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REDUCING THE MAINTENANCE BURDEN OF SHIPBOARD COLLECTIVE PROTECTION SYSTEMS

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ABSTRACT

Chemical, biological, and radiological (CBR) weapons continue to pose a threat to U.S. Navy ships in the global war on terror. Shipboard Collective Protection Systems (CPS) provide defense against this threat on ships throughout the U.S. Naval fleet. CPS provides a nearly transparent layer of defense with a limited maintenance burden on the crew as compared to other systems aboard ship. The Shipboard CBR Protection Branch of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has sought to reduce the maintenance and manning burden of CPS through a number of completed and ongoing projects. Although the number of ships employing CPS continues to increase throughout the fleet, the maintenance and manning burden for CPS will continue to decrease through persistent research and development efforts.

EXECUTIVE SUMMARY

The Shipboard CBR Protection Branch of NSWCDD, a division of the Naval Sea Systems Command (NAVSEA), is the Navy's lead laboratory for the research, development, and lifecycle management of shipboard CPS. Several efforts undertaken by NSWCDD have significantly reduced the maintenance requirements of shipboard CPS. These efforts, including CBR filter development to allow for greater dust loading and increased life, design of an automated filter maintenance monitor, and creation and deployment of bag-style pre-filters, have resulted in increased reliability of CPS and reduced maintenance needs.

Among the potential weapons that can be used against U.S. Navy ships, airborne CBR threats can be among the hardest to track and protect against. CPS provides an effective defense against airborne CBR threats. These systems provide an excess of filtered, contaminant-free air to a space, thus over-pressurizing the zone and allowing personnel to carry out their missions without the need for individual protection equipment (IPE) such as masks, suits, and gloves.

The protection afforded by the use of Collective Protection (ColPro) requires additional maintenance and manning when compared to conventional ventilation systems. The maintenance involved ranges from visual equipment inspections involving the ship's crew to large-scale CBR filter change-outs involving Navy certification organizations. While CPS requires relatively little planned maintenance, the critical role of CPS in the safety of the crew dictates the need for diligence in the performance of system maintenance.

NSWCDD continues to incorporate the principals of reduced maintenance and reduced manning in a number of current projects. Ongoing efforts include development of a shipboard CPS automation suite and design of an electrically enhanced pre-filter that may extend service life over the current pre-filters. The goal of these efforts is to further reduce the maintenance needs of ColPro systems and provide the warfighter with systems that are reliable, easy to maintain, and capable of effective CBR protection.

OVERVIEW OF COLLECTIVE PROTECTION SYSTEMS

Until the 1980s, shipboard chemical and biological defense involved bulky IPE such as masks, gloves, and suits that had to be worn continuously in a contaminated or threat environment. This equipment provides exceptional protection against the harmful effects of CBR agents, but may hinder or prevent personnel from executing a critical mission. While operating in IPE, personnel experience limited vision and speaking ability, loss of dexterity, heat stress, inability to eat and difficulty drinking, and increased breathing resistance. A contamination-free environment was needed to carry out specialized missions and allow personnel to perform effectively. The concept of ColPro was borne from this requirement.

Collective protection consists of specialized equipment and procedures employed to create a contamination free environment in which mission-critical personnel can operate without donning full IPE. CPS supplies a space with an excess of clean, filtered air, creating a protective overpressure environment in which all air leaks will flow out of the protected space or zone, preventing contaminant intrusion. CPS achieves clean air overpressure with high-pressure fans, filtration equipment, decontamination stations, and ingress/egress airlocks. Figure 1 shows the major components of shipboard CPS.

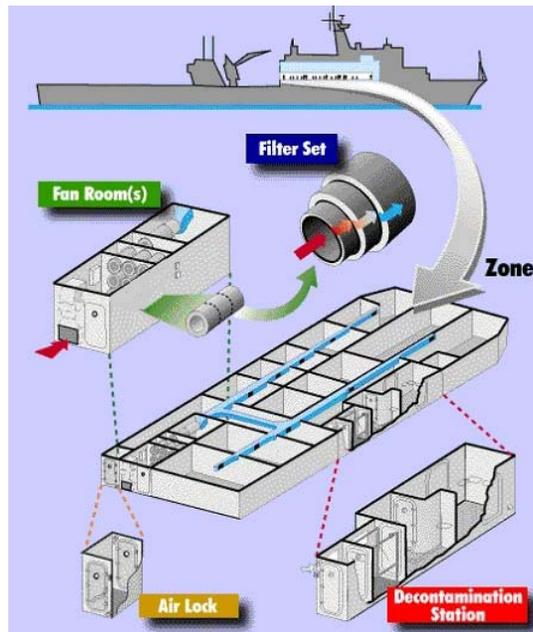


Figure 1. Notional Diagram of Shipboard CPS Components and Layout

Filtration of incoming air is one of the most important elements of CPS. Supply air is filtered against particulates (chemical aerosols and biological and radiological particles) using high-efficiency particulate arresting (HEPA) filters. These filters, similar to the commercially available HEPA filters, use a blown glass fiber media to capture airborne contaminants. Vapor (chemical agent) filtration is achieved with a carbon adsorber impregnated with a number of compounds to promote chemisorption. US Navy

shipboard systems employ the 200 Cubic Feet per Minute (CFM) M98 CBR filter set in Total Protection (TP) areas (see Figure 2), and a 2000 CFM box-style HEPA filter in Limited Protection (LP) areas (see Figure 3). The difference between TP and LP zones will be discussed in later sections.



Figure 2. (a) 200 CFM M98 CBR Filter Set (b) Shipboard M98 Filter Bank



Figure 3. 2000 CFM LP HEPA Filter Installed

The operation of ColPro zones depends upon maintaining the overpressure within the zones and preventing the infiltration of contaminants into these spaces. In order to protect the zone integrity, ingress and egress components must be installed so that the zone pressure can be maintained at all times. Three types of ingress and egress openings are used on shipboard systems: pressure locks, airlocks, and decontamination stations.

The armed services employ ColPro to protect the warfighter in a wide range of applications beyond US Navy ships; mobile medical shelters, field deployable tents, combat vehicles, and permanent land-based structures to name a few. A large number of fixed-site installations within the continental US and abroad, military and civilian, have been outfitted with ColPro systems to keep the occupants safe and maintain continuity of operations in a CBR threat environment. Among shipboard applications, ColPro has been applied to all DDG-51, LHA-1, LHD-1, and LPD-17 class ships and selected AOE-6 and LSD-41 class ships. Organizations such as NSWCDD are continually investigating the integration of ColPro technology in new applications and the next generation of US Navy ship classes.

MAINTENANCE REQUIREMENTS FOR SHIPBOARD CPS

Shipboard CPS is considered a level 3 subsystem of the Climate Control Ship System. The majority of the Planned Maintenance System (PMS) tasks are accomplished at the organization level with a few key tasks performed at the depot level. The organization level tasks focus primarily on the filtration system and maintaining overpressure in the space, two components critical for the success of the system in a contaminated environment. The research and development efforts conducted by the NSWCDD affects a number of the maintenance tasks performed by the ship's force personnel. The organization level CPS maintenance tasks that are most directly affected by this research are TP zone pressurization testing, Navy Standard Impingement Filter (NSIF) cleaning, CBR pre-filter change-out, CBR filter change-out, LP filter gauge inspection, and LP HEPA filter change-out. While this summary does not represent an exhaustive list, it provides an overall picture of the maintenance tasks required to sustain shipboard CPS.

TP Zone Pressurization Test

The pressurization of the entire TP zone, involves operating the system and ensuring all hatches, scuttles, and other openings are closed, and remain closed, throughout the test. Although CPS operates continuously, with the fans providing filtered air to the zone, many of the zone boundary doors and other openings are left open under normal operating conditions. During accomplishment of this Maintenance Requirement Card (MRC), the zone boundary closures must be secured throughout the test to assure maximum overpressure. While conducting this MRC, proper CPS procedures must be followed to assure crewmembers cross zone boundaries through airlocks and pressure locks only. Once the zone boundary doors and hatches have been closed and the zone reaches operating pressure, crewmembers check the zone pressure and the differential pressure across the CBR filters in the CPS inlet plenums or fan rooms depending upon the configuration of the system.

The data from the tests are recorded in a CPS test log. This maintenance task must be accomplished for each CPS zone on the ship; most ships contain more than one zone.

NSIF Cleaning

Airflow to the CBR filter sets first travels through the NSIF, for the purpose of separating very large particles and debris from the air-stream. Unfiltered, this debris could load the critical CBR filter sets with large dust particles relatively quickly, or may damage the CBR filters; therefore, proper maintenance of the NSIF is critical. For each NSIF, crewmembers must remove and clean the filter either in the filter cleaning shop or in service sinks. The NSIF employed for CPS is a large filter constructed from aluminum or stainless steel.

CBR Pre-Filter Change-Out

Current CBR pre-filters, known as “bag” or “sock” pre-filters, have a typical service life of approximately six to nine months, depending on the operating environment. This life will only be achieved if the NSIF is properly maintained. When indicated by the CBR filter differential pressure gauge, the pre-filters are removed, and replacements installed. The pre-filters are snapped in and out of position by hand and do not require tools for removal or installation.

This maintenance task is performed as required and results from a failing differential pressure observed during the TP zone pressurization. If crewmembers replace the CBR pre-filters and the CBR filter differential pressure remains in the red region, the CBR filters must be changed-out. The CBR filter differential pressure increases over time as the filters load with dust particles. Once the filter differential pressure reaches the red region – above a critical value – the CPS fans will be unable to supply sufficient airflow to the protected zone and the zone pressure could be insufficient to prevent agent filtration in the event of an attack. Due to manufacturing variability, a slight variation is observed in the initial pressure drop of newly installed filters. The allowable differential pressure for the CBR filter is 2.5 inwg above the clean condition and is noted after filter installation and system certification.

CBR Filter Change-Out

The Regional Maintenance Center (RMC) under the direction of the In Service Engineering Agent (ISEA) for CPS conducts the change-out of CBR filters. Filter change-out represents a significant effort that requires ample assistance from the ship’s crew. Although the RMC and ISEA lead the effort, typically the ship provides support with several crewmembers – in many cases eight or more – to assist with the operation. This task includes removing all CBR filters, cleaning filter housings and cover plates, installing new filters, and certifying the system. Only the ISEA and select NAVSEA representatives are authorized to test and certify the system after a CBR filter change-out. Depending upon the configuration of the ship, this task can require a total of three to five days of work with crewmembers of the ship typically required for only two days.

CBR filter change-out is required either when indicated by the results of the TP Zone Pressure maintenance requirement or when the filter expiration date is reached. The CBR filters must also be changed-out if any damage occurs after installation due to improper maintenance.

The Program Executive Office (PEO) Ships covers the costs of Shipboard and Conversion, Navy (SCN) CBR Filters upon ship deployment. The Office of the Chief of Naval Operations (OPNAV) covers the costs of Operations and Maintenance, Navy (OMN) CBR filters installed throughout the fleet. If the ships fail to properly maintain

the CBR filters through NSIF and CBR pre-filter maintenance and the CBR filters must be replaced prior to the full service life, then the cost of replacement filters must come from the operational budget of the ship. This represents a cost of \$138k for the average ship – and up to \$282k for the largest CPS equipped ships in the fleet – that fails to perform proper CPS maintenance.

LP Filter Gauge Inspection

The ship's crew must inspect the differential pressure gauges that measure the differential pressure across the LP HEPA filters and record the readings in the CPS test log. Should the differential pressure rise above a pre-determined set point, the filters must be replaced. Similar to the CBR filter set, the allowable differential pressure for LP HEPA filters is 1.0 inwg above the initial differential for the new LP HEPA filters. Filters with differential pressures above this value are performing in the red region and must be changed-out. This task requires a crewmember enter the CPS LP fan rooms and visually check the gauges. CPS fan rooms can be relatively difficult to access and are loud requiring personal hearing protection equipment (PPE).

LP HEPA Filter Change-Out

The LP HEPA filters are changed-out once the LP HEPA differential pressure reaches the maximum differential pressure allowed. Change-out of these filters requires a significant labor effort relative to other CPS PMS tasks, as these filters are 24 in. x 24 in. x 12 in., and are often located in difficult to access spaces. The time required to perform this maintenance is four hours for two personnel, and can often require the support of several other crewmembers as well. Although the periodicity task is “as required”, the frequency of change-out is approximately every eighteen months provided the NSIF maintenance is performed properly.

Although the LP HEPA filter change-out is organization level maintenance, the system must be certified by the ISEA or an authorized NAVSEA representative. Due to the system certification requirement and the periodicity of CBR filter change-out, the LP HEPA filter change-out is typically conducted in conjunction with the depot level CBR filter change-out. This leaves every other LP HEPA filter change-out as part of a depot level maintenance evolution for ships equipped with both LP and TP zones.

CPS Maintenance Impacts

The impact of maintenance requirements of shipboard CPS across the fleet is summarized in Table 1 below. This table represents the total man-hours of maintenance required annually for all CPS equipped ships in the US Naval fleet to be performed by ship's force personnel. In general, CPS onboard ships requires relatively minimal and infrequent maintenance in comparison to other ship systems.

As shown in this table, approximately eight man-years of labor are required to maintain shipboard CPS throughout the fleet. It must be noted that these estimates are based on an average across the fleet; the size and number of fan rooms and the number of filter housings in each fan room varies depending upon the ship class. It is also important to note that this estimate does not include several other significant costs, most importantly labor costs for RMC and ISEA personnel, technical reach-back support costs, annual gauge calibration, and material costs.

Table 1. Calculation of Total Annual Manpower Requirements per Ship Class of Ship's Force Labor to Complete CPS PMS throughout the US Navy Fleet

Ship Class	Number of Ships in Class with CPS	Average Total Man-Hours of Maintenance Required per Ship	Total Man-Hours of Maintenance Required for Ship Class Fleet Wide ^(1,2)
AOE-6	4	272	1088
DDG-51	28	285	7980
DDG-51 FLT IIA	17	166	2822
LHA-1 ⁽³⁾	4	120	480
LHD-1 ⁽³⁾	7	264	1848
LPD-17 ⁽⁴⁾	2	226	452
LSD-41 ⁽⁵⁾	9	57	513
Total Man-Hours for Entire Fleet per Year			15183
Total Man-Years for Entire Fleet per Year			7.6

Note:

- (1) This manpower calculation does not include the costs associated with the ISEA, NAVSEA, or the RMC.
- (2) The number of ships with CPS increases annually as a result of new ship construction and the CPS Backfit Program.
- (3) Each ship in the LHA and LHD class has a different CPS configuration.
- (4) Only two ships in the LPD-17 ship class have been commissioned as of this publication; however, as noted in note (2), additional ships are under construction in this class and will be commissioned in the near future.
- (5) Only LSD-44 and later ships have CPS.

Several areas can be and have been improved in CPS maintenance. These areas include filter life extension and automation of some routine maintenance tasks. The reduction of required maintenance for CPS is an ongoing effort and all new systems are designed with maintenance and supportability considered throughout the design cycle.

COMPLETED EFFORTS

M98 HEPA FILTER DUST LOADING SUITABILITY TESTING

NSWCDD was tasked with a portion of the testing for four candidate non-woven filter medias for possible use in the 200 CFM HEPA filter. Prior to fielding a new filter media for the HEPA filter in the M98 filter set, several tests must be conducted to determine the suitability of the media. The goal was to determine if any of the four media met the minimum efficiency performance requirement while increasing the dust capacity relative to the current media, as shown in Table 2. An increased dust capacity would indicate that the media would have a longer service life.

Table 2. Typical Properties of the Tested Filter Media as Provided by the Manufacturer

Characteristic	Grade A	Grade B	Grade C	Grade D	Grade E
Pressure Drop, inwg @ 5.33 cm/s ⁽¹⁾	1.10	1.04	1.14	1.40	1.30
Basis Weight, lb/3000 ft ²	42	48	48	53.9	48
Caliper, in.	.015	.016	.016	.016	.016
Tensile, MD, g/in.	>3,500	>3,000	>3,000	>3,000	>4,000
Tensile, CD, g/in.	>1,700	>1,500	>1,500	>1,800	>1,700

Notes:

(1) This value represents the differential pressure for new filters.

(2) Tested as per ASHRAE 52.1 with ASHRAE synthetic test dust.

A dust load test allows for the examination of differential pressure across the filter with respect to the amount of dust collected in the filter in accordance with American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 52.1. The amount of dust captured is measured in two ways: measurement of the mass of dust captured by the filter versus the mass of dust used to challenge the filter and by a dust spot efficiency test. A dust spot efficiency test is conducted by comparing dust in the air stream at points upstream and downstream of the filter.

This evaluation included the building of a dust load test stand conforming to Society of Automotive Engineers (SAE) standard J726 and procuring prototype filters manufactured with the new media. The test stand was configured to deliver a known amount of dust at a constant rate to the test filter while measuring the differential pressure across the filter. Using data from this test, the differential pressure as a function of dust load for different filter media could be compared. Dust load capacity is based on special test dust, which alone is not truly representative of atmospheric particle size distributions, thus, this data is generally used only as an indicator to compare different filters with respect to each other.

The above media types were all fabricated into M98 style filter prototypes. These prototypes were challenged with ASHRAE test dust through a series of tests as directed

by NSWCCD [1]. As a result of the study, it was determined that the Grade B and Grade C media had no advantages with regard to dust loading. The Grade D media was damaged before testing could be completed. The Grade A media showed higher dust capacity than the Grade E media, the media employed throughout the fleet at the time of this study.

As a result of this project, Grade A filter media became an approved media for manufacture of M98 HEPA filters. M98 filter sets employing Grade A media have been manufactured and are currently fielded in both shipboard and land-based systems.

DEVELOPMENT OF THE M98 PRE-FILTER TO EXTEND FILTER LIFE

One of the most important components of the CPS filtration system is the CBR pre-filter. The pre-filter reduces the dust load on the HEPA particulate filter portion of the M98 CBR filter set and drastically extends the life of the filter. A new CBR pre-filter was developed and shipboard tested by NSWCCD.

The CBR filter set has two change-out criteria; filter age and differential pressure. The filter age requirement is based on the protection performance of the filters in a threat environment while the differential pressure requirement is based on the fresh air flowrate requirement to maintain overpressure for the system. As mentioned above, the CBR filter sets load with dust over time and the differential pressure across the filters increases. Once the differential pressure reaches a certain level the fan and filtration system will not perform optimally, regardless of the age of the filters. If the fan and filtration system performance is reduced significantly by loaded filters, insufficient fresh air will be supplied to the zone and the zone may not maintain adequate overpressure to prevent agent infiltration in the event of an attack. Any extension of the life of the CBR filter set affords a large cost savings to the fleet. This increase in life is accomplished through reduced dust loading by pre-filtration.

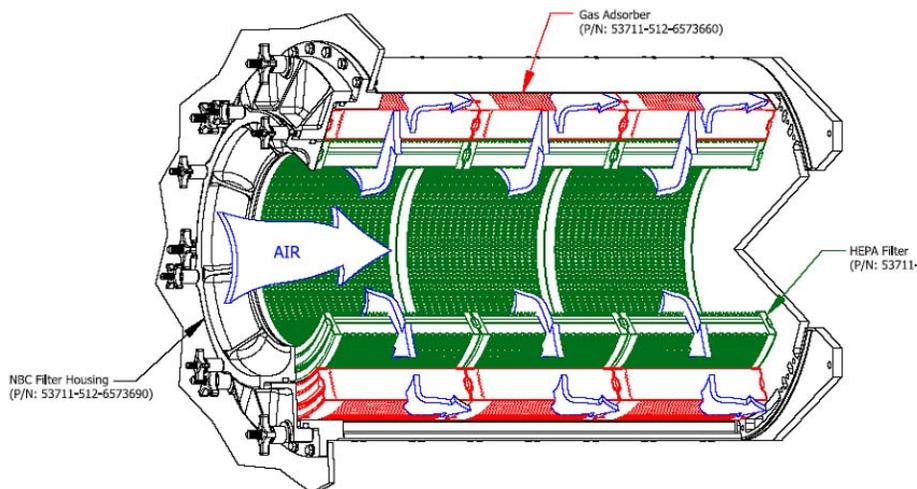


Figure 4. Flow Through CBR Filter Set

Unlike the LP HEPA filter, for which the air flows perpendicular to the inlet and outlet face through the filter without changing direction, the M98 filter set is a radial filter set. Figure 4 shows the airflow path through the M98 CBR filter set: air flows in axially, through the filters radially, and exits the filter housing axially. In order to integrate with this filter configuration, a radial pre-filter was developed to fit inside the M98 filter set. The pre-filter is located along the inner green surface of the HEPA filter in the M98 filter set in Figure 4.

In 1999, NSWCCD completed development on a new style CBR pre-filter that greatly reduced dust loading and thus increased the service life of the CBR filter set. The new-style pre-filter consists of a three layer filter that fits inside the cylindrical M98 filter set: the inner layer that the air first encounters provides rough pre-filtration, the second layer supplies high-efficiency pre-filtration, and the outer filter bag serves as the primary structure of the pre-filter and presents an additional filtration layer. The pre-filter in service prior to the advent of the bag pre-filter consisted of a cylindrical, pleated media filter with a rigid construction. Figure 5 shows the bag-style pre-filter.

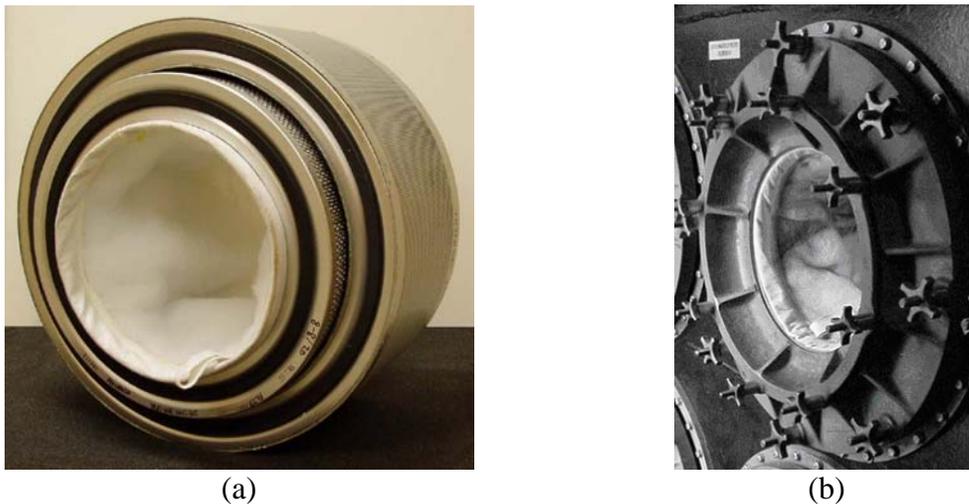


Figure 5. (a) Bag-Style M98 CBR Pre-Filter with M98 Filter Set (b) Bag-Style M98 CBR Pre-Filter Installed in a Shipboard M98 Filter Housing

The new design pre-filter offers two primary advantages over the cylindrical pre-filter in service prior to 2000: improved filtration performance and reduced maintenance burden.

The multi-layer construction of the new design offers vastly improved dust loading capability over the cylindrical pre-filter. The bag pre-filter provides superior filtration efficiency for particle size ranges found in typical inlet air entering the filter system resulting in less dust in the air-stream reaching the CBR filter sets. In standard filter efficiency testing, the bag pre-filters also presented a greater dust loading capacity than the cylindrical design [2]. These factors reduce the dust loading of the CBR filters and thus extend the filter service life in harsh environments.

With the increased dust load capacity, the bag-style pre-filter also possesses greater service life than the cylindrical pre-filter. This effect results from the lower differential pressure across the pre-filter under the same level of dust loading than the cylindrical pre-filter. Thus, while loaded with equal amounts of dust, the bag pre-filter experiences a lower differential pressure and thus requires less frequent change-out. The change-out criterion for the pre-filters is differential pressure based. The bag pre-filter reduces the change-out frequency from six months to approximately six to nine months.

Additionally, the bag pre-filter employs a less complex replacement procedure than the previous cylindrical pre-filter design. The cylindrical pre-filters required the installation of a securing bar retained by the HEPA cover nuts to lock the pre-filters in place as shown in Figure 6. The loosening and tightening of the HEPA cover nuts to remove the securing bar altered the pressure on the HEPA gaskets and invalidated the system leak test performed for system certification, potentially reducing the effectiveness of the system and requiring system re-certification.



Figure 6. Cylindrical CBR Pre-Filter Retention Bar Incorrectly Installed Over a Bag Pre-Filter

The bag pre-filter employs a flexible retention ring integrated in the construction of the filter to secure the pre-filter and a fabric loop for easy removal (See Figure 5 (a)). The retention ring eliminates the need for the retention bar and allows crewmembers to remove and replace pre-filters by hand without disturbing the HEPA cover nuts. As the cover nuts are not affected by the removal and installation of the bag pre-filter, system re-certification is not required, representing a significant cost savings to the fleet.

This reduction in complexity lessened the manpower required to perform maintenance on the pre-filters. Thus both the periodicity of the maintenance and the labor required to perform the maintenance procedure were reduced with the implementation of the bag pre-filter throughout the fleet.

Two other benefits offered by the bag pre-filter design were reductions in the direct cost associated with the pre-filter and the storage burden on the ship. First, the new design is manufactured using less expensive materials and less labor-intensive manufacturing techniques than the cylindrical pre-filter. This results in a per-housing cost reduction from \$90 per filter housing to \$25 per filter housing. With the longer service life of the pre-filters, this translates to a cost savings of approximately 78-percent

annually over the cylindrical pre-filters. Table 3 lists the annual costs associated with the cylindrical and bag pre-filter across the fleet equipped with CPS as an example.

Table 3. Total Annual Procurement Cost Reduction for Cylindrical CBR Pre-Filter and Bag CBR Pre-Filter

Pre-Filter	Number of CBR Filter Housings	Average Number of Change-Outs per Year	Pre-Filter Cost per Filter ⁽¹⁾	Total Cost Annually ⁽²⁾
Cylindrical Pre-Filter	3266	2.0	\$90.00	\$587,880.00
Bag Pre-Filter	3266	1.6	\$25.00	\$130,640.00
Total Cost Savings				\$457,240.00

Notes:

- (1) Cylindrical pre-filter based on last costs as of last order in 1998 [2].
- (2) Based on average change-out periodicity under typical operating conditions.

The second benefit attributed to the bag-style pre-filter results from the construction of the pre-filter. The more flexible pre-filter is stowed in a more compact configuration than the cylindrical pre-filters. The smaller space requirement results in an 84-percent storage space reduction. With storage space at a premium in the fleet, this reduction was a major improvement for CPS as a whole.

The third benefit resulted from the improved pre-filter change-out procedure that reduced the manpower required and the improved change-out frequency. Combined, the reduced maintenance resulted in a manpower savings of 3.0 man-years, or 40-percent of the current total manpower burden, annually across the fleet.

The bag pre-filter has been in service for 5 years and has provided many benefits over the prior cylindrical design. The improved dust loading capacity and longer service life have extended the life of the CBR filters employed throughout the fleet and have significantly reduced the maintenance and costs associated with pre-filtration.

LP HEPA IMPROVEMENT EFFORTS

As part of a project to provide the Navy with an environmentally qualified LP HEPA filter, two filter manufacturers were contracted to supply filters to be examined for potential use aboard ship. Before this task, the design of the LP HEPA filters in service in the fleet had not completed all of the rigorous environmental testing required, such as shock, vibration, and salt fog, to be employed aboard ship and had not been tested to determine whether the filters met the HEPA filtration efficiency performance requirement.

All filters that were tested within the scope of this task passed post-environmental filtration efficiency testing well above the HEPA filtration efficiency performance requirement, with the exception of a filter that was compromised when it was modified to fit inside the test stand.

The new LP filters will improve the LP system logistics, as they are significantly less likely to be damaged during installation than the older LP HEPA filters due to the

addition of faceguards. Figure 7 shows the new LP HEPA and the older LP HEPA filter installed in the CPS Laboratory at NSWCDD. Note the significant damage on the inlet face of the older style filter that results from handling and installation.

Once installed, the ISEA or an authorized NAVSEA representative subjects all LP filters to a leak test to assure system integrity. A leak test challenges each filter bank with a simulant and measures for the possible occurrence of leaks through the filter bank, either through damaged filters or filter gaskets. The new LP filters have proven easier to install with systems typically passing on the first leak test; the older LP filters required the addition of gasket material to the housing by crewmembers during installation and usually failed initial leak testing due to damaged filters.



Figure 7. New LP HEPA Filter (Left Side) and Old LP HEPA Filter (Right Side)

With regard to filter sturdiness during installation, the redesign also proved successful. Employing the older LP HEPA filter design during a typical LP HEPA filter change-out, approximately 10% extra filters were procured to replace filters damaged during installation. With the new filter design, the number of additional filters required to compensate for loss due to installation damage was reduced to 1 to 3-percent.

Additionally, the pre-installed LP HEPA filter gaskets saved approximately 0.7 man-years of labor fleet-wide, or 9-percent of the current total manpower required, as the sailors were not required to set the gaskets by hand.

This project resulted in an improved and environmentally qualified LP HEPA design. The redesigned LP HEPA filters have been instituted in the supply system under the already existing NSN for the previous LP HEPA filter.

LP HEPA SERVICE LIFE EXTENSION INVESTIGATION

A task was developed to research how to extend the life of the LP HEPA filter, which is currently eighteen months on average. Many aspects were examined, including changing the filter media, filter design, and the possibility of adding pre-filtration to the

system. Ultimately, the current LP HEPA system configuration was determined to be the best balance of filtration efficiency, cost, and logistical footprint.

Several potential medias and filter designs were explored to increase the dust load capacity of the LP HEPA filter. The first step was to examine efficiency curves from the media manufacturer to compare airflow resistances and estimate whether or not the medias would reach HEPA performance levels in the LP filter configuration media airflow velocity. Subsequent to the filtration efficiency evaluation, prototype HEPA filters containing three medias were manufactured for dust load tests. Through this study, the current filter configuration employing Grade C media demonstrated the lowest life cycle costs, by virtue of the filter replacement cost and length of service life, while meeting the filtration performance requirements. Thus, the results of the study verified the current media and configuration as the LP HEPA filter of choice.

The current LP HEPA filter configuration was shown to provide the optimal filter for the system, leaving pre-filtration as the next solution to extend filter service life. Several factors impact the suitability of pre-filter and each was considered in the course of this study. These factors are size, filtration performance, cost, and additional logistical burden.

Pre-filter size is determined by LP HEPA inlet plenum space constraints. Deep, rigid pre-filters provide the highest efficiencies because they contain more filter media than shallower filters. However, deep pre-filters are nearly as expensive as HEPA filters and would require bulky holding frames not feasible in the confined inlet plenum.

With the size constraints defined, the filtration efficiency of each of the pre-filter candidates was examined to determine the most suitable candidates. The efficiency as a function of particle size of the 200 CFM pre-filter and the 2000 CFM pre-filter candidates was compiled per ASHRAE 52.2 initial efficiency procedures. The efficiency curves in Figure 8 were generated in the 0.3 to 10-micron range that forms the majority of atmospheric particles that bypass the NSIF. Based on this data, filters with efficiencies lower than the original cylindrical CBR pre-filter at their respective rated flows, such as Pre-Filter B, were eliminated.

The results of the efficiency comparison eliminated all of the flat media candidates, leaving only the two pleated media filters as the candidates for the LP HEPA pre-filter. The dust load efficiencies showed the potential service life extension by 100%, which translates to a 2 to 3 year service life.

The next step in pre-filter selection was to rank price and service life using dust load capacity testing as the service life indicator. Based on lowest differential pressure, Pre-Filter A was selected as the most suitable candidate over Pre-Filter C.

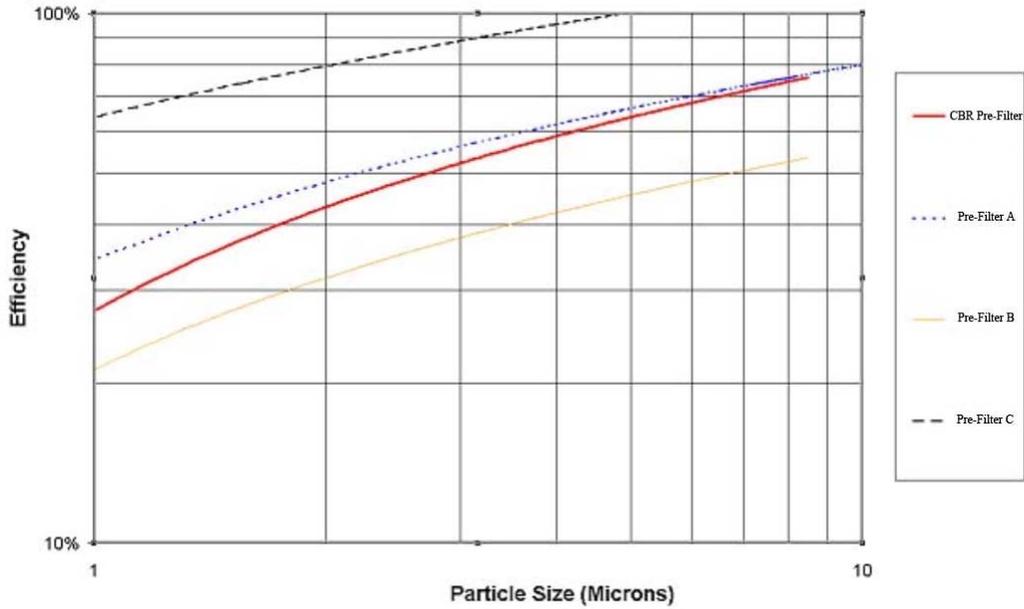


Figure 8. LP HEPA Pre-Filter Efficiency Comparison

Finally, a field study of Pre-Filter A was performed. The pre-filters were installed on one LP zone aboard a ship with two LP zones, with the other LP zone left without pre-filters to act as a baseline. Figure 9 depicts the change in differential pressure from installation to the removal of the pre-filters. The lower dust loading extends the life of the filter and thus this study demonstrates the protection of the LP HEPA filters provided by pre-filtration.

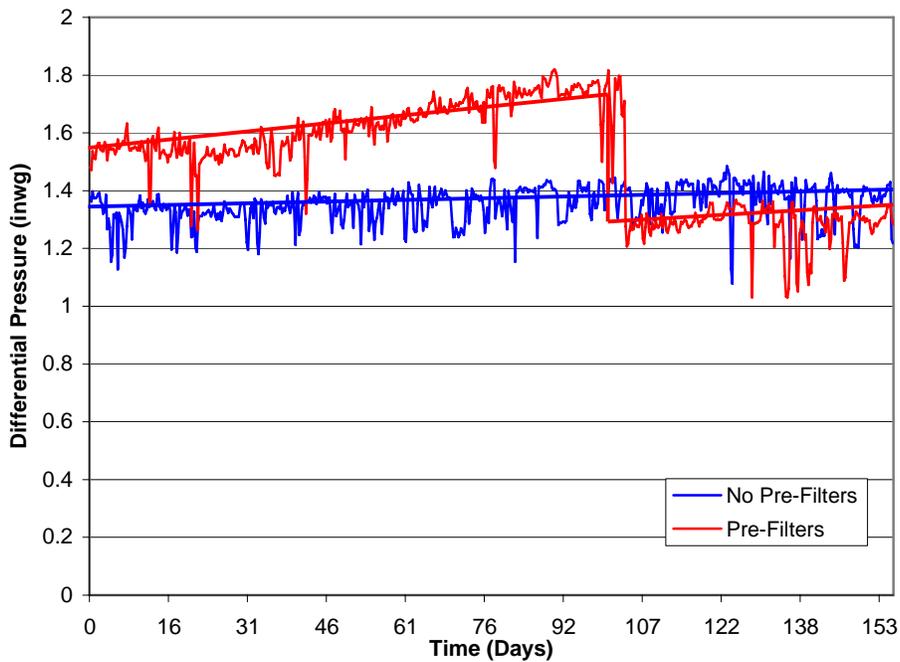


Figure 9. LP HEPA Differential Pressure Comparison Field Test Data with Pre-Filters and Without

Extending the trends observed during this study, pre-filtration has the potential to extend the service life of the LP HEPA Filter from eighteen months to three years or more. Based on the data gathered from the field study, the pre-filter life was estimated as approximately three to four months with a differential pressure change-out criterion. The change-out frequency depends heavily upon the environment in which the ship operates, and thus this is merely an estimate.

Based on the results of this study, although limited to only two systems on one ship, pre-filtration shows a small potential benefit for the fleet. The system could potentially provide a 10-year Navy savings of \$700k overall in LP HEPA filter procurement cost reduction even if the service life of the pre-filter were as low as three months as illustrated by Tables 4 and 5. The logistics and maintenance burden of replacing the LP HEPA filters would be cut approximately in half. These costs do not include the cost of filter leak testing, which must be performed by the CPS ISEA after every LP HEPA filter change-out.

Table 4. LP HEPA Filter and Pre-Filter Procurement Costs

Equipment	Unit Cost
LP HEPA Filter	\$300.00
Pre-Filter	\$8.00
Shock Cord Housing	\$3.75

Table 5. Projected Total Annual Procurement Cost Reduction for LP HEPA Filter and Pre-Filter

Pre-Filter	Equipment	Initial Cost	Change-Out Cost	Life (Years)	10 Year Cost ⁽¹⁾	10 Year Savings
None	LP HEPA	\$0.00	\$300,000.00	1.50	\$2,000,000.00	\$0.00
With Pre-Filters	LP HEPA	\$0.00	\$300,000.00	3.00	\$1,000,000.00	
	Pre-Filter	\$0.00	\$8,000.00	0.25	\$320,000.00	
	Shock Cord Housing	\$3,750.00	Negligible	---	\$3,750.00	\$676,250.00

Notes:

(1) Based on approximately 1000 LP HEPA filters in US Navy fleet.

However, the overall benefit of installing pre-filters on the LP zones must be balanced by the requirement for crewmembers to change-out pre-filters quarterly. This cost will be partially offset by the less frequent LP HEPA filter change-out that requires system certification by the ISEA or designated NAVSEA representative. Another logistical consideration of pre-filter implementation is the need for available space to store pre-filters on the ship: approximately three to four pre-filters per LP HEPA per year.

Currently, the testing originally planned for this project has been completed; however, as the field testing represents only two systems on one ship for a limited period of time more extensive testing is required to confirm the results observed in this study prior to recommendation for implementation of the LP HEPA pre-filter fleet wide. NSWCDD is currently planning an additional testing program to confirm the results of

this study, however, the relatively small cost savings to the fleet and the limited number of LP CPS in the fleet makes additional investigation unlikely.

ONGOING/UPCOMING EFFORTS

DEVELOPMENT OF THE CPS FILTER MAINTENANCE MONITOR

In order to reduce the burden on the cognizant workcenter (W/C) for CPS, a filter maintenance monitor (FMM) is currently under development. The FMM will provide automated monitoring of the differential pressure across three different types of filters in the CPS. This automated monitoring reduces the maintenance burden for CPS and assures proper operation of the system.

Filter maintenance must be accomplished in a timely manner whenever a deficiency exists to assure proper operation of CPS equipment. This maintenance assures that the fans are operating optimally and providing the required overpressure that will prevent agent intrusion in the CPS zone during a CBR attack. Figure 10 shows an early conceptual layout of the FMM with each of the key components indicated.

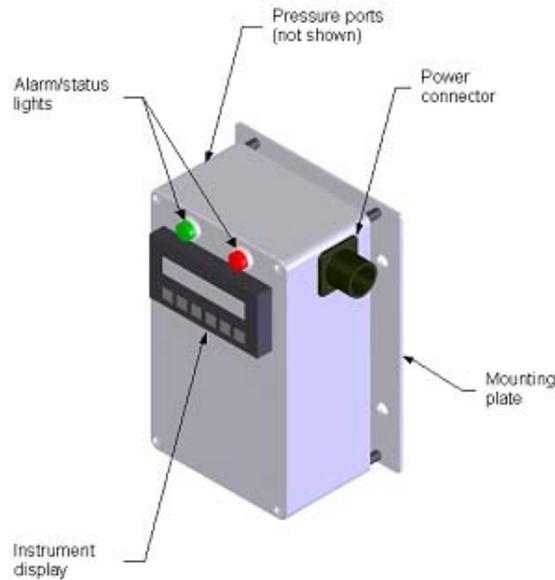


Figure 10. Early Conceptual Filter Maintenance Monitor (FMM) Layout

The FMM replaces the current, mechanical pressure gauge with a unit that utilizes a chip based pressure sensor and a digital microprocessor to measure the differential pressure across several filter types in ColPro systems. Once measured, the FMM determines if the differential pressure has reached a level at which maintenance is required and transmits an alarm if necessary to a local alarm panel and the Damage Control Quarters (DCQ) System aboard DCQ equipped ships. The FMM will serve three types of filters in CPS: NSIF, CBR filters, and LP HEPA filters. Without an alarm from the current differential pressure gauge, the crew is not aware of a deficiency until the next maintenance period for the affected filter set.

The FMM affects the maintenance for each CPS filter type with the most significant impact on the MRC concerning the performance of a zone pressurization test in a CPS TP zone. The FMM is predicted to reduce the total number of steps for this maintenance requirement by 25%. With regard to the LP HEPA filter, the maintenance requirement outlining inspection of the differential pressure readings may be completely eliminated, as the DCQ will perform this function on a continuous basis.

The maintenance requirement for the NSIF entails scheduled cleaning regardless of the differential pressure. The requirement for monthly cleaning could potentially be changed to an “as required” task to be accomplished based on an alarm from the FMM. The periodicity may potentially change from monthly to bi-monthly depending upon the environment in which the ship operates.

Table 6 lists the potential man-hour savings from the addition of the FMM to each type of filter set throughout the fleet. Through automated alarms, the FMM offers a potential reduction of nearly 2 man-years of maintenance fleet wide.

Table 6. Projected Total Annual Man-Hour Reduction for CPS Maintenance with FMM Implementation

Filter Type	Man-Hours of Maintenance per Year per Zone	Number of Zones in Fleet	Total Man-Hours of Maintenance for Fleet	Projected Man-Hours of Maintenance per Year per Zone ⁽¹⁾	Projected Total Man-Hours of Maintenance for Fleet ⁽¹⁾	Projected Total Man-Hour Reduction
LP HEPA Filters	4	124	496	0	0	496
CBR Filters ⁽²⁾	24	251	6024	18	4518	1506
NSIF ⁽³⁾	12	375	4500	6	2250	2250
Total Man-Hours for Entire Fleet per Year						4252
Total Man-Years for Entire Fleet per Year						2

Notes:

- (1) Proposed changes based on NSWCCD estimates. Actual man-hour and periodicity requirements must be verified through operational testing.
- (2) CBR potential man-hour reduction is based on an estimated total time reduction of 25%.
- (3) NSIF total reduction assumes maintenance may be performed bi-monthly with FMM.

In addition to the manpower savings that result from the reduced periodicity in the filter MRCs, the FMM has the potential to offer additional savings through the reduced load on CPS fan motors and prevention of prematurely loaded CBR filter sets. Approximately 10 CPS fan motors across the fleet must be rewound due to overloading as a result of overloaded filter sets at a cost of \$3700 per fan motor. Approximately one filter change-out per year occurs as a result of poor CPS filter maintenance. The FMM may play a role in preventing the damage to filters and eliminating the approximate \$143K to the fleet that results annually due to premature filter change-outs.

The FMM is currently in the development stage with plans for environmental testing in FY05 and shipboard testing in FY06. Once development and testing are complete, the FMM may be incorporated into the CPS design for new construction ships.

REDUCED MANNING THROUGH SHIPBOARD CPS AUTOMATION

The primary way in which manning can be reduced for Shipboard CPS is through the use of automation. Although this effort does little to alleviate the maintenance burden on the crew, the manpower required to monitor and control the CPS in a CBR threat environment is substantially reduced. While the operation of CPS under normal conditions does not require any direct action by the crew, functioning in a CBR environment requires a number of individuals to fill operational roles and provide direct communication with Damage Control Central (DCC). These tasks can be accomplished through the use of sensors, zone pressure control, and airlock control.

The FMM project is the first step toward developing and integrating a complete suite of sensors that inform DCC of the status of filter differential pressure, zone overpressure, CPS fan status, temperature and relative humidity in the inlet airstream and throughout the zone, pressure control valve (PCV) position, exhaust fan damper position, and zone boundary door open/close status among others. These critical parameters inform the Damage Control Assistant (DCA) of the operational status of CPS for each zone in a CBR environment. Any system casualty could put the lives of the crew at risk and thus the DCA must remain informed of the CPS status throughout an event. A network of sensors can provide instantaneous information regarding the status of CPS in each zone on the ship.

One of the most critical elements to successful operation of CPS during a CBR event is the integrity of the zone boundary. With all zone boundary doors and closures secured properly as indicated by the sensor suite, the DCA could adjust zone overpressure either through the CPS zone exhaust flow rate with a fan damper or the zone inlet flowrate through the use of a variable frequency drive (VFD) serving the supply fan.

In addition to normal boundary doors, each zone contains at least one CPS airlock. During an attack, personnel wearing IPE may exit the zone through the CPS airlocks. After exiting the airlock, personnel within the zone must wait for the airlock to be purged of contaminants by the clean air from the space. Another shipboard automation effort seeks to introduce a sensor system to monitor the purge time and control the doors and provide a system of green and red lights for personnel.

The CPS automation suite is a continuing effort by NSWCCD. Several of the individual components have reached various stages of development. The CPS automation suite could potentially offer a significant improvement over the current implementation of CPS aboard ship.

INCREASED FILTER LIFE THROUGH ELECTRICALLY ENHANCED PRE-FILTRATION

NSWDD leads the development of an electrically enhanced pre-filter built upon the existing bag pre-filter, making the unit capable of capturing a higher quantity of

particles without a significant increase in cost or differential pressure over the current design. The electric potential across the pre-filter attracts and captures more particles than the existing charge neutral pre-filter. A photo of a prototype of the electrically enhanced pre-filter is shown in Figure 11.

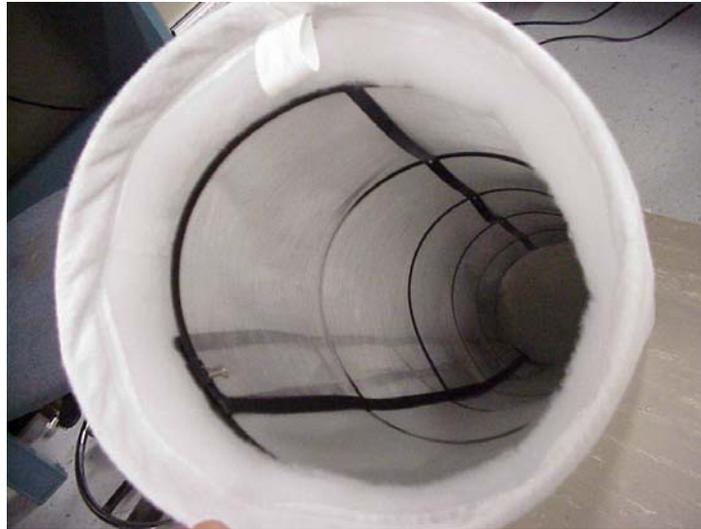


Figure 11. Electrically Enhanced Pre-Filter

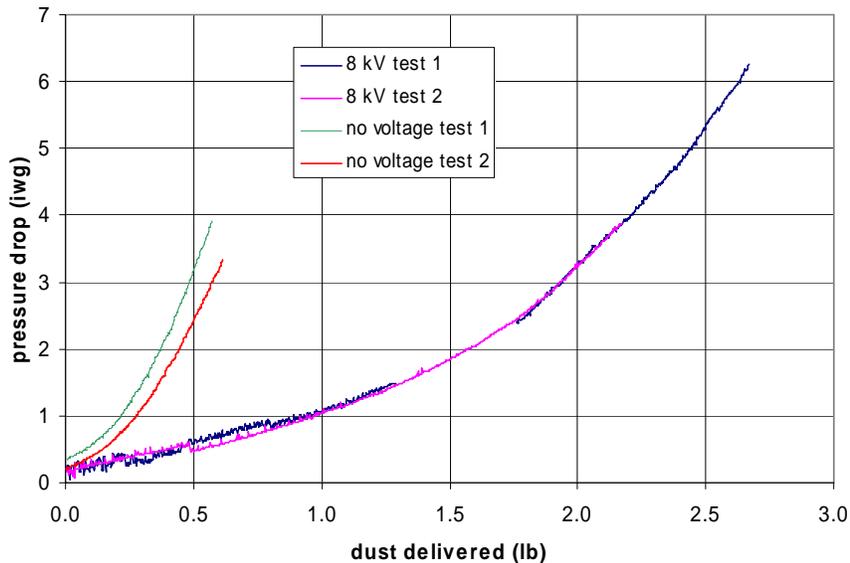


Figure 12. Dust Loading Differential Pressure Comparisons of Electrically Enhanced Pre-Filter

There are a number of benefits to this system with only a small impact on the ship. Preliminary design validation has shown the electrically enhanced pre-filter has a capacity that is four times the standard, non-enhanced pre-filter. Figure 12 shows the dust loading performance for the electrically enhanced pre-filter. As the differential pressure curves indicate, the significant increase in loading capacity for the electrically enhanced pre-filter presents no commensurate differential pressure increase. The low amperage for the pre-filter places no noticeable load on the electrical system of the ship;

the power required to operate the electrically enhanced pre-filters for an entire ship is less than one watt. Additionally, self-limiting power supplies have been incorporated in the design to prevent a high current draw to reduce the hazard posed by accidental contact of personnel conducting maintenance.

The increase in loading capacity translates to an increased pre-filter service life and thus a reduced change-out frequency. Although the electrically enhanced pre-filter has shown early promise to provide up to a four fold increase in service life in the laboratory, it is estimated that the filter will increase service life by three to four times in the operational environment. This increased capacity has been estimated to result in a change-out frequency of every eighteen to twenty-four months, as opposed to the current six to nine month periodicity.

The current cost of the bag pre-filter is approximately \$25 per unit for the Navy Standard Housing, which handles 600 CFM of air. Early cost estimates for the electrically enhanced pre-filter indicate a unit cost of approximately \$45, representing an increased procurement cost for pre-filters. However, the increased service life of the electrically enhanced pre-filter will reduce the change-out frequency, and thus reduce the annual procurement costs for CBR pre-filtration. Table 7 lists the annual procurement costs associated with the electrically enhanced pre-filter based on estimated service life and cost information.

Table 7. Projected Total Annual Procurement Cost Reduction for Bag CBR Pre-Filter and Electrically Enhanced CBR Pre-Filter

Pre-Filter	Number of CBR Filter Housings	Number of Change-Outs per Year	Pre-Filter Cost per Filter ⁽¹⁾	Total Cost Annually ⁽²⁾
Bag Pre-Filter	3266	1.6	\$25.00	\$130,640.00
Electrically Enhanced Pre-Filter	3266	0.6	\$45.00	\$88,182.00
Total Cost Savings				\$42,458.00

Notes:

- (1) Number of change-outs per year estimated based on projected service life.
- (2) Electrically enhanced pre-filter cost estimated based on prototype designs.
- (3) Based on average change-out periodicity under typically operating conditions.

Table 8. Projected Total Annual Man-Hour Reduction for Bag CBR Pre-Filter and Electrically Enhanced CBR Pre-Filter

Pre-Filter	Total Man-Hours per Change-Out for the Fleet	Number of Change-Outs per Year	Total Annual Man-Hours for the Fleet ⁽¹⁾
Bag Pre-Filter	956	1.6	1530
Electrically Enhanced Pre-Filter	956	0.6	574
Total Man-Hour Reduction for Fleet per Year			956
Total Man-Year Reduction for Fleet per Year			0.5

Notes:

- (1) Number of change-outs per year estimated based on projected service life.

With the man-hours required to execute the pre-filter maintenance task, this single maintenance item requires 241 man-days, or almost one man-year, to complete fleet-wide. By reducing frequency to every eighteen to twenty-four months, the maintenance required would lessen to 60 to 80 man-days fleet wide. This reduction, approximately three-quarters of a man-year, or 6-percent of the total CPS manpower requirement fleet-

wide, would have a significant impact on the CPS maintenance schedule and budget. Table 8 lists the annual ship's force labor required for pre-filter change-out.

The electrically enhanced pre-filter development continues and will begin long-term laboratory testing in FY05. Upon completion of testing and further development into a field ready system, the electrically enhanced pre-filter could be implemented into all current and new construction land-based and shipboard CPS applications.

INTENDED IMPACT ON CPS MAINTENANCE

Maintenance requirements for shipboard CPS have been scrutinized and significantly reduced since the introduction of the system aboard ships in the 1980s and this process continues today.

Some of the previously completed tasks have already resulted in a significant reduction of maintenance requirements for CPS. Initially, the CBR filters required yearly replacement, causing a great strain on ship's force. Research and development efforts on the filters and filter media along with development of the bag pre-filter have extended the filter service life.

The maintenance efforts described in this paper intend to reduce the time and manning requirements for CPS maintenance even further. These reductions are summarized in Table 9.

Table 9. Summary of Maintenance Impacts of Ongoing Efforts

Effort	Target	Current Maintenance	Projected Maintenance	Impact/Change
Filter Maintenance Monitor	Reduced Labor	Visually inspect gauges and record data in CPS logbook	Remote monitoring and recording (local inspection as required)	2.0 - 2.2 man-year and \$37K - \$143K savings across fleet
CPS Automation	Reduced Manning	Various Tasks Accomplished by Crewmembers in CBR Environment	Monitor and Control CPS in CBR Environment Remotely from DCC	Dependent upon Final Configuration
Electrically Enhanced Pre-Filter	Reduced Periodicity	Replace as required: typically every 6 months	Increase capacity 2 to 3X to typical replacement every 12 to 18 months	0.4 - 0.5 man-year and \$32K - \$57K savings across fleet

As this table shows, if these efforts are completed and implemented as planned, the potential impact upon shipboard CPS maintenance is significant: potentially, these efforts could reduce the manpower requirement of 7.6 man-years fleet-wide by approximately 2.4 to 2.7 man-years; a reduction of 31 to 36-percent. Additionally, a cost savings of \$32K to \$200K is also possible.

These efforts target the same goals that the US Navy is working toward: reduction of manning through an increase in product development and automation.

CONCLUSIONS

Shipboard CPS, serves as a primary line of protection against chemical, biological, and radiological weapons, and allows crews to operate effectively and safely in a contaminant-free environment. These systems integrate with a minimum impact on ship systems, creating a nearly transparent layer of protection.

The maintenance required to keep these systems operating, however, is less than transparent. Well-trained personnel are required to properly maintain these systems and keep CPS at peak readiness. Fleet-wide, the maintenance required accounts for approximately eight man-years of ship's force labor annually. Although this number is low in relation to the importance of this system, the development of new technology has been and will continue to be advanced and implemented by the CBR Defense community to further reduce the maintenance and manning requirements of CPS.

The NSWCDD and fellow organizations in the CBR Defense community are working to develop quality solutions that both enhance capabilities against new and emerging CBR threats while simultaneously reducing the maintenance and manning burden of deployed shipboard CPS. These efforts, including automation packages and enhanced filtration units, will serve to ease the maintenance requirements of shipboard CPS.

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