EVALUATION OF THIRTEEN SPILL RESPONSE TECHNOLOGIES

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, when improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory helps provide an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency; the granting of permits and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes assessment activities undertaken to evaluate and stimulate the manufacture and use of thirteen spill response prototypes, concepts, and devices. The information in this report is useful to those who develop, select, or evaluate equipment for cleanup of spills or waste sites or for the protection of response personnel and equipment.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
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CONTENTS

FIGURE

TABLE

ACKNOWLEDGEMENTS

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SECTION 1

INTRODUCTION

During the 1970's, considerable research was carried out by USEPA's Office of Research and Development (ORD) under the authority of the Clean Water Act (PL 92-500) to develop innovative technology to assist in the identification, control, and cleanup of spills of hazardous materials. Passage of more recent environmental laws such as the Resource Conservation and Recovery Act (RCRA) of 1976 and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 provided further incentive for the development of specialized techniques and equipment to assess, facilitate, and accomplish hazardous materials cleanups. In addition, 1982 amendments to the Patent and Trademark Laws (PL 96-517) to encourage licensing of Federally-owned inventions created an easier method by which private companies could make use of USEPA-developed devices that show practical potential.

The primary purpose of this study was to inform persons actively engaged in hazardous waste management of thirteen devices, concepts, or prototypes for detection, containment, and cleanup of hazardous chemicals that had been developed over the earlier period of about ten years under authority of the Clean Water Act with support of USEPA's Office of Research and Development. All of the systems had practical uses and some had been successfully demonstrated. Nevertheless, prior to the passage of more demanding environmental laws, none of the systems had elicited sufficient interest for commercial production to be undertaken. Therefore, a second objective was to conduct a limited assessment of the practical application of these systems within the context of current regulatory needs by documenting and analyzing comments by persons who examined either the item or the literature on the item.

The thirteen different devices, concepts, or prototypes capable of detecting, containing, or cleaning up hazardous substances and selected for this study were:

<u>Detection</u>

- Cholinesterase Antagonist Monitors (CAM-1 and CAM-4) - devices for detecting organophosphate or carbamate pesticides in water by the inhibition of cholinesterase enzyme activity.

- Hazardous Materials Identification Kit (HMIDK) - a portable test kit capable of analyzing for 36 hazardous organic and inorganic substances in the field.

- Insoluble Sinkers Detectors - two separate devices to detect and locate denser-than-water organic pollutants in the bottoms of rivers, ponds, lakes, and streams.

- Lactate Dehydrogenase Test Method (LDH) - a field screening test for detecting chlorinated hydrocarbons in water by the inhibition of lactate dehydrogenase enzyme activity.

- Oxidation/Reduction Field Test Kit - a device for identifying chemically-incompatible wastes in the field by measuring redox potentials.

- Particle Size Analyzer - a device that uses stop-action photography to measure the size of oil droplets in oil/brine mixtures.

Containment

- Leak Plugger System - a rifle-like device that injects polyurethane foam to plug leaks in tanks, drums, pipes, and other vessels.

- Foamed Concrete - quick-setting, rigid, non-porous concrete to be used by first responders to build self-supporting temporary dikes around spills.

- Vapor Control Coolants - the use of Dry Ice to inhibit the release to the atmosphere of toxic and/or flammable fumes from spilled volatile chemicals.

- Vapor Control Foams - surface foams to inhibit the release to the atmosphere of toxic and/or flammable fumes from spilled volatile chemicals.

Collection

- Capture and Containment Bag - a large polyethylene bag designed to be attached to or placed against leaking tanks, drums, pipes, etc. to collect leaking liquids.

- Emergency Collection System - a segmented 7,000-gal capacity polyurethane-coated bag with suction hose and pumping unit to collect liquid chemical spills.

- Sorbent Oil Recovery System - a mobile system to collect oil from the surface of lakes, streams, and rivers in open-celled, flotable polyurethane cubes that are then retrievable for recycle.

The approach used to inform potential users and manufacturers about the above-mentioned prototypes, devices, and concepts included presentations, publications in trade magazines, exhibits at conferences, mailings of USEPA project summaries and technical reports, and exchanges of information and comments by telephone. For eight of the thirteen items, one-page descriptions (see Appendix A) were developed because USEPA project summaries or reports were either not available or were too lengthy for the initial needs of the project. USEPA project summaries were distributed for the other five systems.

In addition to the review of the opinions of the participants in the study on the various devices, additional activities were conducted for several of them. These further activities included value engineering analyses on the CAM-4 and the emergency collection system; design, construction, and testing of the capture and containment bag; field testing of several prototypes by interested parties; and the development of a handbook on the vapor control foam concept.

Based on the interest exhibited by the respondents and review of their comments on the practicality of each system, an appraisal was made of the potential for practical application of each item.

SECTION 2

CONCLUSIONS

Thirteen prototypes, devices, or concepts were evaluated to determine their potentials for practical application. The evaluations were conducted by summarizing the comments offered by potential users and manufacturers after they were provided with information and/or had an opportunity to test a particular prototype, device, or concept. Of the thirteen items, five were determined to have immediate practical application in their present form; four were expected to have aplication after modification; the other four were found to have a low potential for practical application at the present time.

The five prototypes, devices, or concepts found to have immediate practical applications were: the oxidation/reduction field test kit; the particle size analyzer; the leak plugger; the vapor control foams; and the capture and containment bag. Of these, the capture and containment bags were subjected to the most extensive evaluation. On the basis of this evaluation, the manufacturer of prototype bags, B.F. Goodrich, concluded that the bags were "extremely viable" for spill response and would be an attractive product for some manufacturer if priced at $300 to $400 each.

The spill response systems expected to be practical after modifications were: the cholinesterase antagonist monitors (CAMs); the hazardous materials identification kit (HMIDK); vapor control coolants; and the emergency collection system. Review of the respondent's comments indicated that the CAMs needed increased sensitivity while the HMIDK required simplification for use by technicians in the field. The use of Dry Ice as a vapor suppressant was attractive, but sources of the coolant appeared to be a limiting factor for actual use. The emergency collection system requires changes in design and materials to reduce its cost.

The systems found to have low potential for practical application based on the responses of potential users and manufacturers included: the insoluble sinkers detectors; the lactate dehydrogenase (LDH) test method; foamed concrete; and the sorbent oil recovery system. These systems either duplicated existing hardware or had other disadvantages which made it unlikely that they would find use.

SECTION 3

RECOMMENDATIONS

Recommendations on some of the specific devices, concepts, or prototypes included in this study are presented below.

CAMs - Modify CAM-4 to respond to a lower detection limit.

HMIDK - Simplify the kit so that it can be used by technicians with minimal training. Also, reduce the cost of the kit and assure availability of replacement parts, preferably from a single manufacturer.

Particle Size Analyzer - Pursue work started by two private firms to replace manual photo-analysis with computer analysis of a photo-imaging display function.

Foamed Concrete - Modify the prototype generator to increase portability and reduce cost.

Vapor Control Foams - Publish the new handbook on foams, developed as a result of this study, and distribute it to spill responders.

Capture and Containment Bag - Make the results of this study available to small-to-medium manufacturing firms that may produce this equipment on a commercial scale.

Emergency Collection System - Modify the collection bag so that it is less costly or can be reused.

SECTION 4

METHODS AND RESULTS

The thirteen spill response prototypes, concepts, or devices selected for this program were subjected to a variety of assessment activities, including:

- Contacting selected potential users or manufacturers of the response systems to learn of their interest in one or more of the subject items;

- Providing information to the contacted groups and individuals by presentations, publications, mailings, exhibits, and phone calls; and

- Documenting and analyzing comments offered by the contacted groups and individuals on the items reviewed.

Table I lists the activities used to provide information to users and manufacturers for each technology.

The selection of initial contacts for the study was based on SAIC's knowledge of the manufacturers, research and development staff, experts, and special interest groups who would most be likely to have an interest in learning more about these prototypes, concepts, or devices and would have the experience and expertise to provide critical evaluations of the potential for application of the systems to actual field situations. Those who showed interest after their initial exposure to the information on the prototype, concept, or device were provided with more detailed information through mailings of one-page descriptions, or by being referred to the USEPA project summaries and technical reports. Those who wanted to examine or test certain items, such as the CAMs, the hazardous materials identification kit (HMIDK), or the capture and containment bag, were provided with the device on loan.

One page descriptions (with photographs) of the devices (see Appendix A) were developed for eight of the thirteen prototypes where brief documents were not available. Descriptions were not prepared for the insoluble sinkers detectors or the leak plugger because assessment activities were completed before the idea for these abbreviated summaries had been developed. The USEPA project summaries for the vapor control collants and the vapor control foams were sufficiently concise to serve the purposes of this project and were used instead of developing new one-page descriptions. The lactate dehydrogenase (LDH) test method was added to the program too late to develop a descriptive sheet; the existing project summary was used.

TABLE I. GENERAL ASSESSMENT ACTIVITIES FOR PROTOTYPES, CONCEPTS, OR DEVICES

	One-page descriptions	Project summaries or reports	HAZMAT '83 Conf.	Uncontrolled Hazardous Waste Site Conf. 1983	Presentation to Nat'l Fire Academy	Presentation to Nat'l Tank Truck Carriers, Inc.	Presentation to Assn. of American Railroads	Presentation to Amer. Petroleum Institute	Phone Contacts with users, manufacturers	Mail to Environment Canada for inclusion in technical review	Value Engineering Analysis	Publish in "Pollution Engineering"
Cholinesterase Antagonist Monitors	X	X	X	X					X	X	X	X
Hazardous Materials Identification Kit	X		X	X					X			
Insoluble Sinkers Detector		X							X			
Lactate Dehydrogenase Test Method		X							X			
Oxidation/Reduction Field Test Kit	X		X	X					X	X		X
Particle Size Analyzer	X	X	X				X	X	X	X		X
Foamed Concrete	X		X	X			X	X	X	X		X
Leak Plugger		X			X		X	X	X	X		
Vapor Control Coolants		X	X	X				X	X	X		X
Vapor Control Foams		X	X	X	X			X	X	X		X
Capture & Containment Bag	X		X	X	X	X	X		X	X		
Emergency Collection System	X		X	X	X	X	X	X	X	X	X	X
Sorbent Oil Recovery System	X		X						X	X		X

After presenting information on each prototype, concept, or device to a wide range of potential users and manufacturers, the authors received, reviewed, and analyzed the comments from all sources. Commentors who made significant contributions to the assessment of particular devices are listed in Appendix B.

Further assessment activities were conducted for the prototypes, concepts, or devices that received high interest. For example, the capture and containment bag was redesigned and fabricated by a major manufacturing company for field testing by five spill response groups. These additional activities were intended to encourage potential users and manufacturers to commercialize the spill response systems.

The following subsections describe the methods and summarize the results and analysis of the assessment activities for each prototype, including the additional activities that were conducted for a few. Presentation follows the order: detection, containment, and collection. Extensive description of the device is provided only where a one-page summary is not included in Appendix A.

CHOLINESTERASE ANTAGONIST MONITORS

The cholinesterase antagonist monitors (CAMs) were originally developed for the U.S. Army to detect nerve gases in the atmosphere. Later, they were modified to detect organophosphate and carbamate pesticides in water by Midwest Research Institute under contract to the USEPA [1,2]. Both a laboratory model (CAM-1), and a newer field model (CAM-4) capable of detecting 0.1 to 0.26 ppm depending on the pesticide, were developed. Both units operate by inhibiting enzyme activity. See Appendix A for a more complete description of these devices.

Assessment Activities for the CAMs

A number of industrial and governmental agencies expressed preliminary interest in the CAM devices for a wide range of uses, including monitoring of ground and drinking water quality (USEPA's Toxic Substances Division and the Drinking Water Research Division); tracing of pesticides (USEPA's Office of Pesticide Programs, USDA's National Monitoring and Residues Analysis Laboratory, U.S. Forest Service, Society of American Foresters, the Association of Consulting Foresters, and the Tennessee Valley Authority); and monitoring of industrial health and safety (NIOSH and OSHA).

The opinion was expressed that the high detection levels (i.e., low sensitivity) for tese devices preclude their use for drinking water monitoring and reduce their effectiveness as spill monitoring devices where detection in the low parts per billion level is needed. It was suggested by some of the reviewers that these devices may be useful for monitoring pesticide overspray during application and for spills in waterways, where higher concentrations may be expected.

A value engineering analysis on both the CAMs by a subcontractor, B&M Technologies Service, Inc., concluded that while the CAM-1 is obsolete, the CAM-4, with a few modifications, is a well-built, cost-effective analytical instrument that compares favorably with other commercial monitoring instruments in cost, ease of manufacture, and expected serviceability (see Appendix C). On the basis of these observations and further discussion with Midwest Research Institute, all further study was limited to the CAM-4 device.

Potential for Practical Application of the CAM

Based on a consensus of opinions expressed by the reviewers, there is a moderate level of interest among potential users and manufacturers for the application of the CAM instruments. The major limitations of these devices are their relatively poor sensitivity, their limited quantitative abilities, and the short shelf-life of their pads and reagents. In addition, most government agencies judged that the frequency of use of the devices would not benefit from the reduced cost/analysis offered while other commercial instruments met their lower detection limit requirements. The potential for CAM-1 is further inhibited by its outmoded circuitry. Based on the comments offered, if the detection level of the CAM could be lowered to the low to middle parts per billion range without a substantial increase in unit cost, these devices would be in high demand among most of the groups contacted during this study.

HAZARDOUS MATERIALS IDENTIFICATION KIT

In 1978, the USEPA and the U.S. Army Chemical Systems Laboratory (CSL) developed a kit to test for water quality indicator parameters that could detect (not necessarily identify) the presence of hazardous materials in water [3]. Under an interagency agreement between the USEPA and the U.S. Army, a hazardous materials identification kit (HMIDK) was subsequently developed [4]. The kit, capable of identifying 36 hazardous substances in water and soil, is described in more detail in Appendix A.

Assessment Activities for the HMIDK

Attendees at the HAZMAT '83 Conference expressed considerable interest in the HMIDK and 50 requests for more information were received. However, after receiving additional literature and a letter offering a possible loan of a kit, none of the recipients showed further interest. Mailing of the one-page description of the HMIDK to spill response/cleanup organizations resulted in limited response. Military representatives expressed interest in the kit for field identification of pesticides and chemical warfare agents. Other comments from recipients of information indicated that the kit was too complex for field use by relatively unskilled technicians, did not analyze a sufficiently wide range of compounds, required frequent use to assure proficient operation and reliability of the reagents, and, in general, was too costly. Repackaging of the reagents in vials and providing assurance that all replacement reagents could be obtained from a single source, rather than requiring a series of vendors or manufacturers, were suggested as modifications that would make the kit more attractive.

Potential for Practical Application of the HMIDK

The hazardous materials identification kit has a moderate potential for application if its cost and complexity can be reduced. Because there presently is a strong demand for chemical identification kits, some markets may exist for the kit in its current form among well-funded groups with good chemical backgrounds. Potential markets include the U.S. Army and Navy, spill response organizations, and government agencies involved in spill response and enforcement. No potential manufacturers were identified in this study.

INSOLUBLE SINKERS DETECTORS

The insoluble sinkers detectors are two separate devices developed by Rockwell International Corporation, under contract to the USEPA [5], to detect the presence of denser-than-water chemical pools or globules in lakes, rivers, and streams. One of the detectors is designed to be anchored to the bottom of a watercourse. When a heavy organic chemical such as carbon tetrachloride contacts the device, a large drop in conductivity occurs and activates a radio transmitter to an on-shore receiver that in turn activates the recorder, an alarm system, or both.

The other insoluble sinkers detector consists of a mapping system based on the principles of underwater acoustics. United States Patents 4,410,966 and 4,507,762 on the device have been assigned to the USEPA. This system, which functions by measuring the reflection of emitted sound waves from the bottom of a watercourse, can detect an insoluble layer as little as one centimeter in thickness by the difference in echo patterns. Currently, the echoes are measured by oscilloscope.

Potential for Practical Application of the Insoluble Sinkers Detectors

Soon after the beginning of this study, both of these prototypes were eliminated from further assessment activities when it was determined that neither had a high probability of becoming available for use. The conductivity-based unit was never developed beyond the bench scale and Rockwell International advised SAIC that a private company had subsequently developed, patented, and was selling a device similar but superior to the acoustic device at lower cost. The commercial device is an upgraded "fish finder."

LACTATE DEHYDROGENASE TEST METHOD FOR DETECTING CHLORINATED HYDROCARBONS

The lactate dehydrogenase (LDH) test method was developed as an easy and rapid assay for chlorinated hydrocarbons in water. It can be used for field screening, compliance testing, and for meeting emergency response needs [6]. The test, based on the oxidation of nicotinamide adenine dinucleotide in the presence of inhibited lactate dehydrogenase enzyme, can be monitored by the change in pH. It is sensitive to most classes of high molecular weight chlorinated hydrocarbons but will not detect low molecular weight compounds such as trichloroethylene and carbon tetrachloride. Interfering compounds include cyanide, heavy metals, alkylating agents, and other hydrocarbons.

Assessment Activities for the LDH Test

Potential users and manufacturers of the LDH test identified several existing methods that provide better ways to detect chlorinated hydrocarbons, including other enzyme tests and gas chromatography. It was noted that false negatives are possible because of the rather high detection limit (500 to 1000 ppb) and that interfering agents frequently encountered in common waste waters could produce false positives.

While some commentors felt that the detection limits, sensitivity, and uniqueness of the test were good, an approximately equal number of respondents suggested that sensitivity (detection limit) needed to be increased by as much as two orders of magnitude. One potential manufacturer believed that increasing sensitivity would also reduce interference by heavy metals and alkylating agents. While comments on expected cost were few, one potential manufacturer estimated that a kit containing 20 tests should cost between $75 and $150 per test. Respondents felt that the test could be used to screen industrial influent and effluent waters, various hazardous wastes, and chlorinated municipal water supplies, as well as to screen for PCBs and chlordane in emergency situations.

Several modifications were suggested for the test. These included extending the shelf life by packaging the reagents in sealed samples and including blanks and standards with the test to assure its reliability. One reviewer suggested that evaporation of water from the samples would concentrate the chlorinated compound and allow improved sensitivity. Another recommended the use of an air impinger and inclusion of a pH test liquid to broaden the scope of the test to include oils and soils.

Potential for Practical Application of the LDH Test Method

For the test to be useful at the levels recomended for protection of aquatic life (1-3 ppb) or for protection of human health (less than 1 ppt), modification to function at much lower detection limits is required. In its current form, the test is only useful for analyzing for gross contamination, tracking and locating large spills, and determining the source of spills. On the basis of the comments offered, SAIC recommends that other available test methods be considered for field use.

OXIDATION/REDUCTION FIELD TEST KIT

The oxidation/reduction field test kit was developed under contract to the USEPA by Princeton Testing Laboratory [7] to assist in the rapid segregation of containers of strong oxidizing agents from containers of strong reducing agents when the identities of the materials are unknown. A one-page description of the technique and apparatus is given in Appendix A.

Assessment Activities for the Oxidation/Reduction Field Test Kit

Activities for the oxidation/reduction test kit resulted in high interest in the kit. Demonstration at the HAZMAT '83 Conference produced many comments that the kit had a high potential for practical application. The kit has been used successfully and with advantage during cleanup at several hazardous waste sites. While one potential problem noted was than an inexperienced operator could misclassify certain volatile, flammable organics (e.g., styrene and acrylonitrile) as oxidizers, thus creating a dangerous situation, another commented that it was unlikely that incompatible spills would occur in the same area simultaneously.

There was also considerable interest by potential manufacturers of the kit. One manufacturer has continued to request information on the kit and has produced and successfully tested six kits. This firm will soon produce and market the kits as dictated by the demand. Another manufacturer also agreed to manufacture the kit if the USEPA wrote a one-page description of the device listing all suppliers or evaluated a device provided by the manufacturer and included that evaluation in a USEPA bulleting or similar technology transfer medium. USEPA agreed to this request. A device manufactured by this firm was successfully tested and is now in production. A third manufacturer indicated they had developed an idea for a device, but plans for manufacture had not been made.

Potential for Practical Application of the Oxidation/Reduction Field Test Kit

The oxidation/reducton field test kit is presently available as a commercially manufactured item and has been used at several cleanups of uncontrolled hazardous waste sites. The kit continues to be specified in procurements for cleanup actions to avoid accidental mixing of incompatible materials.

PARTICLE SIZE ANALYZER

The particle size analyzer (PSA), developed by Rockwell International Corporation under contract to the USEPA [8] for use on off-shore oil platforms, can analyze the oil droplet size distribution in oil/brine and other oil/water mixtures. This provides valuable information when selecting or seeking to improve the operation of oil/water separators. See Appendix A for a more complete description of the analyzer.

Assessment Activities for the Particle Size Analyzer

Eight oil/water separator manufacturers showed a high degree of interest in the analyzer after reviewing the one-page description of the analyzer and further information was provided to all. After extensive discussion with SAIC, one firm is now interested in developing an improved particle size analyzer in collaboration with a major optical equipment company. The latter firm is attempting to adapt an image analyzing computer to the particle size analyzer, which will eliminate the need for a photographic technique and provide much faster analyses. This firm believes the particle size analyzer may have important medical applications as well.

Most respondents (potential users and manufacturers) agreed that the usefulness of the analyzer in research, in waste treatment, or for industrial processes was dependent on keeping the cost down or reducing it further. The representative of one major oil company expressed the opinion that no comparable instrument existed and that capital cost would not be a deterrent to use, while the need for a specially trained technician would be. This person also suggested that the PSA should be adapted to analyze mixtures under pressure since existing separators use pressurized systems.

Other commentors reiterated the need to reduce the cost of the equipment, particularly the photographic portion, and expressed concern over the need for a technically-oriented person to develop and analyze the photos. Nevertheless, the opinion was expressed that the PSA would be an excellent tool to use on a drilling platform as an aid in deciding when to take oil/water separators out of service.

Potential for Practical Application of the Particle Size Analyzer

The particle size analyzer has high potential for practical application, particularly if it can be improved to provide results more rapidly. Application in the medical profession would increase its potential further.

FOAMED CONCRETE

Rapidly setting foamed concrete was developed by MSA Research Corporation under a contract with the USEPA [9] to contain hazardous chemical spills by the rapid formation of a free-form dike or diversion structure. The technique is described in Appendix A.

Assessment Activities for Foamed Concrete

Definitive interest in the foamed concrete system was not indicated. A representative from a spill response company stated that a foamed concrete system would be very expensive, infrequently used, and, consequently, not justifiable.

Potential for Practical Application of Foamed Concrete

This prototype is relatively expensive and has a limited area of application. In addition, a less costly, more mobile, and commercially available polyurethane foam dike pack substantially reduces the market potential for the foamed concrete.

LEAK PLUGGER

The leak plugger was developed for the USEPA by Rockwell International Corporation [10] to temporarily stop leakage from punctured or slashed tanks or other containers. The prototype is a rifle-like device attached to a back-pack with canisters of the polyol and diisocyanate precursors of the urethane foam (Figure 1). The two foam ingredients are mixed in the chamber of the "rifle" and forced from the applicator tip to form a mushroom-like foam on both the inside and outside of the leaking container.

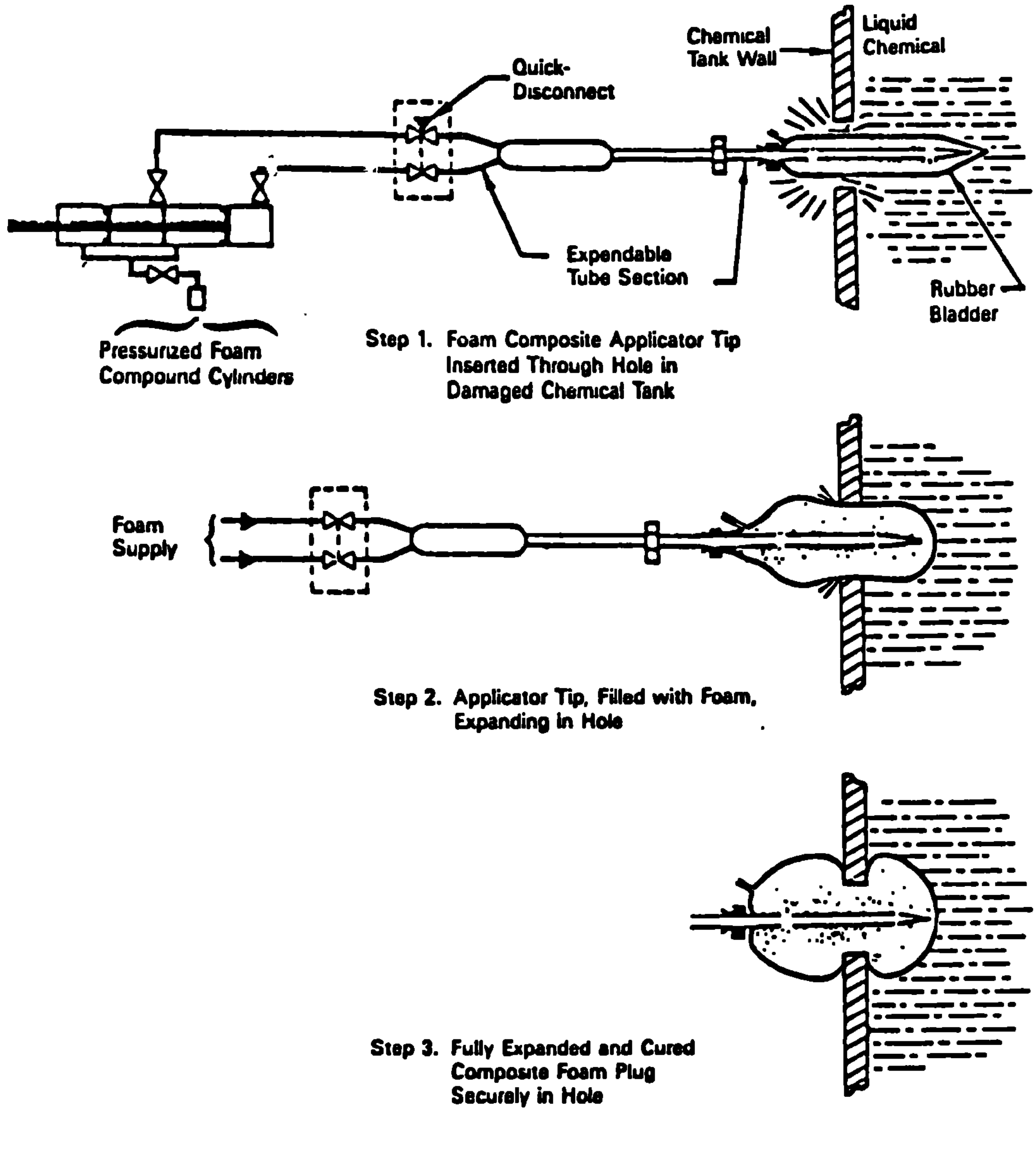

Figure 1. Action of the Leak Plugger.

Assessment Activities for the Leak Plugger

A number of comments were received regarding the leak plugger prototype. A potential manufacturer was interested in working with the USEPA to produce a leak plugger similar to the prototype but the proposed system was rejected by the agency as inferior to the prototype. During this study, SAIC was advised that Rockwell had developed and patented (U.S. Patent 4,329,132) an improved model of the plugger using styrofoam instead of polyurethane.

Representatives of the National Fire Academy did not believe that fire companies could justify the leak plugger because of its high cost, short shelf life (approximately one year) and anticipated infrequent use. On the other hand, representatives of the Association of American Railroads felt the device could be useful in controlling small leaks at train derailments or in switching yards. Oil company representatives thought the unit would be useful to fire companies and cleanup contractors.

Potential for Practical Application of the Leak Plugger

A modified leak plugger currently is being used by U.S. Coast Guard Strike Team divers to plug leaks in boats and prevent sinking. However, because of the high price, low shelf life (about two years), and the special equipment needed to refill it, even the modified plugger has only a moderate potential for practical applications.

VAPOR CONTROL COOLANTS

This concept was developed by MSA Research Corporation with support from the USEPA. The report [11] describes the successful control of vapors from spilled hazardous liquids, but the technique for distributing Dry Ice over a spill area is not efficient.

Assessment Activities for Vapor Control Coolants

Limited interest resulted in comments that the approach seems to be of no practical use for general response preparedness and planning, nor for discrete spills.

Communication with a Dry Ice equipment manufacturer revealed that Dry Ice is not used widely nor in large quantities in most industries and would not normally be available in proximity to spilled volatile chemicals. A representative of the Compressed Gas Association pointed out that liquid carbon dioxide is more widely used and that a machine is available for conversion of liquid carbon dioxide to a spray of solid carbon dioxide snow. This machine, used to cool non-refrigerated railroad cars, could possibly be available for use on spilled volatile liquids. However, modifications would be necessary to increase the throw range to more than the 20 feet now achievable.

Potential for Practical Application of Vapor Control Coolants

Vapor control coolants have a low potential for practical application. Few industrial plants meet the criteria of storing hazardous volatile liquids and having large quantities of Dry Ice available to make this concept practical. Both logistics and equipment issues would need to be resolved before the use of liquid carbon dioxide in a snow conversion machine could become practical for controlling hazardous vapors.

VAPOR CONTROL FOAMS

The vapor control foams concept was developed by MSA Research Corporation (MSAR) under contract to the USEPA [12] by testing the ability of various commercial firefighting foams to suppress vapors from 17 different volatile liquids. Based on these tests and a review of the literature, MSAR developed a table indicating the proper foam types to use for controlling vapors from spills of 36 volatile materials. The USEPA also has prepared a motion picture film of tests conducted by MSAR.

It should be noted that the technology for vapor control foams is expanding rapidly, ranging from reducing volatilization of toxicants at a spill site to preventing and suppressing fires from spills of highly explosive fuels. Foams vary greatly in their chemical makeup, compatibility with spilled compounds, quarter-drainage times, expansion ratios, and methods of application.

Assessment Activities for Vapor Control Foams

The National Fire Academy is now training firefighters on the use of foams for vapor control. Part of this training involves viewing of the USEPA film. Based on activities at the HAZMAT '83 Conference, an instructor for a commercial course on oil and hazardous materials spills also promoted the use of the film and several fire companies requested information about manuals on the use of foams.

Contacts at Hill Air Force Base revealed that MSAR, under a U.S. Air Force contract [13], has developed a portable foam vapor suppression system for responding to spills of hydrazine and nitrogen tetroxide using foams mixed with either a polyacrylic additive (for hydrazine) or a pectin additive (for nitrogen tetroxide). This system, also equipped with a pump and bag system for collection of spilled material, will be available during the downloading of Titan missiles.

A presentation to the American Petroleum Institute resulted in comments that the MSAR report contained information useful in preplanning response activities and procedures. However, it was also noted that assuring availability of the correct foam would be a logistics problem.

After review of the USEPA report by MSAR, the use of vapor control foams is being considered (November 1985) for recommendation by the ASTM. Also, as a result of reading the report, the Ohio State Fire Marshal offered test burn pits and firefighters for further testing by USEPA. In his opinion, the report contains information that would be useful in the training courses that Ohio provides to some 12,000 firefighters.

Potential for Practical Application of Vapor Control Foams

Since the initial USEPA report on foams for vapor control, use of this technology has grown immensely and is currently widespread. The USEPA will soon provide a handbook on the selection and use of foams for vapor control [14].

CAPTURE AND CONTAINMENT BAG

The capture and containment bag was first developed by MSA Research Corporation under a contract with the USEPA [15] to collect spills from ruptured tanktrucks and railroad cars. Appendix A presents a one-page description of the equipment and its use.

Assessment Activities for the Capture and Containment Bag

The initial assessment activities for the bag system generated considerable interest, most of which was overwhelmingly positive. Based on this reaction, the USEPA sought a manufacturing firm to produce additional bags for field testing by potential users. (All the bags fabricated in the original study had been destroyed during testing to failure.) A competitive procurement sent to 11 manufacturers resulted in 3 proposals (even though the financial incentive was only $2500 to produce at least 5 bags). Award was made to B.F. Goodrich Company, who proposed a 1000-gal capacity polyethylene bag weighing about 25 lbs and fitted with a 30-ft long, 4-in. diameter transfer tube.

Approximately thirty firms had expressed an interest in field testing the bags. Of the thirty, twelve submitted proposals describing tests they would perform on bags loaned to them. Proposals were accepted for the specific testing noted from five organizations:

- Association of American Railroads
    - Leaking bottom outlet in the center of a tank car (wild car)
    - Puncture leak in the lower end of a tank car (typically caused by the linkage knuckle of a trailing car)
    - Dome leak on an overturned tank car
    - Leaking locomotive fuel tank.

- Fairfax County Fire Department
  - Tank truck leak
  - Tank car gash
  - Leak on a grassy slope.
- Houston Fire Department
  - Collection of wastewater from a safety shower
  - Gash in tank car
  - Dome leak on tank truck
  - Wild car leak
  - Leak on roadway
  - Leak in grassy ditch
  - Leak from stationary tanks
  - Pressurized valve flange leaks.
- Spill Recovery of Indiana, Inc.
  - Leaking drop valve on an upright tank in a flat grassy area, onto a flat paved area, and near a ditch
  - Exposure of a bag to sub-freezing temperatures
  - Leaking drums.
- Texas A&M University, Engineering Extension Service
  - Repetitive filling on a flat concrete surface
  - Other tests proposed but not completed.

A total of approximately 250 individuals from fire and police departments, privatre manufacturing and spill response firms, and state and federal agencies conducted or observed the various tests. Of these, about 72% believed that the bag is a feasible method for responding to spills.

Encouraged by the positive results of the bag tests, by the interest in them, and by the numerous suggestions offered for improvement of the prototype, B.F. Goodrich performed a market research study at its own cost to determine whether the bag should be commercialized. Analysis of comments solicited from fire chiefs, state fire marshals, chemical manufacturers, and cleanup contractors in this survey indicated that 66% of the 63 respondents (out of 439 contacted) felt the bag had some potential. The observed 6% of weepage rate over 24 hours was not considered excessive by 85% of the respondents. Half of those providing expected cost information were willing to pay over $200 and 28% were willing to pay over $400.

B.F. Goodrich concluded that the bag concept, with bags priced at $300 to $400 each, was "extremely viable" but that the weepage would have to be eliminated in a final design. The company's investigators also pointed out that compatibility with the spilled material could not be overlooked when using the bag. Ultimately, Goodrich decided that fabrication was best accomplished by another company where the liability/benefit ratio would be more attractive.

Potential for Practical Application of the Capture and Containment Bag

The capture and containment bag received more interest than any of the other prototypes. Most of the comments were positive and indicated the bag would fill a real need in the trucking industry, in the railroad industry, for firefighting, and in private and government spill response.

EMERGENCY COLLECTION SYSTEM

The emergency collection system was developed for the USEPA under contract by MSA Research Corporation [16] for the collection and temporary containment of hazardous and non-hazardous land spills. A more complete one-page description of the system is given in Appendix A.

Assessment Activities for the Emergency Collection System

Little interest was expressed by potential users for this prototype, even after mailing the one-page description and exhibiting the device at the HAZMAT '83 Conference. In spite of this low level of interest, it was learned that a similar system was being built for the U.S. Air Force to collect potential propellant spills during downloading of Titan missiles.

The National Fire Academy commented that the estimated minimum cost of $9000 for the system was too high for use by fire departments. Others commented that the use of pillow bags with portable pumps and hoses was much more cost-effective.

A value engineering analysis concluded that the application potential was uncertain and that "additional design research to meet commercially acceptable criteria of cost, manufacturability, and desired field performance" was needed (Appendix C).

Potential for Practical Application of the Emergency Collection System

Aside from the interest by the U.S. Air Force, the emergency collection system currently is not of high interest. Although it offers quick response capabilities for spilled liquids, the high cost of the disposable bag discouraged most potential users.

SORBENT OIL RECOVERY SYSTEM

The sorbent oil recovery system was developed under a USEPA contract to Seaward International, Inc. [17]. The device distributes polyurethane cubes over floating oil spills. The oil-saturated cubes are then recovered, squeezed free of oil, and reused. A more complete description of the system is provided in Appendix A.

Assessment Activities for the Sorbent Oil Recovery System

A representative of Seaward confirmed the opinions of other respondents that recovery of the oil-saturated cubes was inefficient and that the weight of the system was too great. Others commented that superior equipment was already on the market and that most spills occur on rivers that are too wide for the sorbent oil recovery system. Nevertheless, as a result of a presentation to the American Petroleum Institute, a German researcher sought information, believing that the cubes could be effective (and less of a problem when washed ashore) when storms delayed the cleanup of oil spills.

Potential for Practical Application of the Sorbent Oil Recovery System

There appears to be little current interest in this system in its present form. Undefined improvements would be needed to transform the system into a competitive prototype.

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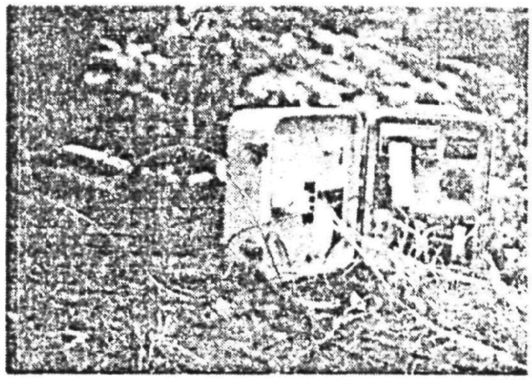
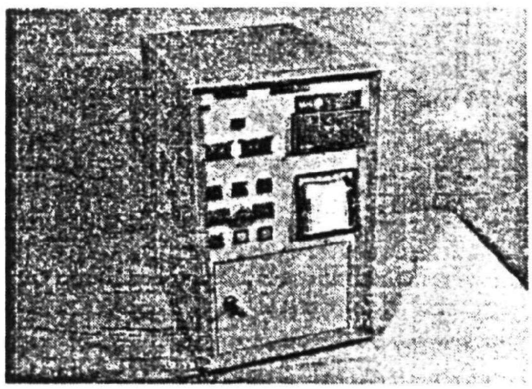
APPENDIX A

ONE-PAGE DESCRIPTIONS OF SPILL RESPONSE PROTOTYPES, CONCEPTS, OR DEVICES

Pesticide Detection Devices

Description: Aqueous organophosphates and carbamate pesticides can be detected in the parts-per-million range using either of two devices called cholinesterase antagonist monitors (CAM's). One of these devices is designed for the laboratory (CAM I) and the other is designed with more rugged construction for use in the field (CAM IV). Both work on the same principal: water is pumped through a special 3/4-inch pad impregnated with a cholinesterase enzyme such that the enzyme cannot be swept from the pad; electrodes on each side of the pad measure increases in voltage which occur only when organophosphate and/or carbamate pesticides are in the water. Any increasesin the measured voltage across the pad are directly proportional to the concentrations of the pesticides in the water. In addition, the laboratory model (CAM I) is coupled to an alarm system which can be set manually at the desired monitoring level. The field model is equipped with a strip chart recorder. The enzyme pads are reusable over numerous samples provided there are no organophosphate or carbamate pesticides present in the samples.

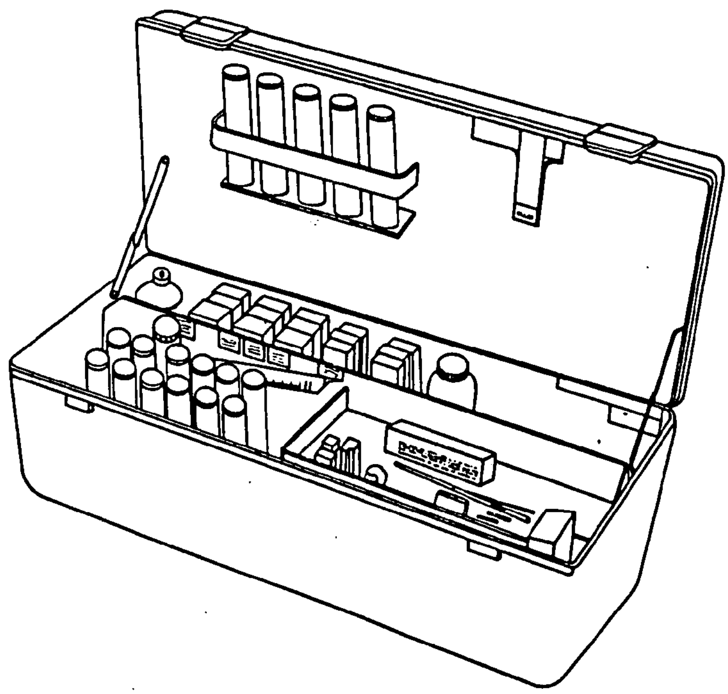




Practical Applications: CAM I is ideally suited for use at pre-outfall stations throughout a pesticide manufacturing facility. In the event of a spill or a malfunctioning treatment unit, CAM I can sound an alarm and even actuate automatic flow control systems. Water treatment and distribution plants can use CAM I as an early warning system at intake pipes to detect organophosphate and carbamate pesticides. CAM IV can be used by pollution control officials to track pesticide spills and to assess the danger of such spills to downstream sources of drinking water. CAM IV can also be used to quickly determine levels of pesticides in industry discharge pipes.

Availability: Free information on CAM I and CAM IV is available by contacting Mark Evans at JRB Associates, (703) 734-4381. Call collect for full reports on each of these devices, including field and laboratory test results, drawings, and complete parts lists needed to build these devices.

Hazardous Materials Identification Kit



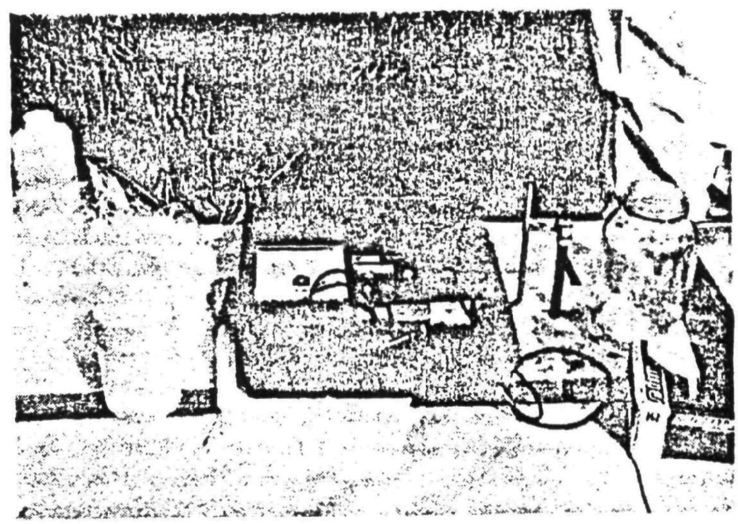
During the response to hazardous chemical spills and uncontrolled hazardous waste sites, the identity of contaminants is often unknown. Compact, portable analytical equipment for rapid pollutant identification is critical to effect efficient emergency response activities. However, nearly 300 materials are classified as hazardous substances by EPA (Federal Register, 16 February 1979), and a field kit capable of rapidly and accurately identifying each of these substances would be too unwieldly to be practical. Thus, thirty-six representative hazardous materials (toxic metals, anions, organic compounds) were selected and a field kit was designed to identify these and related substances (IAG-D6-0096).

The identification (ID) kit consists of two major components: (1) an inverter/shortwave UV lamp unit for photochemical and thermal reactions and (2) a package with reagents and auxiliary equipment, including test papers, detector tubes, spray reagents, spot test supplies, and thin-layer chromatography apparatus. Equipment to facilitate the recovery of contaminants from water and soil is also included. The field identification kit contains detailed operating instructions and data cards for each of the 36 representative hazardous substances.

Identification of groups of contaminants, rather than quantification of specific substances, is the intended use of the identification kit. The ID kit can be used in conjunction with the Hazardous Materials Detection Kit, which contains a pH meter, spectrophotometer, conductivity meter, and other analytical equipment. Utilization of both kits can improve identification capability, particularly for inorganic materials. For example, cyanide and fluoride cannot be distinguished by the ID kit alone; however, when the kits are used concurrently, identification becomes possible.

Oxidation Reduction Field Test Kit

Description: It's a very simple device; simple to use and simple to assemble. Just obtain a portable pH meter capable of measuring electromotive force in millivolts and prepare test solutions of 0.001N ferrous ammonium sulfate and 0.001N potassium dichromate. Test material is measured into plastic beakers containing the test solutions; the readings taken on these solutions determine whether the test material is an oxidizer, a reducer, or neither.

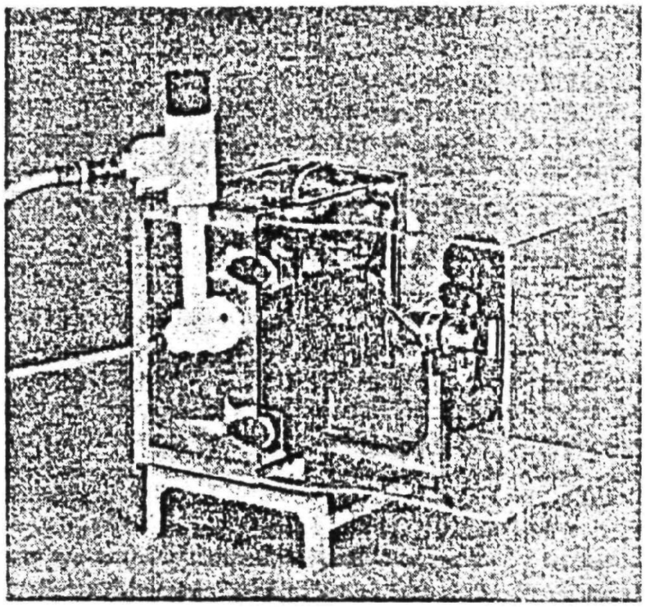


Practical Application: Particularly useful for state agencies, this simple device has been used at several uncontrolled hazardous waste sites for separating potentially reactive drummed wastes. By segregating oxidizing wastes from reducing wastes, clean-up personnel can be protected from the violent explosions and reactions that can result from mixing incompatible chemicals. The technicians that have used this device often had minimal previous training with analytical equipment or with the handling of hazardous wastes. In every case, however, the drums were segregated quickly (2-5 minutes/drum), efficiently, and with no injury or dangerous incidents.

Availability: You can make it yourself. All we want are your comments. For more free information and instructions, please contact Mark Evans at JRB Associates, (703) 734-4381. Call collect.

Particle Size Analyzer

Description: Developed for use on off-shore oil platforms, this portable (32 pounds) automated apparatus applies time-lapse photomicroscopy to determine the number, size, and density of spherical entities in semi-transparent fluid matrices. The device can analyze the oil drop size distribution in oil-brine and other oil-water mixtures to provide valuable information in selecting or improving the performance of oil separation equipment or in developing new oil separation systems. Oil-brine can be diverted directly from a flow stream with a common 5/8" garden hose and fed into the system through a pressure-reducing standpipe. The fluid then passes into a flow-through cell where it is photographed through a microscope at designated intervals.

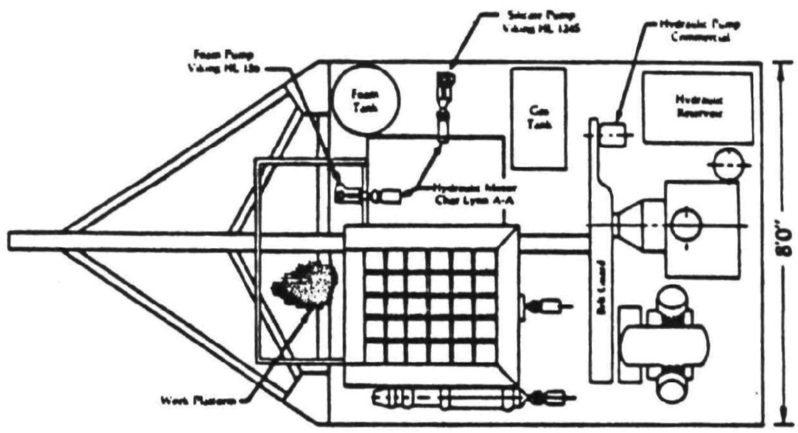


A solenoid valve interrupts the flow for a brief moment during photographing as a strobe and reflecting assembly provide electronic flash illumination to facilitate "stop-action" photography. By comparing photographs taken at known time intervals, the diameter, distribution, and rise rate of oil drops in the fluid can be ascertained and their densities determined by applying Stokes Law.

Practical Application: Because of the system's unique flow-through cell and horizontal viewing axis, it can measure the diameter of particles in the 2 to 100 micrometer range under flowing conditions, and without introducing significant shear forces which can adversely affect the oil-drop population. Unlike conventional methods for characterizing particle size distribution, this system is capable of measuring the density of the photographed objects as well as their size. Thus the system can differentiate between oil drops, gas bubbles, and sand grains or other foreign materials such as shell fragments. Although developed for off-shore oil production, the system is also applicable to on-shore production. In fact, it can be used to characterize the size and distribution of any immiscible substance in a semi-transparent fluid matrix. It is designed to be safely operated in explosive atmospheres, meeting all N.E.C. Class 1, Division 1, Group D Requirements for operation where explosive concentrations of hydrocarbons are known to exist.

Availability: For additional information on this device, please contact Mark Evans at JRB Associates, (703) 734-4381. Call collect. Comments or ideas on the practical utility of this device are encouraged.

Foamed Concrete



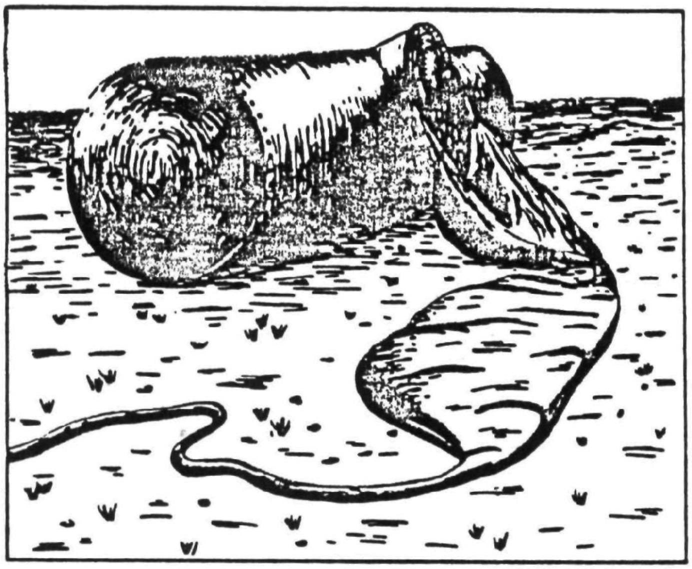
Field Unit

Description: Hazardous chemical spills can be controlled rapidly through the installation of free-form dikes and flow diversion structures composed of quick-setting foamed concrete. Foamed concrete has a density of about 40 pounds per cubic foot and sets up extremely fast (2-3 seconds). The result is a gelled structure with sufficient strength to build self-supporting dikes over 2 feet in height. The initial gel set is capable of impounding liquids immediately after being placed. Once set, it forms a rigid, non-porous, chemically resistant barrier. The equipment and raw materials required for applying foamed concrete are simple and are commercially available. Needed are cement, water, sodium-silicate solution, concentrated foam, a mixer for blending a cement-water slurry, a slurry pump, a preformed foam generator, a storage tank, and a nozzle. These materials can be trailer-mounted and are suitable for a pick-up truck operation. The types of substrate present at a site are not a critical factor; tests on clay, shale, chipped limestone, grass, and weed-covered ground have been successful. In addition, such chemicals as methanol, 1,1,1-trichloroethane, phenol, acetone cyanhydrin and acrylonitrile do not affect the gel set action.

Practical Application: Foamed concrete is particularly useful to Federal and state chemical spill response teams, spill clean-up contractors, truck lines, railroads, and fire companies. Costly clean-ups can be avoided, and environmental damage caused by spilled chemicals can be kept to a minimum.

Availability: For additional information, please contact Mark Evans at JRB Associates, (703) 734-4381. Call collect. Comments or ideas on the practical utility of this device are encouraged.

Capture and Containment Bag

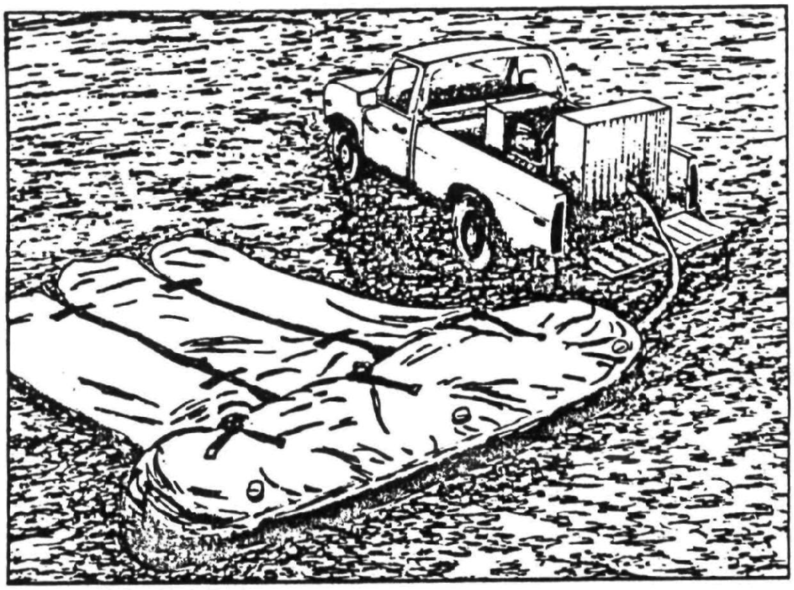


Description: Here is a simple and practical method for capturing and containing hazardous and non-hazardous spills from ruptured tank trucks and railroad cars. It is a double-walled containment bag made of two types of polyethylene, one inside of the other. The inner material is clear with a heat-sealed seam and the other material is fiber-reinforced with a sewn seam. The dimensions of the bag are approximately 20 feet long by 8 feet wide with a 10-foot wide apron at one end and a transfer tube approximately 30 feet long by 4 inches in diameter at the other end. The bag weighs approximately 16 pounds and can be stored in less than 2 cubic feet of space. Long tie lines attached to the apron of the bag allow it to be positioned for a large variety of leak configurations. The transfer tube at the bottom of the bag enables the captured liquid to be transferred to secondary containment. During field tests, the bag was used to collect over 1,000 gallons of liquid from a leaking tank car without any leakage. The polyethylene material was also demonstrated as a suitable barrier for fabricating emergency holding ponds.

Practical Applications: The capture and containment bag is a simple and practical first-response device for controlling spills resulting from bulk transport accidents. It is an excellent on-board tool for emergency spill containment in tank trucks and rail tankers and is also ideally suited for use by State and local emergency response teams. The unit is lightweight, easy to store, and inexpensive ($50 to $200/bag) depending on production rates (1981 estimates).

Availability: Prototype bags may soon be available on a free-loan basis to selected interested parties. All we want are your comments. For more free information and instructions, please contact Mark Evans at JRB Associates, (703) 734-4381.

Emergency Collection System



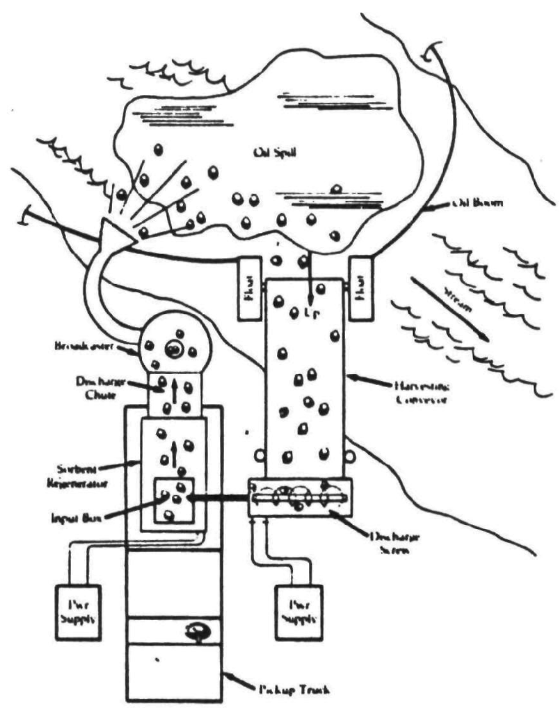
Description: A prepackaged pumping and storage system has been proven effective for the collection and temporary containment of hazardous and non-hazardous land spills. The system features a series of urethane-coated bags into which spilled materials are pumped for temporary storage. In addition to the collection bags, the system consists of a gasoline-powered pumping unit and 30m (100 ft) of suction hose mounted on a reinforced aluminum pallet for easy transport on a pick-up truck. The bag unit has a total capacity of 26,500 l (7,000 gal) and consists of three cylindrical bags fed by a header bag which stabilizes the system on sloping ground. At a spill site, quick release of the bag unit is accomplished through a special bag housing made of corrugated aluminum. Once the bag is deployed and unfolded, the quick-disconnect fittings are used to attach the hoses and pump. The pump fills the header bag which serves as a manifold to evenly fill the other three bags. If applied to a tank truck leak, it is possible to modify the system so that hoses can be connected simultaneously to the tank itself and to liquid on the ground.

Practical Applications: The pump and bag system can be used to collect accidental spills which occur during transport of hazardous materials or at industrial sites. The speed of the pump and bag collection system can significantly lower the high clean-up costs that often result from accidental chemical spills that pollute soils, groundwater, and surface waters. Because it fits readily on a pick-up truck, a van, or dual-wheeled railroad vehicles, this system can be easily transported to a spill site making it ideal for use by professional spill response teams in both the private and public sectors. The entire packed system is only 4 feet by 4 feet and a single tankful of fuel will provide up to two hours of pumping time.

Availability: For more information, including a full report on this device, please contact Mark Evans at JRB Associates (703) 734-4381.

Sorbent Oil Recovery System

Description: Avoid wasted time and increase efficiency during oil spill clean-ups with a sorbent distribution and recovery system. The device uses a pneumatic broadcaster to distribute open-celled polyurethane cubes over floating oil spills. The saturated sorbent is then harvested from the water through an inclined, open-wire mesh conveyor, and oily water is squeezed from the sorbent in a converging belt press or regenerator. Once regenerated, the uniformly-designed cubes (2/3" per side) can be reapplied to the spilled oil. Tests of this system have been conducted using spilled diesel fuel and lubricating oils at boat speeds ranging up to 5 knots in both calm and rough water. Oil has been collected at rates of up to 10.5 cubic meters per hour, and the oil content of the recovered liquids has varied from 38 to 79 percent.



Sorbent Oil Recovery System
Deployed at a Stream

Practical Application: This system is useful for the recovery of spilled oil from the surface of river, estuarine, and harbor waters, particularly because it is less sensitive to wave and current action than conventional oil spill clean-up equipment. In addition, the use of this device significantly reduces supply and disposal problems associated with other sorbent clean-up techniques because the sorbent cubes can be reused both at the spill site and at more than one spill. The system is highly mobile and can be transported in two pick-up trucks. It is also operable from vessels or from a combination of one or more small boats, a dock, or the shore.

Availability: You can build it yourself with off-the-shelf components. All we want are your comments. For more free information and instructions, please contact Mark Evans at JRB Associates, (703) 734-4381.

APPENDIX B

CONTRIBUTORS TO ASSESSMENT ACTIVITIES ON SPILL RESPONSE SYSTEMS

On the following pages are tabulated the names, affiliations, and locations of the persons who assisted SAIC in this study by providing information or comments on specific technologies. The technologies are identified for each contributor in the Table by the code numbers indicated.

Code No.	Technology
1	CAM-1 and CAM-4
2	HMIDK
3	Insoluble Sinkers Detectors
4	LDH
5	Redox Monitor
6	Particle Size Analyzer
7	Foamed Concrete Dike
8	Leak Plugger
9	Vapor Control Coolants
10	Vapor Control Foams
11	Capture & Containment Bag
12	Emergency Collection Bag
13	Sorbent Oil Recovery System

APPENDIX B. CONTRIBUTORS TO ASSESSMENT ACTIVITIES ON SPILL RESPONSE SYSTEMS

CONTRIBUTOR	AFFILIATION	LOCATION	PROTOTYPE
J. Barber	Society of American Foresters	Bethesda, Md	1
J. Barlan	Compressed Gas Assoc.	Arlington, VA	9
D. Bervick	Dow Chemical Corp.	Midland, MI	9
J. Betschart	Hill Air Force Base	UT	12
J. Brown	Monsanto, Corp.	Anniston, AL	1
W. Burgess	MD Water Resources Admin.	Annapolis, MD	7
B. Cage	Midwest Research Institute	Kansas City, KS	1
F. Cole	Facet Enterprises, Inc.	Tulsa, OK	6
R. Collins	B.F. Goodrich Co.	Bethesda, MD	11
L. Cording	LaMotte Chemicals Co.	Chestertown, MD	5
J. Covington	Natl Emergency Training Cntr	Emmitsburg, MD	8,10,11
L. Damico	Aero Tech Laboratories	Ramsey, NJ	11
R. Dashiell	McTighe Industries	Bohemia. NY	6
G. Dennison	Princeton Testing Laboratories	Princeton, NJ	4,5
L. Doemeny	NIOSH Div. of Phys. Sciences	Cincinnati, OH	1
Dr. Eastwood	US Army Corps of Engineers, Superfund Design Center	Omaha, NB	2
D. Eitel	Shell Chemical Co.	Axis, AL	1
H. Enger	Crawley Environmental Srvcs Corp.	Seattle, WA	13
A. Ennis	Assoc. of Consulting Foresters	Bethesda, MD	2
J. Fetter	Spill Recovery of Indiana	Indianapolis, IN	2,5,7
M. Fingas	Environment Canada	Ottawa, Ont, CA	13
A. Fischer	Lancy International	Zelienople, PA	6
D. Frayley	Clean Rivers Corp.	Portland, OR	6
J. Gallaway	Exxon Corp.	Houston, TX	6
C. Geraci	NIOSH Div. of Phys Sciences	Cincinnati, OH	2
J. Gibeault	Analtrad Int'l, Inc.	Quebec, CA	5
E. Haines	Goodyear Tire & Rubber Co.	Akron, OH	11
C. Harrison	Natl Tank Truck Carriers, Inc.	Washington, DC	11

APPENDIX B. (cont'd)

CONTRIBUTOR	AFFILIATION	LOCATION	PROTOTYPE
S. Harrison	Union Carbide Agricultural Pdts Co.	RTP, NC	1,4
C. Harvey	Carbonic Industries	Richmond, VA	9
G. Hersh	Rochester Fire Dept.	Rochester, NY	10
R. Hiltz	MSA Research Corp.	Evans City, PA	10,12
W. Hollis	Natl Agricultural Chemicals Assn	Washington, DC	1
R. Holm	Rhone-Poulenc, Inc.	Monmouth Jnctn, NJ	1
T. Hoover	USEPA, Southeast Envir. Res. Lab	Athens, GA	4
W. Huget	Cryogenic Soc. of America	Oak Park, IL	9
L. Karr	Naval Civil Eng. Laboratory	Port Hueneme, CA	6
B. Katz	Illinois Chemical Corp.	Highland Park, IL	13
R. Kibler	US Air Force Enviro Policy Group	Washington, DC	9
J. Marquis	Vacpar, Inc.	Vicksburg, MI	13
A. Mason	Assn of American Railroads	Washington, DC	6,11
J. Mason	Fram Industrial Filter Corp.	Tulsa, OK	
R. Mayeaux	Louisiana State Police	New Orleans, LA	2
C. McDaniel	USDA Natl Monitoring & Residue Analysis Lab	Gufort, LA	1
K. McLaughlin	Alert Laboratories, Inc.	Canton, OH	4
R. Melvold	Rockwell International Corp.	Canoga Park, CA	8
R. Meyer	Rockwell International Corp.	Canoga Park, CA	3
J. Nakao	CA Dept. of Health Services	Sacramento, CA	2
J. Neisess	USDA Forest Service	Washington, DC	1,8
E. Norman	National Foam Co.	Lionsville, PA	9,10
D. Norton	Monsanto Corp.	Anniston, AL	8
M. Norton	Instafoam Products	Jolliet, IL	8
B. Offenhartz	B&M Technological Services, Inc.	Boston, MA	1
S. Palmieri	NJ Taxation Dept	Trenton, NJ	5
W. Polett	Walpole, Inc.	Mt. Holly, NJ	11
D. Rhodes	Centrifical Systems, Inc.	Houston, TX	13
P. Roeser	Cecos International	Buffalo, NY	5
T. Roller	Libbey-Owens Ford Co.	Rossford, OH	1

CONTRIBUTOR	AFFILIATION	LOCATION	PROTOTYPE
W. Russer	Canvas Fabricators	Gaithersburg, MD	11
D. Ryan	Ohio State Fire Marshall	Reynoldsburg, OH	10
R. Sarriera	R.E. Sarriera Associates	Santuce, PR	1
R. Schaffer	Centec Corp.	Reston, VA	2
R. Schaller	Donaldson Co., Inc.	Minneapolis, MN	6
R. Schmitt	USEPA, Office of Pesticide Pgms	Washington, DC	1
R. Scholten	Milwaukee Railroad	Chicago, IL	11
D. Seely	GCA Consultants	Bedford, MA	5,11
J. Seymour	Envirotech Services, Inc.	Praire du Sac, WI	2,4
S. Shaw	Seaward International Corp.	Falls Church, VA	13
J. Sheffy	SOHIO	Houston, TX	6
J. Silk	OSHA, DOL	Washington, DC	1
A. Silvestri	Chemical Systems Laboratory	Aberdeen, MD	1,2,4
J. Sinclair	US Coast Guard	Washington, DC	8
A. Sladek	Philadelphia Fire Dept.	Philadelphia, PA	10
A. Stevens	USEPA, MERL, DWRD	Cincinnati, OH	1,3
F. Stevens	Lancy International	Zelienople, PA	6
J. Stewart	Katz Bag Co.	Indianapolis, IN	11
J. Tew	Amer. Assoc. of Textile Chemists & Colorists	RTP, NC	9
K. Thorn	Welding Institute of Canada	Oakville, Ont, CA	9
M. Totten	Chemical Manufacturers Assn	Washington, DC	1
J. Townsend	Texas A&M Oil & Hazardous Material Training Div.	College Station, TX	10
S. Tsoukalas	Applied Biology, Inc.	Atlanta, GA	4
R. Urban	Tennessee Valley Authority	Chattanooga, TN	1
S. Wales	Research Plastics	Salem, MA	11
D. Walker	Fluor Engineering	Irvine, CA	10
J. White	Fram Industrial Filter Corp.	Tulsa, OK	6
M. Young	Giffolyn Co.	Houston, TX	11
P. Zaine	Sigma Treatment Systems	Chester Springs, PA	6

APPENDIX C

EVALUATION OF CAM-4 AND THE EMERGENCY COLLECTION SYSTEM

by

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ABSTRACT

Two prototype devices, the CAM-4 pesticide monitor and the emergency collection system, designed under previous contracts to the U.S. Environmental Protection Agency, Office of Research and Development (EPA/ORD), have been examined to identify potential design cost savings, identify areas for design improvement, and assess their potential for commercial production.

The CAM-4 device, designed by Midwest Research Institute (MRI), is described in the EPA report, "CAM-4, A Portable Warning Device for Organophosphate Hazardous Material Spills" (1). The CAM-4 (Cholinesterase Antagonist Monitor) is a semi-automated field unit for toxicity-level detection of dissolved organophosphate and carbamate pesticides. Two tasks relating to this device were performed. First, two inoperative CAM-4 units and an inoperative CAM-1 were examined. The two CAM-4 units were refurbished and returned to working order, and a demonstration kit containing appropriate reagents was prepared. Second, the CAM-4 was subjected to a value engineering analysis. This analysis indicates that the CAM-4 can be manufactured for $1,746. Additional cost reductions of 30% or more can be achieved if the systems are manufactured in lots of 25 to 100 units. Estimates of reagent manufacturing costs, including the cost of enzyme pads, are less than $1 per unit. The projected cost per test to the CAM-4 user is only one-fortieth of the current cost of a chromatographic pesticide analysis carried out by a commercial testing laboratory.

The commercial potential of the CAM-4 design was assessed by comparing the CAM-4 with analogous commercial field instruments for monitoring residual chlorine in natural waters (2, 3). The chlorine monitors and the CAM-4 are comparable in cost, manufacturability and serviceability. Significant shortcomings of the CAM-4 design are an unreliable fluid-handling system and a data output system that is both costly and difficult to interpret correctly. Possible redesign approaches have been described. The redesigned system is expected to be significantly easier to operate, improving marketability. Manufacturing costs of the redesigned system are estimated to be significantly less ($500) than the present CAM-4 design. The projected redesign effort is straightforward. On the basis of its outstanding potential, further applications research on the CAM technology is recommended.

The emergency collection system, designed by MSA Research Corporation, is a prepackaged pumping and storage system for the collection and containment of hazardous land spills and is described in the EPA report, "Emergency Collection System for Spilled Hazardous Materials" (4). The device consists of two major components: a skid-mounted gasoline-powered pumping unit, and a

disposable collection bag. The value engineering analysis of this device indicates that the pumping unit can be manufactured for $5,381 when built in quantities of 100 units. A cost-reduced pumping unit can be manufactured for $1,045 in the same quantity.

The cost of manufacturing the disposable collection bag remains uncertain. At the recommendation of MSA Research Corporation, Helios Industries, MSA's bag manufacturer, was contacted for cost quotations. Quotes received were $15,000 for the original segmented bag and $8,038 for a pillow redesign (5). Ralph H. Hiltz of MSA, has suggested alternate cost estimates of $7,000 and $5,000, respectively, for commercial bag designs incorporating additional design modifications (see Appendix B). Using even the lowest cost estimate, the value engineering analysis indicates that the cost of manufacturing the disposable collection bag strongly influences system costs. Further design development is recommended to achieve acceptable trade-offs among cost, manufacturability and field performance characteristics.

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CONTENTS

FIGURES

FIGURES

Number		Page

SECTION 1

INTRODUCTION

Two prototype devices, developed under previous contracts to the U.S. EPA, ORD, for detecting, containing and/or cleaning up chemicals in the environment, have been examined to identify potential design cost savings, identify areas for design improvement, and assess their potential for commercial production. The devices are the CAM-4 water monitor designed by Midwest Research Institute and the emergency collection system designed by MSA Research Corporation.

The CAM-4 (Cholinesterase Antagonist Monitor) is a semi-automated field unit for toxicity-level detection of dissolved organophosphate and carbamate pesticides. Two tasks relating to this device were performed. First, two inoperative CAM-4 units were restored to working order, and a demonstration kit containing appropriate reagents was prepared. Second, the CAM-4 design was subjected to a value engineering analysis. The emergency collection system, a prepackaged pumping and storage system for the collection and containment of hazardous land spills, was subjected to a value engineering analysis.

Work carried out on the CAM-4 pesticide detection system is described in Sections 4 (Instrument Refurbishment) and 5 (Evaluation). The two CAM-4 units obtained for refurbishment were both inoperative upon receipt, and several parts were missing. Problems identified included broken electrical connections, broken water pumps and deteriorated plumbing. The engineering documentation was inadequate, and vendor part numbers did not always conform to components actually found in the units. Nevertheless, both units were restored to good working order.

The evaluation of the CAM-4 system was based on specifications published in EPA Report No. 600/2-80-033, January 1980 (1). Additional information was gained as a result of repairing the two units. Prior reports on the CAM-1 (6), and excerpts from a manual on an updated CAM-1 device, MRI's CAM-3 (7), were also used in the analysis. The total costs of manufacturing the CAM-4 prototype and the CAM-4 reagents in various lot quantities were determined based on the current costs of the system components specified. Labor costs were estimated according to standard manufacturing practices. Commercially available chlorine water monitors were used as a basis for developing commercial standards for cost, manufacturability, serviceability, and ease of use (2, 3, 8, 9). This comparison helped identify a number of limita tions in the CAM-4 design. Possible design changes to overcome these limitations and improve the marketability of the CAM-4 prototype design were explored.

The value engineering analysis on the emergency collection system is presented in Section 6. The evaluation was based on information contained in EPA Report No. 600/2-77-162, August 1977 (4), along with additional information obtained directly from MSA, including drawings and design updates (10). Current costs for the pumping component of the emergency collection system were obtained for the specified subassemblies. Alternate sources of subassemblies were identified, labor costs were estimated, and the total costs for building the unit in various lot quantities were determined. Possible design changes to reduce costs were explored, and a minimum cost system was specified. Initial costs to be faced in initiating production were estimated. For the disposable collection bag, the second major component of the emergency collection system, cost quotations obtained from a vendor (5) recommended by MSA Corporation and MSA's own cost estimates (10) were used in the cost analysis (see also Appendix B). These quotations indicate that the cost of the collection bag is likely to dominate the overall system cost.

SECTION 2

CONCLUSIONS

CAM-4

The analyses performed in the course of evaluating the CAM-4 system, together with the experience gained in repairing and operating two CAM-4 units, support the following conclusions:

1. The CAM-4 design specified by Midwest Research Institute can be manufactured for $1,746 in single-unit quantities. When built in 25- to 100-unit quantities, á 30% or higher discount on standard parts is expected to decrease manufacturing costs to $1,200 or less. Discounts of this magnitude are expected when original equipment manufacturers are approached, rather than equipment distributors.

2. Estimated costs of bottled reagents manufactured in 200-unit quantities are under $1 per unit. Enzyme pads manufactured according to published procedures in quantities of 3,500 are expected to cost about $0.10 per pad. When manufactured using MRI's proprietary batch processing procedures, enzyme pads cost less than $0.01 per pad according to William B. Jacobs of Midwest Research Institute (4).

3. Sales prices for the CAM-4 unit based on the above manufacturing costs are $3,000 to $4,365. Suggested reagent prices of $10 for buffer (500 ml), $5 for substrate, and $1 per enzyme pad provide customary profit margins.

4. The cost per test calculated for a typical day's use in the field is one-fortieth the current cost of a chromatographic pesticide analysis performed by a commercial testing laboratory ($40-$50 per test).

5. Low-cost chlorine water monitors manufactured by EPCO and IBM Instruments (2, 3, 8, 9) were used to establish standards of cost and performance applicable to a critique of the CAM-4 prototype design. The CAM-4 was comparable to the commercial chlorine monitors in cost, manufacturability and serviceability. CAM-4 design shortcomings identified are as follows:

- The digital printer ($575) is an unnecessarily costly means of data output.

- The fluid-handling design can contribute to undetected errors in data output and incorporates a water pump that requires replacement after less than 1000 hours of operation.

* The data outputs are recorded as cell voltages, which require user interpretation, and hence a high level of user familiarity with the technology.

6. Approaches to prototype redesign that would serve to eliminate these shortcomings are:

* Substitute a liquid crystal display for the digital printer at a cost savings of approximately $500.

* Redesign the fluid-handling system around peristaltic pumps of acceptable reliability.

* A complete update of the CAM-4 electronics design, incorporating a microprocessor, would permit the convenience of pad change alerts and alarm warnings, as well as direct data output of pesticide concentration.

The manufacturing cost of the suggested redesigned CAM-4 is estimated to be about $500 less than the present design.

7. Any potential manufacturer of CAM-type instrumentation can expect to invest some product design effort to assess design variables, set instrument specifications, develop prototypes, develop and document commercial protocols, and develop secondary applications of the technology. While the CAM-4 design of 1976 requires updating to become commercially acceptable, the level of redesign effort could be quite modest. The redesign analysis indicates that a three- to six-month product development effort at a cost of $25,000 to $50,000 could lead to a successful initial product.

EMERGENCY COLLECTION SYSTEM

The analyses performed in the course of evaluating the emergency collection system support the following conclusions:

1. The system, as specified, is designed to meet high standards of performance and durability. Exceptionally durable components were chosen.

2. As specified, the pumping unit can be assembled easily from readily available standard components at a manufacturing cost of $5,381 in quantities of 100 units.

3. A less durable and less easily deployed pumping unit can be built for as little as $1,045. However, this design may not be as safe as the design originally specified.

4. Product acceptability will depend on appropriate marketing information as well as thorough field testing of any proposed alternatives to the original design approach.

5. The price quotations received for the original segmented bag and a pillow bag design, $15,000 and $8,038, respectively, are high for a disposable item. However, these prices are appropriate for small-quantity (1 to 100) custom orders and are not indicative of commercial manufacturing practices.

6. The commercialization potential of the collection bag, and thus the emergency collection system, is uncertain at present.

SECTION 3

RECOMMENDATIONS

The engineering analyses reported here are intended to contribute to an assessment of the commercialization potential of two technologies, the CAM-4 pesticide monitor and the emergency collection system.

CAM-4

The convenience and low cost per test of the CAM-4 instrumentation suggest that this technology may become an effective tool in a variety of pesticide monitoring applications. Some examples of applications are the analysis of run-off from agricultural pesticide spraying, the analysis of pesticide residuals in vegetation and/or soil, and process control measurements in pesticide manufacturing. Further work is recommended to implement the design improvements described in this report.

EMERGENCY COLLECTION SYSTEM

The cost of this system is influenced greatly by the cost of the 7,000-gallon collection bag, a disposable item. Current cost quotations by Helios Industries are very high ($8,000 to $15,000), indicating that this aspect of the system design requires further investigation (5). MSA's own estimate (10) is only $5,000 to $7,000 for bag designs incorporating further modifications (see also Appendix B). Additional design research is recommended in order to meet commercially acceptable criteria of cost, manufacturability and desired field performance.

SECTION 4

REFURBISHMENT OF THE CAM-4

This chapter describes the work and events involved in refurbishing a CAM-4 prototype for demonstration at the Hazardous Materials Management Conference in Philadelphia, July 12-14, 1983.

Initially, one CAM-4 unit and one CAM-1 unit were received with instructions to repair the device in least need of repair. The CAM-1 device was badly deteriorated and was received with improperly secured circuit boards that were damaged in transit. An examination of the CAM-1 unit, built in 1972, revealed that most mechanical parts would probably need replacement due to extensive corrosion. A printed circuit board contained a burned-out resistor indicating that circuits had been damaged by overvoltage. Therefore, this device was not refurbished.

After it was decided to repair the CAM-4 device, a second CAM-4 was received to provide spare parts so that time delays caused by ordering new parts would be minimized. The problems that were diagnosed and repaired consisted of broken electrical connections, broken water pumps and deteriorated plumbing.

The lack of adequate engineering documentation available for these units considerably prolonged the repair process. No working drawings are available, and vendor part numbers from 1976 had to serve for part specifications. In performing diagnostics, it was necessary to reconcile differences in construction between the two CAM-4 units, as well as differences between observed performance characteristics and those documented in the CAM-4 report. As an example of the latter, the sampling rate of the refurbished CAM-4 units is 650 ml/min. The CAM-4 specified sampling rate is 200 ml/min (1). The CAM-4 user is advised that the observed rate and the specified rate are both consistent with good instrument performance (1, 6, 12). Units received a final check-out with active enzyme pads.

One refurbished CAM-4 unit (Control No. L/A 9629) was turned over to the JRB Project Manager on July 1 together with a demonstration kit containing appropriate reagents. The list of items delivered are shown in Table 1. The JRB Project Manager was trained in the operation of the CAM-4 in preparation for demonstrating the instrument at the Hazardous Materials Management Conference.

As a small addendum to the refurbishment task, the second CAM-4 unit (Control No. L/A 9630) was also refurbished and returned to the EPA Project

Officer along with the remainder of the unused disposable items that were purchased. The broken CAM-1 was also returned to EPA.

TABLE 1. CAM-4 UNIT AND DEMONSTRATION KIT

1 CAM-4, control number L/A 9629, refurbished, with accessories:
2 enzyme pad holders
1 vacuum/pressure bulb
1 power cord
2 silastic pump tube
5 paper rolls, thermographic printer
1 bottle for substrate
1 demonstration kit, containing:
25 enzyme pads, active
2 enzyme pads, inactivated
Ingredients for 4 x 200 ml batches of substrate
1 bottle trisbuffer (1 + lit)
4 vials, 16 mg substrate
4 pasteur pipettes
1 beaker (50 ml)
2 vial inhibitor concentrate
1 bottle tris (solid)
1 bottle substrate (solid)
1 vial inhibitor (solid)

SECTION 5

EVALUATION: CAM-4

INTRODUCTION

The CAM-4 cholinesterase antagonist water monitors are semi-automated field units for toxicity-level detection of dissolved organophosphate and carbamate pesticides. The performance characteristics of CAM monitors have been documented in EPA-sponsored instrument evaluations (1, 6, 12). More recently, Midwest Research Institute (MRI) scientists have used CAM instrumentation effectively in commercially-sponsored industrial and agricultural research (11).

The CAM-4 system, designed by Midwest Research Institute, was evaluated on the basis of specifications published in EPA Report No. 600/2-80-033, January 1980 (1). Additional information was gained from the repair of two CAM-4 units, as reported in Section 4. Prior reports on the Model CAM-1 (6, 12) and excerpts from the model CAM-3 manual (7) were also used in the analysis.

The CAM-4 evaluation had the following objectives:

* Develop manufacturing costs for the CAM-4 and for the CAM-4 reagents, as specified;
* Develop design criteria for a commercial prototype, and apply these criteria to a critique of the CAM-4 design;
* Suggest effective redesign approaches;
* Estimate development and manufacturing costs of the redesigned CAM-4.

The total costs of manufacturing the CAM-4 prototype and the CAM-4 reagents in various lot quantities were determined. The cost analysis was based on current vendor information obtained for the system components specified. Suppliers contacted and prices obtained are detailed in Appendix A and are cited in the Reference section. Labor costs were estimated assuming standard manufacturing practices and a burdened rate of $30 per hour.

Commercial water monitors of similar design and analogous function were used to develop commercially acceptable standards of cost, manufacturability, serviceability, and ease of use (2, 3, 8, 9). When these standards were applied to an analysis of the CAM-4, design strengths and limitations were identified. Possible design changes were explored to improve the marketability of the CAM-4 prototype design.

In addition, an estimate was made of the start-up costs involved in manufacturing the CAM-4.

SYSTEM DESCRIPTION

Over the past twelve years, Midwest Research Institute has designed and constructed a series of CAM instruments for continuously monitoring natural waters for the presence of subtoxic to toxic levels of organophosphate and carbamate pesticides. The model CAM-1 (6, 12), designed in 1972, and its recent update, CAM-3 (7), are fully automated research instruments for bench-top use. The portable CAM-4, designed in 1976, is an equally sensitive instrument designed for field use (1). It can operate on a 12V DC battery as well as on 110V AC. The simpler, less costly CAM-4 design is well suited for the design evaluation, since the objectives of the evaluation are to minimize manufacturing costs and optimize commercial performance.

The operation of CAM instruments depends on the inactivation of the enzyme cholinesterase by organophosphate and carbamate pesticides. The extent of inactivation depends on pesticide concentration and the nature of the pesticide. Enzyme activity is gauged by assessing the rate of conversion of an enzyme-hydrolyzable substrate to detectable products. Common features of CAM instruments are the electrochemical detection of reaction products, an immobilized enzyme preparation reusable for several analyses, and a sampling cycle that permits discrete analyses as well as continuous monitoring.

CAM instrument design, as represented in the CAM-4 schematic shown in Figure 1 and the block diagram in Figure 2, promotes pesticide detection and monitoring in the following way. A porous pad coated with entrapped enzyme is clamped firmly inside an electrochemical cell assembly. Two detector electrodes contact the enzyme pad on opposite sides. During a sampling cycle, the enzyme is exposed to the water sample and to substrate in a precisely timed sequence. First water is pumped through the pad, permitting dissolved pesticide to reduce the activity of the enzyme. Next, residual water is displaced by a stream of air. Finally, a stream of substrate is pumped through the enzyme pad and a constant 2uA current is applied to the electrodes. The cell voltage is printed out on the digital printer. The next sampling cycle begins automatically unless manually interrupted.

The cell voltage printed out at the end of the sampling cycle may be interpreted as follows. Characteristically low voltages are observed in the presence of hydrolysis product concentrations produced by an active enzyme preparation. When the sample contains pesticide concentrations equal to or greater than the detection threshold of the instrument, a rise in cell voltage of 10 mv or greater from one sampling cycle to the next signals the presence of dissolved pesticide. The voltage rises in direct response to the concentration of hydrolysis product produced by enzyme partially or completely

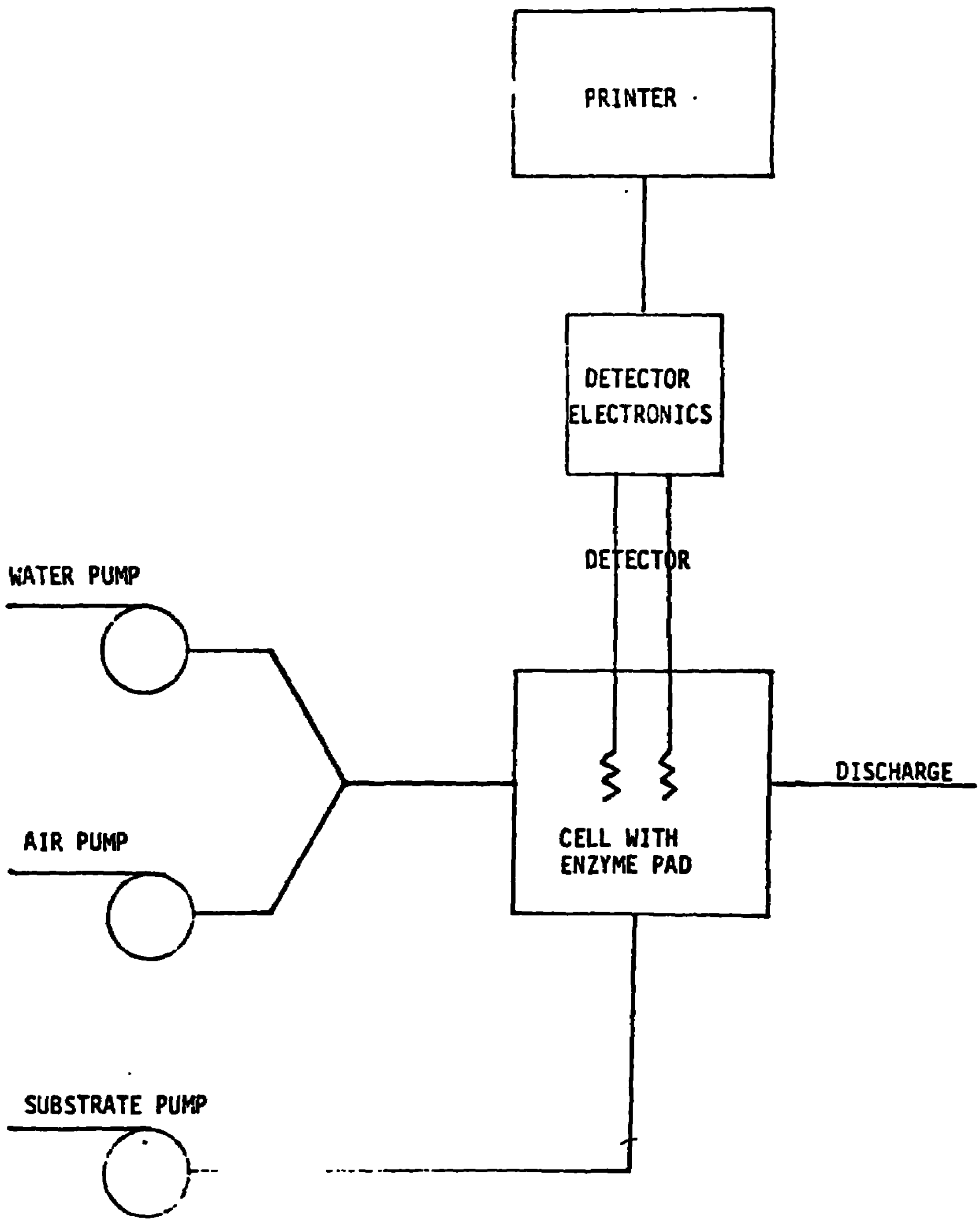

FIGURE 1. SCHEMATIC CAM-4

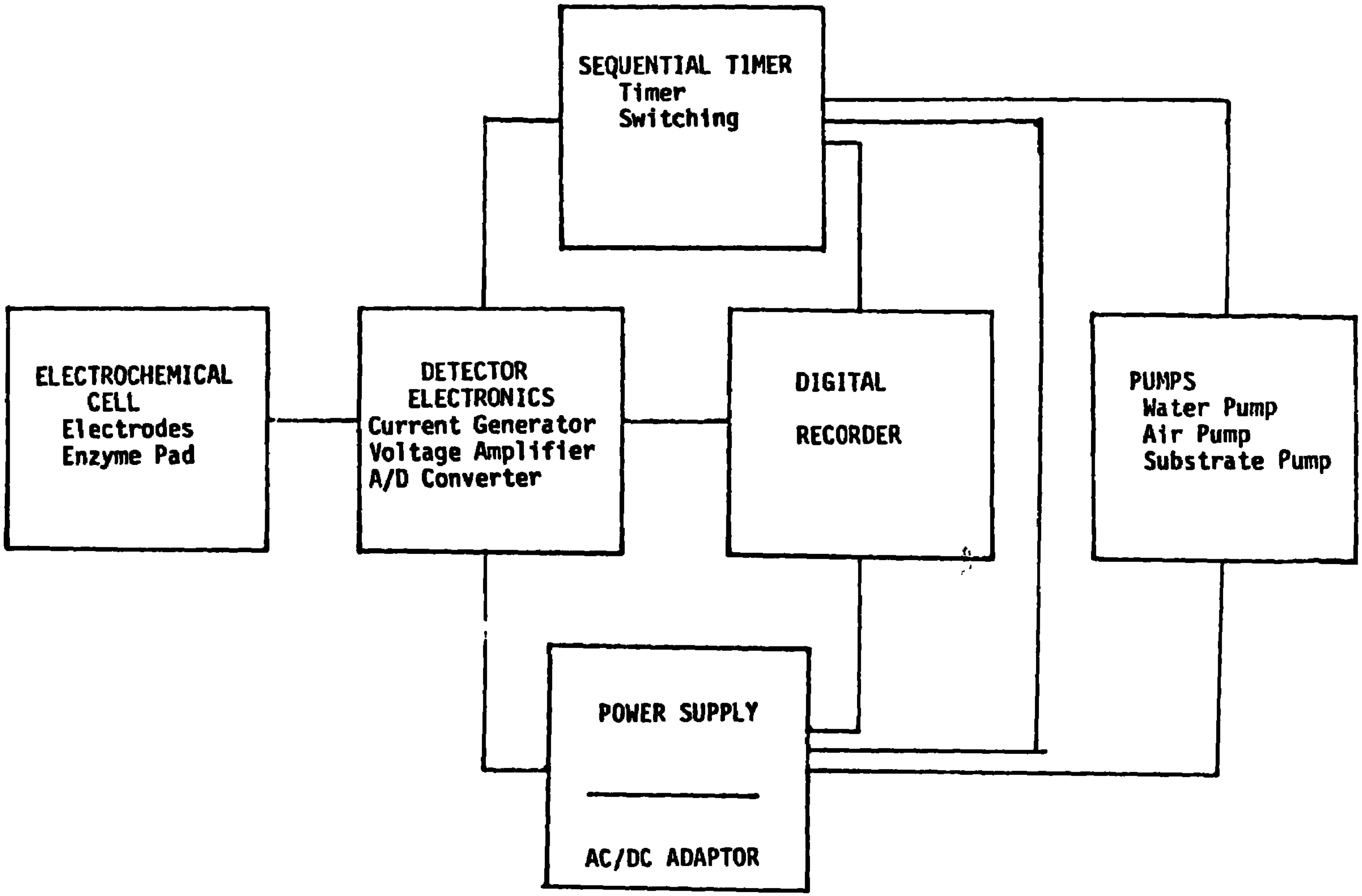

FIGURE 2. BLOCK DIAGRAM, CAM-4

inactivated by pesticide. As noted in the CAM-4 specifications summarized in Table 2, instrument response includes a detection threshold of 0.1 parts-per-million (ppm) for the most toxic pesticides, a linear response range for ppm levels of pesticides, and an overrange response. The latter occurs whenever a fresh or partially inactivated enzyme pad is completely inactivated.

The CAM-1 and CAM-3 automated monitors have convenience features that are eliminated in the CAM-4 design. An audible alarm voltage threshold can be set to signal the presence of pesticides. The degree of inactivation of enzyme pads is monitored by computer logic circuits. An exhausted enzyme pad is removed automatically and a fresh pad inserted in the electrochemical cell assembly. A strip chart recorder is provided for continuous recording of cell voltages.

The CAM-4 operator must interpret the digital recorder printout to determine the presence and concentration of pesticides and to determine when enzyme pads require changing. Enzyme pads are changed manually. A cell voltage output jack is provided for the optional use of a chart recorder.

COMPONENT DESCRIPTION

Although the CAM-4 design described in EPA-600/2-80-033 (1) did not include a complete unified bill of materials, most components could be identified from the parts list and from examination of the CAM-4 units refurbished (see Section 4). A complete parts list with prices and vendors is included in Appendix A. Major components are discussed below. A more complete description, including circuit diagrams, is included in the EPA report (1).

Case Assembly

A sturdy fiberglass carrying case, roughly in the shape of a rounded cube, opens in the middle to provide two, six-inch deep compartments that house the instrument components. Each compartment is covered by a panel containing the operator controls. The right half of the case contains most of the electrical components, while the left half contains the mechanical components (pumps, motors, pad holder, water inlet and outlet, etc.). When set up on a bench (or, less conveniently, on the ground), all controls and indicators are easily accessible. A recessed socket for a 110V AC power cord is provided in the right-hand compartment, together with a pair of DC input terminals for 12V operation.

Electronics

The electronics of the CAM-4 are contained on three printed circuit boards: (a) a "DVM" board, which performs analog to digital conversion for the signal transmitted by the cell voltage amplifier, and which provides the constant current source for the electrochemical cell; (b) a power supply board, which provides the required voltages (+15V, -15V, +5V and +5V

TABLE 2. SPECIFICATIONS, CAM-4

The CAM water monitor detects organophosphate and carbamate pesticides in the ppm range. Detection limits are 0.1 ppm for the most toxic pesticides. The measurement principle uses pesticide inhibition of the enzyme cholinesterase.

Semi-automated operation permits continuous monitoring with rapid response. Rugged construction and portability make the CAM-4 well-suited for field use.

PERFORMANCE SPECIFICATIONS

Printer Output: Peak voltage, electrochemical cell. Operator determines correspondence to pesticide concentration.

Detection Limit: 10 mV shift

Linear Response Range: 10 mV - 200 mV; proportional to pesticide concentration.

Reproducibility: ± 20%

Overrange Response: 250 mV shift

Detection Cycle: 3 minutes

Substrate Flowrate: 1 ml/min

Sample Flowrate: 200 ml/min

REAGENTS

Substrate: 2.5 x 10^{-4} M butyrylthiocholine iodide in 0.08 M TRIS buffer, pH 7.4

Enzyme Pad: 0.4 - 0.8 units of horse serum cholinesterase

Calibrator: 0.2 ppm DDVP

ELECTRICAL REQUIREMENTS

110 V AC, 60 Hz or 12 V DC

PHYSICAL CHARACTERISTICS

Dimensions: 12" x 11" x 14"

Weight: 30 lbs.

Cell Voltage Output: Provided for recorder unregulated) to the rest of the system, using 40V AC and 4V AC inputs from the inverter; and (c) a timer and switching board, used to power and control the pumps and time current generation and print-out. In addition, an inverter unit, mounted on the right-hand front panel to minimize heating problems, provides 110V AC, 40V AC and 5V AC to the power supply board, using either 110V AC or 12V DC for input. The inverter is required because the pumps and the digital printer do not operate off standard +12V or +5V supplies; this component could be eliminated if different motors were specified or if 12V DC field operation was not required.

Pump Assembly

This assembly, mounted behind the left-hand panel of the case, consists of three pumps plus associated tubing and wiring. The water pump draws in a 400 ml sample over the course of a two-minute cycle; the sample is pumped through the immobilized enzyme pad. At the end of this period, the water pump is turned off and the air and substrate pumps are turned on. Approximately two liters of air is pumped through the cell for one minute to remove excess liquid from the enzyme pad. Simultaneously, the substrate pump sends 1 ml of substrate solution to the enzyme pad. During the final forty seconds of substrate pumping, a 2 uA constant current is applied to the cell, and the cell voltage is recorded.

All three pumps are constant speed devices; this is particularly critical for the substrate pump, since a constant speed is necessary to provide a constant baseline voltage. All pumps are readily accessible for servicing or replacement and are available from standard sources (13 - 15).

Cell Assembly

The cell assembly is the only item in the CAM-4 that is not available from standard sources. It is currently manufactured for Midwest Research Institute for in-house use (11). It consists of two perforated platinum electrode holders held against the enzyme pad by springs. Two separate inlets are provided, one for substrate and one for water samples or air. Waste is discharged through a single outlet on the opposite side of the enzyme pad. The electrodes are contained in injection-molded holders made of Cyclolac plastic and are fitted to the enzyme pad holder using O-ring seals to provide a leak tight unit. The two electrode leads are imbedded in the plastic electrode holders and are connected to the constant current power supply.

Printer

The printer is a DATEL Systems DPP7-D1, which provides digital output (four digits plus decimal point) on thermal paper. According to the manufacturer, this model has been discontinued and replaced with a model operating on AC voltage only (16). The circuitry provides for one digital output during each three-minute cycle; this output corresponds to the peak voltage of the cell during the cycle. During continuous monitoring of water samples that do not contain pesticide, the cell voltage will drift slowly higher, but the change is only about 1 mv (0.001 V as printed) per three-minute cycle. When the inlet sample contains pesticide, the voltage will increase at a faster rate. Monitoring may be continued for several cycles to improve the accuracy of the results. Monitoring of high concentrations of pesticides will cause the enzyme pad to deteriorate rapidly and will require frequent pad changes. An increase of 10 mV or more per three-minute cycle should be interpreted as indicating a significant level of pesticide. However, the CAM-4, unlike its predecessors, does not provide a separate "alarm" indicator, and the operator must make the interpretation of hazardous pesticide levels from the printed data. The operator must also interpret the data to determine when the enzyme pad needs to be replaced.

COMPONENT AND SYSTEM COSTS

The parts list for the CAM-4, together with updated prices and vendors, is provided in Appendix A. This list has been used to prepare Table 3, which presents a summary of the costs organized according to the major subassemblies of the CAM-4. The total cost of components for the manufacture of a single unit is $1,440. Component costs for the manufacture of 25 or 100 units may be estimated by assuming original equipment manufacturer discounts of 30% and 50% respectively, which would reduce the costs per unit to $1,008 and $720.

TABLE 3. PARTS COST, CAM-4

PART NO.	COMPONENTS	COST ($)
63, 64, 75-80, 82	Case Assembly	267.90
	PC Board Assembly	
1-20	DVM Board	149.96
22-32	Power Supply Board	19.52
33-62	Timer and Triac Switch Board	39.32
70-74	Mounting Hardware	10.72
	Pump Assembly	
81	Water Pump	34.00
86	Air Pump	8.75
83-85	Substrate Pump	158.00
89	Tubing and Sumps	4.15
87, 88, 90	Cell Assembly	131.00
65	Printer	575.00
66-69	AC/DC Adapter Assembly	42.14
	TOTAL PARTS	1,440.46

The burdened cost of components is typically 115% of the discounted cost to provide for overhead. Labor in assembly is minimal due to the modular design of the CAM-4. The bulk of the labor is required for populating the printed circuit boards, final checkout, and quality control. We estimate that, in quantity production, two hours of labor would be required per unit. Labor costs for assembly of a single prototype unit are not particularly meaningful; we have estimated three hours. The burdened cost of labor in electronics manufacturing is taken as $30 per hour. Thus, the manufacturer's cost for 1, 25 or 100 units is estimated as $1,746, $1,219 and $888 respectively.

Selling prices may be estimated by multiplying the burdened manufacturer's cost by 2.5; this accounts for the costs of advertising, distribution, sales, and profit. On this basis, we estimate the selling price of the CAM-4 as $4,365, $3,048 and $2,220 for quantities of 1, 25 and 100. The estimate for a quantity of one is not particularly meaningful given that development costs and start-up costs are ignored.

Reagent Costs

The CAM-4 reagents specified consist of the enzyme pad, substrate solution and a calibration solution. An estimate of enzyme manufacturing costs will be discussed first. Cholinesterase, the major initial cost, is sold by Sigma Chemical Company for $135 per gram in single-gram quantities (17). If enzyme pads are prepared according to the procedures detailed in EPA-600/2-80-033 (1), this quantity is sufficient to prepare 2800 pads, i.e. a cost of $0.048 per pad for enzyme. Based on the same procedures, the time estimated to prepare and test a standard lot of 350 pads is three hours at a burdened rate of $30. Thus the cost of labor, $0.26 per pad, is considerably greater than the cost of enzyme. The cost of the remaining materials -- foam pads, starch, aluminum hydroxide and buffer -- is negligible by comparison. Thus the overall burdened cost per pad is about $0.31. However, the manufacturing process could be streamlined considerably if forty sheets (3500 pads) were processed at once rather than four sheets (350 pads) as specified. Such a procedure should reduce the manufacturing cost to about $0.10 per pad. Mr. William Jacobs of MRI has indicated that the current cost for manufacture is $0.01 or less, when MRI proprietary batch processing procedures are employed (11).

It should be noted that the shelf life of enzyme pads is excellent; five-year old pads, used in refurbishing the CAM-4, had acceptable enzyme activity.

The substrate solution consists of butyrylthiocholine iodide (2.5×10^{-4} M) in 0.08 M TRIS buffer (pH 7.4). At this pH, butyrylthiocholine is unstable, requiring that fresh solutions be prepared daily. The cost of materials is approximately $0.21 per 500 ml if materials are bought in small quantities; a half-liter is sufficient to conduct 450 tests, or roughly continuous operation for a 24-hour period.

It is typical for instrument manfuacturers to make substantial profits on the sale and distribution of reagents. For example, the butyrylthiocholine iodide could be separately packaged in preweighed form; the TRIS buffer could be packaged the same way or sold in 500 ml polyethylene bottles. Typical prices, based on the practices of other manufacturers, would be $1 per enzyme pad, $5 per package of butyrylthiocholine iodide, and $10 per bottle of TRIS buffer. The cost to the consumer, under $35 per day for continuous monitoring, is less than the cost of a single test done by a commercial testing laboratory ($40 to $50).

CRITIQUE OF THE CAM-4 DESIGN

The objective of the original CAM-4 design effort, to construct a substantially cost-reduced CAM instrument without loss of pesticide sensitivity, has been met successfully. The cost analysis presented in the previous section attests to the success of the cost reduction, while the results of the CAM-1/CAM-4 comparison, published in the CAM-4 report (1), show comparable instrument performance.

Manufacturability, reliability, serviceability, and ease of use must also be considered to assess the potential of the CAM-4 as a commercial prototype. Reasonable criteria for these factors can be developed by comparing the CAM-4 to residual chlorine water monitors manufactured by EPCO and IBM Instruments. Instruments used in this comparison are the EPCO Chlortect, Models 2000, 3500 and 4000, and the IBM Instruments EC/250 (2, 3, 8, 9).

The chlorine monitors are priced between $2,000 and $4,000 and offer features suitable for bench-top operation in secondary applications as well as continuous monitoring in environmental field applications. As in the CAM-4, fluid handling is automated, and electrochemical detection is used. The instruments are designed in modular fashion so that features suited to specific applications -- 12V DC adaptability, ruggedized case construction and pumping units, choice of data output technique, etc. -- can be incorporated in or added onto the basic core design. The total market for chlorine monitors is in the range of 100 to 200 units per year.

A schematic published for the EPCO Chlortect (2), may be compared to the CAM-4 schematic in Figure 1. Requirements for fluid handling are roughly similar. The EPCO electrochemical cell is appreciably more complex than the CAM-4 cell. The EPCO instrument uses a liquid crystal display, while the CAM-4 produces data output on a thermographic printer. These differences aside, the instruments share a fundamentally similar design approach.

In so far as manufacturability is concerned, the CAM-4 is entirely comparable to the IBM and EPCO instruments. All three instrument designs are based on a modular design approach. Components are readily accessible for routine servicing and replacement. For the same reason, they are all roughly equally easy to manufacture. Similarly, the selling price estimated for the CAM-4, approximately $3,000, is comparable to the EPCO and IBM chlorine monitors.

However, in the context of a low-cost field monitor, the use of a digital printer in the CAM-4 adds unnecessary cost without commensurate benefits.

(The cost of the printer is about one-third of the cost of the total system.) Use of a liquid crystal display, together with a low-cost microprocessor and some random access memory (possibly built into the microprocessor chip), could permit data storage and review. Reviewed data could be recorded manually. More to the point, this change in the electronics and display would permit the instrument to calculate automatically baseline slopes and pesticide concentrations. In addition, pad change and "alarm" condition alerts could be incorporated at little extra cost. These changes would contribute to the ease of use (and marketability) of the CAM-4 and would greatly reduce the training time and operator skill level.

Several reliability problems are inherent in the design of the fluid handling system of the current CAM-4. In both of the CAM-4 units refurbished, the water pumps were inoperative, although it was clear that neither unit had been in service for anywhere near the nominal 1000-hour lifetime. In both cases, the problem was traced to a perforated pump diaphragm, which was punctured by the actuating spring.

Another problem, observed in field tests (1) and confirmed in our laboratory, occurs when the CAM-4 is operated at an elevation below that of the water sample being analyzed -- for example, when operated below deck in a boat, or when the water sample is placed on a shelf above the CAM-4 in the laboratory. The small head of water pressure present under these conditions is sufficient to prevent the air pump from flushing out the exit tube, leading to incorrect results in the measurement cycle. As discussed in the next section, both problems could be cured by the use of standard peristaltic pumps.

REDESIGN OF THE CAM-4

The CAM-4 design critique in the previous section suggests that component costs, overall instrument manufacturability, and serviceability meet commercial standards. However, design changes are desirable to improve ease of use, marketability and reliability of fluid handling.

To improve reliability, the CAM-4 water and substrate pumps should be replaced by peristaltic pumps designed for field monitoring. The specifications of Masterflex peristaltic pumps are suitable (13). Use of a peristaltic pump for sampling should eliminate the problem of limited diaphragm lifetime discussed in the previous section. Use of silicone tubing with a Masterflex-type pump will greatly improve tubing lifetime, which in the current CAM-4 design is the limiting factor in the substrate pumping system. In addition, use of a peristaltic pump in the sample line should eliminate the problem of negative fluid pressure when the CAM-4 is located below the level of the inlet.

Replacement of the digital thermographic printer by a liquid crystal display would save about $550, greatly reducing the overall cost of components. Additional savings may be achievable in the power supply. However, to improve ease of use, several additional components would be required, specifically, a microprocessor, read only memory, clock and (if not provided on the microprocessor) a small random access memory. The total cost of these components is under $20. Given that the original CAM-4 was designed in 1976, it is not surprising that microprocessor-based technology was not used. In any instrument designed in the 1980's, however, mircoprocessors are essential for "user friendly" instrumentation and to reduce overall cost while increasing ease of use and marketability.

A microprocessor-based display could provide a variety of outputs including direct voltage display and review as is provided in the current CAM-4 print-out; correction for baseline drift, which presently must be estimated by the operator; direct calculation of pesticide concentrations; and light emitting diode (LED) alerts for alarm conditions and pad replacement. Similar alerts could also be provided for internal diagnostics. Such changes in the design, which are suggestive but hardly comprehensive, could be provided at a net savings of approximately $550 compared to the current (1976) CAM-4 design.

The cost of such a redesign effort is not excessive. We estimate that an experienced engineering team could complete the work required in three to four man-months. However, given the relative novelty of the technology required and the relative scarcity of personnel skilled in the field, even relatively established instrumentation manufacturers might find it necessary to subcontract much of the work, which could cause a delay in project completion. Furthermore, there will be a temptation to redesign all of the CAM-4 electronics around a microprocessor-based control system. This could reduce overall parts costs even further but would increase the time and cost required for the redesign. Depending on the level of effort, an updated CAM-4 redesign could be accomplished for $25,000 to $50,000.

SECTION 6

EVALUATION: EMERGENCY COLLECTION SYSTEM

INTRODUCTION

The emergency collection system designed by MSA was evaluated based on information contained in EPA Report 600/2-77-162, August 1977 (4). Additional information, including drawings and design updates received from MSA, was included in the analysis reported. The vendor information used in the value engineering analysis is cited in the Reference section of this report.

Current costs, availability and catalogue information on the components specified were obtained for the analysis of the pumping unit. Alternate sources of components were identified. Labor costs were estimated and the total costs of building the unit in various lot quantities were determined. Possible design changes to reduce costs were explored, and a minimum cost system was specified. The initial cost to a potential manufacturer was estimated.

Vendor quotes obtained through MSA for the manufacture of the disposable collection bag, including two different design approaches, were incorporated into the analysis (5). Ralph H. Hiltz of MSA Research Corporation has commented on the vendor quotations in his letter of August 23, 1983 included in Appendix B. He has suggested alternate, lower cost estimates for collection bags manufactured to commercial practice. His cost estimates include additional design modifications to reduce manufacturing costs. The vendor quotations and the Hiltz estimates are used in the cost analyses presented. Even when the lowest cost estimate is used in the value engineering analysis, the manufacturing cost of the disposable collection bag dominates the cost of the emergency collection system.

SYSTEM DESCRIPTION

The emergency collection system for spilled hazardous materials was designed as a complete skid-mounted system that could be put on the bed of a pick-up truck and quickly transported to a spill site. Figure 3 shows the emergency collection system in operation.

The system consists of a gasoline engine-driven pump that removes spilled materials through a hose and delivers it to a 7000-gallon holding bag (Figure 4). The suction hoses are coiled on reels. Piping and valving are provided to minimize the number of field connections.

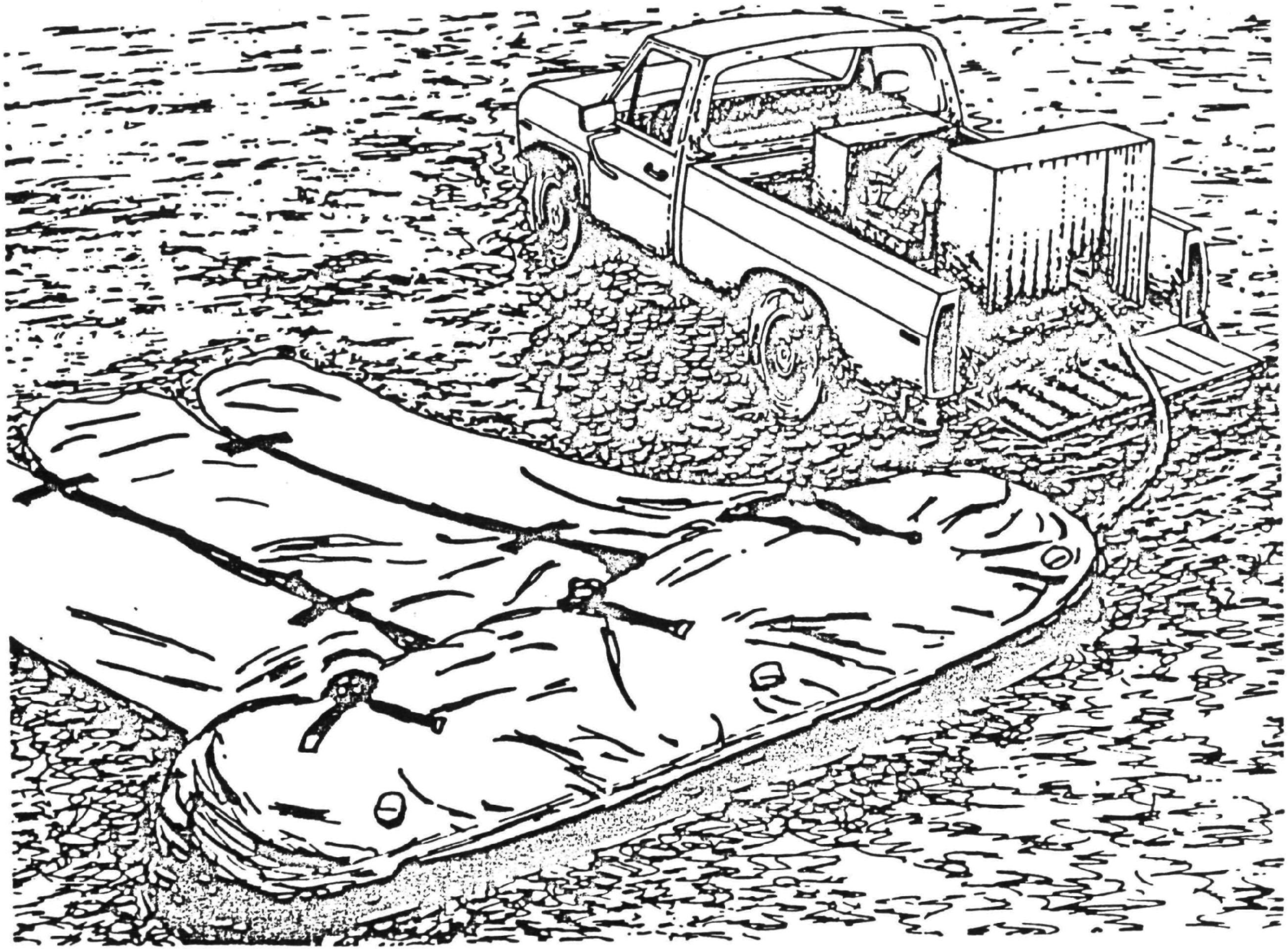

FIGURE 3. EMERGENCY COLLECTION SYSTEM

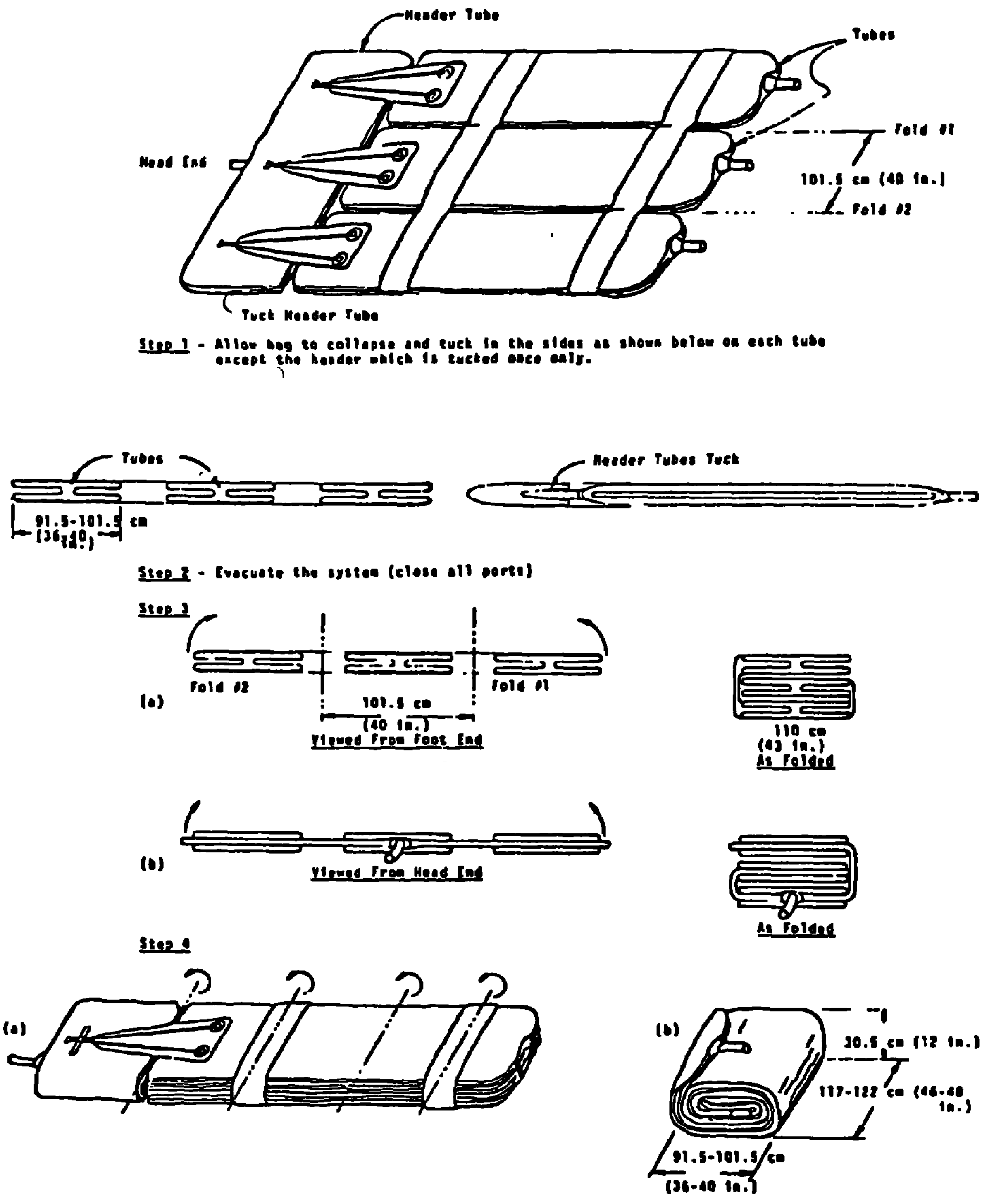

FIGURE 4. SEGMENTED COLLECTION BAG

The objective of providing a system that can be deployed quickly and easily on sloping ground has significantly influenced the final design. The two fifty-foot lengths of suction hose are stored on reels so that they can be easily unrolled. One suction hose is permanently connected to the pump, and the other has hose connections with quick disconnect fittings. Valving is provided so that spilled materials can be removed simultaneously from two collection points. A second storage bag can also be connected in tandem with the first without stopping the pump. Automatic valves in the quick disconnect couplings prevent leakage when a bag is connected or removed. In addition, the bag is packaged so that it can be deployed rapidly and is specifically designed to be stable on sloping ground.

Another design objective is that all components be of a high-quality material to withstand the effects of a wide and unknown range of spilled materials. All metal parts that are exposed to the flowage are constructed of 304 or 316 stainless steel. Hose linings are either teflon or cross-linked polyethelene and are graded for chemical/acid transfer. The bag is made of a material that will not be seriously weakened after exposure to many chemicals for 24 hours.

In short, little expense has been spared in the design of the system. It is meant to be a top-quality system that will have low maintenance and relatively long life. It can be deployed rapidly and operated easily by semi-trained personnel.

COMPONENT DESCRIPTION

The major components of the emergency collection system, as specified in the EPA report (4), are described below. A more detailed description of each component can be obtained by contacting the suppliers referenced in this report and by obtaining the MSA drawings cited in the EPA report (4).

Pump: ITT Marlow Pump
Self-Priming Centrifugal - Model 1 1/2 HE-19 (18, 19)

This is a stainless steel pump, close coupled to a 3 HP Briggs & Stratton gasoline engine. It is equipped with internally cooled, mechanical face seals. It is self-priming, once a priming chamber is manually filled, with a maximum lift of 25 feet. It will pump 50 gallons/minute at about 55 feet of head.

Suction Hose: Gates Rubber Co.
Acid/Chemical Hose - 45 HW (20, 21)

Two 50-foot lengths of this two-inch ID hose are supplied. The end fittings on each hose are stainless steel male pipe threads. One hose is wound up on a "live storage" reel that is permanently connected to the pump suction through one leg of a three-way valve. The other hose is stored on a plain reel and can be attached to the end of the first to reach spills farther away.

Alternatively, it can be attached to the other leg of the three-way valve for dual suction.

Alternate Supplier: MGT, Inc., Canada, "Coronado" product line (22).

Suction Selector Valve: Quality Control
Three-way Fulport Rotor Valve (23, 24)

This two-inch stainless steel valve is a three-port design that allows the suction of the pump to be connected to either or both of the suction hoses.

Suction Line Fittings: Ever-Tite Coupling Co.
Cam Type, Quick Couplings (25, 26)

Two male parts (Part A adapters) and two female parts (Part D couplers) are provided. They are of stainless steel and have two-inch female pipe threads on one end. They allow the two lengths of suction hose to be connected together or used in tandem, a coarse strainer to be attached, and connection to be made through a tank car adapter to the tank car opening. These connections are made by screwing the coupler or adapter to the pipe nipple on the hose. The connection is completed by pushing the two pieces of the quick coupling together and locking it in place by pulling down the handles.

Alternate Supplier: Parker-Andrews (27, 28)

Coarse Suction Strainer (29)

This screen can be made of a relatively open mesh or perforated metal. It is attached at the end of the suction hose as it enters the spill and prevents gravel from entering the hose.

Discharge Hose: Industrial Products Group
Titeflex R276 Conductive Hose (30, 31)

Ten feet of this one and one-half inch diameter hose is provided. It has a teflon inner liner which is impregnated with carbon to make it electrically conductive. The hose is reinforced with fiberglass and stainless steel wire braid. It is connected to the storage bag.

Discharge Fittings: Hansen Manufacturing Company
LL20-H51 and LL20-K51 (32, 33)

These are two-inch quick connect fittings with integral shut-off valves in both the male and female parts. These valves act automatically so that when the connection is broken, there is no leakage from either end. One female part (the socket) is attached to the discharge hose. Two male parts (the plugs) are manifolded to the pump discharge. This allows a second bag to be connected while the first full one is removed without stopping the pump.

Alternate Supplier: Dover Corp. - Kamvalok (34, 28)

Hose Reels: G.B. Hannay & Son
One each of C-8226-33-34 and 8226-33-34 (35, 36)

These reels are used to store the suction hose. One has stainless steel internals and a small joint. This allows the hose to be permanently connected to the pump suction before it is unrolled. The other reel does not have this feature. Both reels have a hard crane for hose retrieval.

Alternate Supplier: Philadelphia Valve Co.

Piping Assembly (29)

The piping assembly permanently connects the pump to the two discharge and suction connections. It incorporates a basket-type strainer (McMaster-Carr 9874K15) in the suction line to prevent particles from entering the pump. We assumed that it was made up from:

2-inch stainless fittings		1 1/2 stainless fittings
1	90° bend	2
	45° bend	2
	lateral	1
2	close nipple	6
	3" nipple	4
	12" nipple	1
1	24" nipple	1

Storage Bag: Helios Industries (5)

A 7000-gallon fabric bag is used to hold the spill. It is manufactured from urethane-coated two-ply nylon. It consists of three bags connected by a header bag, MSA Part Number C-3077 (4). This design is stable on sloping ground. It serves only as a temporary holding tank for the hazardous material. The contents must be pumped out into another tank to be transported for final disposal. The bag is intended to be thrown away after use.

Bag Holder (37)

The fabric storage bag is itself stored within an aluminum housing. This housing is fabricated from corrugated sheet. It has a quick opening dam to provide access to the bag.

Skid (37)

The skid is constructed of aluminum. The pump, hose reels, bag holder and piping assembly are attached to it. Lifting lugs are provided so that the entire assembly can be lifted on/off the truck.

COMPONENT AND SYSTEM COSTS

The system as specified by MSA was broken down into its individual components. Manufacturers or distributors of the components were contacted to get current prices. Vendor communications are cited in the Reference section. Prices were requested on quantities sufficient to build one, fifty and one hundred collection systems at a time. For the pumping unit that would be assembled by the system manufacturer, labor was estimated based on typical shop practices. Labor costs were calculated based on a fully burdened rate of $30 per hour.

The results of this cost breakdown study are shown in Table 4. For building the pumping units, the total cost to the manufacturer for labor and materials is: $6,925 for one; $5,622 for 50; and $5,381 for 100. As shown in Table 4, the total cost to a manufacturer is $20,381 when the cost of the disposable collection bag is added. If we mark-up the cost of materials by 15% to reflect overhead and wish to sell the equipment for a typical mark-up of two and one-half times its cost, the unit selling price for 100 units becomes $58,078.

TABLE 4. COST OF COMPONENTS

COMPONENT	COST ($) PER SYSTEM WHEN BUILT IN QUANTITES OF: 1	50	100	VENDOR REF.
Engine Driven Pump	952	857	814	18, 19
Hose Reel With S.S.	770	732	693	35, 36
Hose Reel For Storage Only	280	266	252	35, 36
Suction Hoses (2)	1,320	950	865	20, 21
Discharge Hose (with ends)	420	420	360	30, 31
Basket Suction Strainer	428	364	364	29
Suction Selector Valve	475	356	356	23, 24
Discharge Fittings-Sockets (2)	718	647	647	32, 33
Discharge Fittings - Plugs (1)	280	252	252	32, 33
Gas/Priming Can (1 Gal)	18	14	14	29
Suction Line Fittings (2 pair)	167	142	142	25, 26
Coarse Strainer	5	4	4	29
NPT Hose Ends (4)	88	79	79	29
Miscellaneous Hardware	10	10	10	29
Material for Piping Assembly	207	187	187	29
Skid Material	178	71	71	37
Burdened Labor ($30/hour)	255	120	120	
Bag Holder Material	234	91	91	37
Burdened Labor ($30/hour)	120	60	60	
Bag*	15,000	15,000	15,000	5
SYSTEM COST	21,925	20,622	20,381	

* An alternate estimate of $7,000 has been suggested by MSA Research Corporation for a modified bag design (10). See Appendix B.

It should be noted that the value of the labor added by the system assembler is small. The major thing that he is providing is the design for an integrated, prepackaged system. The end user could put together a similar system, which would not be as nicely packaged, for almost half the cost of the specified system.

POSSIBLE COST REDUCTIONS

There are a number of areas where design or material changes could be made to reduce the cost of the system. In many instances, these changes have a negative impact on the life, ease of use, and possibly the safety of the system. It is beyond the scope of this project to study the implications of every possible design change. However, in discussing the options, we have tried to point out the questions that must be answered before the changes are made.

Table 5 summarizes design modifications that will result in reductions in cost from the MSA-specified design. Table 5 also presents the potential cost savings when one, fifty and one hundred modified units are built at a time. Vendor references for component specifications and costs are also provided. Details of the potential modifications are described below.

Hose

Use of a Gates 45 HW one and one-half inch diameter hose (20, 21) instead of a Titeflex metal braid hose (30, 31) would reduce the cost by $320. However, build-up of static electricity could become a problem. Use of a rubber hose (Gates 39 HW) for both suction and discharge would save $1026 (20, 21). Use of a spiral reinforced PVC hose (Tigerflex General Purpose or Pacific Echo Spiralite 120) for suction and discharge would increase the savings to $1515 (22, 38, 39). However, with rubber or PVC, static build-up could be a hazard, and rapid degradation could occur with some spilled materials.

By carrying the pump to the spill, a short length of PVC spiral reinforced suction hose could be used together with approximately 100 feet of flat PVC hose (Kuriyama Flat PVC or Pacific Echo Spiralite 210) for discharge (22, 38, 39). This would result in a savings of $1558 and would eliminate some of the connectors. The weight of the pump, 65 pounds, makes this a feasible option. In these cases, the hose would be treated virtually as a disposable item, although it must be capable of retaining its strength long enough to pick up a single spill. However, moving the pump close to the spill could present an explosion hazard.

Using one size smaller diameter hoses would reduce the price of hose by about 10% and is thus probably not worthwhile.

TABLE 5. POSSIBLE COST REDUCTIONS

COMPONENT	SAVINGS PER UNIT WHEN BUILDING: 1	50 UNITS	100	VENDOR REFS.
1. Hose				
a. Replace Titeflex with 1 1/2 Gates	320	340	290	20, 21
b. Use rubber water hose for suction and discharge	1,026	835	690	20, 21
c. Use spiral PVC	1,515	1,201	1,056	22, 38, 39
d. Use flat PVC for discharge	1,558	1,243	1,098	22, 38, 39
2. Hose Reels				
a. Eliminate both reels	1,050	998	945	35, 36
b. Use two dry storage type	490	465	441	35, 36
3. Pump				
a. Use a cast iron pump	705	634	603	40, 19
b. Use a plastic pump	677	623	588	41, 42
4. Piping Assembly				
a. Use galvanized steel	165	149	149	29
b. Use PVC	181	164	164	29
5. Suction Valve				
a. Two S.S. Butterfly	278	206	206	46, 47
b. Two PVC ball	362	270	270	48, 49
c. Single suction port	475	356	356	23, 24
6. Suction quick connects				
a. Steel	112	121	121	28
b. Plastic	140	131	131	28
7. Discharge Quick Connects				
a. Single Hansen coupling	389	353	353	32, 33
b. Single connection with PVC valves	909	830	830	32, 33
c. Two connectors with steel Hansen couplings	526	473	473	32, 33
d. Two connectors with brass Hansen couplings	637	574	574	32, 33
8. Suction Strainer of Plastic or Steel	358	303	303	29
9. Fabric Cover for Storage Bag	304	116	116	estimate
10. Storage Bag*				
a. Pillow bag (7000 gal.)	5,354	5,354	5,354	5
b. Pillow bag (5000 gal.)	6,962	6,962	6,962	5

* R.H. Hiltz of MSA Research Corporation has suggested that a cost reduction of $8,000 to $10,000 may be realized if additional design modifications are implemented (10). Appendix B.

Hose Reels

The hose reels can be eliminated at a savings of $1050. If dry storage reels (Hannay C-8226-33-34) are used in place of the specified reels, the savings would be $490 (35, 36). In either case, it would take longer to deploy the system at the spill site.

Pump Material

A pump made of cast iron (ITT Marlow 2AM32) (40, 19) could be substituted for the stainless unit at a savings of $705. This substitution would require periodic rebuilding of the pump to replace corroded components at a cost of about $180. A plastic pump (Marland 864326-974-853) could also be used at a savings of $677 (41, 42). However, plastic is susceptible to chemical attack, as well as to rapid wear from abrasive materials in the pumpage. A study would be required to determine relative material lifetimes under field conditions. Gorman-Rupp pumps promise similar cost benefit trade-offs (46, 47).

Piping Assembly

The assembly could be constructed from galvanized steel (saving $165) or PVC (saving $181) (29). As with the hose and pump material, the lifetime of the assembly might be reduced.

Suction Valve

This valve can be replaced by two stainless ball valves, Milwaukee BB-SS300, (46, 47) saving $278, by two Hayward PVC ball valves (48, 49), saving $362, or eliminated entirely (saving $475). Use of two ball valves is equivalent to the single three-way valve in versatility. Eliminating the valve completely means that spilled material cannot be removed from two areas simultaneously.

Suction Quick Connects

A savings of $112 could be achieved by using steel couplings. Use of plastic would save $140 (28). Material lifetime might be shortened.

Discharge Quick Connects

If only one connection were provided at the pump discharge, it would be necessary to shut down the pump while changing bags. The savings would be $389. If this single connection used PVC valves at the bag and pump end for shut off, the savings would be $909. There would be no leakage as long as the operator closed the valves before disconnecting the line.

If two connectors are provided, as in the current design, the material used for the Hansen couplers (32, 33) could be changed to brass (saving $637) or steel ($526). Material lifetime might be reduced.

Suction Strainer

The basket-type strainer on the pump inlet could be made of plastic or steel instead of stainless (29). For either substitution, the savings would be $358.

Storage Bag Holder

This aluminum box could be eliminated. The storage bag could instead be encased in a quick-opening valve cover at estimated savings of $304.

Storage Bag

Any system manufacturer would have to look closely at finding ways to reduce the cost of the storage bag. In our opinion, cost reduction by a factor of 5 to 10 is desirable to increase the commercial viability of the system. It is by far the most expensive item. In addition, the bag is intended to be thrown away after use.

A less expensive pillow-type bag has been designed more recently by MSA under an Air Force Contract. The general design for this bag is shown in Figure 5. The price quote from Helios Industries for the pillow bag design is $9,646 (quantity 1 to 100) for a 7000-gallon capacity bag and $8,038 (quantity 1 to 100) for a 5000-gallon capacity bag (5). The cost savings with respect to the original MSA design are $6,962 and $5,354, respectively. It should be noted, however, that a pillow bag, when filled, will only be stable on level ground. On sloping or uneven ground, a pillow bag would require a stabilizing support structure. MSA Research Corporation has suggested additional design modifications in the interest of cost reduction. The modifications and their estimated impact on cost are discussed in Appendix B. A modified segmented bag is expected to cost $7,000, a modified pillow bag, $5,000.

Additional cost reductions may be realized if automation can be introduced in the bag manufacturing process. The cost of special jigs and fixtures to support automation must be recoverable through quantity orders. Reducing the cost per bag to a commercially viable level may be possible if markets can be identified that will support sufficiently high-quantity orders.

REDUCED COST SYSTEM

Based on the preceding work, we can define a new system whose major design premise is to keep costs down. In this system, the pump would still be mounted on the skid but would be constructed of cast iron. Spiral reinforced PVC hose would be used. The hose would be coiled and placed on the skid (i.e., no hose reels) when not in use. Connections would be made with PVC quick connects. Two suction connections with PVC valves would be provided. A PVC suction strainer within PVC skid piping would be used. A single discharge connection with PVC ball valves would be provided, and the system would use a pillow bag stored in a fabric cover.

1. Bag
2. Ground Cloth
3. Carrying Case
4. Inlet
5. Outlet
6. Vent Pipe
7. Relief Valve
8. Pipe Cap

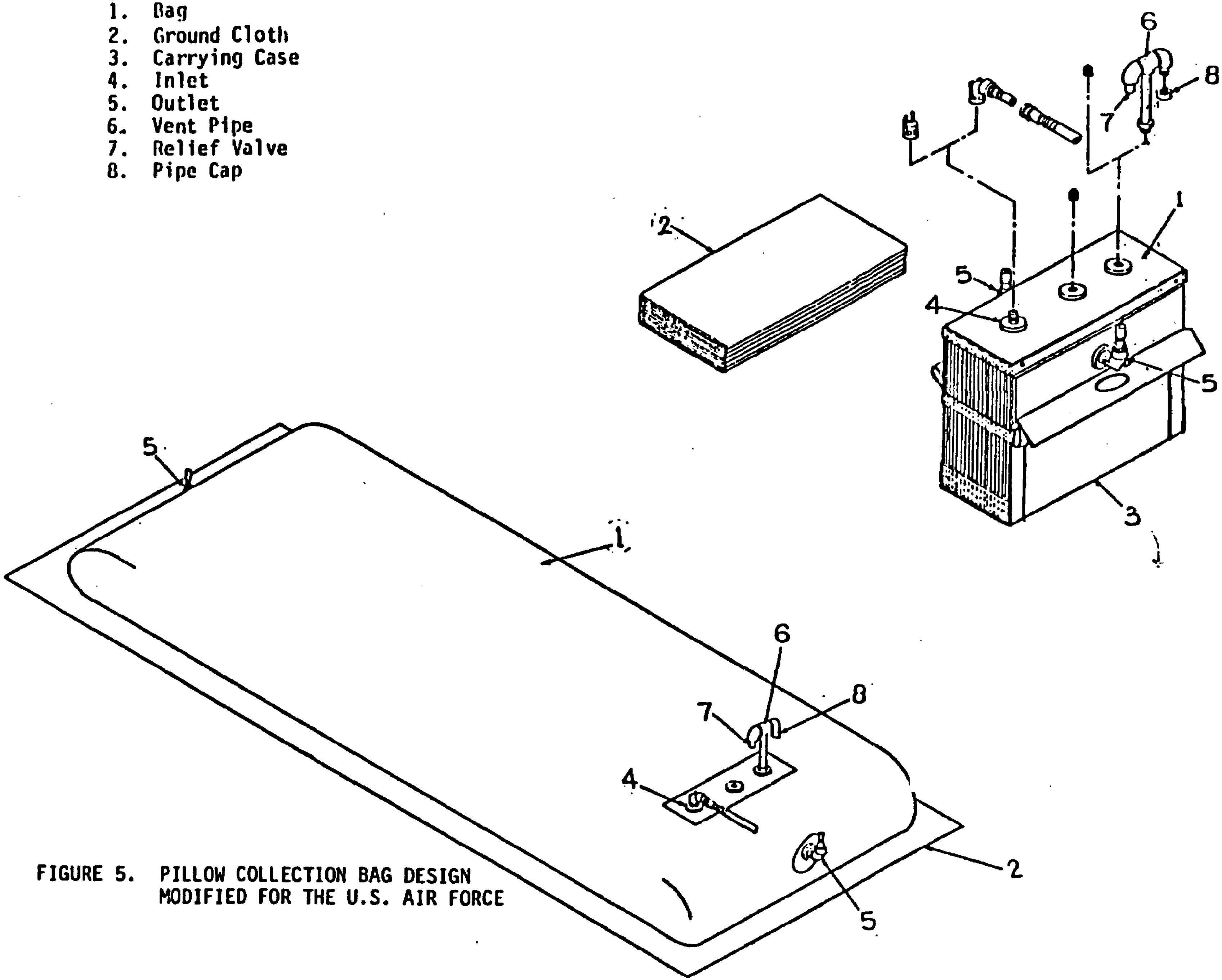

FIGURE 5. PILLOW COLLECTION BAG DESIGN MODIFIED FOR THE U.S. AIR FORCE

The revised system costs, which incorporate most of the cost savings presented in Table 5, are shown in Table 6. This system would not be as easy to deploy or operate. Furthermore, components might fail more rapidly than in the system specified by MSA. The pillow bag would require an additional support structure if used on non-level ground. Typical selling prices are noted in Table 7.

TABLE 6. COSTS COMPARED

	QUANTITY 1	50	100
System I, MSA	21,925	20,622	20,381
Pumping Unit	6,925	5,622	5,381
Storage Bag	15,000*	15,000	15,000
System IIa, (Cost Reduced)	11,258	10,803	10,691
Pumping Unit	1,612	1,157	1,045
Bag (Pillow Design - 7000 gallon)	9,646**	9,646	9,646
System IIb, (Cost Reduced)	9,650	9,195	9,083
Pumping Unit	1,612	1,157	1,045
Bag (Pillow Design - 5000 gallon)	8,038	8,038	8,038

* Alternate estimates of $7,000 and ** $5,000 were obtained from MSA Research Corporation (see Appendix B).

TABLE 7. SELLING PRICE*

System I, MSA	58,078
Pumping Unit	14,953
Replacement Storage Bag (7000 gal.)	43,125**
System II, Cost Reduced	25,596
Pumping Unit	2,487
Replacement Storage Bag (5000 gal.)	23,109

* Selling Price = [(cost of material)1.15 + burdened labor]2.5

** An alternate selling price of $19,125 is obtained when using the cost estimate of $7,000/bag provided by MSA Research Corporation (Appendix B).

INITIAL MANUFACTURING COSTS

Any potential manufacturer will face start-up costs before production can begin. These costs will be associated with design review, preparation of drawings and preparation of manufacturing facilities. The additional costs associated with advertising and marketing are not considered.

The goal of the design review will be to select each item in the system. Questions such as those raised in the cost reduction discussion will have to be answered. Firm quotations must be obtained from all vendors. This stage will require the services of an engineer and a purchasing agent. It will result in component specifications and system sketches for drafting. It is estimated that 80 hours of engineering time and 40 hours of purchasing time will be required for the skid-mounted pump unit. The disposable bag will require an additional design effort focussed on fine-tuning the bag design. It is estimated that 100 hours of engineering effort will be sufficient to develop a design with acceptable trade-offs among manufacturability, cost, and field performance characteristics. This redesign effort should be conducted in close consultation with potential bag manufacturers and will require an estimated 20 hours of support from the purchasing agent.

The next step would be for a draftsperson to produce shop drawings from the engineer's sketches. This would be straight forward and would require 40 hours plus 2 hours for engineering services.

The manufacturing area would also have to be set up. The amount of set-up required is small even when quantities of 100 units are envisioned. This is because the amount of labor involved per system is so small. Some time will be spent on producing templates, jigs and fixtures. Between this and the establishment of a quality control and testing procedure, we estimate 25 hours of work by a shop foreman.

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52. Schweber, Bedford, Massachusetts. Quotation from Virginia Bruce, Sales Representative, June 1983.

53. Arrow, Woburn, Massachusetts. Quotation from Sales Representative, June 1983.

54. Impact Sales, Canton, Massachusetts. Quotation from Donald Terrasi, Sales Representative, June 1983.

55. Semiconductor Specialists of America, Inc., Rutland, Vermont. Quotation from Virginia Kelley, Sales Representative, June 1983.

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61. Skydyne, Port Jervis, New York. Quotation from Mike Barnansky, Sales Representative, June 1983.

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63. Rotron Inc./EG&G, Wakefield, Massachusetts. Quotation from Sales Representative, June 1983.

64. Cambion, Cambridge, Massachusetts. Quotation from Sales Representative, June 1983.

65. Cronin Electronics, Cambridge, Massachusetts. Quotation from Sales Representative, June 1983.

66. Cole-Parmer Instrument Company, Chicago, Illinois. Quotation from Julia Sturgeon, Sales Representative, June 1983.

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APPENDIX A

CAM-4 PARTS LIST

Parts	Description	Manufacturer or Supplier	PART #
DVM BOARD (FIGURE 5a)			
Printed Circuit Board		Teletron	1
ADC-1100	Analog to Digital Converter	Analog Devices	2
IC1	LM741CN Operational Amplifier	National Semiconductor	3
IC2	7400 Quad Nand Gate	National Semiconductor	4
IC3	MC846P	Motorola	5
T1	2N3904 NPN	Semiconductor Specialists	6
T2	2N3905 PNP	Semiconductor Specialists	7
T3	2N3565 NPN	Semiconductor Specialists	8
T4	MPF102 FET	Semiconductor Specialists	9
Z1	ZB82A Zener	Semiconductor Specialists	10
D1, D2	1N914 Diodes	Semiconductor Specialists	11
C1, C2	22 µf/25 v Tantalum caps.	Newark	12
C3	0.02 µf Mylar cap.	Newark	13
R1, R5	3.3 KΩ 1/4 w Resistor	Newark	14
R2	1.5 KΩ 1/4 w Resistor	Newark	15
R3	1.0 KΩ 1/4 w Resistor	Newark	16
R4	2.7 MΩ 1/4 w Resistor	Newark	17
R6	470 Ω 1/4 w Resistor	Newark	18
P1	50 KΩ Trimpot 3006P-1-503	Bourne Newark	19
P2	1 MΩ Trimpot 3006P-1-105	Bourne Newark	20
* Resistors are 1/4 w unless otherwise identified.			21
POWER SUPPLY BOARD (FIGURE 5b)			
Printed Circuit Board		Teletron	22
BR1	Bridge Rectifier W110	Semiconductor Specialists	23
BR2, BR3	Bridge Rectifier KBPC8005, KBPC1005	Semiconductor Specialists	24
Regulator 1	7805	Semiconductor Specialists	25
Regulator 2	4195	Semiconductor Specialists	26
IC1	LM555CN	National Service	27
C1, C2	220 µf/35 v Electrolytic		28
C3	5,000 µf/10 v Electrolytic		29
C4	0.1 µf Electrolytic		30
R1	3.3 Ω, 1/2 w		31
R2	220 Ω 1/4 w		32
TIMER AND TRIAC SWITCH BOARD (FIGURE 7)			
Printed Circuit Board		Teletron	33
IC1	Timer LM555CN	National Semiconductor	34
IC2, IC3, IC4	TTL Decade Counter 7490	National Semiconductor	35
IC5	Decade Decoder 7442	National Semiconductor	36
IC6	Triple 3 input Nand 7410	National Semiconductor	37
IC7	Dual 4 input Nand 7420	National Semiconductor	38
IC8	8 input Nand 7430	National Semiconductor	39
IC9, IC10	Optical Isolators 7N28	Motorola	40
IC11	DTL Gates 660P	Motorola	41
T1	2N3905	Semiconductor Specialists	42
T2, T3, T4, T5	2N3565	Semiconductor Specialists	43
T6	2N3906	Semiconductor Specialists	44
T7, T8	RCA Triac Type 40526	Semiconductor Specialists	45
D1, D2	Trigger Diode MBS4991	Semiconductor Specialists	46
D3	IR170 Rectifier	Semiconductor Specialists	47

Parts	Description	Manufacturer or Supplier	
TIMER AND TRIAC SWITCH BOARD (FIGURE 7) Contd.			
Z1	Zener (15 v) 2B15A	Semiconductor Specialists	48
P1	1 MΩ Trimpot Spectral Type 43P105	Semiconductor Specialists	49
P2	50 KΩ Trimpot Spectral Type 43P504	Semiconductor Specialists	50
C1	1 uf Mylar	Newark	51
C2, C3, C6	0.005 uf	Newark	52
C4	4 uf/250 v Electrolytic	Newark	53
C5	0.022 uf Electrolytic	Newark	54
R1, R2, R3, R4	1.2 K Electrolytic	Newark	55
R5	10 K Electrolytic	Newark	56
R6	1,500 Ω Electrolytic	Newark	57
R7, R8, R9, R10	3.3 K Electrolytic	Newark	58
R11, R12, R13, R14	180 Ω Electrolytic	Newark	59
R15, R16	42 K Electrolytic	Newark	60
R17, R18	8.2 K Electrolytic	Newark	61
R19	3 KΩ 6 w Electrolytic	Newark	62
INVERTER AND OTHER PARTS (FIGURES 2, 3, 6, 8)			
Case	Model 92500	Skydyne, Inc.	63
Hardware Mounting Panels		Teletron	64
Printer	DPP-7	Datel	65
Inverter	Model 12-115	Nucleonic Products, Inc.	66
Transformer	UP6377		67
Transformer	40 v CT Type 18A1487	Burstein Applebee	68
Regulator (5 v)	LM309		69
PC Sockets	225-22221-401(117)	Amphenol	70
Card Guide (6 req.)	T-309-48	Cambion	71
Spacers	T-101-300	Cambion	72
Extractor (6 req.)	S-200	Cambion	73
Extrusions for card cage	XTS-802-36	Cambion	74
Binding Posts	Type 29-1	Grayhill	75
SW1	Type 7693K2 4PDT	Cutler Hammer	76
SW2, SW3, SW4	MTA106D	Alco	77
Leds (3 req.)			78
AC Connector			79
AC Power Cord			80
Water Pump, Gear	Delrin Plastic No. 7012	Cole Parmer	81
Air Blower	Sprite Tubeaxia/fan	Rotron	82
Substrate Pump	Rotor	Scientific Industries	83
Substrate Pump	Tubing Support	Scientific Industries	84
Substrate Pump	Outboard Bearing Plate	Scientific Industries	85
Air Pump	Aquarium Type	Hush	86
Electrochemical Cell Holder		Teletron	87
Electrochemical Cell Injection Molded with Platinum Anode and Cathode		MRI	88

CAM-4 PARTS LIST UPDATE, VENDORS AND COSTS

PART NO.	MANUFACTURER OR SUPPLIER	COST LIST PRICE	VENDOR REF.
DVM BOARD			
1	P.M. Associates (Set-Up 90.00)	7.65	50
2	Analog Devices	132.00	51
3	Schweber	.75	52
4	National/Arrow	.25	53
5	Motorola/Impact Sales	.93	54
6	Arrow	.08	53
7	Arrow	.46	53
8	Arrow	.24	53
9	Semiconductor Specialists	2.00*	55
10	Semiconductor Specialists	.75*	55
11	Arrow	.02 (2)	53
12	Greenshaw	.81 (2)	56
13	Millgray/Greenshaw	.99	56
14	Schweber	.08	52
15	Schweber	.08	52
16	Schweber	.08	52
17	Schweber	.08	52
18	Schweber	.08	52
19	Gerber	1.20	57
20	Gerber	1.20	57
POWER SUPPLY BOARD			
22	P.M. Associates; (Set-Up 90.00)	7.65	50
23	Semiconductor Specialists	1.10	55
24	Semiconductor Specialists	3.85	55
25	Harvey Electronics	.60	58
26	Semiconductor Specialists	1.50	55
27	Schweber	.40	52
28	Gerber	.63	57
29	Gerber	3.24	57
30	Arrow	.14	53
31	Gerber	.33	57
32	Schweber	.08	52
TIMER AND TRIAC SWITCH BOARD			
33	P.M. Associates; (Set-Up 90.00)	7.65	50
34	Schweber	.40 (2)	52
35	National/Arrow	.33	53
36	Gerber	.44	57
37	National/Arrow	.25	53
38	National/Arrow	.25	53
39	National/Arrow	.42	53

PART NO.	MANUFACTURER OR SUPPLIER	COST LIST PRICE	VENDOR REF.
40	Motorola/Sager	.90 (2)	59, 60
41	Motorola/Sager	2.25	59, 60
42	Arrow	.46	53
43	Arrow	.24 (2)	53
44	Arrow	.12	53
45	Semiconductor Specialists	4.00* (2)	55
46	Semiconductor Specialists	1.00* (2)	55
47	Semiconductor Specialists	5.00*	55
48	Semiconductor Specialists	.48	55
49	Semiconductor Specialists	1.75	55
50	Semiconductor Specialists	1.75	55
51	Impact Sales	.26	54
52	Gerber	.11 (3)	57
53	Arrow	.23	53
54	Arrow	.21	53
55	Arrow	.14 (4)	53
56	Arrow	.17	53
57	Arrow	.12	53
58	Arrow	.14 (4)	53
59	Arrow	.11 (4)	53
60	Arrow	.18 (2)	53
61	Arrow	.12 (2)	53
62	Arrow	.14	53
CASE			
63	Skydyne, Inc.	107.90	61
64	MC Speciality	55.00 (2)	62
82	Rotron	17.60	63
PRINTER			
65	Datel (AC only)	575.00	16
AC/DC ADAPTOR			
66	Nucleonic Products	15.00*	--
67	Stancor/Gerber	10.05	57
68	Stancor	15.00*	--
69	Gerber	2.09	57
PC BOARD MOUNTING HARDWARE			
70	Schweber	3.12	52
71	Cambion	.17 (6)	64
72	Cambion	2.00*	64
73	Cambion	.18 (6)	64
74	Cambion	3.50*	64
FRONT PANEL, MISCELLANEOUS			
75	Sager	1.62 (3)	58, 59
76	Cutler Hammer/Impact Sales	1.50	54

PART NO.	MANUFACTURER OR SUPPLIER	COST LIST PRICE	VENDOR REF.
77	Sager	2.25 (3)	58, 59
78	Gerber	.60 (3)	57
79	Cronin Electronics	15.15	65
80	Beldon/Gerber	2.34	57
PUMPS			
81	Cole-Parmer/Greylor	34.00	13, 14, 66
83, 84, 85	Scientific Industries	158.00	15
86	Cole-Parmer	8.75	13, 66
89 (not listed)	VWR (tubing, traps)	4.15	67
ELECTROCHEMICAL CELL			
87	MC Specialty (holder assembly)	28.00	62
88	Engineering Estimate; (mold charge 300.00)	85.00	--
90 (not listed)	MC Speciality (holder)	18.00	62

* Part not identified, cost estimated by device type.
() Quantity used in assembly.

MSA Research Corporation • Evans City, Pennsylvania 16033 • Telephone 412/538-3510

23 August 1983

APPENDIX B

Dr. Barbara Offenhartz
B & M Technological Services, Inc.
520 Commonwealth Avenue
Boston, MA 02215

Dear Dr. Offenhartz:

With reference to our telephone conversation of August 22, 1983, the following are the areas where cost cutting modifications could be made to the emergency collection system.

As we discussed, the costs for bags you have received from Helios are out of line with what I expect if the bags were made to commercial practice. I am sure Helios is quoting a price based upon the current Air Force specification they are meeting. I am sure the pillow bag could be obtained for a price around $5000 and the segmented bag for about $7000.

The above assumes the following: plastic flanges with standard gasketing, a fold and roll type of package rather than the accordian pleats required by the Air Force, and standard hardware rather than positive closure quick disconnects.

It should be noted in selecting a bag design that pillow bags will roll on a slope as shallow as one-half degree.

The box to house the bag could be eliminated and the bag stowed in some other fashion. The Air Force uses a tear away plastic carrier which protects the bag which is relatively expensive. Additionally, it provides easier handling when moving the bag.

Modifications can also be made in the storage of hoses. In the current configuration one reel has an integral connection through an internal rotating seal. This could be eliminated and replaced with external manual connections for the hoses to the pumping system. It is possible to consider elimination of the hose reels completely. A simple box could be used to hold coiled hoses. Note that the minimum bend radius for 2" chemical hose is 5". This bend can be achieved using the reel. If the hose is hand coiled, even directly into a box, 2 in" should be added to the inside bend radius because of the rigidity of the hose.

The pallet is formed aluminum. It was selected because of weight. A wooden pallet would be significantly cheaper but should be treated for chemical resistance.

The above are the main areas for cost reduction. Some other reductions could be made by changes in the plumbing. The three way valve could be replaced by 2 two way ball valves, and the positive closure provision of the quick disconnects could be eliminated. I have some problem with the latter. The cost difference is small but the hazard factor is large. Without positive closures the hazardous material can leak out when disconnecting hoses, etc. More importantly, actuation of the system without all connections properly made can result in uncontrolled discharge of the hazardous material being collected.

I hope the above will be beneficial to your report. Based upon our cost analysis of one year ago, these modifications taken collectively would reduce the price by about 40%.

Sincerely,

Ralph H. Hiltz

/bhh

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

Project Officer: Mary K. Stinson (201) 321-6683

16. ABSTRACT

Thirteen spill response devices, concepts, or prototypes, developed under previous contracts to the U.S. Environmental Protection Agency for detection, containment, and cleanup of chemicals, were evaluated by potential users and manufacturers. The main goal of this project was to inform potential users and manufacturers of the existence and technical functions of each concept, device, or prototype; its stage of development; and its intended uses. The evaluations in this report were offered by potential users and manufacturers after they examined the devices or the available technical literature on the devices. The 13 devices included: the capture and containment bag; the cholinesterase antagonist monitors (CAM-1 and CAM-4); the emergency collection system; foamed concrete; the insoluble sinkers detectors; the hazardous materials identification kit (HMIDK); the lactate dehydrogenase (LDH) test method; the leak plugger; the oxidation/reduction field test kit; the particle size analyzer; the sorbent oil recovery system; vapor control coolants; and vapor control foams. The activities used to inform potential users and manufacturers about the devices included presentations, mailings, exhibits at conferences, and publications in trade magazines. In addition, value engineering analyses were performed for two prototypes. These activities resulted in many valuable comments from potential users and manufacturers which may be beneficial to future development programs for these and similar devices. The study generated a high degree of interest in most of the prototypes.

17. KEY WORDS AND DOCUMENT ANALYSIS

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