closing and damage		
	(c) shall be capable of adjustment by the wearer		
	(d) Main line valves shall be designed and constructed to conserve gas in the event of a regulator failure, shall be provided in addition to gas container valves, unless this type of failure will not affect performance		
	(e) Hand operated emergency by pass must be supplied. This is used to allow the wearer to breath and conserve gas in the event of a regulator failure. (g) This valve shall be colored red.	NIOSH Test No. 26	Cairns Pioneer regulator has a "failed open" mechanism rather than an emergency by pass, which is acceptable to NIOSH.
	(f) valves should be distinguishable by sight and by touch		

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.85-4 Weight requirement	(a) The completely assembled and fully charged apparatus shall not weigh more than 16 kg. (35 pounds); however, where the weight decreases by more than 25 percent of its initial charge weight during its rated service life, the maximum allowable weight of a completely assembled and fully charged apparatus shall be 18 kg. (40 pounds).		The total weight of apparatus includes the cooling garment. Empty/Dry.
	(b) Where an apparatus employs equipment which contributes materially to the wearer's comfort, e.g., a cooling system, the completely assembled and fully charged apparatus shall not weigh more than 18 kg. (40 pounds) regardless of the decrease in weight during use.		
11.85-5 Inhalation Resistance	Inhalation resistance shall not exceed 32 mm (1.25 inch) water at 125 lpm.	Inhalation resistance will be measured in facepiece while mounted to dummy head/breathing machine (11.85-3, pg 28) NIOSH Test No. 2 & 4	
11.85-6 Exhalation resistance	(c) Exhalation resistance shall not exceed 51 mm (2 inch, above mask static pressure, water at 85 lpm. (d) Static pressure in mask shall not exceed 38 mm (1.5 inch) water.	Inhalation resistance will be measured in facepiece while mounted to dummy head/breathing machine (11.85-3, pg 28) NIOSH Test No. 4 & 7	
11.85-7 Exhalation valve test	Dry valve and valve seat leakage shall not exceed 30 lpm at 1 inch water.	Testing with mask mounted to dummy head of breathing machine. NIOSH Test No. 4	

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.85-8 Static flow test	Flow from apparatus shall be greater than 200 lpm when facepiece pressure is zero gage and full container pressure.	Tested on the cam driven breathing machine. NIOSH Test No. 27? & R-004	This test will only last for "2 or 3 minutes" at the 200 lpm flow rate.
11.85-10 Service time	(b) Open circuit apparatus will be classified according to the length of time it supplies air or oxygen to the breathing machine. (c) The service time obtained on this test will be used to classify the open circuit apparatus in accordance with 11.53.	Service time will be tested on a breathing machine per 11.85-3 NIOSH Test No. 15	
11.85-12 CO ₂ Test	CO ₂ limits: $\leq$ 30 min-2.5%; 1 hr-2.0%; 2 hr-1.5%; 3 hr-1.0%; 4 hr-1.0%.	(a) Apparatus will be tested on a breathing machine at 14.5 respirations per minute w/10.5 lpm. The machine will exhale a concentration of 5% CO ₂ into the facepiece. The apparatus will be tested at $27^{\circ} \pm 2^{\circ}\text{C}$ ($80^{\circ} \pm 5^{\circ}\text{F}$).	
11.85-13 Tests at low temperature	(a) The applicant shall specify the minimum temperature for safe operation of the apparatus.	(b) The apparatus will be precooled at the low temperature, specified by the applicant, for 4 hours. NIOSH Test No. R-003	The apparatus shall function properly, no obscured vision, no discomfort to the wearer caused by airflow resistance or chemical changes in operation. (f) Axillary low temperature parts may be used for these tests.
	(c) The apparatus will be worn in this low temperature by two separate subjects in this environment, according to applicants directions, for it's rated service time.	(d) Testing will consist of 1 min rest followed by 1 min stepping, 30 cycles per min onto and off an 8.5 inch box. NIOSH Test No. 36	

Requirement (Section No.)	Description of Requirement	Test Method or Specification cited	Notes from discussions with NIOSH
11.85-14 Man Tests	(a) Man tests 1 thru 4 will be conducted to simulate workloads of the mining industry. Subjects will be NIOSH personnel.	(e) Breathing resistance, pulse, respirations, and CO ₂ levels will be measured at 2 min intervals. NIOSH Test No. 32	The man tests do not determine duration. If the wearer runs out of air during man test we do not fail the certification.
11.85-17 Man Test 6	Specific to liquified breathing gas systems. The primary purpose of the test is to verify operation in other than vertical positions.	(c-e) Tests will be conducted with the wearer lying face down, on each side, and on wearer's back. A test will be conducted in each of these positions with a full charge, ¾ charge and ¼ charge. Oxygen content of the breathing gas will be monitored continuously. NIOSH Test No. 30	Duration is determined on the breathing machine at 40 lpm, 24 cycles per minute. For the AWPS this would be for 2 hours.
11.85-18 Man test performance requirements	(a) The apparatus shall satisfy the respiratory requirements of the wearer for the specified service time. (b) Fogging shall not obscure vision, and wearer shall not experience discomfort due to fit or other characteristics.	Relative Humidity is required to remain below 50% on most of the tests.	
	(c) There are specific requirements for the maximum breathing gas temperature at a given humidity level. Most are over 100°F. Refer to chart in 11.85-18 page 31 for more details.		NIOSH has stated that they have no minimum temp requirement. The primary driver is whether or not the wearer is comfortable.
11.85-19 Gas tightness	Six subjects will be tested with mask on, in an atmosphere of 1,000 ppm of isoamyl acetate (banana oil), for two min. None shall detect the odor or taste.	NIOSH Test No. 19	
Specific man test requirements	30 CFR Part 11 Subpart H 11.85: Tables 1 thru 4. Attached.		

The following are issues not addressed in title 30 but are applicable to the AWPS:

1) Recharge Station	NIOSH does not test or certify recharge equipment. NIOSH has a breathing air recharge station in their lab that is capable of 2200 psi. We many bring our own recharge station for testing.
2) Units required	NIOSH will require 2 complete units for testing, one of which they may keep for display.
3) Electrical components	NIOSH has stated that electrical components can be used in respirator, but they must be clearly marked "not approved by MSHA".
4) Quick disconnect fittings	QD's may be acceptable for cryogenic lines. However for breathing gas lines, CGA specs must be followed.
5) LCG testing	A liquid cooling garment need not be used in NIOSH certification testing. However, if an air cooling garment is to be incorporated the garment is not required, but the orifice/connections to the garment are required to be on the apparatus (to simulate the proper air flow).
6) Static air flow	The 200 lpm flow requirement specified in 11.85-8 will be a brief test of ~1-2 min of flow with a full container, and 20% full container. The breathing machine will normally work the respiratory at 40 lpm, with peaks at 120 lpm. The mask pressure must not go negative for a test period of the duration of the unit.
7) Liquid level indicator	The liquid level indicator should be functional in all orientations. We may complete tests in our facility, develop the worst case scenarios in given orientations, and submit the information to NIOSH to evaluate. This can be done any time prior to actual certification testing.
8) Oxygen percentage	The range of the Oxygen percentage of the breathing gas is 19.5 -23.5 % O ₂ .
9) QC manuals	NIOSH requires QC manuals to be present during certification testing.