To the Graduate Council:

I am submitting herewith a thesis written by Anne Carol Prosser Ostergaard entitled "Evaluation and Analysis of Waste Generation and Cost Trends Related to Pollution Prevention Opportunities in the Government-Owned Research and Development Laboratory Setting." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for a degree of Master of Science, with a major in Environmental Engineering.

Professor R. Bruce Robinson

We have read this thesis
and recommend its acceptance:

Accepted for the Council

Associate Vice Chancellor
and Dean of The Graduate School

Evaluation and Analysis of Waste Generation and Cost Trends Related to Pollution Prevention Opportunities in the Government-Owned Research and Development Laboratory Setting

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Anne Carol Prosser Ostergaard

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ABSTRACT

Laboratory operations perform extremely diverse activities and account for less than 1 percent of the hazardous waste generated nationwide; consequently, until recently, pollution prevention activities were not strongly emphasized or documented. Due to the laboratories' roles in society, however, pollution prevention opportunity assessments and implementation in the laboratory environment are essential. Laboratories are often where new production and operational innovations originate and where many of tomorrow's engineers and scientists are educated and indoctrinated. The initial integration of pollution prevention concepts in the laboratory can result in significant reductions in waste in future operations. The Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) recognized that the integration of pollution prevention into its activities was essential and supported this study as well as other pollution prevention activities, including implementation.

This study established a methodology and gathered data in an iterative manner. The 1992 M&C Division's activities that generated nonradioactive Resource Conservation and Recovery Act (RCRA) hazardous wastes were examined. First, through data gathering, these operations were defined, and waste sources were determined. Current and potential pollution prevention opportunities were also identified and quantified. Due to the increased hazard of these wastes and related materials, additional precautionary activities are required. These added requirements and quantifiable associated costs were identified by gathering data from the initiation

of a purchase requisition requesting a hazardous material through future disposal of the resulting nonradioactive RCRA hazardous waste. The added requirements and associated costs were placed in one of four categories: (1) procurement, (2) general environmental, safety, and health, (3) usage and storage, and (4) waste management. The added costs were also categorized by the type of funding: (1) direct research and development (R&D) funding, (2) M&C overhead funding, (3) ORNL overhead funding, (4) U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management (EM) funding, and (5) non-ORNL funding, such as costs incurred by corporate auditors. The trends related to waste generation, pollution prevention, added requirements, and added quantifiable cost data were evaluated.

The resulting data showed that during 1992, M&C had generated 331 items totaling 10,557.8 kilograms (kg) of nonradioactive RCRA hazardous waste. Implemented options had already impacted a total of 149 items totaling 9,195.2 kg of waste. Potential options, if pursued by M&C, would impact 98 to 172 items totaling 939.5 to 1,252.3 kg of waste. The total added costs by funding source for these materials and wastes and the total improved productivity expressed as cost avoidance for implemented and potential options were:

Funding Source	Total Cost of Meeting Added Requirement	Total Improved Productivity from Implemented Options	Total Potential Improved Productivity from Potential Options
Direct R&D	$300,000	$100,000	$100,000 to $200,000
M&C Overhead	$500,000	$200,000	$50,000 to $100,000
ORNL Overhead	$100,000	$50,000	$10,000 to $20,000
EM	$500,000	$200,000	$100,000 to $200,000
Non-ORNL	$10,000	$6,000	$3,000 to $4,000

In general, this study found that a laboratory needs to combine information from several guidance documents and references to meet its unique pollution prevention needs. Also, because of the variety of work performed by a laboratory and resulting variety of waste streams generated, when a laboratory performs a pollution prevention opportunity assessment, it should evaluate waste generation and cost data for trends based on combinations of several units of measure and categories, not just based on mass and total cost. For instance, while evaluating the data compiled based on waste type and on type of waste generating activity, the mass-based trends were found to differ from the item-based trends. In this study, this variation was determined to be significant when the added requirements were examined, and the associated quantifiable costs were determined to be incurred on an item or event basis. Furthermore, when the cost data were assessed based on funding source, major costs were shown to be incurred by the M&C Division even though waste transportation, storage, treatment, and disposal activities were funded through EM, not by the M&C Division. Finally, several trends were observed related to pollution prevention applications. For example, source reduction had been used extensively in R&D applications as well as in support activities, and source reduction activities resulted in a higher degree of improved productivity, expressed as cost avoidance, than did recycling, reuse, or neutralization.

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LIST OF SYMBOLS AND ABBREVIATIONS

AIHCE	American Industrial Hygiene Conference and Exposition
ASO	Analytical Services Organization
AVID	Accelerated Vendor Inventory Delivery
BMP	best management practice
BNL	Brookhaven National Laboratory
DOE	U.S. Department of Energy
Elim.	elimination
EM	DOE-Headquarters Assistant Secretary for Environmental Management
Energy Systems	Lockheed Martin Energy Systems, Inc.
EPA	U.S. Environmental Protection Agency
EPO	Environmental Protection Officer
ES&H	environmental, safety, and health
Genral	general
gm	gram
HEPA	high-efficiency particulate air
Hg	mercury
HMIS	Hazardous Materials Inventory System
HP	health physics or health physicist
hr	hour

HSWA	*Hazardous and Solid Waste Amendments*
H2O2	hydrogen peroxide
ICP	Inductively Coupled Plasma Spectroscopy
IH	industrial hygiene
IR	Infrared Spectroscopy
kg	kilogram
L	liter
Lab	laboratory
LCA	life-cycle costing, analysis, or assessment
MAM	methacrylamide
MBAM	n'n'-methylene bis acrylamide
Mgt.	Management
mm	millimeter
MPEG	methoxy poly(ethylene glycol) methacrylamide
MSDS	Material Safety Data Sheet
M&C	Metals and Ceramics
m^3	cubic meter
Neut.	Elementary Neutralization
Neutralization	Elementary Neutralization
NU	Elementary Neutralization
OH	overhead
ORNL	Oak Ridge National Laboratory

ORR	Oak Ridge Reservation
PCB	polychlorinated biphenyl
PEGMA	poly(ethylene glycol) 1000 dimethacrylate
PIES	Pollution Prevention Information Exchange System
PPE	personal protective equipment
PPOA	pollution prevention opportunity assessment
PPR	Pollution Prevention Representative
PR	purchase requisition
Prev.	Prevention of Elementary Neutralization
PWA	process waste assessment
P2	pollution prevention
QA	quality assurance
RCRA	*Resource Conservation and Recovery Act*
RC	reclassified as not a RCRA waste or eliminated
RC/Elim.	reclassified as not a RCRA waste or eliminated
Reclassification/Elim.	reclassified as not a RCRA waste or eliminated
RFD	request for disposal
RR	recycle or reuse
R&D	research and development
SARA	*Superfund Amendments and Reauthorization Act*
SPCC	Spill Prevention, Control, and Countermeasures
SR	source reduction

Store/Usage	Storage/Usage
TCA	total cost assessment
TDEC	Tennessee Department of Environment and Conservation
TSDF	treatment, storage, and disposal facility
VOC	volatile organic compound
WAC	Waste Acceptance Criteria
yr	year

CHAPTER 1.0

Introduction

Over the past several decades, many environmental, safety, and health (ES&H) acts, regulations, and requirements have been established and expanded by the federal, state, and local governments. These requirements gradually instituted more stringent limitations and added responsibilities on facilities and personnel managing hazardous materials and wastes (Arbuckle et al. 1993). These added restrictions have either directly or indirectly required or supported pollution prevention-related activities.

The 1984 *Hazardous and Solid Waste Amendments* (HSWA) to the *Resource Conservation and Recovery Act* (RCRA) included the first pollution prevention-based requirements. RCRA required hazardous waste generators and treatment, storage, and disposal facilities (TSDF) to establish waste minimization programs (EPA 1984). These initial requirements, however, were minimal and resulted in varying levels of activities. Consequently, the *Pollution Prevention Act of 1990* was passed and required pollution prevention-specific reporting within part of the *Superfund Amendments and Reauthorization Act* (SARA) reporting starting in 1991 (Arbuckle et al. 1993). Several states have also enacted pollution prevention-based regulations, such as the *Tennessee Hazardous Waste Reduction Act of 1990.* Many other state regulations have set new standards impacting the management of hazardous materials and the resulting hazardous wastes (Arbuckle et al. 1993). Federal agencies, such as the U.S. Department of Energy (DOE), have also established internal pollution prevention-related orders and must

comply with other requirements such as Executive Orders (DOE 1994a). In addition to the impact of the myriad of regulations, the implementation of activities that reduce the quantity and toxicity of materials and wastes has been encouraged by:

- the increased cost of managing hazardous materials and wastes,
- the potential cost avoidance and increased productivity from implementing pollution prevention options, and
- increased public pressure (EPA 1992).

To support pollution prevention activities, several documents have been published by the U.S. Environmental Protection Agency (EPA) and other federal agencies such as the DOE, state agencies, universities, and trade associations. Although EPA issued a 1990 guidance document supporting pollution prevention in laboratories, *Guides to Pollution Prevention Research and Educational Institutions*, pollution prevention within the nation's laboratories has not received significant attention. These laboratories have been a low priority because they generate many small and varied waste streams, which total less than 1 percent of the nation's hazardous waste.

The diverse government- or privately-owned laboratory facilities may be used for:

- educational purposes to teach established scientific principles,
- research and development (R&D), including bench- or pilot-scale studies,
- direct support for existing production or operational activities,
- chemical analysis support performed for customers, or
- a combination of any of these possibilities (EPA 1990).

Because of the laboratories' roles in society, pollution prevention opportunity assessments and implementation in the laboratory environment are essential. Laboratories are often where new production and operational innovations originate and where many of tomorrow's engineers and scientists are educated and indoctrinated. For instance, if researchers have integrated pollution prevention into a new successful bench-scale process, then large reductions in waste generation can be realized in the resulting production-scale operations. Furthermore, like other facilities, pollution prevention in these laboratories can be driven by compliance with ES&H requirements and improved productivity and cost avoidance (EPA 1990; Freeman 1990).

Based on these drivers, an R&D laboratory-based pollution prevention topic was selected and sponsored by the Metals and Ceramics (M&C) Division at the DOE Oak Ridge National Laboratory (ORNL). This study assessed the 1992 M&C activities that used 3- and 4-rated hazardous materials, which resulted in the generation of nonradioactive RCRA hazardous wastes. Due to the increased hazard of these materials and wastes, additional precautionary activities related to the materials and wastes were required. For example, due to carcinogen use, M&C had to maintain a program, perform sampling and assessments, and provide and inspect special storage areas. These 1994 added requirements and related needed resources were identified and estimated. The M&C activities were also documented and examined for current and potential pollution prevention options. Current and potential improved productivity values were then approximated based on estimated cost avoidance of pollution prevention options.

CHAPTER 2.0

Objectives and Scope of Thesis

2.1 Objectives

The overall objective of this study was to determine if M&C's laboratories (1) are incorporating pollution prevention techniques that are not generally known or documented and (2) have other pollution prevention opportunities that could be implemented. Specifically, it was believed that:

- pollution prevention techniques being used had resulted in approximately a 25 percent (by mass) decrease in hazardous waste generation,
- another 25 percent (by mass) decrease in hazardous waste generation could be realized if laboratories were provided with specific guidance, information, and resources and allowed to assess their activities and implement pollution prevention opportunities, and
- 50 percent of existing and possible pollution prevention options would result in improved productivity (cost avoidance) once the added requirements and associated quantifiable costs related to generating hazardous waste were identified and estimated.

The enabling objectives that supported testing the overall objective were:

(1) to define the terminology and the selected laboratory and associated waste generating activities,

(2) to perform a review of available literature to:

- determine appropriate pollution prevention-related applications, and
- ascertain germane added requirements and quantifiable associated costs,

(3) to develop and establish the methodology and data-gathering approach:

- for identifying the waste sources and related pollution prevention opportunities and
- for identifying added requirements and associated quantifiable costs related to M&C activities using 3- and 4-rated materials and generating the resulting hazardous wastes (when compared to operations that do not use 3- and 4-rated materials or that generate less hazardous wastes),

(4) to gather required data, to determine the waste reduction from implemented and potential pollution prevention options, and to estimate the impact of pollution prevention options on productivity, and

(5) to evaluate trends (waste generation, pollution prevention applications, added requirements and associated quantifiable costs, and changes in productivity).

2.2 Scope

2.2.1 Term Definition

Acts, regulations, guidance documents, and generators have used several pollution prevention-related terms, including waste reduction, waste minimization, and pollution prevention, to describe activities that reduce the quantity or toxicity of a

material or waste. These terms also have been inconsistently defined and, therefore, inconsistently used (Freeman 1990). DOE defined waste minimization/pollution prevention to include:

> Activities that involve source reduction and recycling of all wastes and pollutants, and includes those other practices that reduce or eliminate pollutants through increased efficiency in the use of raw materials, energy, water, or other resources, or the protection of natural resources by conservation (DOE 1994b).

Because activities at a DOE laboratory were evaluated, this study adopted DOE's definition, which is referred to as pollution prevention in this report.

Treatment using elementary neutralization was also included because it could be performed in M&C areas. In the RCRA regulations, an elementary neutralization unit is defined and is exempt from TSDF permitting. Elementary neutralization may not be used to remove metals or other hazardous constituents and usually involves adding an acid or base to an aqueous liquid to adjust the pH to approximately 7 (EPA 1994).

2.2.2 Laboratory Setting Selection

As summarized in Chapter 1.0, the M&C Division at ORNL was chosen for this study. During data gathering in 1993 through 1994, the M&C Division was mainly providing technical support in the area of high-temperature materials related to technologies used by the government and private sectors. This technical support

included basic and applied research, engineering development, and industrial interactions. The M&C Division also performed activities supporting this R&D work, such as technical photography (ORNL 1993a). Specifically, the laboratory activities that used 3- and 4-rated hazardous materials and generated the resulting nonradioactive RCRA hazardous waste in 1992 were defined. The 1994 added requirements impacting these activities and related data were then assessed.

CHAPTER 3.0

Literature Review

This literature review focused on information that discussed pollution prevention opportunity assessment and costing methodologies and pollution prevention applications related to the examined M&C R&D and support activities. The gathered information has been presented starting with more general topics that lead to more specific topics. This discussion of reviewed literature was organized based on relevant components related to: (1) pollution prevention programs, (2) pollution prevention opportunity assessments, (3) wastes and pollution prevention options related to R&D and support activities, (4) costing methodologies, and (5) requirements and resources related to 3- and 4-rated materials and resulting nonradioactive RCRA hazardous wastes at ORNL.

Many articles, guidance documents, and references reviewed generally addressed pollution prevention. These resources either described:

- the recommended elements of a pollution prevention program and the process for establishing this program or
- the process steps for performing a pollution prevention opportunity assessment and the potential resulting options.

Several reviewed documents were not included because they addressed aspects of pollution prevention that did not directly apply to this study. This report only includes references containing information used to support this study.

3.1 Program Components Related to Assessment and Costing Methodologies

The resources concerning setting up a program were reviewed for any components that would be pertinent to a pollution prevention opportunity assessment, such as an element that addressed materials and waste management costs and cost avoidance. Many articles and references discussed the process for establishing a pollution prevention program. These program-based references described similar elements and included:

- the EPA interim final *Guidance to Hazardous Waste Generators on the Elements of a Waste Minimization Program* (EPA 1993a),
- *Hazardous Waste Minimization* (Freeman 1990),
- articles from journals and publications, such as "Waste Minimization-Part 1, Prepare an Effective Pollution-Prevention Program" (Rittmeyer 1991),
- the DOE guidance documents, *Model Waste Minimization and Pollution Prevention Awareness Plan* (DOE 1991a), *Guidance for the Preparation of the Waste Minimization and Pollution Prevention Awareness Plan* (DOE 1993a), and *DOE Order 5400.1 Site WMin/PP Awareness Plans DOE-wide Implementation Guidance-Update* (DOE 1994a),
- the State of Tennessee guidance documents such as *Writing a Waste Reduction Plan: Charting Your Company's Course Towards Better Waste Management* (UT 1993), and
- the program plan written specifically for ORNL, the *Oak Ridge National Laboratory Pollution Prevention Program Plan* (ORNL 1994a).

Because of the similarities among the references examined, only the EPA interim final *Guidance to Hazardous Waste Generators on the Elements of a Waste Minimization Program* was chosen to be presented in this chapter. This guidance document provided an overview of elements of a pollution prevention program:

- top management support,
- characterization of waste generation and waste management costs,
- periodic pollution prevention opportunity assessments,
- a cost allocation system,
- encouragement of technology transfer, and
- program implementation and evaluation (EPA 1993a).

Top management support, encouragement of technology transfer, and program implementation and evaluation elements have continued to be important for the overall program success. However, these elements were already supported at ORNL (ORNL 1994a) and were not directly addressed in this study. Portions of the remaining elements were found to be generally applicable to this study.

The element addressing characterization of waste generation and waste management costs summarized the need for maintaining a waste tracking system and for determining the costs associated with waste management and cleanup. This element recommended that the waste tracking system encompass many parameters related to a waste including the type, amount, hazardous constituents, generation rate, and generation date. It also suggested that the costs associated with waste management and cleanup be established. It advised that generators attempt to include regulatory

compliance oversight and reporting, production impacts, materials costs, transportation costs, TSDF costs, employee health impacts, and potential corrective action costs.

The element addressing a cost allocation system supported assigning waste management costs to the waste generating activity, not to an overhead account. Because the generators would directly fund managing their wastes, by implementing pollution prevention options that reduced waste and decreased costs, generator funding could then be reallocated for other activities.

The section on pollution prevention opportunity assessments acknowledged that several sound assessment methodologies have been used. This discussion summarized the two components that have been addressed in the most successful methods:

- identification of opportunities to reduce waste throughout a process and
- analysis of options based on costs associated with waste management and cleanup (EPA 1993a).

The literature search then targeted references addressing aspects of these components.

3.2 Opportunity Assessments and Options and Costing Methodologies

The references that targeted the process for performing a pollution prevention opportunity assessment, resulting pollution prevention options, and costing methodologies were evaluated for relevant sections.

3.2.1 Pollution Prevention Opportunity Assessment

Many documents were located that described similar processes for performing a pollution prevention opportunity assessment. These references, in addition to previously discussed documents (UT 1993), included:

- EPA guidance manuals including *Waste Minimization Opportunity Assessment Manual* (EPA 1988), *Facility Pollution Prevention Guide* (EPA 1992), and *Guides to Pollution Prevention Research and Educational Institutions* (EPA 1990),
- *Hazardous Waste Minimization* (Freeman 1990),
- articles from journals and other publications, such as "Develop Multimedia Pollution Prevention Strategies" (Chadha 1994), "Case Study: Using a Six-Step Organizational Framework To Establish a Facility P2 Program" (Kikta 1994), "How to Conduct a Waste Minimization Study" (Gemar 1992), "Pollution Prevention Plans - A Practical Approach" (Willis 1991), and "Contrasting Approaches to Pollution Prevention Auditing" (Pojasek and Cali 1991),
- a specific presentation at the 1993 *International Conference and Exhibition on Pollution Prevention in the Laboratory: Cost Effective Solutions to Waste Minimization Programs*, "How to Find Pollution Prevention Opportunities" (Reibstein 1993),
- the *DOE Model Process Waste Assessment Plan* (DOE 1991b), and

- Energy Systems' *Pollution Prevention Opportunity Assessment Training* (Energy Systems 1994a) [based on the *U.S. Department of Energy Model Pollution Prevention Opportunity Assessment Guidance* (DOE 1993b)].

Each of these references described how to perform a pollution prevention opportunity assessment and included varying levels of information on the general steps:

- planning and organization,
- assessment phase,
- feasibility analysis phase, and
- implementation.

Specifically, the EPA's documents *Waste Minimization Opportunity Assessment Manual* (EPA 1988) and *Guides to Pollution Prevention Research and Educational Institutions* (EPA 1990) described the process shown in Figure A-1 in Appendix A. As shown in Figure A-2 in Appendix A, the EPA document *Facility Pollution Prevention Guide* (EPA 1992) described a somewhat more detailed process for establishing a program and performing assessments. The basic format and steps of the assessment activities, however, were still the same.

The *DOE Model Process Waste Assessment Plan* (DOE 1991b) also used the same basic steps as the EPA documents, as seen in Appendix A, Figure A-3. Energy Systems' *Pollution Prevention Opportunity Assessment Training* (Energy Systems 1994a), which was based on the *U.S. Department of Energy Model Pollution Prevention Opportunity Assessment Guidance* (DOE 1993b), followed similar steps as seen in Appendix A, Figure A-4. This approach, however, added a formal graded approach to

the assessment as depicted in Appendix A, Figure A-5. Using this approach, a facility's waste generating activities would first be characterized and documented during a Level I Activity Characterization. Then each characterized waste generating activity would be screened to determine whether it would continue to be assessed or would be eliminated from further consideration. To continue to be assessed, an activity would either have to use or generate a priority material or waste, respectively, or have significant potential for pollution prevention implementation. The activity and associated wastes that would continue through this assessment process would be scored by applying a weighted sums criteria. Finally, a site-specific score value would be selected to further partition the activities. The waste generating activities that received a score equal to or less than this site-specific score value would be assessed informally (Level II) and the activities that received a score greater than this site-specific score value would be formally assessed (Level III) (Energy Systems 1994a).

Each of the guidance documents also contained numerous suggested forms to be used and completed while performing assessments. The forms in laboratory-based guidance were compiled in a question and answer format based on a general laboratory setting. In contrast, the forms in the other guidance documents were directed toward larger processes and activities, such as those found in an industrial setting. Portions of each of the assessment guidance documents and forms included useful guidance concerning assessment activities.

As previously stated, two components for a successful assessment methodology were specified in the EPA's interim final document, *Guidance to Hazardous Waste*

Generators on the Elements of a Waste Minimization Program. Consequently, the basis of these two components was used as the foundation for the methodology used in this study to gather data. Also, the EPA's guidance document for laboratories was used as a basis for developing specific components of this methodology. This reference was selected because the assessment-based references were very similar and because an R&D laboratory setting was being assessed. When appropriate, information obtained from this laboratory-based guide was augmented by incorporating additional detail provided in other references. For instance, in "Contrasting Approaches to Pollution Prevention Auditing" (Pojasek and Cali 1991), the authors compared prescriptive and descriptive approaches to assessments. The descriptive approach was more detailed and the aspects that related to (1) identifying and documenting the examined processes and activities and (2) attempting to account for materials were integrated into this study.

3.2.1.1 Basis of Components of Opportunity Assessment Methodology for Study

As listed in Figure A-1, the planning and organization phase involved obtaining management commitment, setting overall assessment program goals, and organizing an assessment program task force (EPA 1990). The planning and organization phase was completed at the beginning of this study with the M&C Division's commitment to participate in this study and with the definition of the scope of the assessment. An assessment program task force was not created because of the scope of this work; however, M&C personnel supported data collection activities when required.

The assessment phase included several tasks as listed in this document:

(1) collect activity and facility data,

(2) select and prioritize assessment targets,

(3) select assessment team,

(4) review data and inspect laboratories and waste handling facilities,

(5) generate pollution prevention options, and

(6) screen and select options for further study (EPA 1990).

Based on this study's scope and these six tasks, the assessment targets selection in the second task was already completed, and a team in the third task did not have to be defined. The remaining four tasks of the assessment phase were applicable.

The first task of the assessment phase described in the EPA's guidance document discussed compiling waste-related data including:

- sources of the wastes,
- quantity, types, and rates of material procurement, material usage, and waste generation, and
- material balances.

Due to the variability in laboratory-related operations and the resulting wastes, this EPA laboratory-based guide recommended collecting data from long term records. This EPA guide suggested reviewing purchase orders or requisitions, hazardous waste manifests, lab pack packing lists, and sampling program data. The EPA guide also stated that in a laboratory setting the data collection task could be difficult to complete due to limited records availability, the variability of R&D activities, and the many different types of material usage and related waste generation. The laboratory-based guide suggested that a facility may want to concentrate on the consistent higher volume waste streams and

that an activity-specific assessment could be performed prior to starting a new waste-generating R&D activity (EPA 1990). Furthermore, another reference, "How To Conduct a Waste Minimization Study," stated that during an assessment, material and waste information should be quantified to the extent possible, but a mass balance would not be absolutely necessary to successfully evaluate a process (Gemar 1992).

In the EPA's laboratory-based guide, the fourth task summarized data review and laboratory and waste management inspection activities and assessed collected data. An inspection would then be performed to examine the material flow through the facility. Compiling the material flow included investigating the receipt of the material, examining the management and usage of the material and the generation of the waste, and documenting the management and final disposal of the waste. Preliminary pollution prevention options could also be identified during this task.

The fifth task involved identifying potential pollution prevention options. Several sources for identifying potential options were listed, such as information gathered in the previous tasks and from researchers and technicians, chemical and equipment vendor data, technical literature, and government agencies and consultants.

During the sixth task of the assessment phase, the pollution prevention options identified in the fifth task were screened and the more promising options were selected to be evaluated further. This screening could be performed using either informal evaluations or formal quantitative reviews.

The next phase in this pollution prevention opportunity assessment process, as shown in Figure A-1, was the feasibility analysis. The options previously selected for

further evaluation would be initially examined to determine if the options would be technically possible and practical in the assessed areas. Then an economic evaluation of each option would be performed based on the changes in capital and operating costs. The EPA laboratory-based guidance noted that, when possible, standard costing measures such as payback period, return on investment, and net present value should be considered. However, this laboratory-based guidance also stated that when technically feasible options were found not to be cost effective, other societal benefits should be considered (EPA 1990). The EPA's *Facility Pollution Prevention Guide* added an environmental evaluation to this feasibility analysis phase. This environmental evaluation would consider the impact on the quantity and toxicity of waste streams, the potential for multimedia transfer, the effect of potential pollution prevention options on the environment, and energy consumption. This EPA facility-based guide also acknowledged that this environmental evaluation would not always be easy to quantify (EPA 1992). Furthermore, an article entitled "A Multimedia Assessment Scheme to Evaluate Chemical Effects on the Environment and Human Health" discussed a multimedia weighting scheme designed to further analyze the health and environmental effects related to current waste generating processes and activities, and potential pollution prevention options. Because this multimedia assessment methodology used a weighting scheme and not scenario-specific data, the authors acknowledged that it had its limitations (Grimsted et al. 1994). Based on this study's scope, aspects of a health and environmental evaluation were only considered in a qualitative manner.

Specifically, this study considered the added requirements related to 3- and 4-rated hazardous materials and nonradioactive RCRA hazardous waste.

While selecting options for implementation and periodically performing additional pollution prevention opportunity assessments were summarized in the R&D-based guidance, these activities were not included in this study's scope.

3.2.2 R&D and Support Activities-Oriented Wastes and Pollution Prevention

Based on the general assessment guidance documents used and the specific M&C R&D and support areas evaluated, references were examined for relevant waste and pollution prevention option information. Several documents contained general information or listed minimal information related to laboratory settings. However, the majority of general laboratory-oriented waste generation and pollution prevention information was found in the EPA's *Guides to Pollution Prevention Research and Educational Institutions.* The *Hazardous Waste Minimization* reference, which contained general pollution prevention information, also contained R&D-oriented pollution prevention information; however, this information was included in the EPA's references. The remaining applicable documents addressed a specific type of activity or waste stream of interest.

References containing general waste generation and pollution prevention information included the EPA's *Waste Minimization Opportunity Assessment Manual* and *Facility Pollution Prevention Guide* and articles such as "Waste Reduction Techniques: An Overview" (Hunt 1990). These references discussed source reduction

options and recycle and reuse options, and the EPA's *Facility Pollution Prevention Guide* described the activities that were included in source reduction and in recycle and reuse (EPA 1992).

Each of these general references contained several examples of source reduction and recycle techniques. General pollution prevention option examples that potentially applied to this study were found in the EPA's general pollution prevention guidance, *Facility Pollution Prevention Guide,* and were summarized in Appendix A.

The EPA laboratory-based document generalized that laboratory settings used a wide variety of chemicals in small quantities, which ultimately resulted in the generation of waste in quantities of less than 1 gallon per waste-generating event. This document summarized that waste streams related to R&D could include acids, bases, solvents, metals, unused chemicals, and photographic wastes. It stated that wastes also could be generated by art, printing, photography, and maintenance activities. For instance, the photography activities could generate photoprocessing chemicals, and the maintenance activities could generate waste oils (EPA 1990).

3.2.2.1 R&D Activities

Several references were discovered that summarized in varying detail pollution prevention options that could be applicable in R&D activities. In addition to previously discussed documents (EPA 1992; EPA 1990), these references included:

- EPA's "Pollution Prevention Information Exchange System" (PIES),
- specific presentations at the 1993 *International Conference and Exhibition on Pollution Prevention in the Laboratory: Cost Effective Solutions to*

Waste Minimization Programs, "Microscale Chemistry: A Vision for the Future" (Pike et al. 1993) and "Pollution Prevention in the Laboratory: In-House Solvent Recycling Programs" (Stunkel and Kelley 1993),

- specific papers presented at the 1994 DOE *Pollution Prevention Conference X*, "The Solution to Pollution is Microscale Chemistry, Microscale Chemistry and the Three Rs: Recovery, Recycle and Reuse" (Singh 1994) and "Waste Minimization Through Microexperimentation: Barriers to Implementation" (Gatrone 1994),
- the DOE ORNL's *Oak Ridge National Laboratory Degreasing Solvent Process Waste Assessment (PWA) Report* (ORNL 1993b),
- the DOE Y-12 Plant's *Solutions for the Chlorinated Solvent Debacle* (Thompson and Simandl 1991) and *Cleaning without Chlorinated Solvents* (Thompson and Simandl 1994), and
- the M&C Division's *Waste Minimization/Pollution Prevention Study of High-Priority Waste Streams* (ORNL 1994b).

In the EPA's *Facility Pollution Prevention Guide*, examples related to laboratories were listed but not described in detail and included:

- the use of micro or semimicro techniques for analysis,
- increased instrumentation use,
- elimination or reduction of toxic chemicals use in experiments,
- spent solvent reuse or recycle,
- metal recovery from catalysts,

- treatment or destruction of hazardous waste products as the last step in experiments,
- segregation of individual waste streams,
- proper identification and labeling of all chemicals and wastes, and
- mercury recovery and recycle (EPA 1992).

The EPA's *Guides to Pollution Prevention Research and Educational Institutions* summarized several options related to the laboratory setting, which are listed in Table 3-1. This guidance also described several of these options (EPA 1990).

References that discussed microscale chemistry addressed laboratories that were performing either chemical analysis research or implementation. Because M&C's primary research involved metals and ceramics, these references did not directly apply. The basis of these papers, using smaller amounts of materials to obtain needed laboratory results, could, however, indirectly apply to M&C activities (Pike et al. 1993; Singh 1994; Gatrone 1994). Therefore, the philosophy presented in these references was included when examining M&C areas for pollution prevention opportunities.

The numerous solvent-oriented references contained information that was applicable to many of M&C's activities involving the use of solvents. In general, due to the amount of solvents used and health and safety issues, in-house recycling was not considered (Stunkel and Kelley 1993). Instead, material substitution options were pursued. ORNL had performed a pollution prevention opportunity assessment of major solvent degreasing operations. This assessment did not include smaller laboratory-based activities, such as those found in the M&C Division. This assessment identified three

Table 3-1
Laboratory-Oriented Pollution Prevention Options Listed in the
U. S Environmental Protection Agency's Guidance
Guides to Pollution Prevention Research and Educational Institutions

Category of Pollution Prevention Application	**Potential Pollution Prevention Options**
Improved material management practices	• Establish a centralized purchasing program. • Order reagent chemicals in exact amounts. • Encourage chemical suppliers to become responsible partners including accepting outdated supplies. • Establish an inventory control program that can trace chemicals from cradle to grave. • Rotate chemical stock. • Develop a running inventory of unused chemicals for use by other departments. • Centralize waste management and appoint a safety and waste management officer for each department. • Educate staff on the benefits of pollution prevention. • Establish pollution prevention goals. • Perform routine self-audits.
Improved laboratory practices	• Scale down the volumes of chemicals used in laboratory experiments. • Increase use of instrumentation. • Reduce or eliminate the use of toxic chemicals in laboratory experiments. • Preweigh chemicals for undergraduate use. • Reuse or recycle spent solvents. • Recover metal from catalyst. • Treat or destroy hazardous waste products as the last step in experiments. • Segregate individual waste streams, hazardous and nonhazardous wastes, and recyclable wastes. • Ensure that the identity of all chemicals and wastes is clearly marked on all containers. • Investigate mercury recovery and recycling with an outside vendor.

Table 3-1 (continued)

Category of Pollution Prevention Application	Potential Pollution Prevention Options
Improved practices in other departments	• Replace oil-based paints with water-based paints in art instruction and maintenance operations. • Modify paint-spraying techniques. • Reduce generation of pesticide waste. • Collect waste oil and solvents for recycling. • Use biodegradable aqueous or detergent cleaners. • Investigate silver recovery or recycling with an outside vendor for photoprocessing wastes. • Provide training in hazardous waste management practices for students in art and photography courses and facilities management and maintenance personnel.

Source: Adapted from U.S. Environmental Protection Agency (EPA). *Guides to Pollution Prevention Research and Educational Institutions*. EPA/625/7-90/010. Washington, District of Columbia: U.S. Environmental Protection Agency, June 1990.

alternatives: substitution of aqueous solvents for organic solvents, substitution of less hazardous organic solvents or solvent recycle, and elimination or consolidation of some operations (ORNL 1993b). The solvent substitution with either aqueous or less hazardous organic solvents was pursued further during the literature search.

Several solvent substitution-oriented references were reviewed. However, the DOE Y-12 Plant's *Solutions for the Chlorinated Solvent Debacle* and *Cleaning without Chlorinated Solvents* contained information that potentially could address M&C's activities. These documents described ultrasonic aqueous detergent systems and alternative solvent substitutes including Solvent 140, MMK Blend, Anisole, and terpene-based solvents (Thompson and Simandl 1991; Thompson and Simandl 1994).

In 1993, the M&C Division also performed a waste reduction-related evaluation of high-priority waste streams. This evaluation examined some R&D wastes of interest in this study, including certain solvent wastes deemed carcinogens or reproductive hazards, certain oil-based wastes, and acid-based wastes. The solvents discussed in this evaluation were primarily examined to verify that personnel material exposure levels were not greater than recommended limits. The major processes generating oil-based wastes were examined for possible options including replacing oil-based vacuum pumps with oilless vacuum pumps and extending the life of the oil in hydraulic systems and vacuum pumps by filtering the oil to remove particulates and water. The major process generating acid-based wastes was examined for possible options. Due to customer-based constraints, the acid-generating activity could not be changed. However, elementary neutralization in the laboratory was recommended (ORNL 1994b).

Finally, while some applicable information was found on PIES when performing searches, the level of detail of this information varied greatly, access to the system was intermittent, and similar information was available from other references. Therefore, documents previously discussed were used instead. Also, pollution prevention-related information gathered during personnel interviews was extremely important in identifying and evaluating options.

3.2.2.2 Support Activities

Several references were found that summarized in varying detail pollution prevention options that could be applicable in the support activities and to excess or legacy chemicals included in this study. In addition to previously discussed documents (EPA 1992; EPA 1990; ORNL 1994b) and PIES, these references included:

- specific presentations at the 1993 *International Conference and Exhibition on Pollution Prevention in the Laboratory: Cost Effective Solutions to Waste Minimization Programs*, "The Functions of a Hazardous Materials Committee in a Research and Development Laboratory" (Deerhake 1993) and "If You Don't Want to Pay Big to Throw It Away, Don't Buy It in the First Place" (Doob 1993),
- a paper presented at the 1994 DOE *Pollution Prevention Conference X*, "The Development of the Chemical Exchange Warehouse at Lawrence Livermore National Laboratory" (Souza and Patterson 1994), and
- the EPA's *Guides to Pollution Prevention, The Photoprocessing Industry* (EPA 1991), the DOE Brookhaven National Laboratory (BNL) *Silver-*

Contaminated Photographic Waste Process Waste Assessment (PWA) Report (BNL 1994), and the DOE *Oak Ridge National Laboratory Photoprocessing Facilities Process Waste Assessment* (Capps and Harrington 1992).

The EPA's *Facility Pollution Prevention Guide* listed general material management and good operating practices options and examples related to the excess or legacy chemicals and support activities. Detailed descriptions were not provided. These options were listed in Appendix A of this report.

The EPA's *Guides to Pollution Prevention Research and Educational Institutions* summarized several options related to wastes generated from excess or legacy materials and support activities, which are listed in Table 3-1. This guidance also described several of these options (EPA 1990).

References specifically related to improved materials management and control within the laboratory setting addressed evaluating and controlling material purchases and inventorying chemicals on site (Deerhake 1993; Doob 1993). "The Development of the Chemical Exchange Warehouse at Lawrence Livermore National Laboratory" specifically addressed maintaining excess chemicals in a storage area where these chemicals could be requested by another user. This approach avoided waste generation by allowing chemicals to be reused (Souza and Patterson 1994).

As previously discussed, the M&C Division performed an evaluation of its high-priority waste streams, which examined support-related wastes encompassed in the scope of this study. These wastes included certain oil-based wastes and photographic wastes. As previously mentioned, the major processes generating oil-based wastes were

examined for possible options. The major process areas generating photographic wastes were examined for possible options, including using metallic replacement to recover the silver from the photographic waste and, when possible, replacing wet chemistry-based photoprocessing with digitization and photoimaging (ORNL 1994b).

Numerous references were identified that addressed photographic wastes. Two of the listed references were used during this study because these documents contained the most recent developments in the photographic industry. These documents were:

- M&C's *Waste Minimization/Pollution Prevention Study of High-Priority Waste Streams* (ORNL 1994b) and
- the DOE BNL *Silver-Contaminated Photographic Waste Process Waste Assessment (PWA) Report* (BNL 1994).

Vendor data, such as information from the Eastman Kodak Company, were found to also be available, but this information had already been incorporated into the M&C and BNL documents. Specific options identified in the BNL document included:

- digitization and photo imaging,
- chemical inventory control,
- makeup of solutions only in quantities needed,
- fixer reuse,
- metallic replacement using silver recovery canisters,
- electrolytic silver recovery,
- chemical precipitation,
- squeegees for minimizing carryover,

- evaporation,
- plumbingless minilabs,
- low-flow prewash,
- silver recovery from off-specification paper and film, and
- zero silver content photographic film.

As previously discussed, other references that addressed options potentially applicable to this study were used instead of PIES information. Also, pollution prevention-related information gathered during personnel interviews was extremely important in identifying and evaluating options.

3.2.3 Costing Methodology

An extremely large number of references were found that addressed costing methodology information related to pollution prevention. These references either discussed aspects of total cost assessments (TCA) or life-cycle costing, analyses, or assessments (LCA). One article addressing LCA-related information stated that more than a thousand references related to LCA had been identified in a recent bibliography (Bailey 1991). Therefore, only select references were discussed. Documents that listed estimated or actual current costs that would specifically apply to the ORNL wastes examined were also reviewed. In addition to previously discussed documents (EPA 1988; EPA 1992; EPA 1990; Freeman 1990), references used included:

- EPA guidance documents including *A Primer for Financial Analysis of Pollution Prevention Projects* (EPA 1993b),

- articles from journals and other publications, such as "Life-Cycle Costing and Pollution Prevention" (Bailey 1991), "Beyond Waste Minimization: Life-Cycle Cost Management for Chemicals and Materials" (Cohan et al. 1992), "Environmentally Smart Accounting: Using Total Cost Assessment To Advance Pollution Prevention" (White et al. 1993), "Economics of Pollution Prevention: How Waste Reduction Pays" (Rooney 1993), "A Life Cycle Approach to Product System Design" (Keoleian et al. 1993), "Getting to the Bottom Line: How TCA Shows the Real Cost of Solvent Substitution" (Kennedy 1994), "Capital Budgeting for Environmental Professionals" (Torborg 1994), and "New Applications of Total Cost Assessment" (Savage and White 1995),
- a presentation at the 1993 *International Conference and Exhibition on Pollution Prevention in the Laboratory: Cost Effective Solutions to Waste Minimization Programs*, "Total Cost Assessment: An Approach to Project Profitability Analysis" (Savage 1993),
- DOE documents including *Life Cycle Analysis: Integrated Inventory, Environmental, and Economic Analyses* (Barnes et al. 1994) and *DOE/SNL/EPA Joint Effort to Develop Waste Minimization Techniques for DOE R&D Laboratories* (Weitz et al. 1994),
- the DOE "Nationwide Mixed Waste Commercial Disposal Contract" (DOE 1994c), and

- the Energy Systems *Indexing Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems 1994b).

TCA as defined by the EPA would be an economic analysis of pollution prevention projects and would consist of four elements: expanded cost inventory, extended time horizon, use of long-term financial indicators, and direct allocation of costs to processes and products. In contrast, LCA would examine all inputs and outputs of a product or activity during its life to determine the overall impact and related costs. LCA would encompass all aspects of a product or activity, including extracting and processing raw materials; manufacturing, transporting, and distributing a product; using, reusing, and maintaining a product; and recycling and disposing of the spent product (EPA 1992). TCA, per the EPA, could also measure the profitability based on three standard profitability measures: payback period, internal rate of return, and net present value (EPA 1988). As previously discussed, the EPA's laboratory-based pollution prevention guidance also mentioned performing an economic evaluation using standard measures of profitability. However, no forms or additional information was provided.

Several articles addressed various aspects of performing activities related to TCA and LCA, such as capital budgeting or material-specific applications. Many articles did not adopt the EPA's definitions and used TCA, LCA, and other costing terms interchangeably. Numerous articles contained costing information that was more relevant to long-term industry-oriented activities, than to short-term R&D activities.

One article, "Beyond Waste Minimization: Life-Cycle Cost Management for Chemicals and Materials" (Cohan et al. 1992), however, contained a framework for

cost-based information related to electrical utilities that would be useful, with specific modifications, to meet a laboratory's unique needs. This article defined life-cycle cost to include the costs from acquisition through post-disposal. This costing method did not include any long-term costs associated with the material prior to procurement. This article also stated that the cost associated with a material was dependent upon the cumulative impacts of each step in managing this material including the material procurement process, the actual material usage, and the waste management and disposal practices. A material's life-cycle cost was defined to include four cost categories: (1) cost of acquisition, (2) cost of use, (3) cost of disposal, and (4) postdisposal cost.

The article also stated that the cost categories could be subdivided by cost types: (1) tangible direct costs, (2) tangible indirect costs, (3) uncertain or intangible direct or indirect costs, and (4) external or social costs. Table 3-2, which was included in this article, summarized examples of the various types of costs to be considered (Cohan et al. 1992).

Elements of this costing method were used to define the method of identifying added requirements and associated quantifiable costs related to managing 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes. Also, due to the relatively short time frames of R&D activities and M&C R&D activities being funded on an annual basis, a payback period of 1 year or less was used. The payback period was defined as the initial investment in a pollution prevention option divided by the improved productivity expressed as the annual operating improved productivity (cost avoidance) realized from implementing the option.

Table 3-2
Costs to Consider When Evaluating Processes or Activities and
Related Pollution Prevention Opportunities
Associated with Material Usage and Waste Generation

Cost Category	Acquisition	Use	Disposal/ Post-disposal
Direct	• Purchase cost • Taxes • Shipping	• Labor • Equipment • Maintenance	• Transport and/or storage • Recycling, treatment, disposal costs
Indirect	• Training • Handling and storage • Recordkeeping	• Delivery to job site • Training • Industrial hygiene • Regulatory compliance	• Training • Recordkeeping • Environmental health and safety
Uncertain	• Cost of spills and accidents while handling or in storage • Legal liabilities	• Costs of spills, leaks while in use • Equipment failure • Compliance with new regulations • Occupational liabilities	• Costs of accidents or spills • Compliance with new regulations • Legal liabilities • Postdisposal liabilities
Externality	• Emissions or accidental releases while in storage	• Emissions or accidental releases while in use	• Environmental releases during treatment or after disposal

Source: Adapted from Cohan, David; Wapman, Kenneth R., McLearn, Mary. "Beyond Waste Minimization: Life-Cycle Cost Management for Chemicals and Materials," *Pollution Prevention Review*. Volume 2, Number 3. New York, New York: Executive Enterprises Publications Co., Inc., Summer 1992.

Because the wastes studied were RCRA hazardous wastes, these wastes were placed in permitted storage on the DOE Oak Ridge Reservation (ORR) while awaiting treatment and final disposal. Therefore, two documents were used to estimate treatment and disposal costs. Information contained in DOE's memorandum entitled "Nationwide Mixed Waste Commercial Disposal Contract" was used to estimate the cost of disposing of the future waste residues resulting from treating M&C's waste. This document included mixed waste disposal information related to sending waste for disposal to Envirocare of Utah, Inc. and specifically tabulated numerous unit price values based on delivery mode and waste amount. All values were based on volume (DOE 1994c).

To facilitate estimating the relative cost impacts of wastes and related pollution prevention options, Energy Systems compiled *Indexing Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation.* This document included a limited listing of estimated waste storage and treatment costs. These costs were used to estimate the cost of storage and treatment of M&C's wastes (Energy Systems 1994b).

3.3 Requirements and Resources Related to Hazardous Materials and Wastes

The references that addressed specific requirements and contained the resources needed to perform this study in the M&C Division at ORNL were evaluated for pertinent information and data. The resulting references included the following:

- regulations impacting the studied areas,
- internal ORNL requirements, documents, procedures, standards, and forms,
- ORNL material and waste tracking systems,

- ORNL cost accounting systems,
- ORNL-based papers containing related pollution prevention information, and
- personnel interviews.

These references were organized based on requirements and resources related to 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes.

3.3.1 Requirements Related to Hazardous Materials and Wastes at ORNL

The ORNL Pollution Prevention Program was driven by numerous laws, regulations, orders, agreements, and policies (ORNL 1994a). While these requirements impact the overall implementation of pollution prevention in the M&C Division, the added requirements related to 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes needed to be specifically defined. The following laws, regulations, and Energy Systems or ORNL requirements were identified that could impact the use of 3- and 4-rated hazardous materials and the resulting generation of nonradioactive RCRA hazardous wastes included in this study:

- The Energy Systems *Hazardous Materials Inventory Program* procedure ESP-ESH-16 (Energy Systems 1991),
- the Energy Systems *Hazard Communication Program* standard ESS-IH-140 (Energy Systems 1993),
- *ORNL Chemical Carcinogen Control Program* procedure IHP-13 (ORNL 1990),

- ORNL *Facility Authorization Basis Documentation* procedure FS-2.0 (ORNL 1994c),
- *ORNL Laboratory Standard Program* procedure OSHP-003 (ORNL 1995),
- *ORNL Program for the Control of Local Exhaust Ventilation Systems and Associated Devices* procedure IHP-15 (ORNL 1992a),
- HSWA to RCRA, and
- Energy Systems standards and ORNL waste management procedures including the Energy Systems *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992) and the ORNL standard practice procedures *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992b) and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992c).

The Energy Systems *Hazardous Materials Inventory Program* procedure required that each purchase requisition for 3- and 4-rated hazardous materials be approved and signed by designated ORNL management.

The Energy Systems *Hazard Communication Program* standard specified requirements including training, maintenance of Material Safety Data Sheets, labeling, and maintenance of current area-specific hazardous materials inventories. However, this requirement did not distinguish between more and less hazardous materials. This procedure did include a material hazard classification standard and associated labeling requirements, which were used to designate that materials that were more hazardous by

using the rating system from 0 to 4. Specifically, the severity of the hazard in each of three hazard classifications was indicated by selecting an appropriate integer-based rating. The three hazard classifications were health, flammability, and reactivity. The numerical ratings ranged from 0, indicating little or no hazard, through 4, indicating severe hazard or extreme danger. Materials that received a rating of three or four in any of the three hazard classifications were deemed more hazardous. Consequently, these 3- and 4-rated hazardous materials had more requirements applied to them and were managed appropriately (Energy Systems 1993).

The ORNL carcinogen control program procedural requirements impacted materials that were either identified as carcinogens or reproductive hazards. This procedure included a specific listing of materials that, if stored or used, would have to be controlled under this carcinogen program at ORNL (ORNL 1990).

The ORNL *Facility Authorization Basis Documentation* procedure FS-2.0 required all new work that would require the use of 3- and 4-rated hazardous materials be reviewed by a designated group of ORNL personnel to verify that all ES&H requirements would be met (ORNL 1994c).

The *ORNL Laboratory Standard Program* procedure required a chemical hygiene plan for laboratory areas. Each area plan outlined safe handling and use practices for hazardous materials, including using secondary containment for all hazardous materials moved within ORNL, such as between buildings (ORNL 1995).

The *ORNL Program for the Control of Local Exhaust Ventilation Systems and Associated Devices* procedure IHP-15 required that all venting systems be tested

annually. This procedure also required that a smoke test be performed when the high-efficiency particulate air (HEPA) filters associated with these venting systems were replaced with clean HEPA filters (ORNL 1992a).

The regulations associated with the HSWA to RCRA required hazardous waste generators as a minimum to set up and maintain a satellite accumulation area and meet all labeling, reporting, and management requirements. If enough waste was generated and stored, the generator would also have to set up and maintain a 90-day accumulation area and meet associated records and labeling requirements. These regulations included many other requirements such as standards for permitted storage, treatment, and disposal facilities. At ORNL, waste management procedures, including ORNL standard practice procedures *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992b) and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992c), delineated the implementation requirements related to the wastes included in this study. For instance, the radiological control requirements for managing wastes at ORNL specified that each item must be health physics (HP) surveyed and properly tagged and documented. These procedures also required RCRA hazardous waste generators to comply with all of the requirements related to RCRA and to document this compliance. For example, ORNL RCRA hazardous waste generators were required to maintain a logbook for each satellite accumulation area even though this logbook was not required under RCRA.

Additional information related to these requirements, such as performing industrial hygiene (IH) reviews and compliance audits, were also identified during personnel interviews.

3.3.2 Resources Related to Hazardous Materials and Wastes at ORNL

Based on this study's scope, available resources related to Energy Systems and ORNL were identified that could provide information concerning the use of 3- and 4-rated hazardous materials and the resulting generation of nonradioactive RCRA hazardous wastes. In addition to previously discussed documents (ORNL 1994b), the following resources were identified and used:

- reference books containing specific gravity or density information for specific materials and wastes including *Solid Wastes* (Tchobanoglous et al. 1977), the *CRC Handbook of Chemistry and Physics* (Weast 1981), and *The Condensed Chemical Dictionary* (Hawley 1981),
- the Hazardous Materials Inventory System (HMIS),
- the Energy Systems Accelerated Vendor Inventory Delivery (AVID) System and on-site stores system,
- the ORNL Hazardous Waste Tracking System,
- the ORNL cost accounting system,

- one paper presented at the 1994 *American Industrial Hygiene Conference and Exposition*, "Validation of the Use of Professional Judgement in Determining Potential for Exposure to Chemical Reproductive Hazards and Carcinogens in Research Laboratory Operations" (Ogle et al. 1994),
- one paper presented at the 1994 DOE *Pollution Prevention Conference X*, "Waste Reduction Prioritization at the Oak Ridge National Laboratory" (Wasserman 1994), and
- personnel interviews.

At ORNL, HMIS, an electronic tracking system, was used to track the purchase and usage of materials. The Energy Systems AVID System and on-site stores system were used to obtain cost data for materials. The ORNL Hazardous Waste Tracking System was used to track all hazardous wastes generated at ORNL. This tracking started from the point where the hazardous wastes were picked up at the generator's location to where the wastes were ultimately stored, treated, or disposed. An accounting system existed at ORNL that tracked costs charged to various ORNL accounts including M&C accounts. The ORNL Pollution Prevention Program performed a pollution prevention prioritization activity, which provided some information on the source of certain M&C wastes and general pollution prevention information. In addition to the previously discussed M&C evaluation, the M&C Division also performed an assessment of the use of and potential exposure to suspected carcinogens and reproductive hazards in M&C areas. Finally, personnel interviews were used extensively to provide additional information for this study.

CHAPTER 4.0

Resources and Methodology

The methodology used was based on a combination of the guidance documents and other references, and the unique needs of and resources available in the M&C Division at ORNL. The methodology and data gathering encompassed:

- identifying waste sources and pollution prevention opportunities and
- identifying added requirements and quantifiable associated costs.

The methodology and data-gathering approach, and the resources used are summarized in Figure 4-1. The development of the specific components of this methodology was an iterative process. During this process, as resources for gathering data in one section of the methodology were determined, additional information was then required in another area. For instance, when added requirements and associated quantifiable costs related to materials deemed carcinogens and reproductive hazards were identified, the materials to which these requirements applied had to be identified and quantified.

Numerous resources were used to identify and quantify data required, including documents, tracking systems, and personnel interviews. In general, data were then compiled, calculated, and consolidated using electronic spreadsheet and graphics programs and limited manual compilations and calculations. Although compiling the methodology and data was iterative, to minimize repetition, the description of the methodology and data gathering has been divided into the resulting two sections shown in Figure 4-1 and discussed in this chapter.

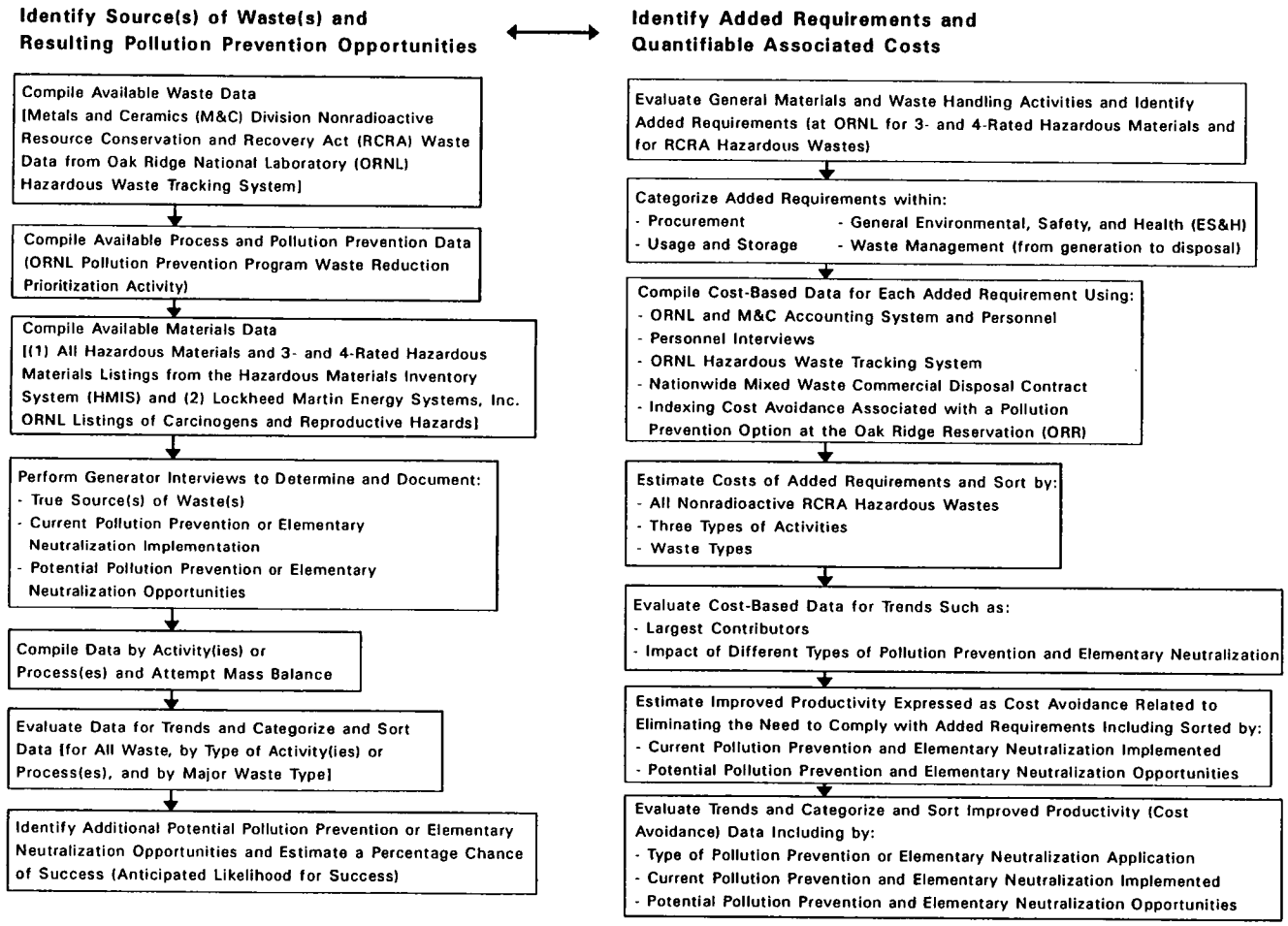


Figure 4-1. Methodology and Data Gathering Approach and Resources

4.1 Identification of Waste Sources and Pollution Prevention Opportunities

Identifying waste sources and resulting pollution prevention opportunities initially required identifying the wastes generated in 1992, the most recent year for which complete waste data were available when this study started. Waste data were obtained through the ORNL Pollution Prevention Program, which provided a down-load of data from the ORNL Hazardous Waste Tracking System. This data set included all hazardous waste that was deemed waste by the generator in 1992. The wastes generated by M&C areas were then extracted from this data set. The resulting M&C data set was sorted to obtain the nonradioactive RCRA hazardous wastes generated in 1992. The resulting spreadsheet's data included the following for each item of waste:

- generator name,
- identification number for the request for disposal form,
- brief description of the waste,
- a designation as to whether the waste was radioactively contaminated or not,
- Industry and EPA hazardous waste number assigned under the RCRA regulations, and
- amount in mass units, kilograms (kg).

Once the data set was sorted for this study, additional fields were added to include:

- a running summation in kg,
- general type of activity (R&D, support, or legacy and laboratory cleanout) and general status of the activity,
- a general description of the waste source (the related process or activity),

- general type of pollution prevention or waste management technique being applied in 1994 (the most recent year for which cost data were available when this study started) and a general description of the technique, and
- general type of potential pollution prevention or waste management that could be applied to the waste and a general description of the technique.

Available process and pollution prevention data were obtained from ORNL's prioritization exercise. This exercise identified the waste-generating processes or activities for specific higher priority wastes (Wasserman 1994). This information was incorporated into spreadsheets containing the data supporting this study.

Available materials data were compiled using HMIS and the *ORNL Chemical Carcinogen Control Program* procedure IHP-13 (ORNL 1990). Using HMIS, the M&C Division was able to sort for and produce printouts of (1) all hazardous materials and (2) all 3- and 4-rated hazardous materials procured in 1992. Based on the nonradioactive RCRA hazardous wastes generated in 1992, the 3- and 4-rated hazardous materials that ultimately result in the generation of these wastes were identified for specific waste types. Using the printouts produced using HMIS, the kg and number of items of 3- and 4-rated hazardous materials were quantified. This information was integrated into the spreadsheets used in this study. Certain 3- and 4-rated hazardous materials managed by the M&C Division have been designated as carcinogens or reproductive hazards (ORNL 1990). Based on the listings in this ORNL procedure, the nonradioactive RCRA hazardous wastes generated in 1992 that were also deemed carcinogens or reproductive hazards were identified.

Using the resulting consolidated data, waste generators were interviewed. The data gathered were verified and refined as appropriate, and missing data were obtained. Specific data gaps addressed through interviews included:

- the source of the waste, which was the causal activity or process that requires the use of the material and the subsequent waste generation,
- the general type of activity or process associated with the waste,
- the general major waste type in which the waste was included,
- the current pollution prevention applications implemented, and
- any potential pollution prevention opportunities including an estimated percentage chance for success.

The percentage chance for success was based on references, the identified source of the waste, and interviews with the waste generators.

The data were then compiled by major waste type and by major type of activity or process, and a mass balance was attempted. Based on the data compiled, the mass balance attempted to equate the 3- and 4-rated hazardous materials procured in 1992 with the resulting nonradioactive RCRA hazardous wastes. The data were also compiled by general pollution prevention application for implemented applications and potential future ones. The potential future applications were compiled based on a 100 percent success rate and on an estimated percentage chance for success. The general pollution prevention and elementary neutralization applications included:

- source reduction,
- reclassification or elimination,

- recycle or reuse, and
- elementary neutralization.

While reclassifying waste or eliminating a process was not specifically listed in the pollution prevention definition, these activities had to be noted. If a process no longer existed, then pollution prevention efforts should not be expended to minimize waste that has been eliminated. Proper waste characterization was also a crucial component in implementing pollution prevention (EPA 1993a). For instance, several wastes within M&C laboratories were originally considered to be RCRA hazardous wastes. When samples of these wastes were taken and analyzed, the wastes were found to not be RCRA hazardous wastes. Finally, the compiled data were evaluated for trends based on several units of measure and combinations of data.

4.2 Identification of Added Requirements and Quantifiable Associated Costs

Materials and waste handling activities were evaluated for added requirements for managing 3- and 4-rated hazardous materials and nonradioactive RCRA hazardous wastes. Quantifiable costs associated with added requirements were estimated. This information was gathered using the ORNL Hazardous Waste Tracking System; DOE, Energy Systems, and ORNL procedures and documents; and personnel interviews.

Based on procedures, documents, and personnel interviews, potential added requirements for 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes generated by the M&C Division were initially identified and listed. The added requirements were further investigated and defined. Specific

requirements that were not included in this study were those found to have had no additional impact, had fixed costs that would not decrease if waste was only reduced in M&C areas, or had costs that could not be quantified.

The added requirements for 3- and 4-rated hazardous materials and resulting wastes were then categorized as:

- procurement,
- general ES&H,
- usage and storage, and
- waste management from generation to disposal.

Figure 4-2 summarizes these added requirements.

Once these tangible added requirements were defined, the components of the associated costs were determined and categorized by the type of funding source. These types of funding sources were categorized as:

- direct R&D funding cost,
- M&C overhead cost,
- ORNL overhead cost,
- DOE-Headquarters Assistant Secretary for Environmental Management (EM) funding cost, and
- non-ORNL funding cost.

Based on the funding structure established by DOE, the funding for RCRA hazardous waste transportation, storage, treatment, and disposal has been provided directly through EM. In specific cases where wastes have been in storage for several years and have

Figure 4-2. Added Requirements Resulting in Associated Quantifiable Costs for 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive RCRA Hazardous Wastes in the Metals and Ceramics Division at ORNL

Notes:

(1) Other added costs are expected to be associated with the use of 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes, such as the added cost associated with the increase in liability from handling, storing, and managing hazardous materials and wastes or the vendors' added requirements for managing 3- and 4-rated hazardous materials and related added cost, which is included as a portion of the price for the material.

(2) Shaded boxes indicate that no added requirements and resulting quantifiable costs were identified for these example areas.

(3) 3- and 4-rated hazardous materials are those materials that receive a rating of 3 or 4 in any of three hazard classifications of health, flammability, and reactivity. Ratings range from 0 to 4, with 0 indicating little or no hazard and 4 indicating severe hazard or extreme danger.

(4) ORNL maintains a listing of materials managed as carcinogens and reproductive hazards.

(5) If ORNL is allowed to use an off-site commercial treatment and disposal company in the future, the cost of treatment and disposal may decrease significantly.

Abbreviations:
BMP- best management practice
DOE - U.S. Department of Energy
Energy Systems - Lockheed Martin Energy Systems, Inc.
ES&H - environmental, safety, and health
M&C - Metals and Ceramics
ORNL - Oak Ridge National Laboratory
RCRA - Resource Conservation and Recovery Act
TDEC - Tennessee Department of Environment and Conservation

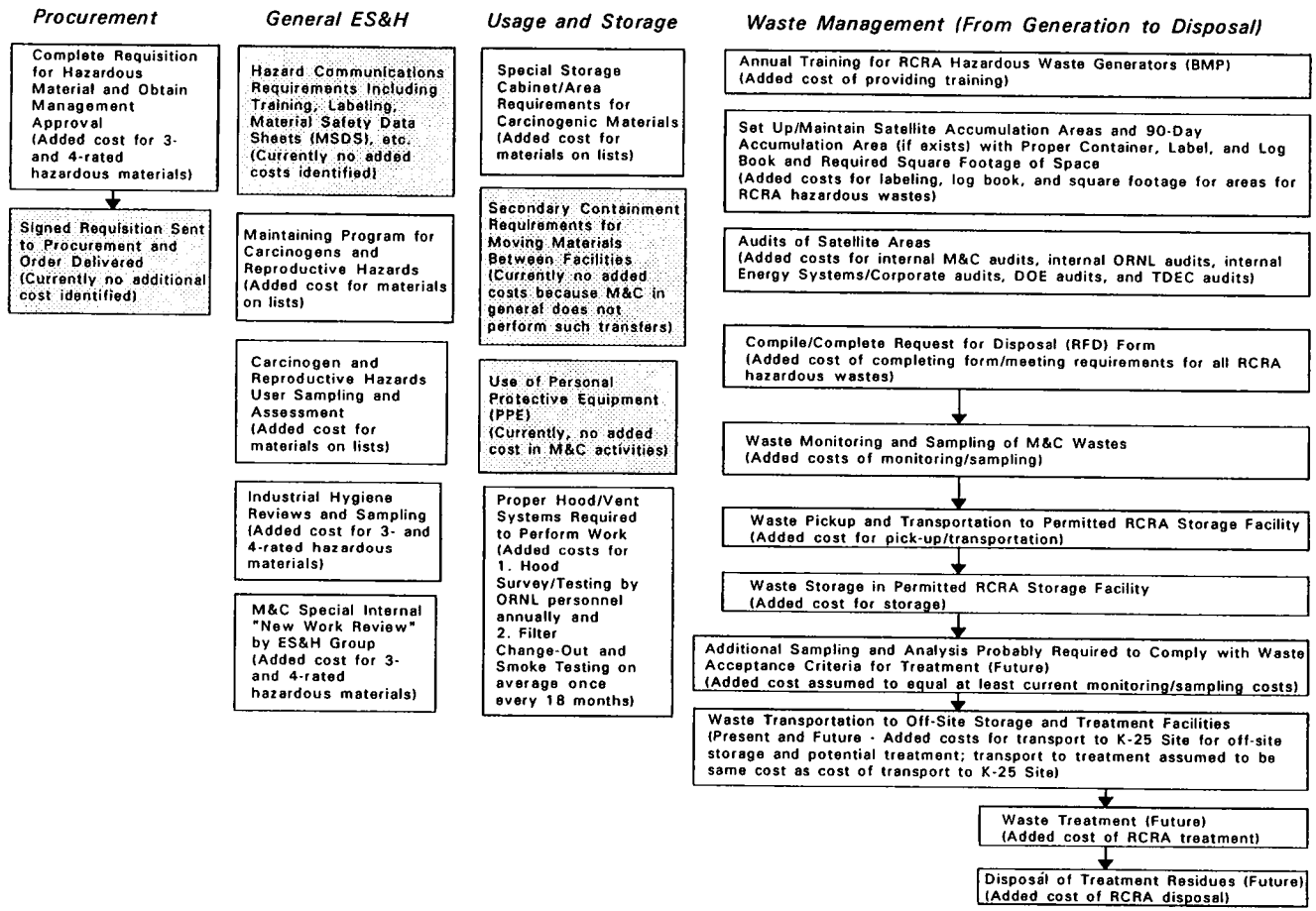

Procurement
General ES&H
Usage and Storage
Waste Management (From Generation to Disposal)
Complete Requisition for Hazardous Material and Obtain Management Approval (Added cost for 3- and 4-rated hazardous materials)
Signed Requisition Sent to Procurement and Order Delivered (Currently no additional cost identified)
Hazard Communications Requirements Including Training, Labeling, Material Safety Data Sheets (MSDS), etc. (Currently no added costs identified)
Maintaining Program for Carcinogens and Reproductive Hazards (Added cost for materials on lists)
Carcinogen and Reproductive Hazards User Sampling and Assessment (Added cost for materials on lists)
Industrial Hygiene Reviews and Sampling (Added cost for 3- and 4-rated hazardous materials)
M&C Special Internal "New Work Review" by ES&H Group (Added cost for 3- and 4-rated hazardous materials)
Special Storage Cabinet/Area Requirements for Carcinogenic Materials (Added cost for materials on lists)
Secondary Containment Requirements for Moving Materials Between Facilities (Currently no added costs because M&C in general does not perform such transfers)
Use of Personal Protective Equipment (PPE) (Currently, no added cost in M&C activities)
Proper Hood/Vent Systems Required to Perform Work (Added costs for 1. Hood Survey/Testing by ORNL personnel annually and 2. Filter Change-Out and Smoke Testing on average once every 18 months)
Annual Training for RCRA Hazardous Waste Generators (BMP) (Added cost of providing training)
Set Up/Maintain Satellite Accumulation Areas and 90-Day Accumulation Area (if exists) with Proper Container, Label, and Log Book and Required Square Footage of Space (Added costs for labeling, log book, and square footage for areas for RCRA hazardous wastes)
Audits of Satellite Areas (Added costs for internal M&C audits, internal ORNL audits, internal Energy Systems/Corporate audits, DOE audits, and TDEC audits)
Compile/Complete Request for Disposal (RFD) Form (Added cost of completing form/meeting requirements for all RCRA hazardous wastes)
Waste Monitoring and Sampling of M&C Wastes (Added costs of monitoring/sampling)
Waste Pickup and Transportation to Permitted RCRA Storage Facility (Added cost for pick-up/transportation)
Waste Storage in Permitted RCRA Storage Facility (Added cost for storage)
Additional Sampling and Analysis Probably Required to Comply with Waste Acceptance Criteria for Treatment (Future) (Added cost assumed to equal at least current monitoring/sampling costs)
Waste Transportation to Off-Site Storage and Treatment Facilities (Present and Future - Added costs for transport to K-25 Site for off-site storage and potential treatment; transport to treatment assumed to be same cost as cost of transport to K-25 Site)
Waste Treatment (Future) (Added cost of RCRA treatment)
Disposal of Treatment Residues (Future) (Added cost of RCRA disposal)

Figure 4-2.

been deemed ORNL legacy wastes, sampling and analyses of these wastes have been funded through EM. Otherwise, the waste-generating organization, such as M&C, has been funding this sampling and analysis cost. Also, resources outside of ORNL, such as Energy Systems, DOE, and the Tennessee Department of Environment and Conservation (TDEC), have incurred costs in supporting RCRA hazardous waste management by performing specific tasks including audits or assessments. Table B-1 in Appendix B details the basis and the equations used for estimating costs and designates the funding categories in which costs were incurred in the 1994 scenario. The quantifiable costs for the tangible added requirements were calculated using spreadsheets. These costs were estimated for:

- all of M&C nonradioactive RCRA hazardous wastes,
- general types of activities, and
- general waste types.

The compiled cost-based data were evaluated for trends to determine (1) the added requirements that were the largest contributors to the associated quantifiable costs and (2) the impact of different types of pollution prevention and elementary neutralization applications on the reduction of added requirements and associated quantifiable costs.

Based on the compiled data, improved productivity measured as cost avoidance values were estimated based on eliminating added requirements through implemented and potential pollution prevention or elementary neutralization options. The improved productivity values measured as cost avoidance for potential opportunities were

estimated (100 percent success and estimated percentage chance of success). The improved productivity data were then categorized, sorted, and evaluated for trends based on:

- type of pollution prevention or elementary neutralization application,
- current pollution prevention and elementary neutralization implemented, and
- potential pollution prevention and elementary neutralization opportunities.

When the scope of a pollution prevention or elementary neutralization option was relatively simple and had minimal or no impact on equipment or personnel activities, the calculations for improved productivity (cost avoidance) were based on the elimination of specific added requirements and associated quantifiable costs. For limited situations, the option was more complex, and additional calculations were performed to determine whether a quantifiable improved productivity (cost avoidance) would actually be realized.

Based on the data gathered and calculations performed using numerous spreadsheets, the resulting printouts were too voluminous to include in total in a report. Therefore, the data were reported graphically, and select data sets compiled in tables in Appendix B.

CHAPTER 5.0

Results and Discussion

The summarized data and results obtained from this study were presented and discussed in this chapter by (1) the sources of wastes and resulting pollution prevention opportunities, (2) the added requirements and quantifiable associated costs, and (3) the evaluation of the overall objective.

5.1 Sources of Wastes and Resulting Pollution Prevention Opportunities

As described previously, data on the waste type, source, generating activity, and implemented and potential pollution prevention opportunities including estimated chances for success were determined for each waste item. The data, as summarized in this chapter, were sorted in several ways by parameters such as generator name, waste type, type of activity, and type of pollution prevention application.

5.1.1 Waste Sources and Generation

The nonradioactive RCRA hazardous wastes generated in 1992 by M&C activities consisted of 331 individual items totaling 10,557.8 kg as summarized in Appendix B in Table B-2. The wastes were sorted by 79 waste types and specific waste types containing at least one material deemed a carcinogen or reproductive hazard were identified (Table B-2). The large number of different waste types was expected due to the variety of work performed and materials used in the M&C areas.

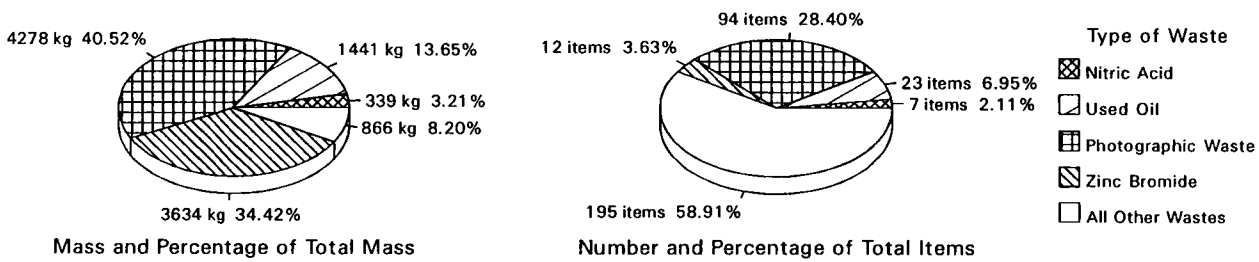
As shown in Figure 5-1, the four largest mass-based waste types were photographic wastes, zinc bromide waste, used oil-based wastes, and nitric acid-based waste and accounted for more than 91 percent by mass of the nonradioactive RCRA hazardous waste. In contrast, Figure 5-1 also shows that the four major mass-based waste types accounted for less than 42 percent of the total number of items from nonradioactive RCRA hazardous waste.

Wastes were also classified by the three generating activities:

- laboratory cleanouts' wastes or wastes deemed as excess or legacy,
- R&D activities' wastes, and
- support activities' wastes (from R&D support activities but not directly from R&D activities).

Legacy wastes were materials from experiments that concluded many years ago and were stored for potential reuse. Due to the length of time, the material could no longer be assigned to its originating experiment. In contrast, materials that were deemed laboratory cleanout or excess wastes could be traced to a relatively recent activity. The specific generating activities and waste were sorted by the three general types of activities (Tables B-2 and B-3).

Two approaches were used to estimate procured materials values, directly assigning values and proportionally assigning values (Table B-2). The values directly assigned from procured data based on waste type were approximately 48 percent by mass and approximately 80 percent by item of proportion-based procured materials values. The directly assigned and proportionally assigned values for the amount of



[Basis: 10557.8 kilograms (kg) or 331 items of nonradioactive RCRA hazardous waste]

Figure 5-1. Value and Percentage by Mass and by Items of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Types Generated in 1992 by the Metals and Ceramics Division at the Oak Ridge National Laboratory (ORNL)

procured 3- and 4-rated hazardous materials were also compared to the resulting nonradioactive RCRA hazardous wastes. The estimated mass of procured 3- and 4-rated hazardous materials ranged from approximately 22 to 48 percent of the mass of the resulting nonradioactive RCRA hazardous waste. On an item basis, the procured 3- and 4-rated hazardous materials ranged from approximately 47 to 60 percent of the number of items of the resulting nonradioactive RCRA hazardous waste. The inability to perform mass balances was expected because the activities performed and the related quantities and types of materials needed and stored in R&D laboratories vary. Therefore, in this scenario, the waste values exceeded the material values.

Trends varied greatly for the generating activities when two different units of measure, mass and items, were used, as shown in Figure 5-2. The legacy and laboratory cleanout activities generated less than 2 percent by mass of the wastes while the R&D- and support-oriented activities generated approximately 52 percent and 47 percent of this waste, respectively. On a mass basis, this trend suggested that legacy and laboratory cleanout wastes accounted for an insignificant amount of waste. However, these legacy and laboratory cleanout wastes accounted for more than 24 percent by item of the same wastes. R&D and support activities only accounted for approximately 46 and 30 percent of these waste items, respectively. The observed variations of the mass-based and item-based values depicted in Figures 5-1 and 5-2 were attributed to the range in the size of containers used to meet M&C's needs, which resulted in significant variations in the mass per item values. The mass-based versus item-based differences based on activity type were not as great as the differences based

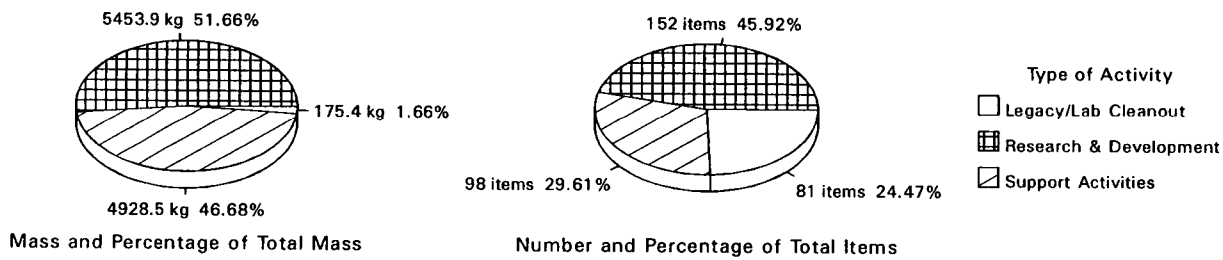


Figure 5-2. Value and Percentage by Mass and by Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by Metals and Ceramics Division Activities at the Oak Ridge National Laboratory (ORNL)

on waste type because the individual waste values had been totaled into three activity categories, not 79 waste types. Totaling the wastes within three categories decreased the range of the mass per item values when compared to the waste type-based values. The average mass per item for the waste types ranged from less than 0.02 kg per item to 302.8 kg per item. By totaling the waste values based on three general activities, the range of the mass per item values decreased and was from 2.2 kg per item to 50.3 kg per item. This decrease then reduced the differences between the mass-based and item-based trends.

5.1.2 Pollution Prevention and Elementary Neutralization Opportunities

Implemented and potential pollution prevention and elementary neutralization options were identified for many of the waste items (Tables B-4 and B-5). Current waste management or implemented pollution prevention options impacting the wastes were summarized. Percentage-based chances for success were estimated for potential options. In general, the chance of success was estimated to be approximately 50 percent, with some options being estimated at a higher percentage of 100 and one lower at 10 percent. The estimation of these percentages was based on information available on potential options and on interviews with the personnel responsible for the related activity. For instance, the likelihood of modifying the barium-waste-generating system, in which barium use was required, was lower than finding nonhazardous solvent replacements for hazardous solvents used in cleaning activities. While the use of personnel interviews provided additional insight concerning the feasibility of potential

options, the resulting percentage values did not provide absolute values but rather indicators to show that all potential options may not be successful. Appendix B contains summaries describing the sources of these wastes and the associated implemented and potential pollution prevention and elementary neutralization options.

The impact of various types of implemented and potential pollution prevention applications on the mass of wastes are depicted in Figures 5-3 and 5-4. Both Figures 5-3 and 5-4 show that the M&C Division had implemented options that significantly reduced waste (mass) from 1992 through 1994, leaving only a small amount of waste uninfluenced. Source reduction implemented by M&C also had the largest mass-based impact of the types of options implemented. Alternately, potential recycle and reuse options appeared to have the greatest anticipated impact on the remaining wastes.

Item-based trends related to pollution prevention and elementary neutralization applications also were evaluated, as seen in Figures 5-5 and 5-6. When compared to the mass-based graphs, the item-based graphs showed that even though M&C had implemented notable options, many generated waste items had not yet been reduced by pollution prevention or elementary neutralization. Implemented source reduction options, however, still had the greatest impact of the applications evaluated, and potential recycle and reuse options account for the largest anticipated impact on the remaining wastes. This trend related to the impact of implemented source reduction and potential recycle and reuse is shown in the pie charts in Figures 5-7 through 5-10. Whether based on mass or number of items, source reduction options accounted for approximately 64 percent and 60 percent, respectively, of the wastes reduced through

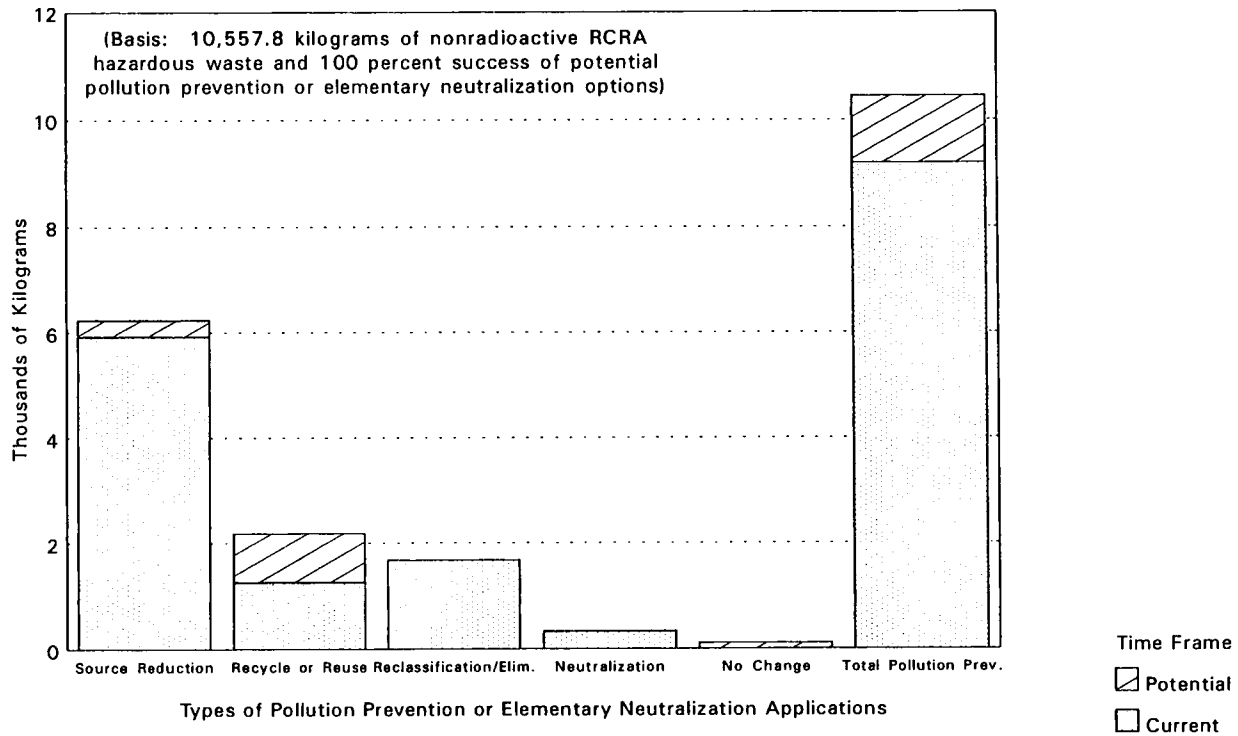


Figure 5-3. Bar Graph of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Complete Success of Potential Options

Abbreviations:
Prev. - Prevention or Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

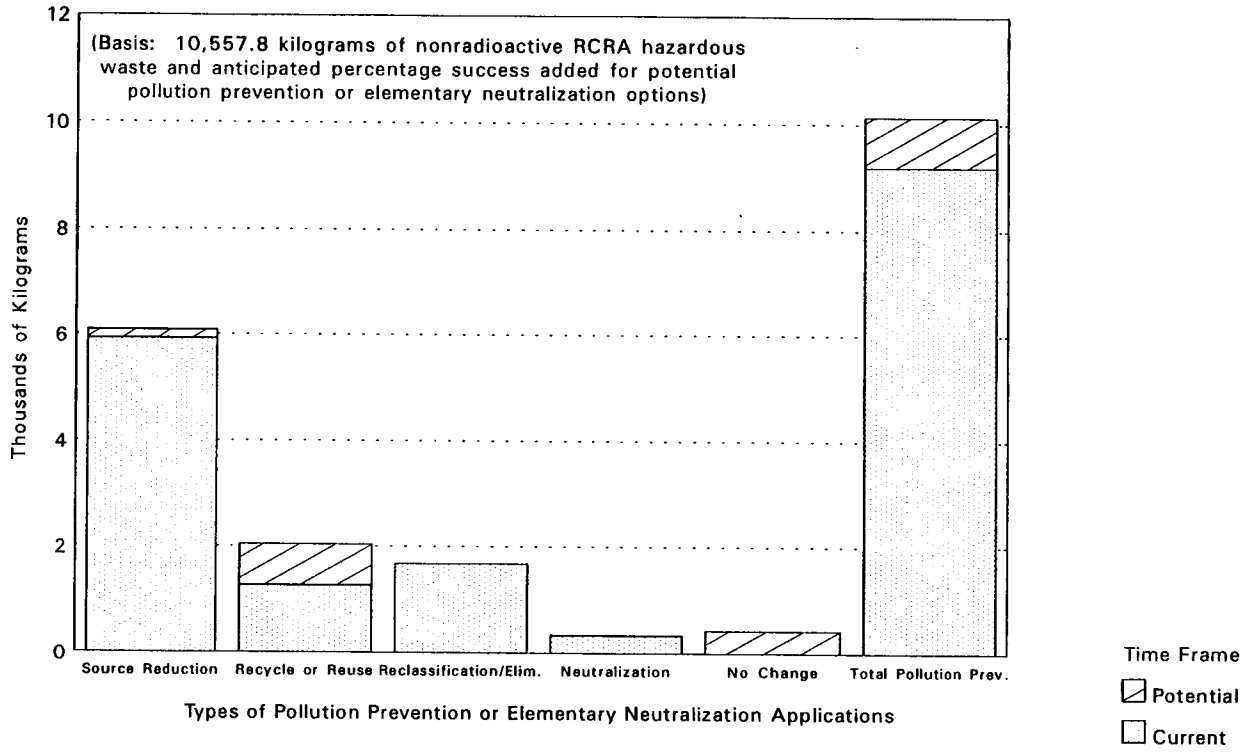


Figure 5-4. Bar Graph of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Partial Success of Potential Options

Abbreviations:
Prev. - Prevention or Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

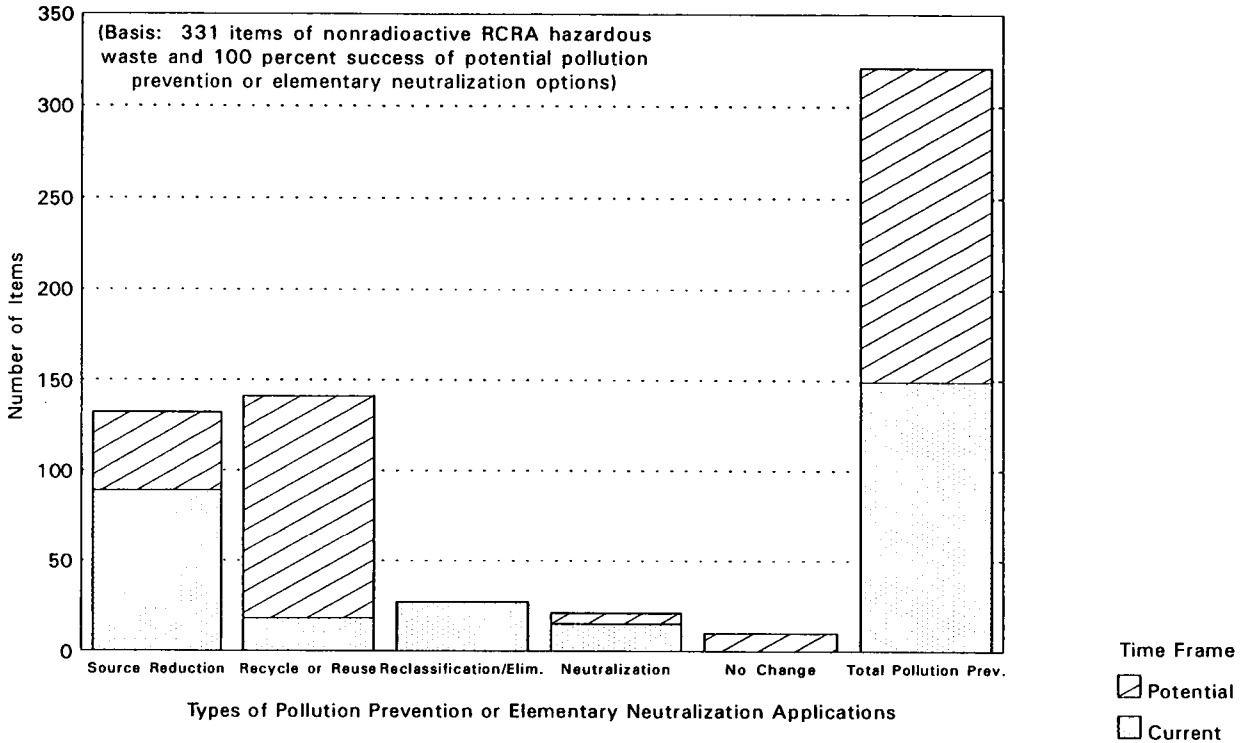


Figure 5-5. Bar Graph of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Complete Success of Potential Options

Abbreviations:
Prev. - Prevention or Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

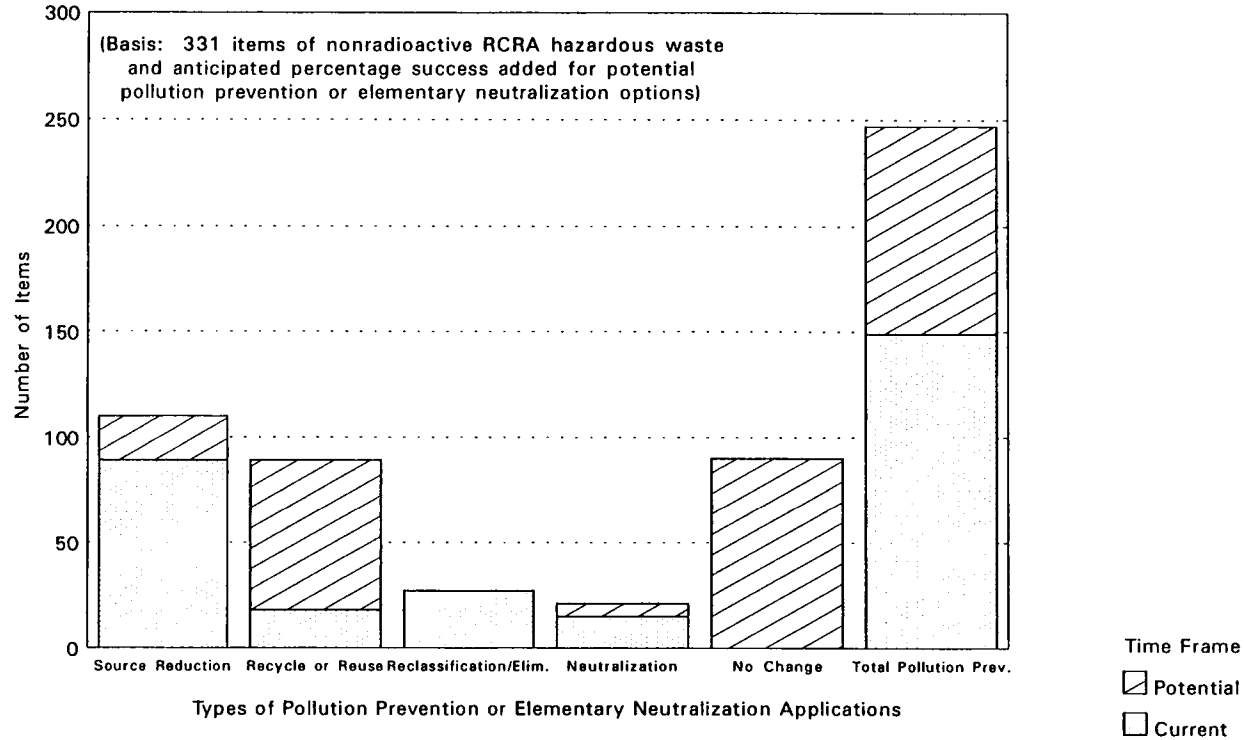


Figure 5-6. Bar Graph of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Partial Success of Potential Options

Abbreviations:
Prev. - Prevention or Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

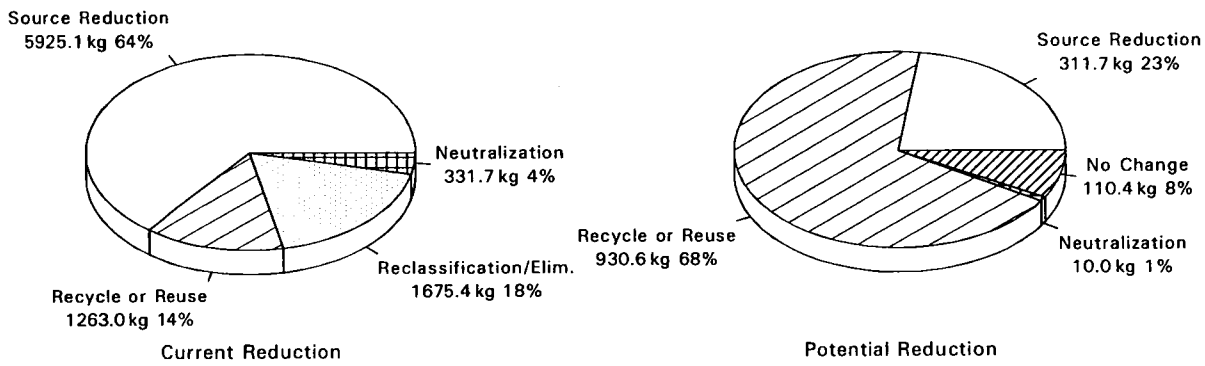
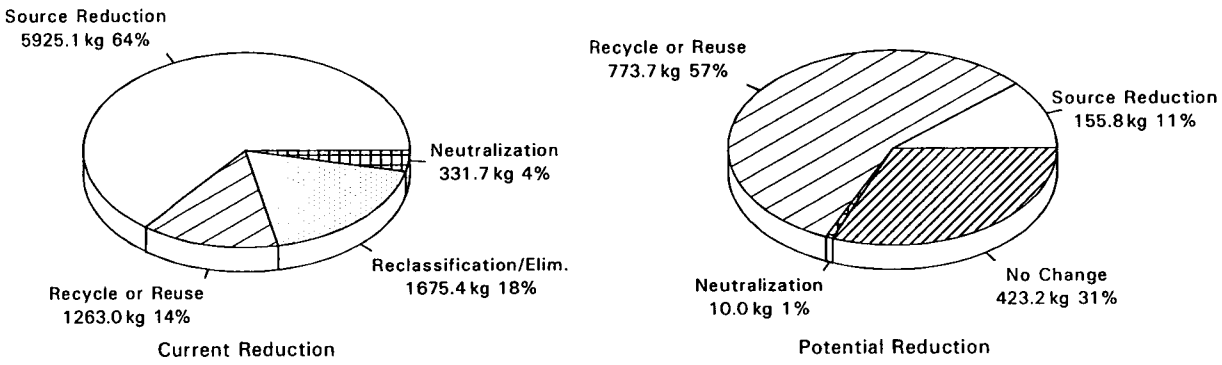


Figure 5-7. Pie Charts of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Complete Success of Potential Options

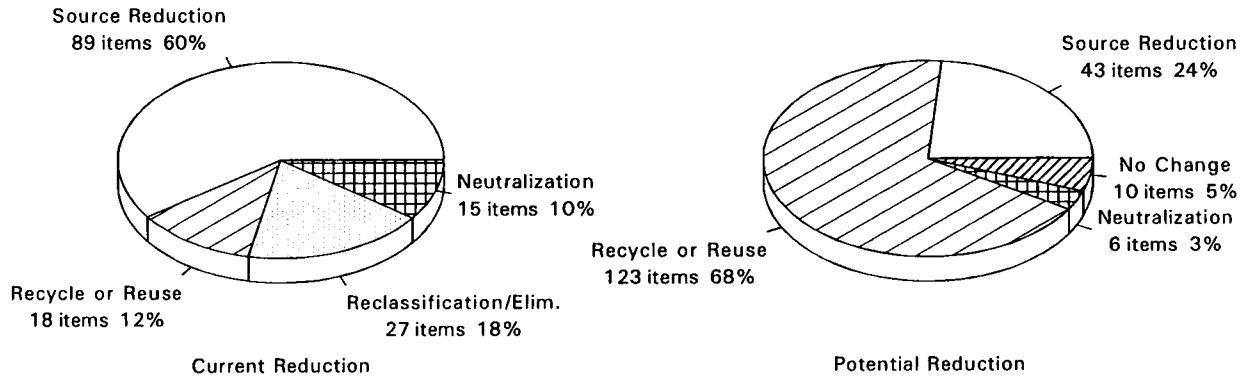
Abbreviations:
Neutralization - Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated



(Basis: 10,557.8 kilograms of nonradioactive RCRA hazardous waste and anticipated percentage success added for potential pollution prevention or elementary neutralization options)

Figure 5-8. Pie Charts of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Partial Success of Potential Options

Abbreviations:
Neutralization - Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated



(Basis: 331 items of nonradioactive RCRA hazardous waste and
100 percent success of potential pollution prevention or elementary neutralization options)

Figure 5-9. Pie Charts of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Complete Success of Potential Options

Abbreviations:
Neutralization - Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

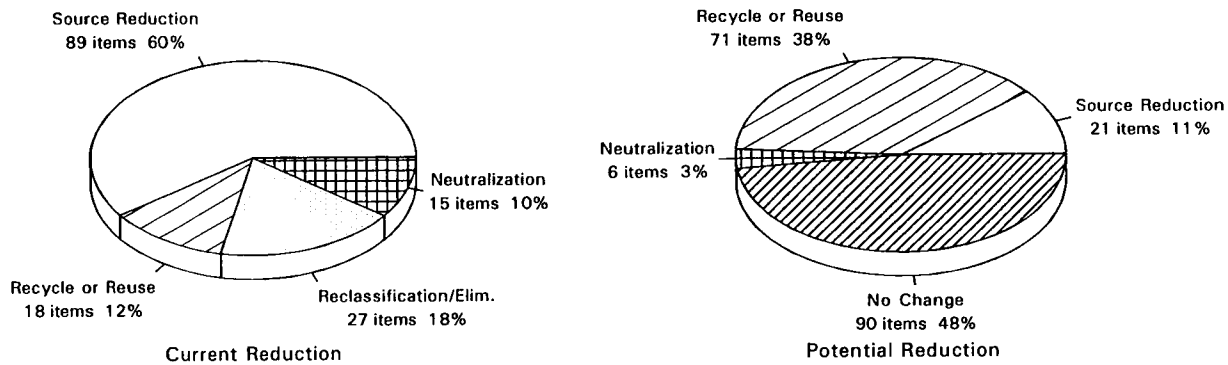


Figure 5-10. Pie Charts of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Elementary Neutralization Application Assuming Partial Success of Potential Options

Abbreviations:
Neutralization - Elementary Neutralization
Reclassification/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

implemented options. Potential recycle and reuse accounted for approximately 57 percent to 68 percent (mass) and approximately 38 percent to 68 percent (items) of the potential waste reduction through potential options.

Proper characterization of the activity, materials, and resulting wastes also was shown to be essential. Figures 5-7 through 5-10 showed that of the amount of wastes reclassified based on activities that had either been eliminated or on wastes that had been sampled and analyzed and determined not to be a RCRA hazardous waste accounted for approximately 18 percent on an item or mass basis of the wastes reduced through implemented options. Without proper characterization, efforts to reduce the wastes related to these activities would be wasted. Also, elementary neutralization within the laboratory affected more than 300 kg of waste within M&C areas and was included in this study to provide a laboratory-based treatment application to use for comparing to pollution prevention applications.

When data were compiled for potential options, wastes that would not be affected by an option were assigned to a no change category. The mass-based (Figures 5-7 and 5-8) and item-based (Figures 5-9 and 5-10) reductions by reduction applications in wastes that were not already reduced were:

- from approximately 11 to 23 percent (mass) and from 11 to 24 percent (items) for potential source reduction,
- from approximately 57 to 68 percent (mass) and from 38 to 68 percent (items) for potential recycle and reuse options, and

- approximately 1 percent (mass) and 3 percent (items) for potential elementary neutralization.

The wastes that were expected to be unaffected by any option ranged from approximately 8 to 31 percent (mass) and from 5 to 48 percent (items).

5.1.2.1 Opportunities Examined by Waste Types

Data related to implemented and potential options were evaluated along with the major waste types (Figures 5-11 through 5-14). Beginning in 1993, M&C performed an evaluation of methods for reducing high priority wastes including photographic-based, nitric acid-based, and used oil-based waste, three of the four major mass-based waste types identified in this study (Figure 5-1). M&C had subsequently pursued plausible options for these wastes (ORNL 1994). The resulting mass-based reductions from all of M&C's implemented and potential options are summarized in Figures 5-11 and 5-12 and parallel the waste type-based generation pattern shown in Figure 5-1. The larger the generated mass of the waste type, the larger the mass reduction. The options and related reductions in M&C's wastes are summarized in Appendix B.

When compared to mass-based data, item-based waste reductions resulting from implemented and potential options showed a different pattern (Figures 5-13 and 5-14), in which the wastes not included in the four major mass-based waste types resulted in the largest overall reduction. This value was followed in descending order by: (1) photographic-based, (2) used oil-based, (3) zinc bromide and, (4) nitric acid-based waste.

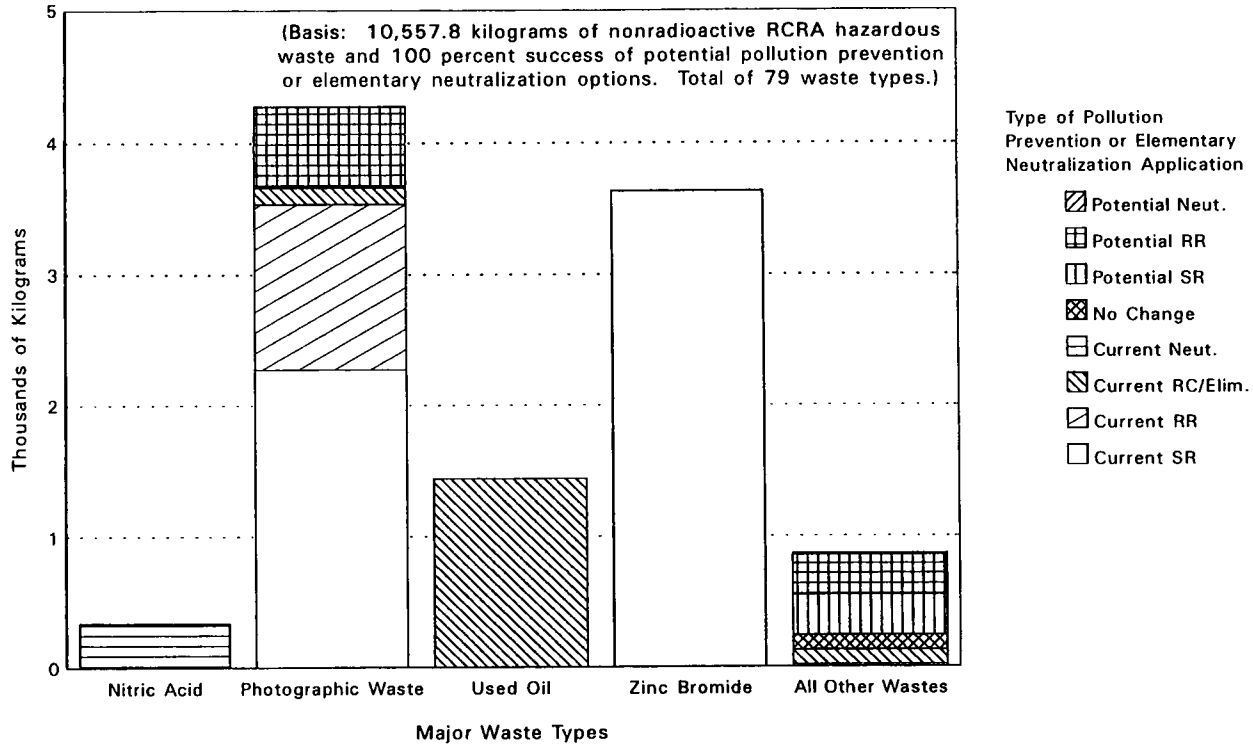


Figure 5-11. Bar Graph of Current and Potential Reductions in Mass of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Types Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) Assuming Complete Success of Potential Options

Abbreviations:
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

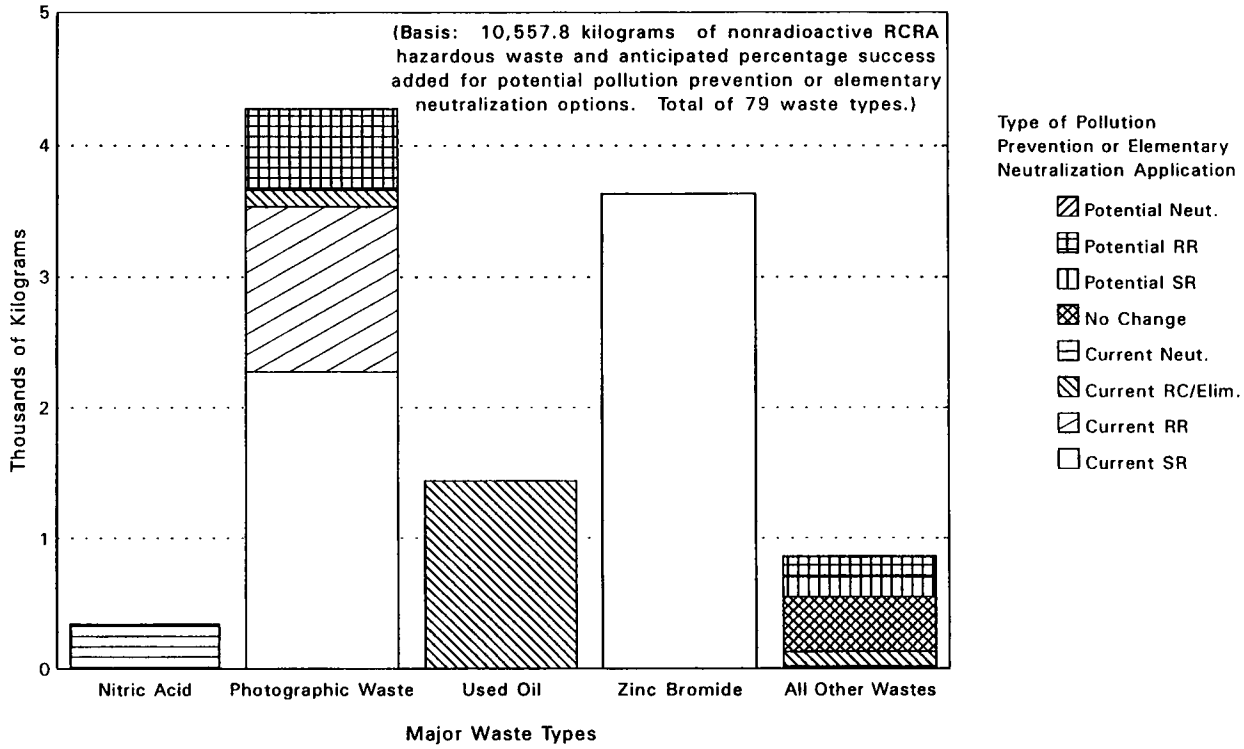


Figure 5-12. Bar Graph of Current and Potential Reductions in Mass of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Types Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) Assuming Partial Success of Potential Options

Abbreviations:
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

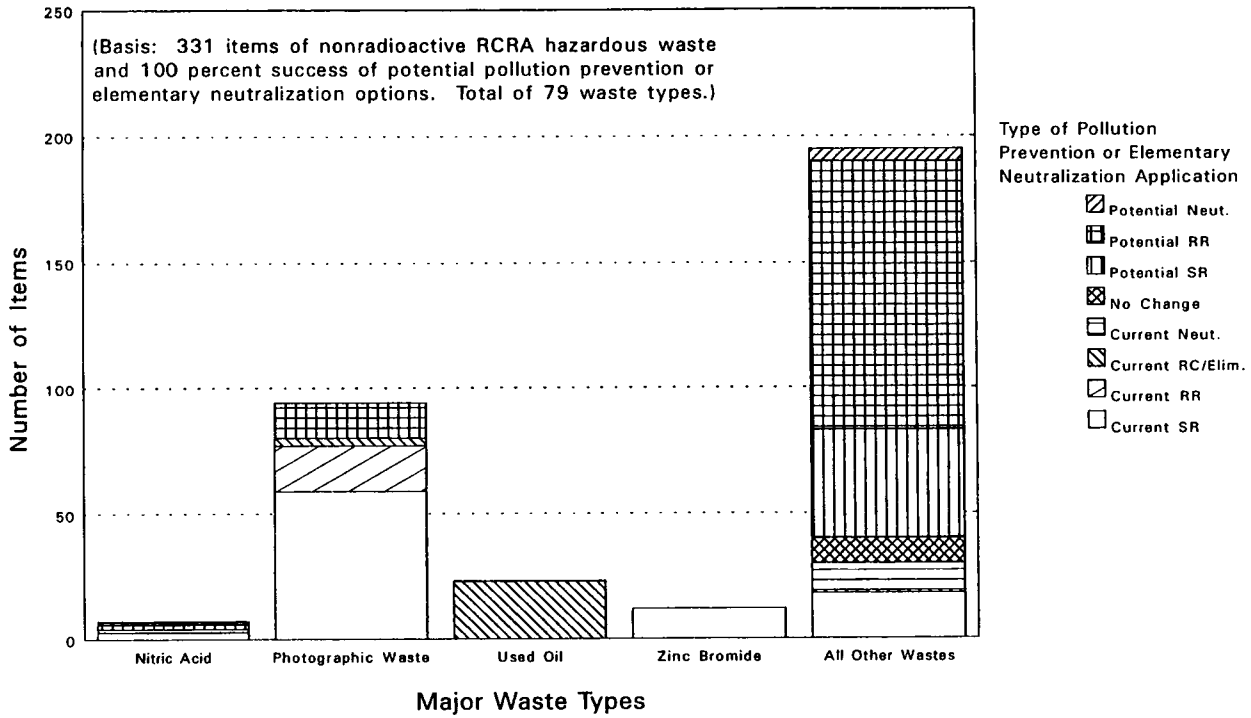


Figure 5-13. Bar Graph of Current and Potential Reductions in the Number of Items of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Types Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) Assuming Complete Success of Potential Options

Abbreviations:
Neut. - Elementary Neutralization
RCRA - Resource Conservation and Recovery Act
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

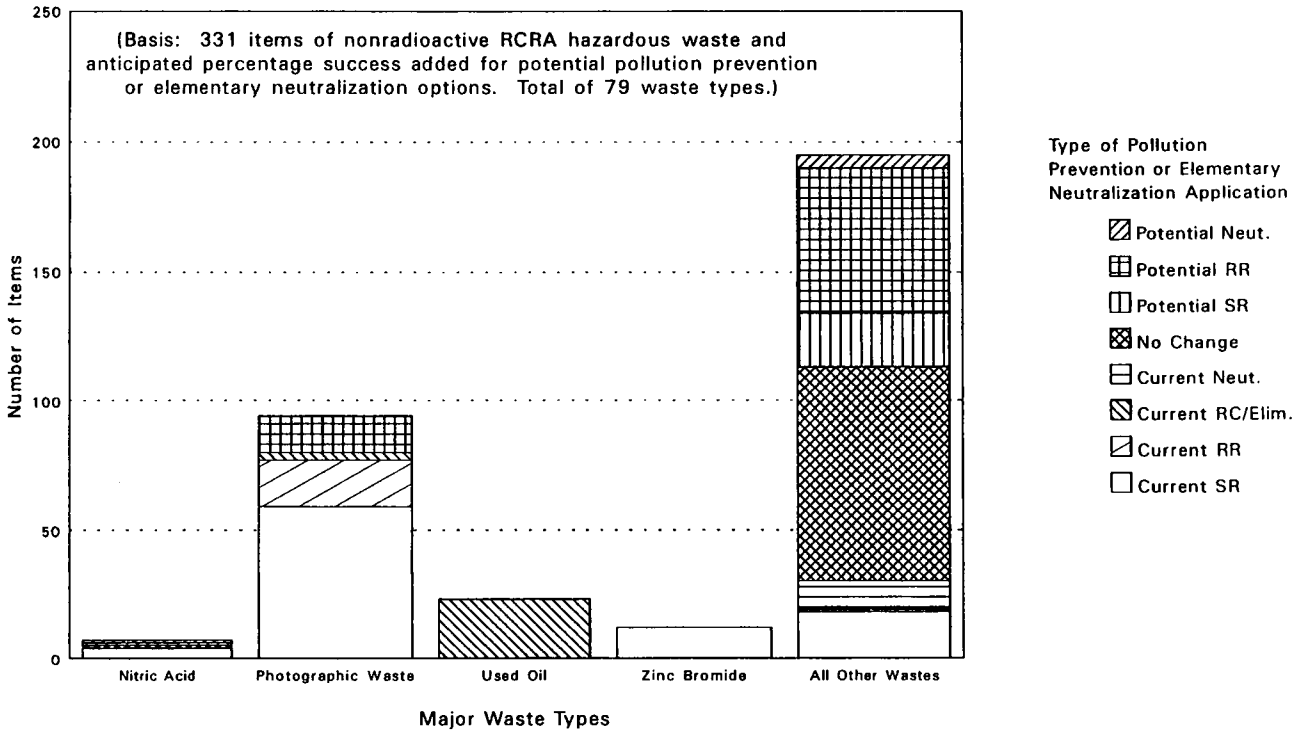


Figure 5-14. Bar Graph of Current and Potential Reductions in the Number of Items of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Types Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) Assuming Partial Success of Potential Options

Abbreviations:
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

Overall item-based reductions also paralleled the waste generation pattern (Figure 5-1). The greater the number of items generated in a waste type, the larger the reduction.

5.1.2.2 Opportunities Examined by Types of Activities

Data concerning implemented and potential options were evaluated along with major types of activities (Figures 5-15 through 5-18). Mass-based data related to activity-categorized waste and associated implemented and potential options were examined (Figures 5-15 and 5-16). The options had the greatest impact on R&D-oriented wastes followed by support-oriented ones. Implemented and potential options applicable to wastes related to laboratory cleanouts or deemed legacy wastes had minimal impact. This trend in reduction paralleled the waste generation pattern (Figure 5-2). The larger the mass generated by the type of activity, the larger the reduction. Also, based on the mass reduced, implemented source reduction was the major type of application used in R&D- and support-oriented areas (Figures 5-15 and 5-16).

When compared to mass-based reductions, item-based waste reductions resulting from the implemented and potential options displayed an overall similar pattern as seen in Figures 5-17 and 5-18. For instance, options associated with R&D-oriented activities resulted in the largest overall reduction value, which was followed by values associated with the options related to support activities and then to laboratory cleanouts and legacy-oriented wastes. However, the relative degree of reduction among the three types of activities varied from the mass-based trend, and the overall item-based reductions closely paralleled the item-based waste generation pattern shown in Figure 5-2. The greater the number of items generated by a type of activity, the larger the

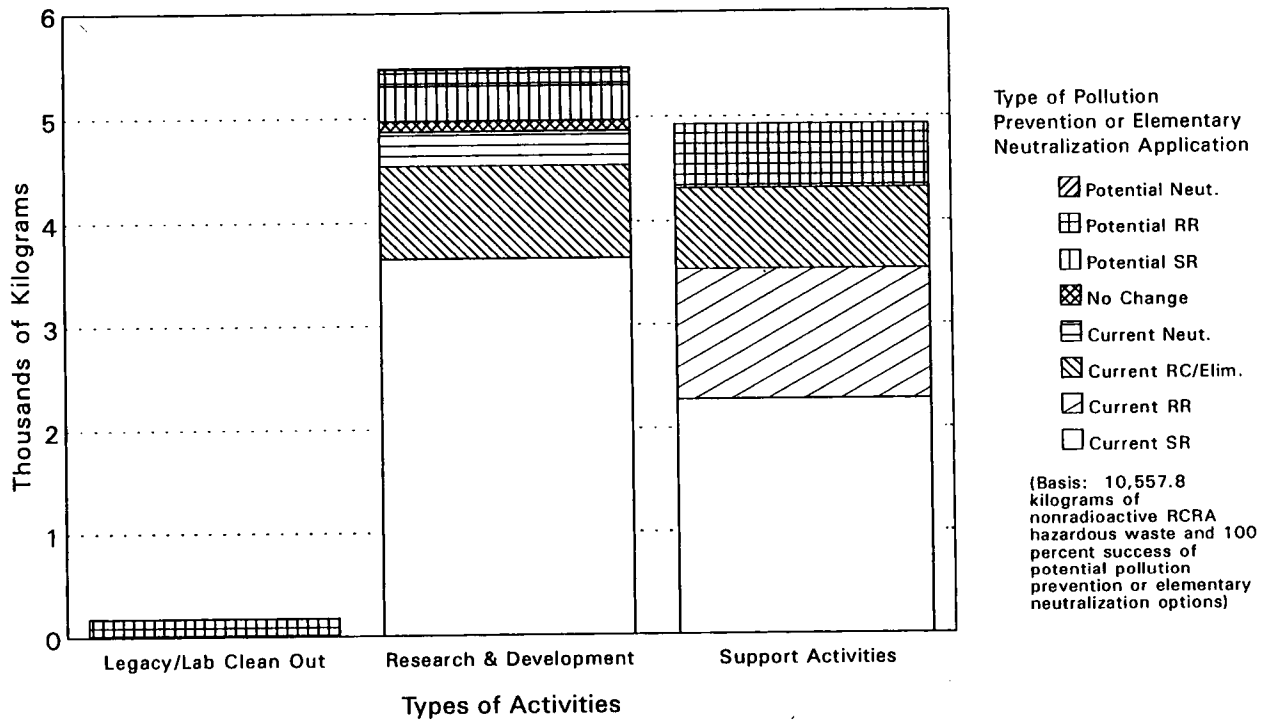


Figure 5-15. Bar Graph of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by Metals and Ceramics (M&C) Division Activities at the Oak Ridge National Laboratory (ORNL) Assuming Complete Success of Potential Options

Abbreviations:
Lab - Laboratory
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

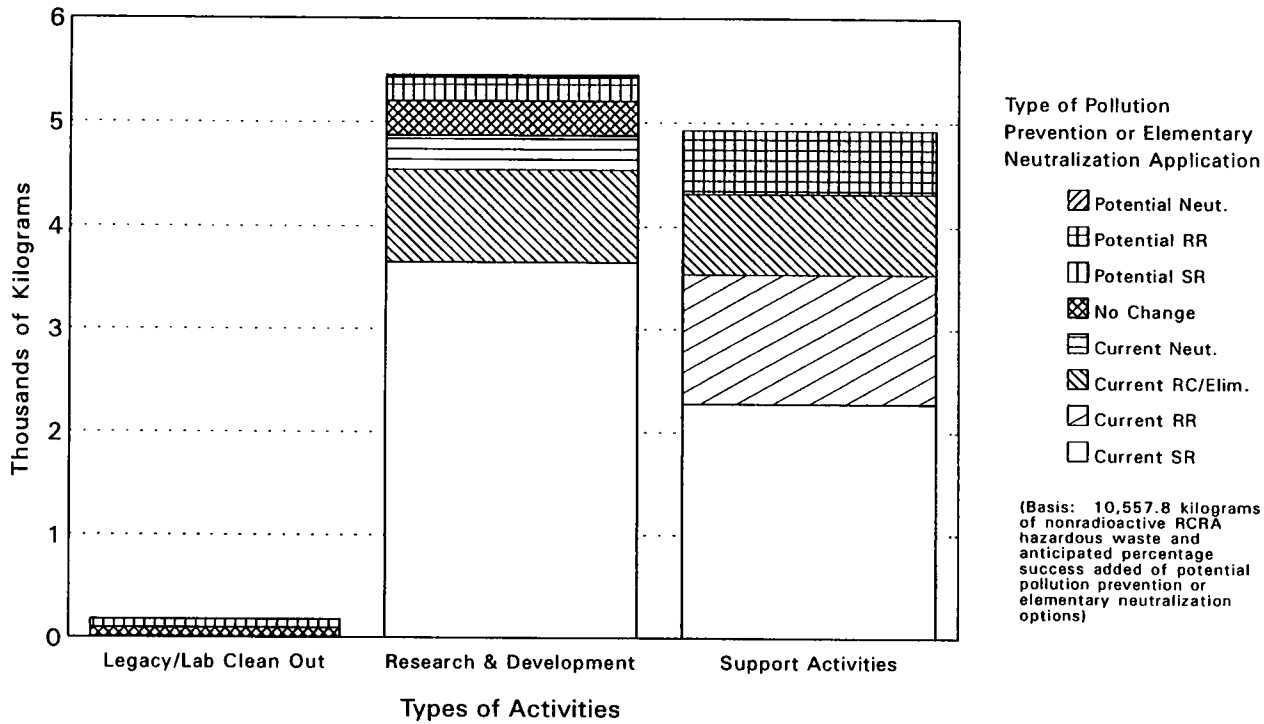


Figure 5-16. Bar Graph of Current and Potential Reductions in Mass of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by Metals and Ceramics (M&C) Division Activities at the Oak Ridge National Laboratory (ORNL) Assuming Partial Success of Potential Options

Abbreviations:
Lab - Laboratory
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

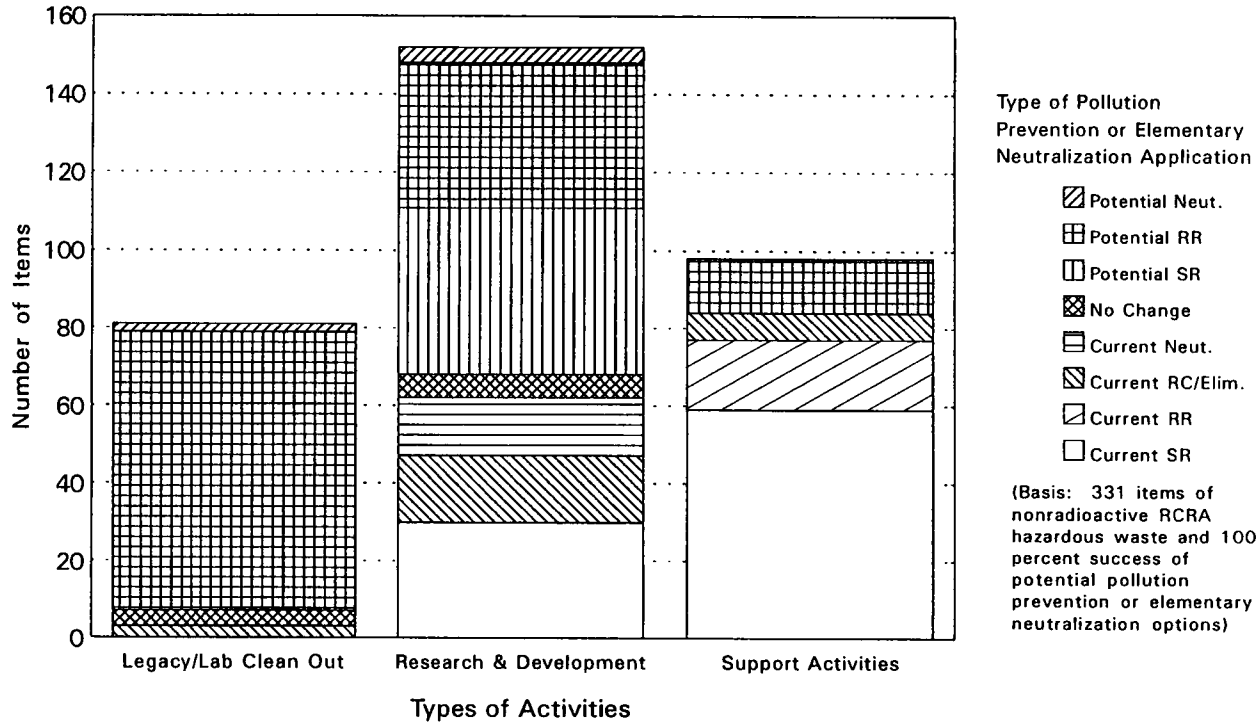


Figure 5-17. Bar Graph of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by Metals and Ceramics (M&C) Division Activities at the Oak Ridge National Laboratory (ORNL) Assuming Complete Success of Potential Options

Abbreviations:
Lab - Laboratory
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

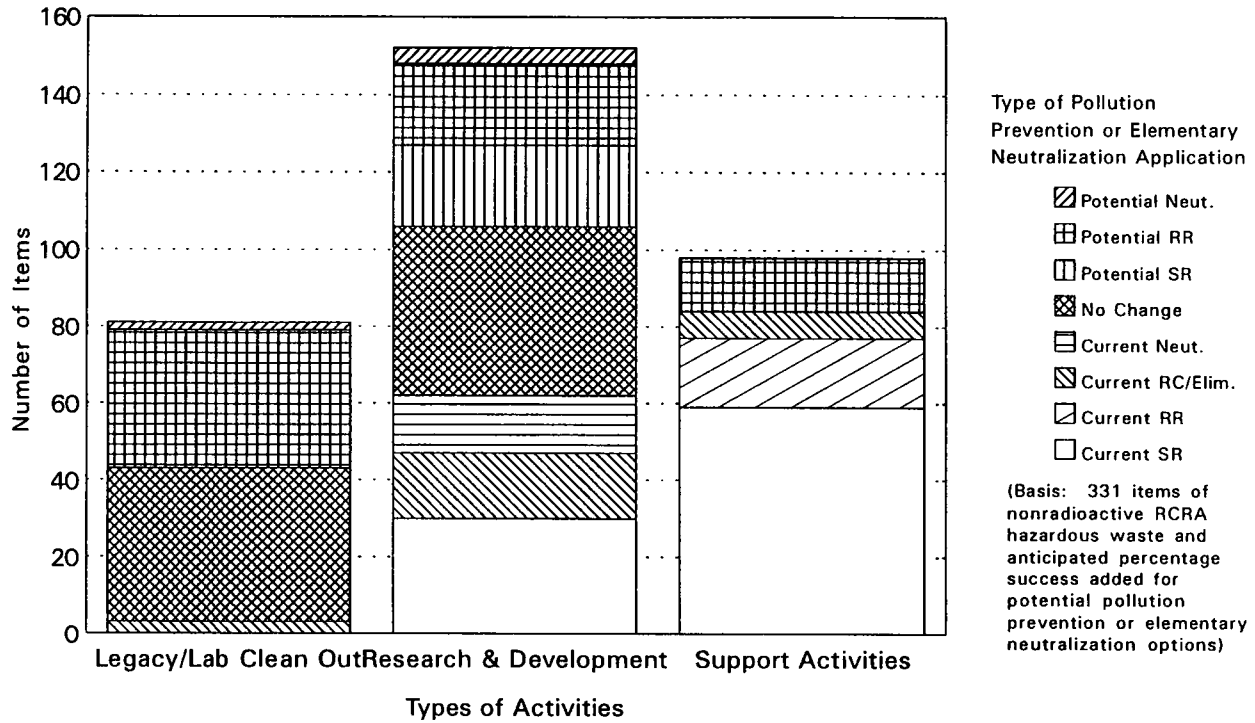


Figure 5-18. Bar Graph of Current and Potential Reductions in Number of Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by Metals and Ceramics (M&C) Division Activities at the Oak Ridge National Laboratory (ORNL) Assuming Partial Success of Potential Options

Abbreviations:
Lab - Laboratory
Neut. - Elementary Neutralization
RR - Recycle or Reuse
SR - Source Reduction
RC/Elim. - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated

reduction. Additionally, implemented source reduction was still a major type of application used in the R&D- and support-oriented areas but had a decreased relative impact as seen in Figures 5-15 through 5-18.

While gathering data, source reduction was observed to be viable if the material that resulted in the generated waste was not vital to the R&D or support activity. In some cases where the material was vital, specific types of potential source reduction options were also identified. For example, acetone and methanol cleaning solvents were not specifically required to clean specimens in R&D activities, but the specimens needed to be clean. Therefore, testing the cleaning ability of other solvents, such as Solvent 140 and MMK Blend, was applicable in these situations. In contrast, when barium waste was being generated from cleaning a system that deposited barium and barium oxide onto silicon wafers, barium could not be eliminated. So material substitution was not viable; however, other source reduction options could be applicable, such as examining the system for potential modifications that would reduce this waste.

During data gathering, recycle and reuse options were also observed to be feasible if the material met the requirements for the specific application, such as the standards required to use a material for R&D versus area maintenance. A solvent may be considered contaminated for use in R&D but not for cleaning vacuum pumps during maintenance activities. Additionally, based on the condition, characterization, and contamination of the waste, recycle and reuse options were also possible for specific waste items deemed as legacy and excess chemicals from laboratory cleanouts.

5.2 Added Requirements and Quantifiable Associated Costs

The 1994 added requirements and quantifiable associated costs for managing 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes were determined (Table B-1). The added requirements and quantifiable associated costs for the studied materials and wastes were qualitatively observed to be incurred on an item or event basis, not a mass basis. The resulting data were organized in many ways, including by requirement categories, funding sources, costs for one item (current scenario), and costs for the last item left in the division. The last item left in M&C was of interest because certain costs, such as maintaining a carcinogen control program, could not be eliminated until this last item was eliminated. The data were also used to calculate the improved productivity (cost avoidance) associated with:

- implemented pollution prevention and elementary neutralization options,
- potential options that were all successful,
- potential options that were expected to be partially successful based on a chance of success, and
- application of different types of options on a single item in M&C in 1994 and on the last one item left in M&C.

The costs and related improved productivity were calculated by waste type and by type of activity through:

- matching procured 3- and 4-rated hazardous materials to RCRA hazardous waste type mass and item values (for instance, correlating mass and item values for procured acetone to values for acetone-based wastes) and

- prorating procured 3- and 4-rated hazardous materials based on waste totals for the nonradioactive RCRA hazardous waste total and the three general activity groupings (for example, assume a total of 100 kg of procured 3- and 4-rated hazardous materials and a total of 200 kg of generated nonradioactive RCRA hazardous waste; if 50 kg of waste were generated by R&D activities, then the prorated procured materials would be 25 kg).

Minor variations related to these two approaches are addressed in Appendix B and did not impact resulting costs because they could only be estimated to one significant figure.

5.2.1 Costs of Managing Hazardous Materials and Resulting Wastes

The examination of managing hazardous materials and resulting wastes identified 18 separate types of requirements that resulted in quantifiable costs (Figure 4-2 and Table B-1). Additionally, even if all of the studied materials and wastes were eliminated, other assessed requirements were found to remain the same (fixed costs for ORNL or costs that would not be impacted if only M&C's wastes were reduced) and were not included. The quantifiable costs associated with the added requirements were calculated and categorized by funding source: (1) direct R&D funding cost, (2) M&C overhead cost, (3) ORNL overhead cost, (4) EM funding cost, and (5) non-ORNL funding cost. The funding sources were of interest because if costs were reduced or increased, M&C would immediately be impacted in the first two categories. As described previously, the added requirements were also divided among four categories:

(1) procurement, (2) general ES&H, (3) usage and storage, and (4) waste management from generation to disposal.

The cost data were also consolidated in total and by waste types and by types of activities (Table B-6). The estimated cost data were calculated and compiled graphically in Figures 5-19 and 5-20. Based on these data, the total costs, by funding category, incurred based on each type of material and waste grouping were:

- approximately $300,000 in the direct R&D funding category,
- approximately $500,000 to $600,000 in the M&C overhead funding category,
- approximately $100,000 in the ORNL overhead funding category,
- approximately $500,000 in the EM funding category, and
- approximately $10,000 in the non-ORNL funding category.

Figure 5-19 showed that even though costs of waste transportation, storage, treatment, and disposal were allotted to EM funding, the waste generating division, M&C, funded a significant portion of managing studied materials and wastes prior to waste transport through direct R&D funding and M&C overhead funding. For instance, approximately 94 percent of the direct R&D funding costs associated with managing the studied materials and wastes were incurred in waste management activities performed before the waste was transported to a permitted storage facility (Figure 5-20). Major waste management requirements associated with these added costs were related to maintaining a satellite accumulation area and attending RCRA hazardous waste generator training. In comparison, approximately 77 percent and 63 percent of the

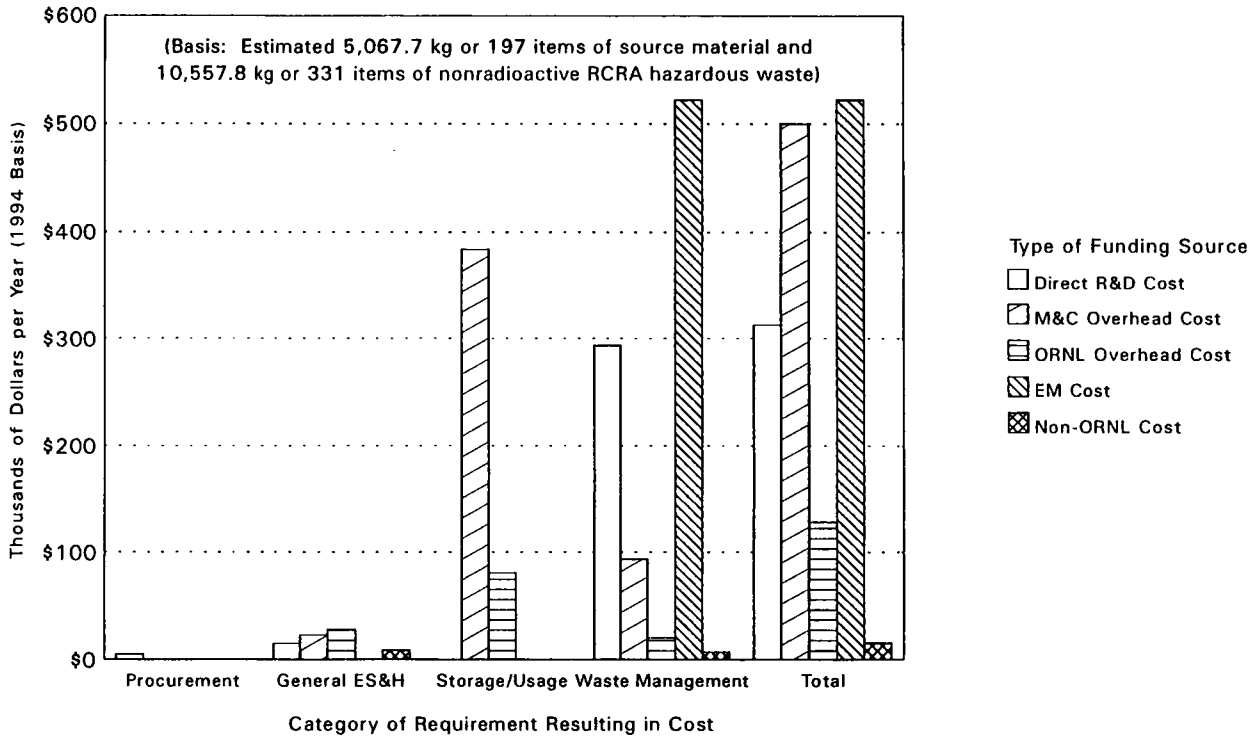


Figure 5-19. Bar Graph of Estimated Quantifiable Costs by Type of Funding Source and Requirement Category Associated with Managing 3- and 4-Rated Hazardous Materials and Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL)

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

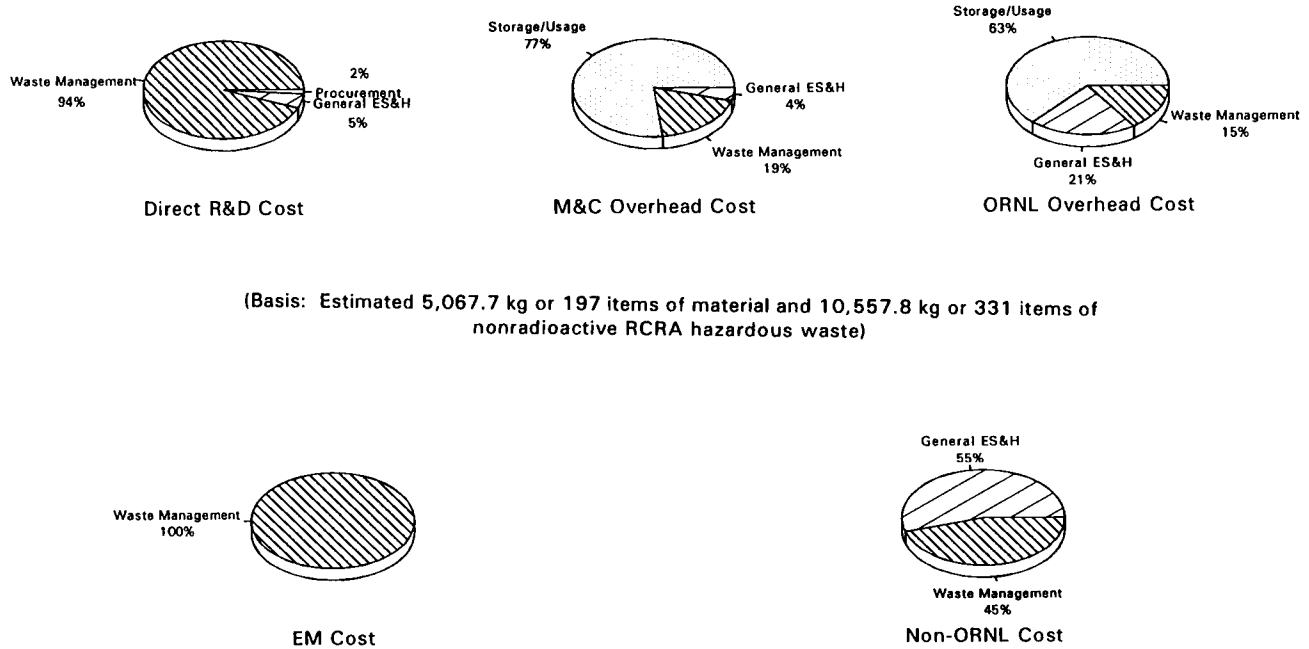


Figure 5-20. Percentage-Based Pie Charts of Funding Source-Based Estimated Quantifiable Costs Associated with Managing 3- and 4-Rated Hazardous Materials and Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL)

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

M&C overhead funding costs and ORNL overhead funding costs, respectively, were incurred supporting the added requirements related to storage and usage of 3- and 4-rated hazardous materials (Figure 5-20). One specific requirement that accounted for a major portion (approximately 75 percent) of the M&C overhead funding level was the cost associated with laboratory hoods and venting systems.

In contrast, several added requirements, such as procurement-related ones, had a relatively minor impact on added costs. Under the current waste management situation at ORNL, the majority of ORNL wastes were placed in storage, which accounts for approximately 13 percent of the total added EM funding costs. Storage was required because approved treatment and disposal have not been established. Future treatment and disposal costs within the waste management category were estimated based on current mass-based documents, and disposal was relatively small (less than 1 percent of the total added EM funding costs). When total funding levels per funding source were evaluated on Figure 5-19, the direct R&D funding and M&C overhead funding costs were as significant as the funding cost for EM.

The qualitative trend related to most costs being incurred on an item basis was examined quantitatively for the 1994 M&C situation. The approximate cost of managing one item of a carcinogenic hazardous material and the resulting nonradioactive RCRA hazardous waste was estimated for three mass-based scenarios: a 0.1-kg item, a 1.0-kg item, and a 10-kg item. The results of these calculations are depicted in Figure 5-21, which shows that the costs associated with each item were essentially the same.

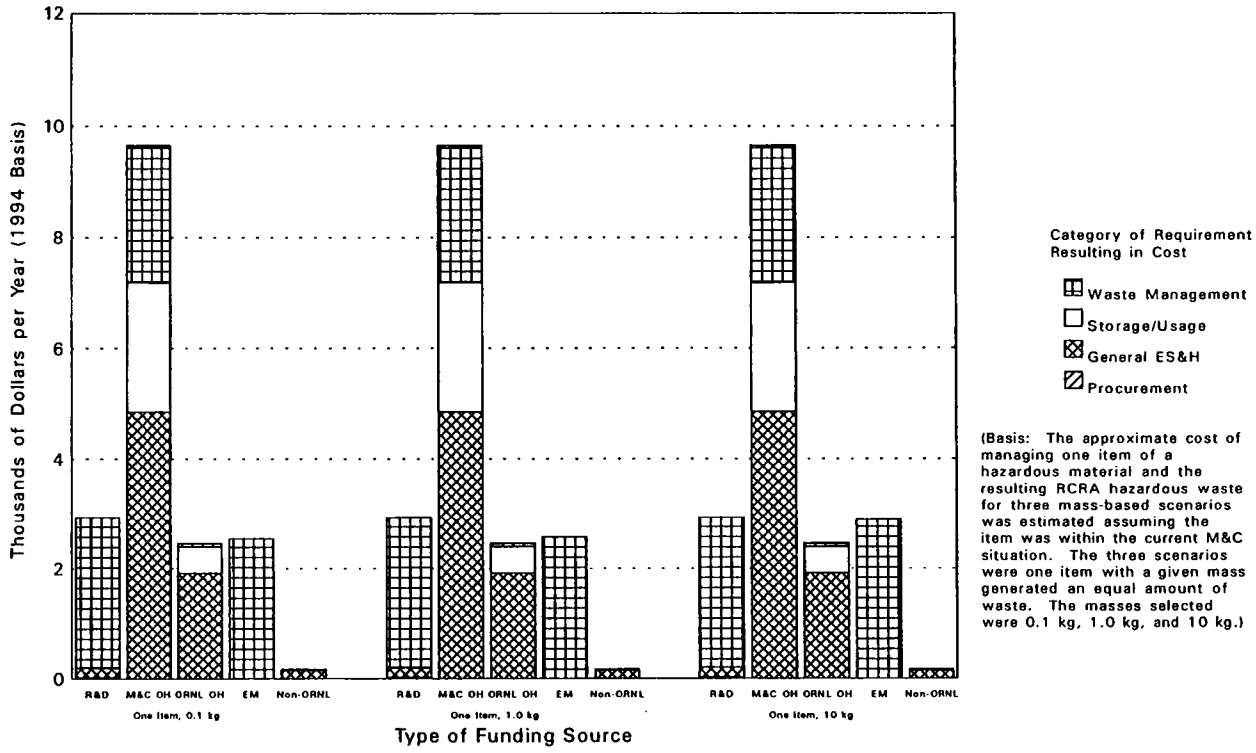


Figure 5-21. Estimated Added Requirements and Quantifiable Costs Associated with Managing 3- and 4-Rated Hazardous Materials and Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by the Metals and Ceramics (M&C) Division at Oak Ridge National Laboratory (ORNL) for Three Scenarios for an Item in the Current M&C Situation

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
OH - Overhead
R&D - research and development

Another potential trend was also qualitatively observed concerning how costs associated with added requirements were incurred. Although all of the costs within M&C would be eliminated if all studied materials and wastes were eliminated, several costs would still be incurred disproportionally if one item was left in the division. For instance, if only one item of a carcinogenic hazardous material was required within the whole M&C Division and it resulted in a nonradioactive RCRA hazardous waste, several requirements would still apply. M&C and other ORNL personnel would still need to maintain or perform certain requirements such as a carcinogen control program, a new work review, a satellite accumulation area, and transport of the waste to storage. This potential trend was examined quantitatively. The approximate cost of managing a single 1.0-kg item of a carcinogenic hazardous material and the resulting nonradioactive RCRA hazardous waste remaining in the M&C Division was estimated. The results of these calculations, as depicted in Figure 5-22, showed that the costs associated with this 1.0-kg item were higher than the values observed in Figure 5-21. The estimated costs were shown not to be incrementally linear, and the estimated costs associated with this last item in the division would be higher than for an item in the 1994 M&C situation. Figures 5-21 and 5-22 also show that the direct R&D funding and M&C overhead funding sources provided major support in either case.

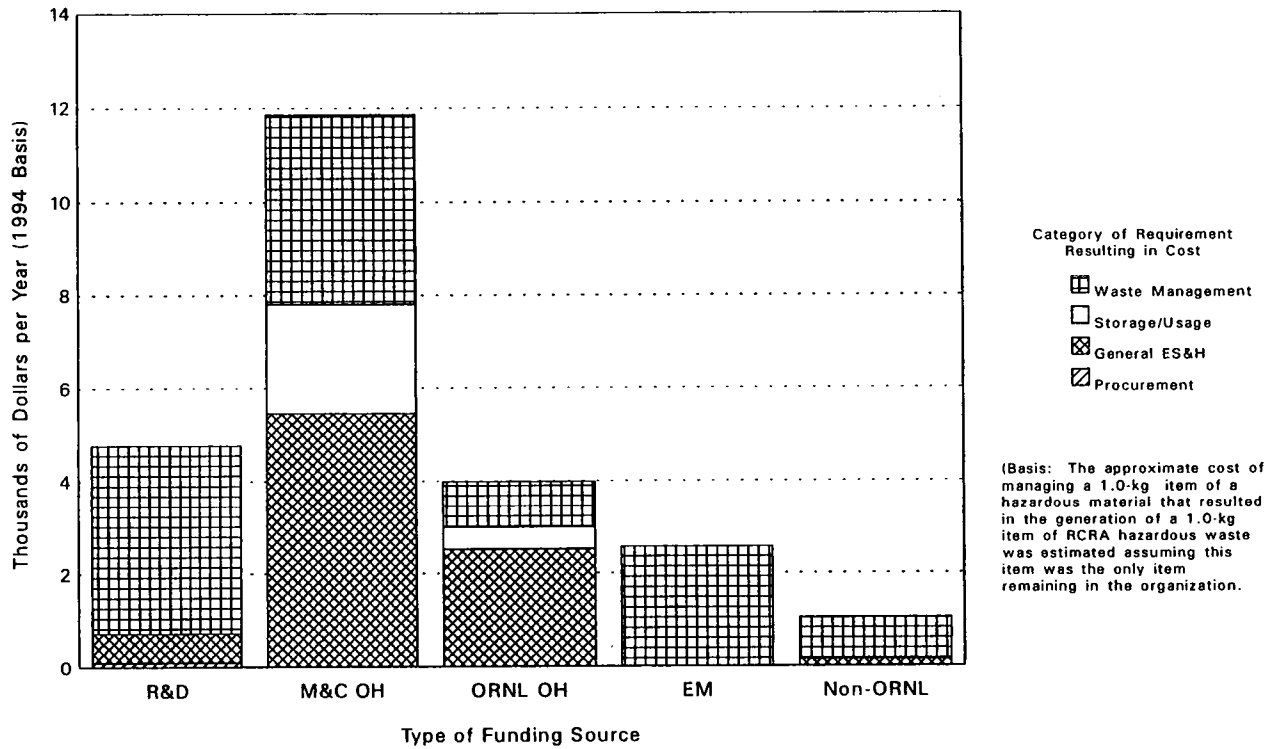


Figure 5-22. Estimated Added Requirements and Quantifiable Costs Associated with Managing 3- and 4-Rated Hazardous Materials and Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) for a Single Item Remaining in the M&C Division

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
OH - Overhead
R&D - research and development

5.2.2 *Cost Avoidance from Pollution Prevention and Elementary Neutralization Options*

Implemented and potential pollution prevention and elementary neutralization options were identified and examined to determine the impact of the options on costs and related productivity. For each option, the identified (Figure 4-2) and quantified (Figures 5-23 through 5-27) costs were examined to verify that performing added requirements would be eliminated and the associated quantifiable costs would be reduced (improved productivity). Implementation costs of each option were also examined to determine if additional costs would be incurred or reduced. These cost data associated with specific options are included in Appendix B.

The current and potential options supported an overall estimated reduction in added requirements and quantifiable costs and increase in productivity within the affected M&C areas. This improved productivity expressed as cost avoidance would allow the resources previously used to comply with these added requirements to be used to perform additional R&D and related support activities. The estimated cost avoidance data summarized graphically in Figure 5-23 are also compiled in Table B-7 in total as well as based on waste types and types of activities. Based on the compiled data, the total avoided costs by funding category for current and potential pollution prevention and elementary neutralization, assuming complete success of the potential options, were:

- approximately $300,000 in the direct R&D funding category,
- approximately $300,000 in the M&C overhead funding category,
- approximately $70,000 in the ORNL overhead funding category,

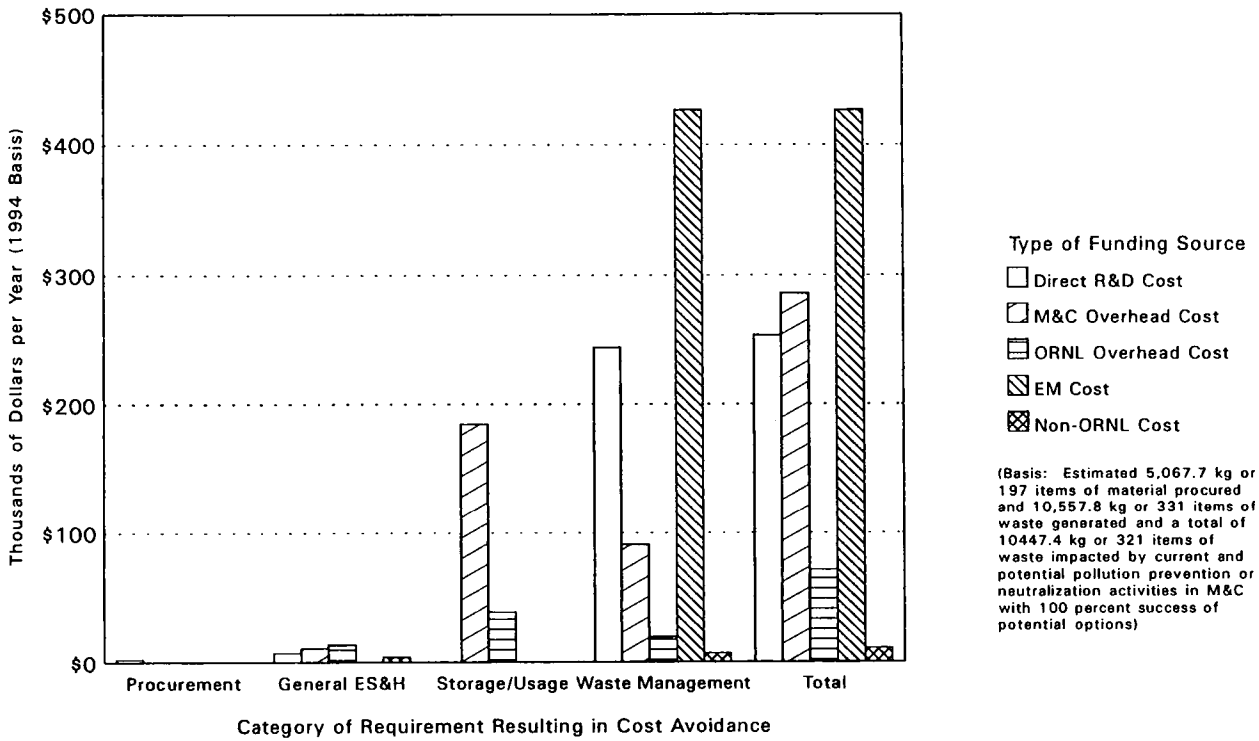


Figure 5-23. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

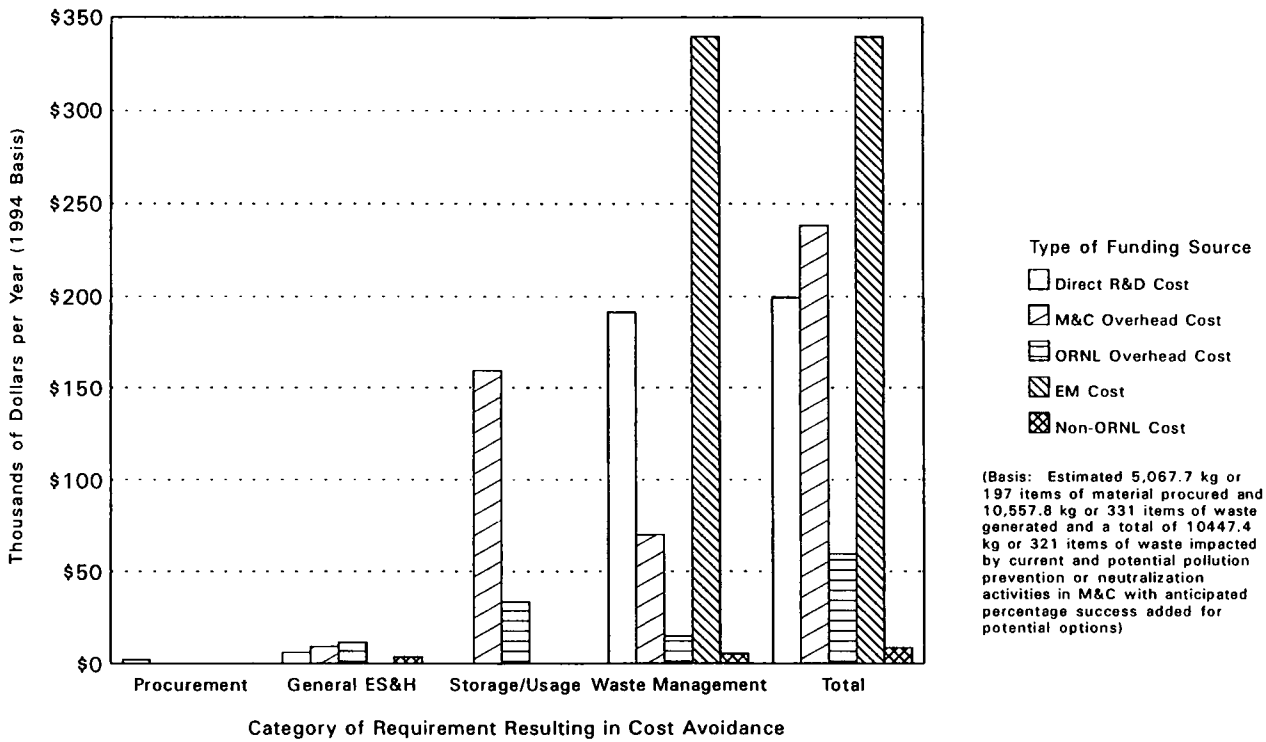


Figure 5-24. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

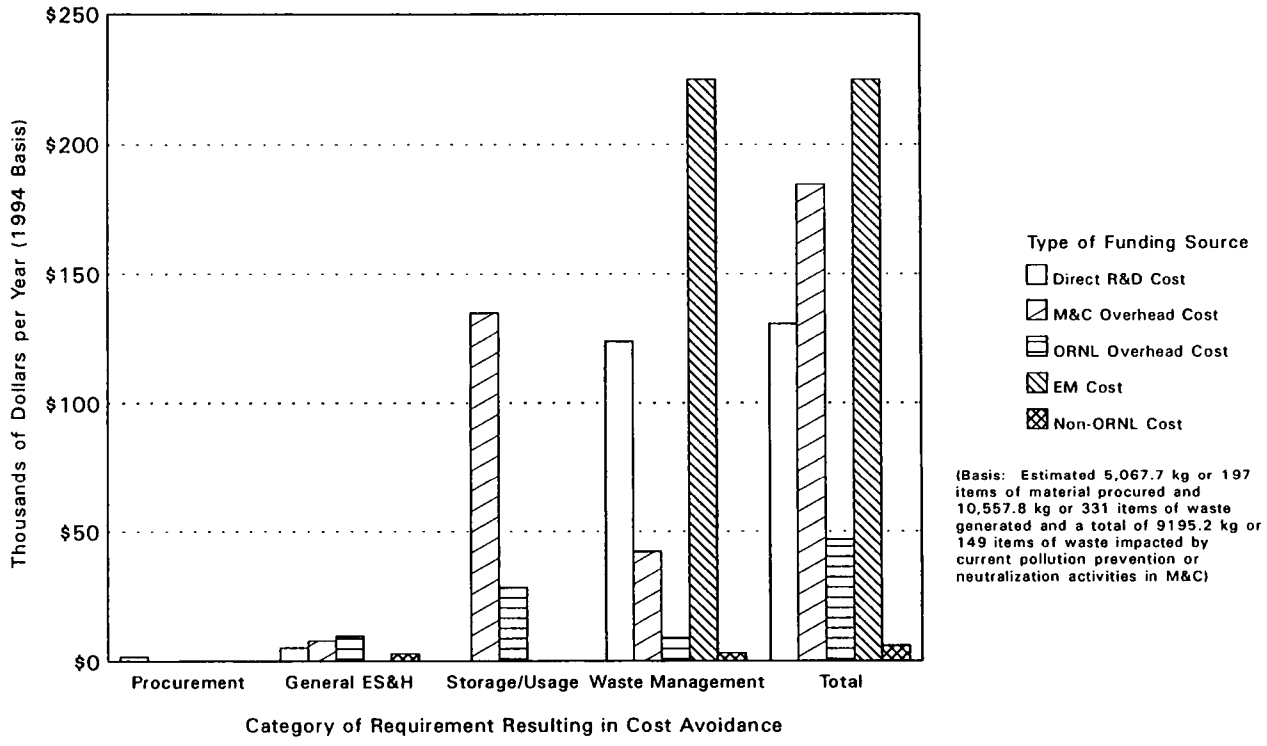


Figure 5-25. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current Pollution Prevention and Elementary Neutralization Activities

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

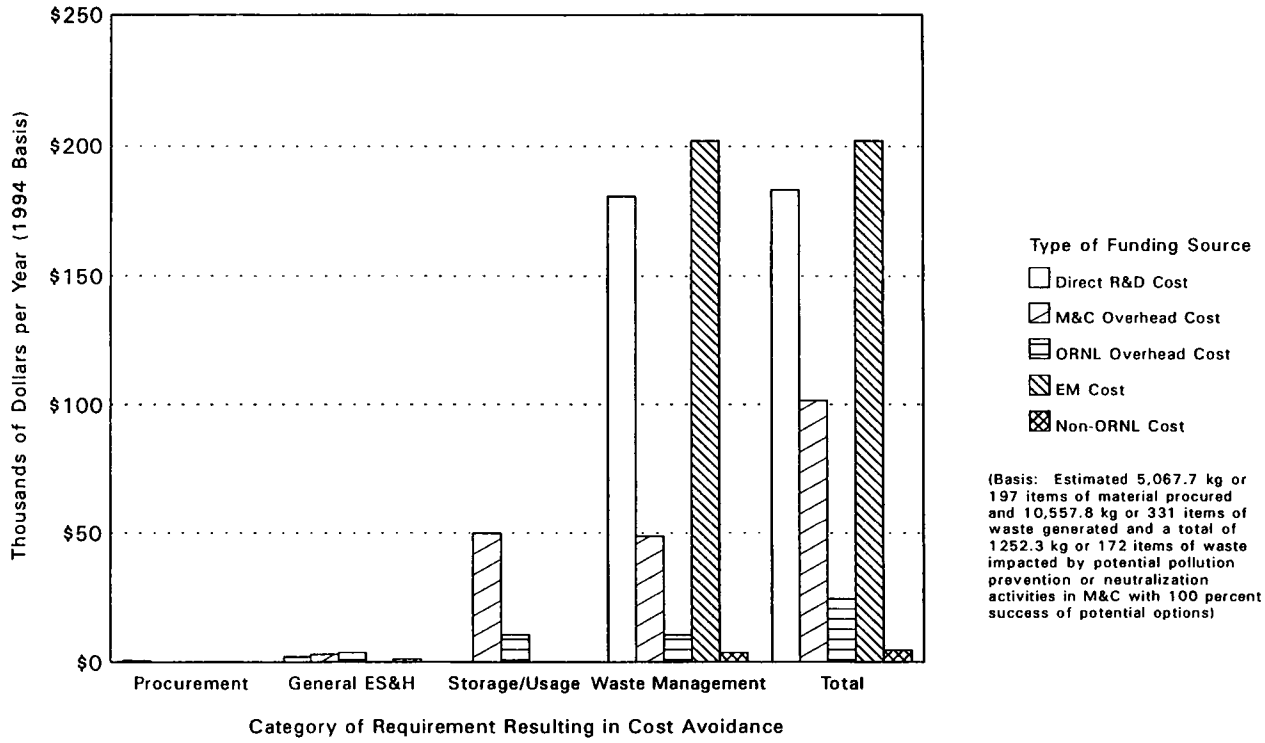


Figure 5-26. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

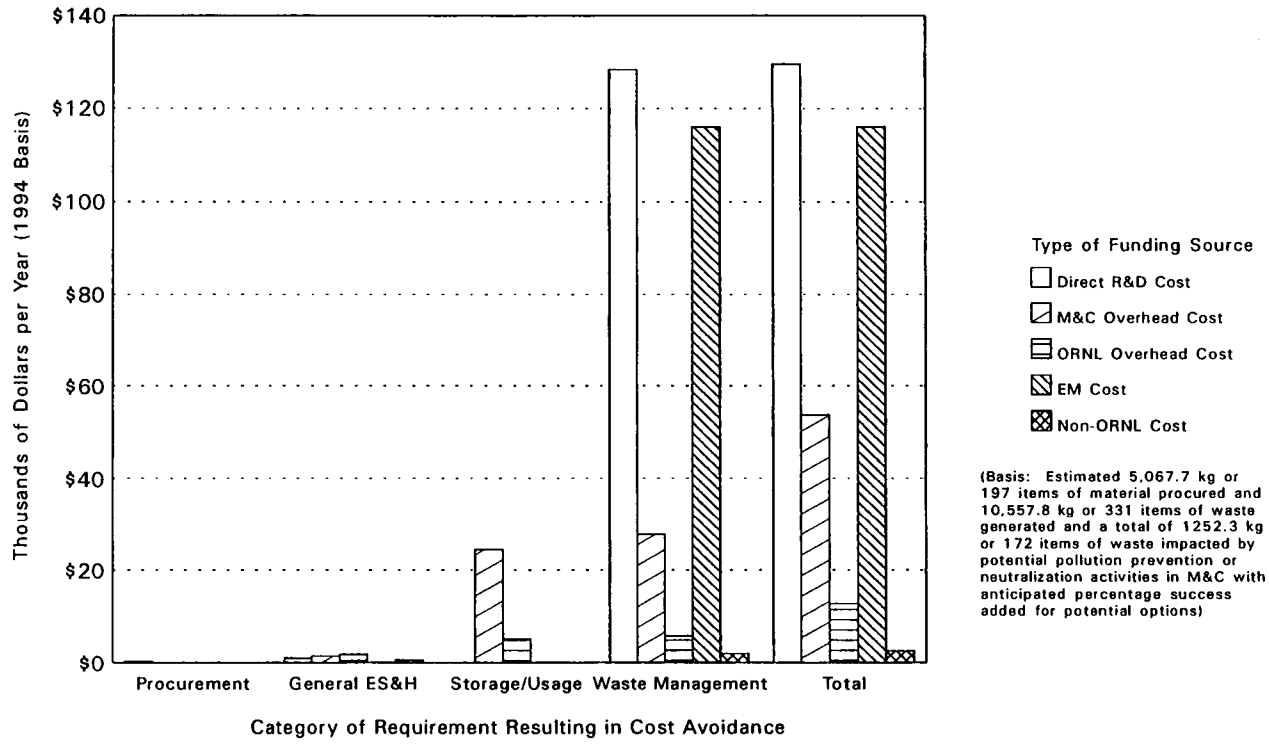


Figure 5-27. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
R&D - research and development

- approximately $400,000 to $500,000 in the EM funding category, and
- approximately $10,000 in the non-ORNL funding category.

As expected, the estimated cost avoidance values summarized in Figures 5-23 through 5-27 show that estimated costs of waste transportation, storage, treatment, and disposal allotted to EM funding were reduced, which allowed resources to be used more productively. These five figures also showed that the M&C Division, which generated the waste, eliminated a significant portion of the added requirements for managing 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes. This elimination resulted in significant cost avoidance, which would allow resources associated with the avoided costs to be used more productively.

Figure 5-23 summarized the estimated reduction in added requirements and quantifiable costs resulting from implemented and potential pollution prevention and elementary neutralization options assuming complete success of potential options. Figure 5-24 depicts the estimated reduction in added requirements and quantifiable costs resulting from implemented and potential options assuming partial success of potential options. Figure 5-25 shows the estimated reduction in added requirements and quantifiable costs resulting from implemented pollution prevention and elementary neutralization activities. Figure 5-26 presents the estimated reduction in added requirements and quantifiable costs resulting from completely successful potential options. Figure 5-27 summarizes the estimated reduction in added requirements and quantifiable costs resulting from partially successful potential options.

All five figures show that the waste generating organization and the waste management organization would each be able to avoid significant costs (improve productivity). However, the relative proportion of the cost avoidance per funding source varied based on the different scenarios depicted in the figures. For instance, in Figure 5-25, the improved productivity realized by M&C overhead funding was greater than the improved productivity of direct R&D funding. In contrast, in Figures 5-26 and 5-27, the improved productivity realized by the direct R&D funding source was greater than the M&C overhead funding source.

The estimated current and potential cost avoidance for the R&D direct funding source was examined and summarized graphically in Figures 5-28 and 5-29. Figures depicting similar data for other funding sources are found in Appendix B. For each funding source, the current and potential improved productivity data represented by cost avoidance values were depicted for the complete success and partial success of potential options. These improved productivity values were also shown for each category of added requirements and in total. The trends related to improved productivity paralleled trends related to the added costs shown in Figures 5-19 and 5-20. For instance, waste management-related costs and avoided costs were extremely significant within the direct R&D funding category. Figures 5-23 through 5-29 also show that significant increases in productivity could be realized by pursuing potential options.

As the cost avoidance values were estimated, the impact of different general types of options on the increase in productivity (cost avoidance) varied. Source reduction appeared to eliminate the need to perform most of the added requirements and

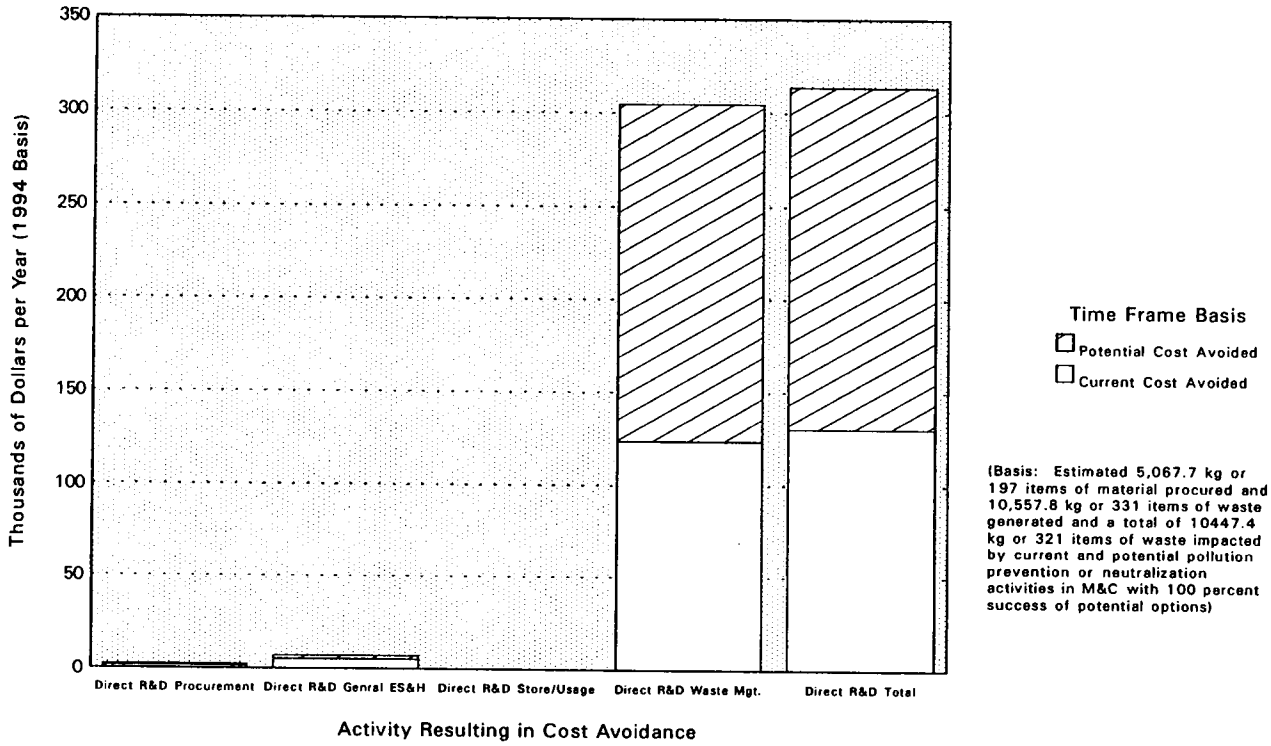


Figure 5-28. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options; Direct R&D Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
R&D - research and development
Store/Usage - Storage/Usage

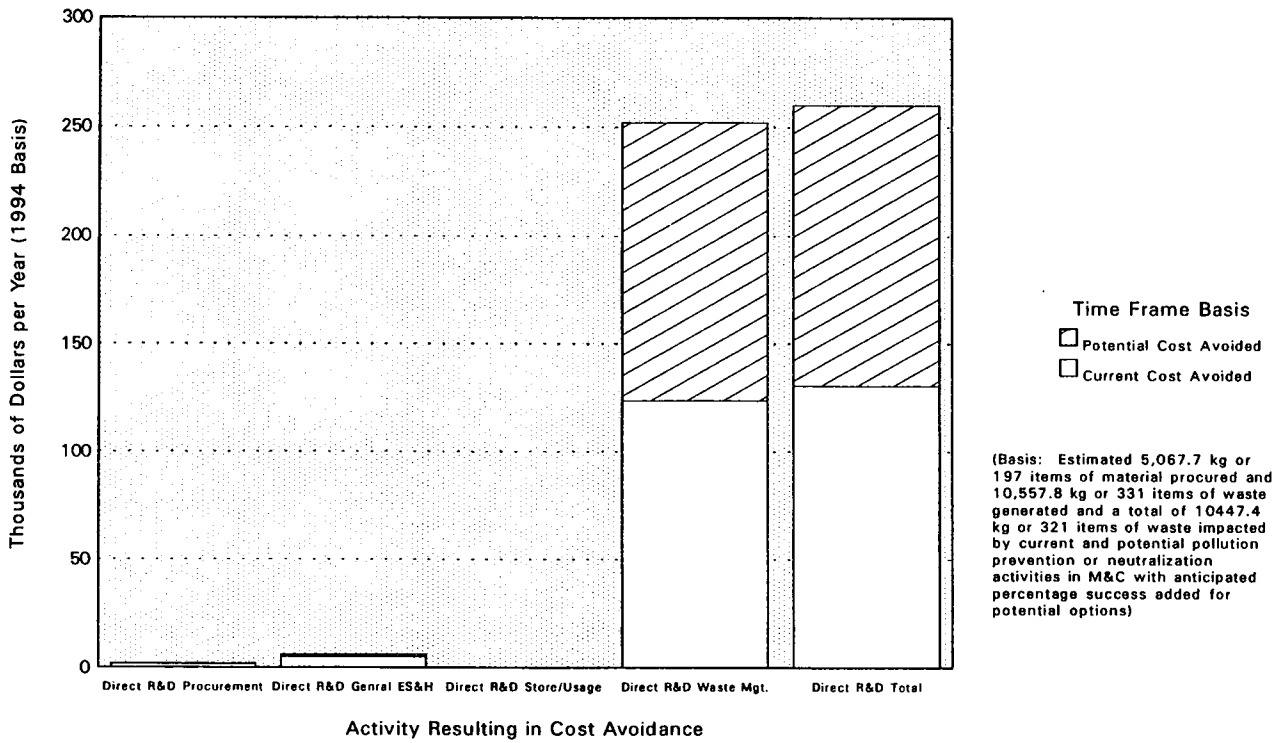


Figure 5-29. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options; Direct R&D Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
R&D - research and development
Store/Usage - Storage/Usage

related costs, while recycling and reuse appeared to reduce about the same amount of added requirements and related costs as elementary neutralization in the laboratory areas. This trend was examined quantitatively. The approximate cost avoidance associated with reducing added requirements for managing one item of a carcinogenic hazardous material and the resulting nonradioactive RCRA hazardous waste was estimated for three option-based scenarios: source reduction, recycle or reuse, and elementary neutralization. The results of these calculations are depicted in Figure 5-30, which shows that the costs avoided by source reduction were much more significant than for the other two types of options. Source reduction resulted in a greater reduction in costs because the costs associated with added requirements related to 3- and 4-rated materials were reduced. In contrast, the recycle or reuse option resulted in approximately the same avoided cost as the elementary neutralization option because the added requirements associated with the materials and wastes still had to be met prior to recycle or treatment.

5.3 Evaluation of Overall Objective

In Chapter 2.0 and Table 5-1, the original overall objective or hypothesis of this study is stated. Based on the first two portions of this objective, the pollution prevention opportunity-based data were consolidated and are depicted in Table 5-1 and Figures 5-31 through 5-33. The data were evaluated on a mass and item basis. As shown in Figure 5-31, approximately 49.4 percent (mass basis) and approximately 19.3 percent (item basis), not the proposed 25 percent, of the reduced waste from

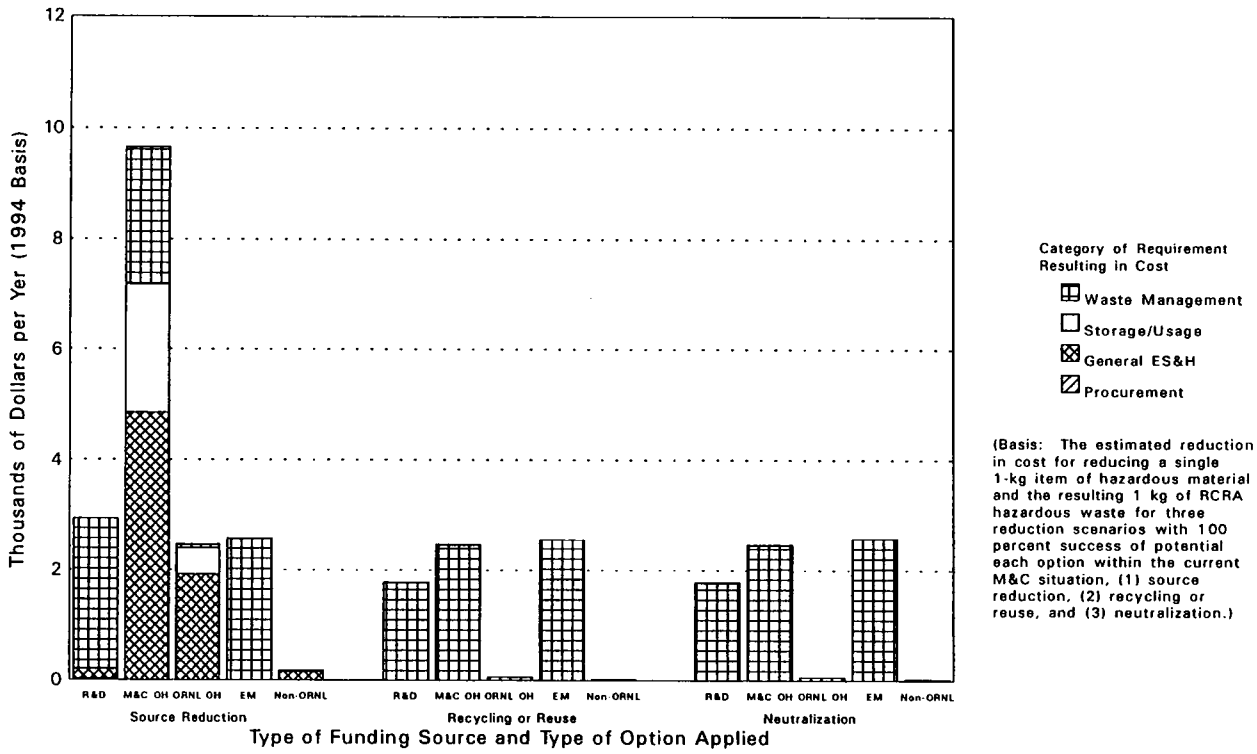


Figure 5-30. Estimated Reduction in Added Requirements and Quantifiable Costs Associated with 3- and 4-Rated Hazardous Materials and Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) for Source Reduction, Recycling or Reuse, or Elementary Neutralization Options Each Applied to One Item

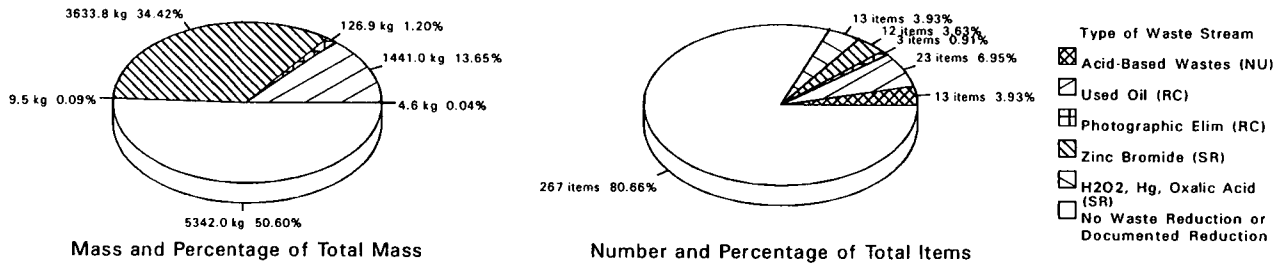
Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
OH - Overhead
R&D - research and development

Table 5-1
Evaluation of Results of the Study Based on the Overall Objective

Elements of the Overall Objective[#]	Element Valid? (Y/N)	Proposed Values	Implemented Pollution Prevention Opportunities	Complete Success of Potential Pollution Prevention Options	Anticipated Success of Potential Pollution Prevention Options
Pollution prevention techniques being used had resulted in approximately a 25 percent (by mass) decrease in hazardous waste generation.	Y	25 percent by mass	50 percent by mass 20 percent by item	N/A	N/A
Another 25 percent (by mass) decrease in hazardous waste generation could be realized if laboratories were provided with specific guidance, information, and resources and allowed to assess their activities and implement pollution prevention opportunities.	Y	25 percent by mass	N/A	12 percent by mass 52 percent by item	9 percent by mass 30 percent by item
Fifty percent of existing and possible pollution prevention options would result in improved productivity (cost avoidance) once the added requirements and associated quantifiable costs related to generating hazardous waste were identified and estimated.	Y	50 percent	100 percent	100 percent	100 percent

Note:
[#] The overall objective is detailed in Chapter 2.0.

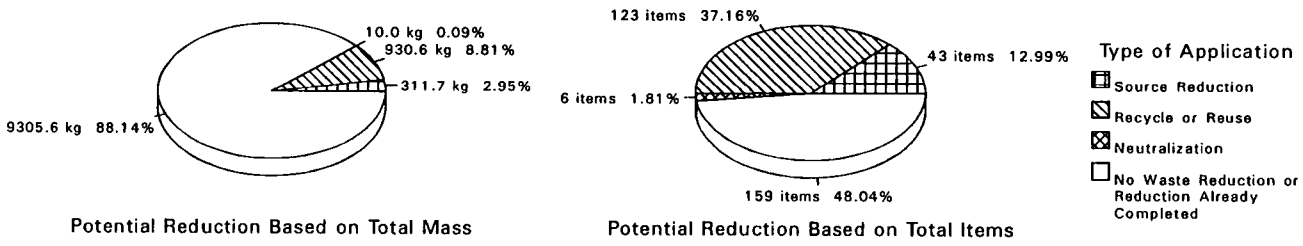
Abbreviations:
N - No
N/A - not applicable
Y - Yes



[Basis: 10557.8 kilograms (kg) or 331 items of nonradioactive RCRA hazardous waste; no waste reduction options were found for 10 items totaling 110.4 kg; potential options were identified for 172 items totaling 1252.3 kg; and implemented pollution prevention activities were documented for 85 items totaling 3979.3 kg.]

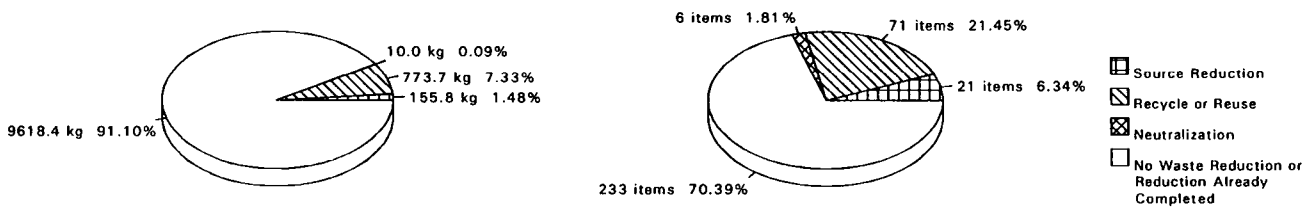
Figure 5-31. Value and Percentage by Mass and by Items of Major Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Streams Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) Impacted by Current Pollution Prevention Activities But Not Documented

Abbreviations:
Elim - Elimination
H2O2 - Hydrogen Peroxide
Hg - Mercury
NU - Elementary Neutralization
RC - Reclassified as Not Being a RCRA Hazardous Waste or Eliminated
RR - Recycle or Reuse
SR - Source Reduction



[Basis: 10,557.8 kilograms (kg) or 331 items of nonradioactive RCRA hazardous waste and 100 percent success of potential pollution prevention or neutralization options; no waste reduction options were found for 10 items totaling 110.4 kg; and reduction activities had already been completed for 149 items totaling 9,195.2 kg.]

Figure 5-32. Potential Reductions by Mass and by Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics Division (M&C) at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Neutralization Application Assuming Complete Success of Potential Options



[Basis: 10,557.8 kilograms (kg) or 331 items of nonradioactive RCRA hazardous waste and anticipated percentage success added for potential pollution prevention or neutralization options; n waste reduction options were found for 10 items totaling 110.4 kg; potential option assumed to fail for 80 items totaling 312.8 kg; and reduction activities had already been completed for 149 items totaling 9,195.2 kg.]

Figure 5-33. Potential Reductions by Mass and by Items of Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Waste Generated in 1992 by the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL) by Type of Pollution Prevention or Neutralization Application Assuming Partial Success of Potential Options

implemented pollution prevention had not been recognized as pollution prevention or documented. When the data related to potential pollution prevention options were evaluated, the complete and partial success scenarios were assessed, as presented in Figures 5-32 and 5-33, respectively. Approximately 8.9 to 11.9 percent (mass basis) and approximately 29.6 to 52.0 percent (item basis), not the proposed 25 percent, of M&C nonradioactive RCRA hazardous waste could be reduced by the potential pollution prevention options that had not been identified prior to the initiation of this study. Finally, based on the cost data listed in Appendix B and summarized in figures in this chapter, all, not the proposed 50 percent, of the potential and implemented options identified during this study would result in an overall improved productivity (cost avoidance). Therefore, qualitatively, the hypothesis was verified, but the actual values varied from those originally listed.

CHAPTER 6.0

Conclusions and Recommendations

Specific conclusions and recommendations of this study are summarized in this chapter based on relationships among (1) waste sources, (2) pollution prevention and elementary neutralization opportunities, (3) added requirements and estimated quantifiable associated costs, and (4) estimated improved productivity (cost avoidance). Highlights of general conclusions and recommendations are summarized in Table 6-1.

When examined based on mass and item units of measure, the distribution of waste data varied when organized by waste type, generating activity, and reduction applications. Within the area studied, a total of 331 items totaling 10,557.8 kg of nonradioactive RCRA hazardous waste was generated. The four major mass-based waste types were photographic wastes, zinc bromide waste, used oil-based wastes, and nitric acid-based waste and in total accounted for more than 91 percent by mass but less than 42 percent by item of the studied waste. The three general waste generating activities were R&D activities, support activities, and laboratory cleanout and legacy wastes. The R&D and support activities accounted for more than 98 percent by mass but less than 76 percent by item of the studied waste. The remaining activity-related waste, wastes from laboratory cleanouts and legacy wastes, accounted for less than 2 percent by mass but more than 24 percent by item. Within M&C, implemented options had already reduced the studied waste by approximately 45 percent on an item basis (149 items) and by approximately 87 percent on a mass basis (9,195.2 kg). Potential

Table 6-1
Highlights of General Conclusions and Recommendations[#]

General Area of Interest	General Conclusions and Recommendations
Methodology	Research and development (R&D) laboratories perform innovative R&D work for essentially all industries and in all technical disciplines and specialties. Therefore, one R&D laboratory-based pollution prevention guidance document cannot be expected to meet all of the specific needs in a given laboratory. Instead, information from several guidance documents and references should be combined to meet the unique needs of each scenario. A data gathering methodology can then be established and available waste source, pollution prevention, and cost information can be identified, quantified, and estimated as applicable.
Data Gathering	The usage rates of hazardous materials and resulting generation rates of wastes were found to vary greatly in an R&D laboratory. This variation was due to (1) the variability in the activities performed and the related quantities of hazardous materials needed and (2) the time frame for storing and using materials and storing wastes. Consequently, data were not available to perform mass balances or simple correlations based on mass. This inability did not significantly hinder the process of identifying and implementing options. Therefore, laboratories should not allow this inability to deter their pollution prevention efforts.
Data Gathering	Properly characterizing a waste and determining the source of a waste were found to be important in assessing an activity for pollution prevention opportunities. In an R&D laboratory setting, the assessment must also determine if the purpose of the material that results in the waste is critical in the activity. Accordingly, during an assessment, the laboratory should determine the characteristics and source of a waste as well as determine if the material is actually a vital component of the R&D being performed. Pollution prevention options can then be tailored to the specific situation.
Data Gathering and Assessment	Before selecting pollution prevention options for implementation, each laboratory should then determine and evaluate the basis for these quantifiable added costs. Based on the resulting understanding of the unique trends related to (1) areas where costs are incurred, (2) the hazardous materials and generated wastes, and (3) potential pollution prevention options, the laboratory can estimate the cost impacts of current activities and pollution prevention alternatives.
Gathering and Assessment of Waste and Cost Data	In laboratories, only using total mass and total cost to assess pollution prevention opportunities may not provide a complete understanding of how wastes are generated and costs incurred. To support these assessments, waste generation and cost data should be evaluated for trends based on combinations of several units of measure and categories, not just based on mass and total cost. These combinations of units of measure or categories may include types of activities, waste types, types of pollution prevention applications, numbers of items, numbers of events, or types and sources of funding.

Table 6-1 (continued)

General Area of Interest	General Conclusions and Recommendations
Cost Data Gathering and Assessment	In an R&D laboratory setting, performing a total cost assessment (TCA) or a life-cycle assessment (LCA) was found to be extremely difficult based on the variability in the type and number of activities performed and the current data and systems available. Nevertheless, quantifiable added costs associated with hazardous materials and the resulting waste can be identified and estimated. This information can then be evaluated for trends concerning how the costs are incurred, which materials and resulting wastes have more impact, and which potential pollution prevention options have more impact. Consequently, although an R&D laboratory may find performing a TCA or LCA very difficult, it should be able to identify and estimate several quantifiable added costs related to hazardous materials and resulting wastes.
Pollution Prevention Implementation	In most laboratories, general options would be identified. However, these options, such as providing pollution prevention awareness training to visiting researchers or performing new work pollution prevention reviews, would not be directly allocated to specific wastes. These options still should be pursued by laboratory facilities, because these general activities provide a foundation from which specific options develop.
Pollution Prevention Implementation Prioritization	Considering only costs in some situations can be a deterrent to pollution prevention implementation. When prioritizing the implementation of pollution prevention options, other considerations, including environmental and operational impacts, should be considered along with reducing costs.
Future Considerations	Although the laboratory examined performed a full range of metals- and ceramics-based activities during the time period of this study, the area studied accounted for a small segment of the country's R&D laboratories. Also, because radioactive materials were managed at the facility examined, added requirements that would not affect other laboratories did impact these R&D operations. Furthermore, work performed by an R&D laboratory was notably different from work performed in other types of laboratories such as analytical laboratories. Consequently, other laboratories should only use this study as a reference along with the other guidance and reference materials available and should perform pollution prevention opportunity assessments and resulting implementation based on their situation. Additional research should be performed (1) to update and expand the methodology and data for the current Metals and Ceramics (M&C) Division scenario, (2) to examine other types of wastes, such as low-level radioactive wastes or industrial wastes within M&C and at the Oak Ridge National Laboratory (ORNL), and (3) in general, to examine other types of laboratory settings such as in analytical, hospital, or university settings.

Note:

Based on the evaluation and analysis of waste generation and cost trends related to pollution prevention opportunities for 3- and 4-rated hazardous materials and resulting nonradioactive Resource Conservation and Recovery Act (RCRA) hazardous wastes generated by the Metals and Ceramics Division at the Oak Ridge National Laboratory.

options could reduce an additional 98 to 172 items (approximately 30 to 52 percent) totaling 939.5 to 1,252.3 kg (approximately 9 to 12 percent) of the studied waste. Consequently, when reductions in wastes from implemented and potential options were totaled, M&C could eliminate the generation of almost all of its RCRA hazardous wastes (approximately 97 percent reduction on an item basis and a 99 percent reduction on a mass basis).

As shown in Table 6-2, the distribution of incurred costs related to added requirements varied based on the funding source and the general types of added requirements. Specifically, most of the costs within direct R&D (94 percent) and EM (100 percent) funding were incurred within waste management. In contrast, most of the costs for M&C overhead (81 percent), ORNL overhead (84 percent), and non-ORNL (55 percent) funding were incurred within general ES&H and storage and usage. Therefore, the general type of added requirements needing the most funding varied among the different funding sources.

Determining that the costs of performing most added requirements were incurred on an item or event basis, not a mass basis, was significant in this study, especially when combined with the previous two conclusions and the impact of different types of reduction applications on improved productivity by funding source. As shown in Figure 5-30 and summarized in Table 6-3, except for the waste management activities funded through EM, the improved productivity resulting from an all-encompassing source reduction option was much greater than that of a recycle or reuse option or an elementary neutralization option. For instance, in Table 6-3, when ORNL overhead was

Table 6-2
Summarized Cost Data by Funding Source and General Type of Added Requirement[#]

Funding Source	Total Cost of Meeting Added Requirements[@]	Added Procurement Cost (Percent of Total)	Added General ES&H Cost (Percent of Total)	Added Storage and Usage Cost (Percent of Total)	Added Waste Management Cost (Percent of Total)
Direct R&D	$300,000	2%	5%	0%	94%
M&C Overhead	$500,000	0%	4%	77%	19%
ORNL Overhead	$100,000	0%	21%	63%	15%
EM	$500,000	0%	0%	0%	100%
Non-ORNL	$10,000	0%	55%	0%	45%

Notes:

[#] Values are those associated with managing 3- and 4-rated hazardous materials and nonradioactive Resource Conservation and Recovery Act (RCRA) hazardous wastes generated in 1992 by the M&C Division at the Oak Ridge National Laboratory. Cost data were based on the 1994 M&C scenario.

[@] Prior to implementing pollution prevention or elementary neutralization options (Figure 5-19).

Abbreviations:
DOE - U.S. Department of Energy
EM - DOE-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
M&C - Metal and Ceramics
ORNL - Oak Ridge National Laboratory
R&D - research and development
% - percent

Table 6-3
Summarized Improved Productivity (Cost Avoidance)
Values for Source Reduction, Recycling or Reuse, and
Elementary Neutralization Options Each Applied to One Item#

Funding Source - General Type of Added Requirement	Total Cost of Meeting Added Requirements@	Improved Productivity of a Source Reduction Option (Percent of Total)	Improved Productivity of a Recycle or Reuse Option (Percent of Total)	Improved Productivity of an Elementary Neutralization Option (Percent of Total)
Direct R&D				
- Procurement	$24	100%	0%	0%
- General ES&H	$181	100%	0%	0%
- Storage and Usage	$0	N/A	N/A	N/A
- Waste Management	$2,729	100%	65%	65%
Direct R&D Total	$2,934	100%	61%	61%
M&C Overhead				
- Procurement	$0	N/A	N/A	N/A
- General ES&H	$4,851	100%	0%	0%
- Storage and Usage	$2,341	100%	0%	0%
- Waste Management	$2,456	100%	100%	100%
M&C Overhead Total	$9,648	100%	25%	25%
ORNL Overhead				
- Procurement	$0	N/A	N/A	N/A
- General ES&H	$1,919	100%	0%	0%
- Storage and Usage	$477	100%	0%	0%
- Waste Management	$60	100%	100%	100%
ORNL Overhead Total	$2,456	100%	2%	2%
EM				
- Procurement	$0	N/A	N/A	N/A
- General ES&H	$0	N/A	N/A	N/A
- Storage and Usage	$0	N/A	N/A	N/A
- Waste Management	$2,573	100%	100%	100%
EM Total	$2,573	100%	100%	100%

Table 6-3 (continued)

Funding Source - General Type of Added Requirement	Total Cost of Meeting Added Requirements@	Improved Productivity of a Source Reduction Option (Percent of Total)	Improved Productivity of a Recycle or Reuse Option (Percent of Total)	Improved Productivity of an Elementary Neutralization Option (Percent of Total)
Non-ORNL				
- Procurement	$0	N/A	N/A	N/A
- General ES&H	$149	100%	0%	0%
- Storage and Usage	$0	N/A	N/A	N/A
- Waste Management	$20	100%	100%	100%
Non-ORNL Total	$169	100%	12%	12%

Notes:

Values are based on an assumed one 1-kg item of 3- or 4-rated hazardous material that resulted in the generation of one 1-kg item of nonradioactive Resource Conservation and Recovery Act (RCRA) hazardous waste within the current (1994) Metals and Ceramics Division situation at the Oak Ridge National Laboratory (Figure 5-30). Cost values were determined to be accurate to one significant figure. Additional significant figures are shown to support understanding the estimation of the percentage values.

@ Prior to implementing pollution prevention or elementary neutralization options.

Abbreviations:

DOE - U.S. Department of Energy
EM - DOE-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
M&C - Metal and Ceramics
ORNL - Oak Ridge National Laboratory
R&D - research and development

examined, 100 percent of the costs of performing added requirements could be avoided by using source reduction while only 2 percent of these added costs could be avoided by using recycle or reuse or elementary neutralization. Therefore, in the area studied and based on the total cost of added requirements by funding source, a source reduction option could result in a much greater improvement in productivity than would either recycle or reuse or elementary neutralization options.

Finally, M&C should pursue the potential options identified in this study because these options could improve productivity (cost avoidance) within M&C by approximately $100,000 to $200,000 per year of R&D direct funding and by approximately $50,000 to $100,000 per year or M&C overhead funding. If M&C is able to implement all of these potential options, then M&C will eliminate the need to perform a significant portion of the added requirements for 3- and 4-rated hazardous materials and RCRA hazardous wastes. The resulting improved productivity (cost avoidance) from all identified options will eliminate most of the added costs that were associated with added requirements (a maximum avoided cost of approximately $300,000 per year of R&D direct funding and $300,000 per year of M&C overhead funding). Based on the encouraging results of this study, M&C and in general, ORNL, should consider performing additional pollution prevention opportunity assessments and cost analyses on other material and waste types, such as low-level radioactive waste or mixed low-level radioactive and RCRA hazardous waste.

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APPENDICES

APPENDIX A

Select Pollution Prevention Opportunity Assessment and Option Information from Specific Available Guidance

This appendix contains adapted versions of tables and figures from guidance documents issued by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE). Tables A-1 and A-2 contain listings of general pollution prevention options listed in Appendix B of the EPA's *Facility Pollution Prevention Guide*. Figures A-1 through A-5 depict pollution prevention opportunity assessment methodologies.

Table A-1
Pollution Prevention Through Good Operating Practices[#]

Category of Pollution Prevention Application	Potential Pollution Prevention Options
Waste segregation	• Prevent mixing of hazardous wastes with nonhazardous wastes. • Store materials in compatible groups. • Segregate different solvents. • Isolate liquid wastes from solid wastes.
Preventive maintenance	• Maintain equipment history cards on equipment location, characteristics, and maintenance. • Maintain a master preventive maintenance schedule. • Keep vendor maintenance manuals handy. • Maintain a manual or computerized repair history file.
Training and awareness	Provide training for the following: • Operation of the equipment to minimize energy use and material waste • Proper materials handling to reduce waste and spills • Emphasize importance of pollution prevention by explaining the economic and environmental ramifications of hazardous waste generation and disposal. • Detecting and minimizing material loss to air, land, or water • Emergency procedures to minimize lost materials during accidents.
Effective supervision	• Closer supervision may improve production efficiency and reduce inadvertent waste generation. • Centralize waste management. Appoint a safety/waste management officer for each department. Educate staff on the benefits of pollution prevention. Establish pollution prevention goals. Perform pollution prevention assessments.

Table A-1 (continued)

Category of Pollution Prevention Application	Potential Pollution Prevention Options
Employee participation	• "Quality circles" (free forums between employees and supervisors) can identify ways to reduce waste. • Solicit and reward employee suggestions for waste reduction ideas.
Production scheduling and planning	• Maximize batch size to reduce cleanout waste. • Dedicate equipment to a single product. • Alter batch sequencing to minimize cleaning frequency (light-to-dark batch sequence, for example).
Cost accounting and allocation	• Charge direct and indirect costs of all air, land, and water discharges to specific processes or products. • Allocate waste treatment and disposal costs to the operations that generate the waste. • Allocate utility costs to specific processes or products.

Adapted from Appendix B, Industry-Specific Checklists of *Facility Pollution Prevention Guide* (EPA 1992).

Table A-2
Checklist for All Industries[#]

Waste Origin or Type	Potential Pollution Prevention Options
Material receiving (packaging materials, off-specification materials, damaged containers, inadvertent spills, transfer hose emptying)	• Use "just-in-time" ordering system. • Establish a centralized purchasing program. • Select quantity and package type to minimize packing waste. • Order reagent chemicals in exact amounts. • Encourage chemical suppliers to become responsible partners (e.g., accept outdated supplies). • Establish an inventory control program to trace chemicals from cradle to grave. • Rotate chemical stock. • Develop a running inventory of unused chemical for other departments' use. • Inspect material before accepting a shipment. • Review material procurement specifications. • Validate shelf-life requirements for stable compounds. • Conduct frequent inventory checks. • Use computer-assisted plant inventory system. • Conduct periodic materials tracking. • Properly label all containers. • Set up staffed control points to dispense chemicals and collect wastes. • Buy pure feeds. • Find less critical used for off-specification materials that would otherwise be disposed. • Change to reusable shipping containers. • Switch to less hazardous raw materials. • Use rinsable and recyclable drums.

Table A-2 (continued)

Waste Origin or Type	Potential Pollution Prevention Options
Raw material and product storage (tank bottoms, off-specification and excess materials; spill residues; leaking pumps, values, tanks, and pipes; damaged containers; empty containers)	• Establish Spill Prevention, Control, and Countermeasures (SPCC) plans. • Use properly designed tanks and vessels only for their intended purposed. • Install overflow alarms for all tanks and vessels. • Maintain physical integrity of all tanks and vessels. • Set up written procedures for all loading and unloading and transfer operations. • Install secondary containment areas. • Instruct operators to not bypass interlocks, alarms, or significantly alter setpoints without authorization. • Isolate equipment or process lines that leak or are not in service. • Use sealless pumps. • Use bellows-seal valves. • Document all spillage. • Perform overall material balances and estimate the quantity and dollar value of all losses. • Use floating-roof tanks for volatile organic compounds (VOC) control. • Use conservation vents on fixed roof tanks. • Use vapor recovery systems. • Store containers in such a way as to allow a visual inspection for corrosion and leaks. • Stack containers in a way to minimize the chance of tipping, puncturing, or breaking. • Prevent concrete "sweating" by raising the drum off storage pads. • Maintain Material Safety Data Sheets to ensure correct handling of spills. • Provide adequate lighting in the storage area. • Maintain a clean, even surface in transportation areas. • Keep aisles clear of obstruction.

Table A-2 (continued)

Waste Origin or Type	Potential Pollution Prevention Options
Raw material and product storage (tank bottoms, off-specification and excess materials; spill residues; leaking pumps, values, tanks, and pipes; damaged containers; empty containers) (continued)	• Maintain distance between incompatible chemicals. • Maintain distance between different types of chemicals to prevent cross-contamination. • Avoid stacking containers against process equipment. • Follow manufacturers' suggestions on the storage and handling of all raw materials. • Use proper insulation of electric circuitry and inspect regulatory for corrosion and potential sparking. • Use large containers for bulk storage whenever possible. • Use containers with height-to-diameter ratio equal to one to minimize wetted area. • Empty drums and containers thoroughly before cleaning or disposal. • Reuse scrap paper for note pads; recycle paper.
Laboratories (reagents, off-specification chemicals, samples, empty sample and chemical containers)	• Use micro or semimicro analytical techniques. • Increase use of instrumentation. • Reduce or eliminate the use of highly toxic chemicals in laboratory experiments. • Reuse and recycle spent solvents. • Recover metal from catalyst. • Treat or destroy hazardous waste products as the last step in experiments. • Keep individual hazardous waste streams segregated, segregate hazardous waste from nonhazardous waste, segregate recyclable waste from nonrecyclable waste. • Ensure that the identity of all chemicals and wastes is clearly marked on all containers. • Investigate mercury recovery and recycling.

Table A-2 (continued)

Waste Origin or Type	Potential Pollution Prevention Options
Operation and process changes (solvents, cleaning agents, degreasing sludges, sandblasting waste, caustic, scrap metal, oils, greases from equipment cleaning)	• Maximize dedication of process equipment. • Use squeegees to recover residual fluid on product prior to rinsing. • Use closed storage and transfer systems. • Provide sufficient drain time for liquids. • Line equipment to reduce fluid holdup. • Use cleaning system to avoid or minimize solvents and clean only when needed. • Use countercurrent rinsing. • Use clean-in-place systems. • Clean equipment immediately after use. • Reuse cleanup solvent. • Reprocess cleanup solvent into useful products. • Segregate wastes by solvent type. • Standardize solvent usage. • Reclaim solvent by distillation. • Schedule production to lower cleaning frequency. • Use mechanical wipers on mixing tanks.
Operation and process changes (sludge and spent acid from heat exchanger cleaning)	• Use bypass control or pumped recycle to maintain turbulence during turndown. • Use smooth heat exchange surfaces. • Use on-stream cleaning techniques. • Use high-pressure water cleaning to replace chemical cleaning where possible. • Use lower pressure steam.

[#] Adapted from Appendix B, Industry-Specific Checklists of *Facility Pollution Prevention Guide* (EPA 1992).

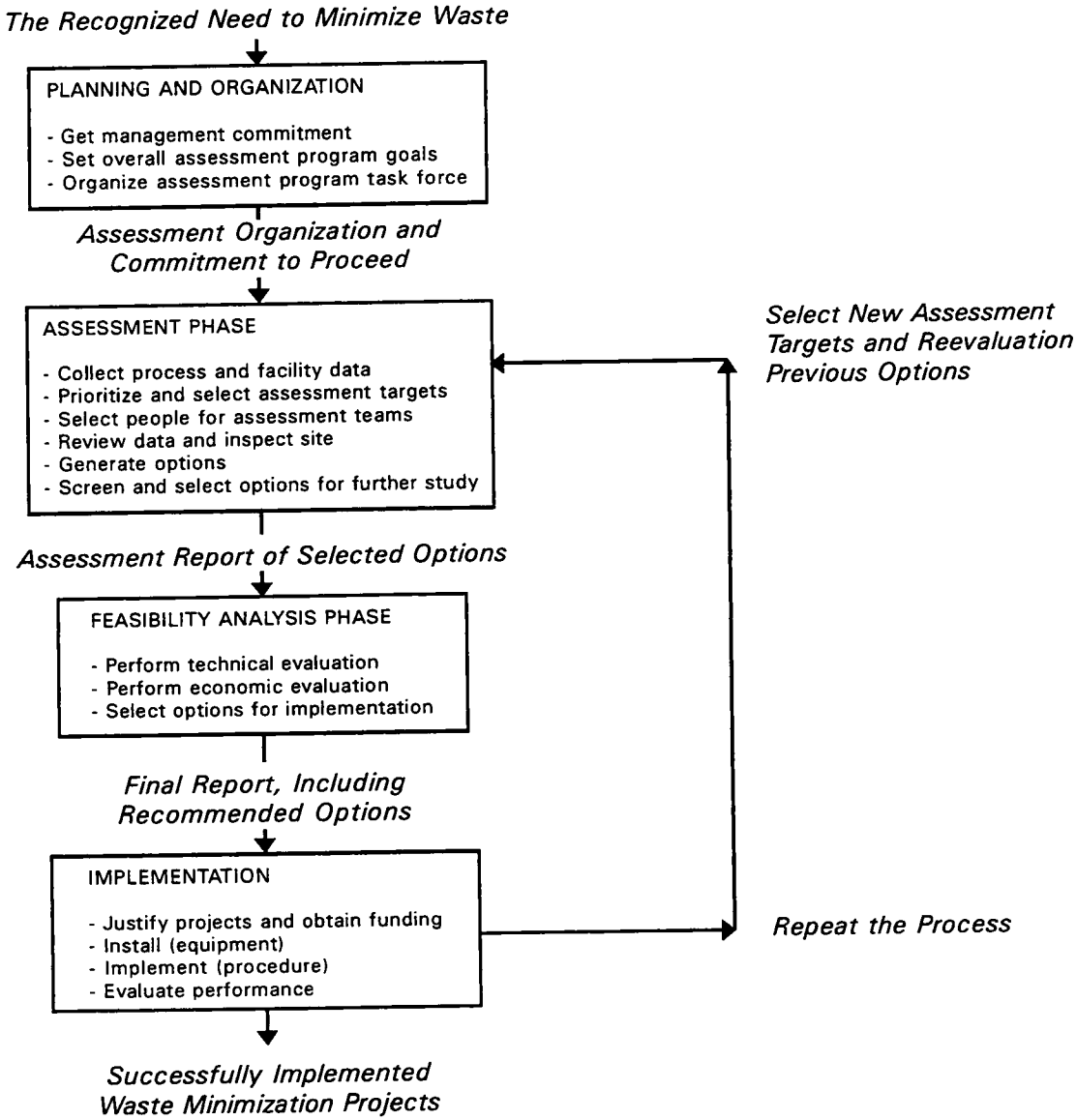


Figure A-1. The Waste Minimization Assessment Procedure

Sources: Adapted from U.S. Environmental Protection Agency (EPA). *Guides to Pollution Prevention Research and Educational Institutions*. EPA/625/7-90/010. Washington, District of Columbia: U.S. Environmental Protection Agency, June 1990. and U.S. Environmental Protection Agency (EPA). *Waste Minimization Opportunity Assessment Manual*. EPA/625/7-88/003. Cincinnati, Ohio: U.S. Environmental Protection Agency, July 1988.

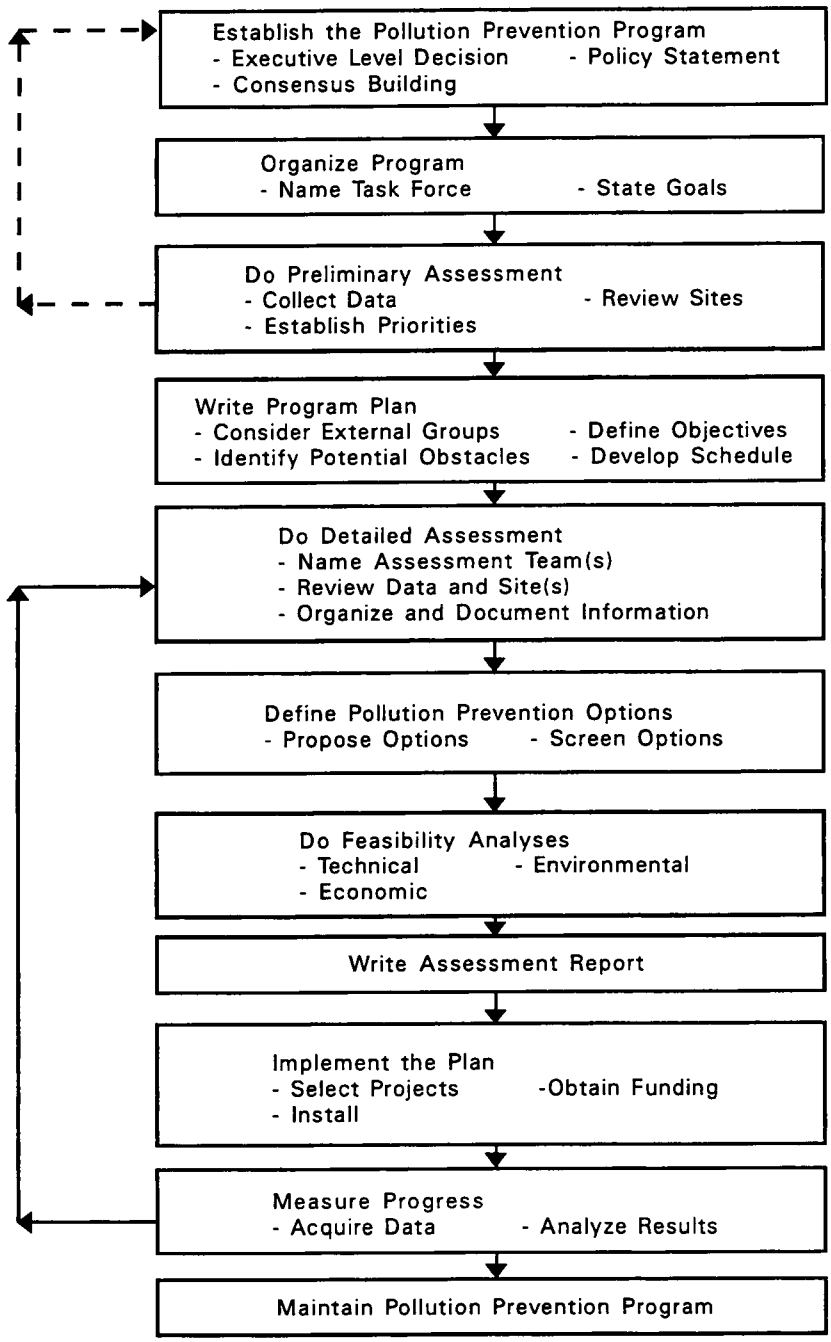


Figure A-2. Pollution Prevention Program Overview

Source: Adapted from U.S. Environmental Protection Agency (EPA). *Facility Pollution Prevention Guide*. EPA/600/R-92/088. Washington, District of Columbia: U.S. Environmental Protection Agency, May 1992.

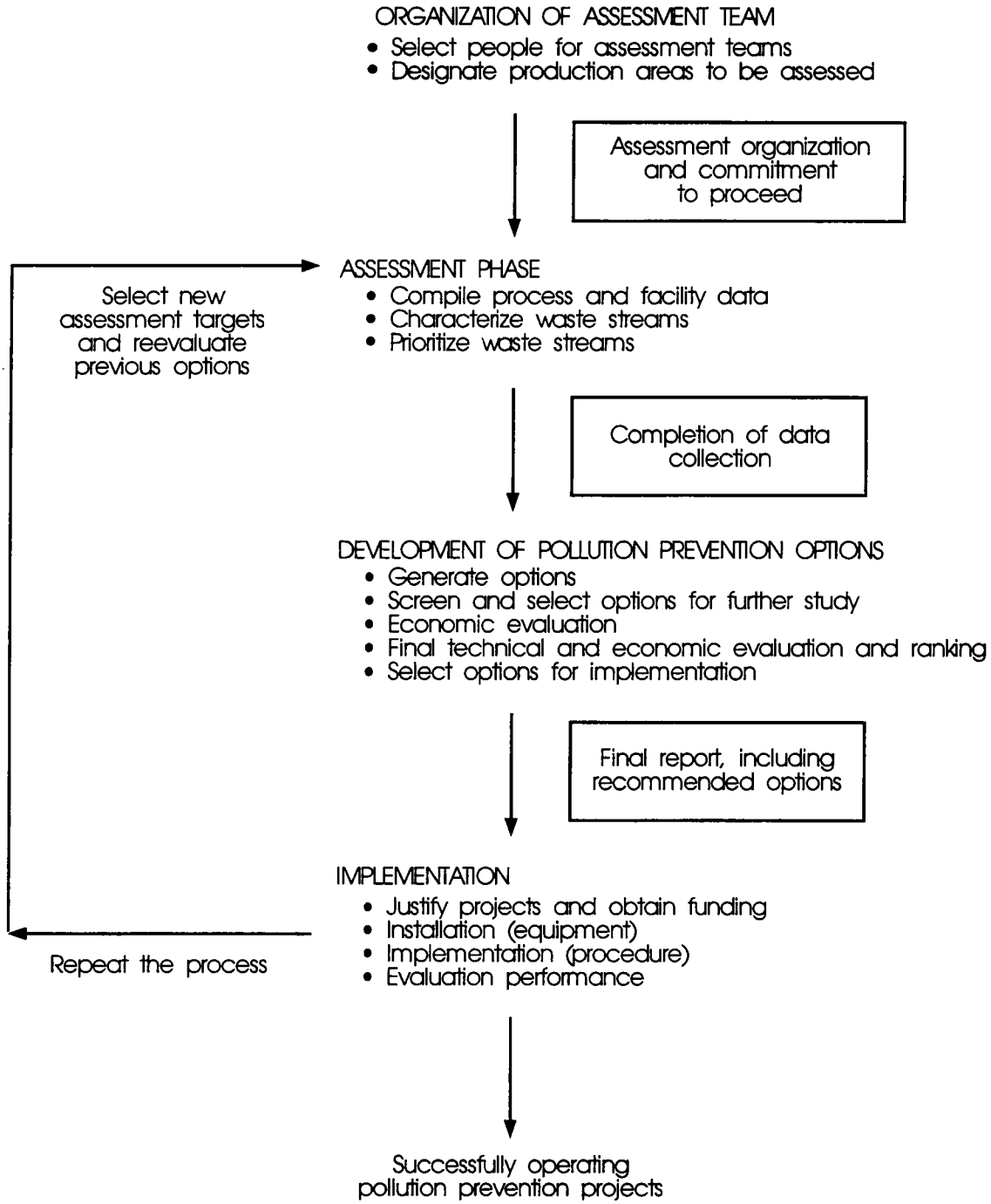


Figure A-3. Pollution Prevention Opportunity Assessment Overview

Source: Adapted from U.S. Department of Energy (DOE). *U.S. Department of Energy Model Pollution Prevention Opportunity Assessment Guidance.* Washington, District of Columbia: U.S. Department of Energy, December 1993.

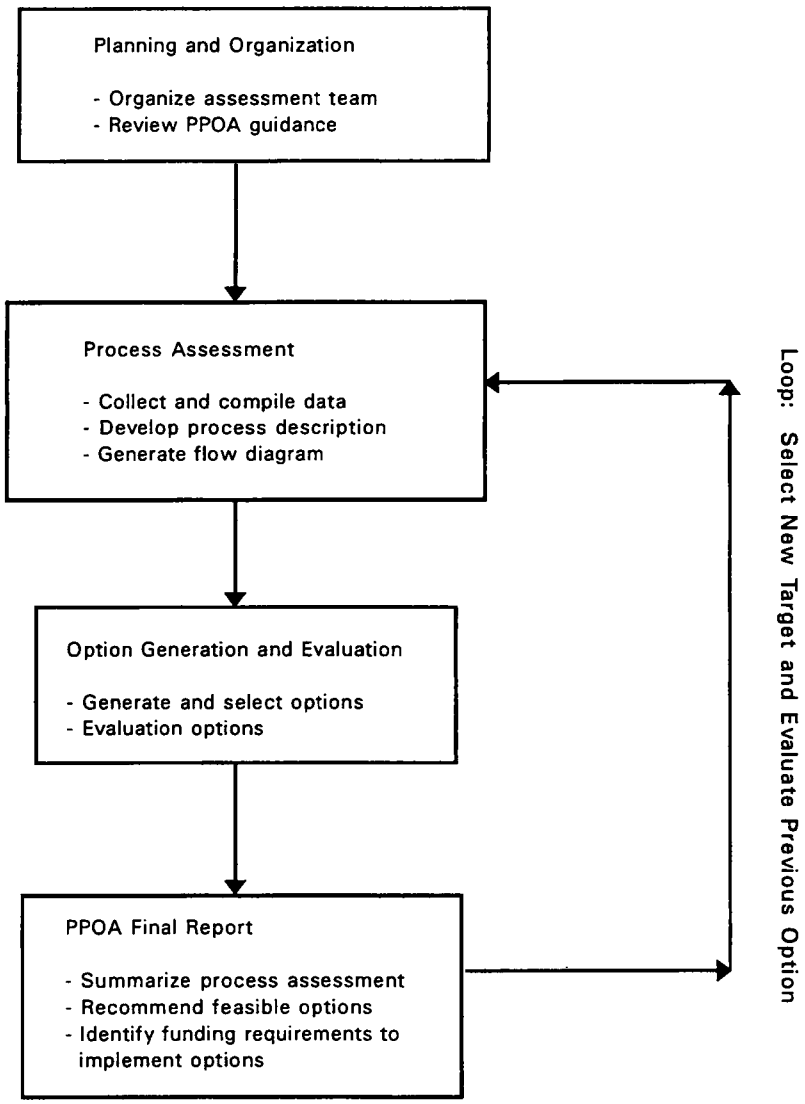


Figure A-4. Pollution Prevention Opportunity Assessment (PPOA) Flow Chart (U.S. Department of Energy's Graded Approach)

Source: Adapted from Lockheed Martin Energy Systems, Inc. (Energy Systems). *Pollution Prevention Opportunity Assessment Training*. Oak Ridge, Tennessee: Lockheed Martin Energy Systems, Inc., Summer 1994.

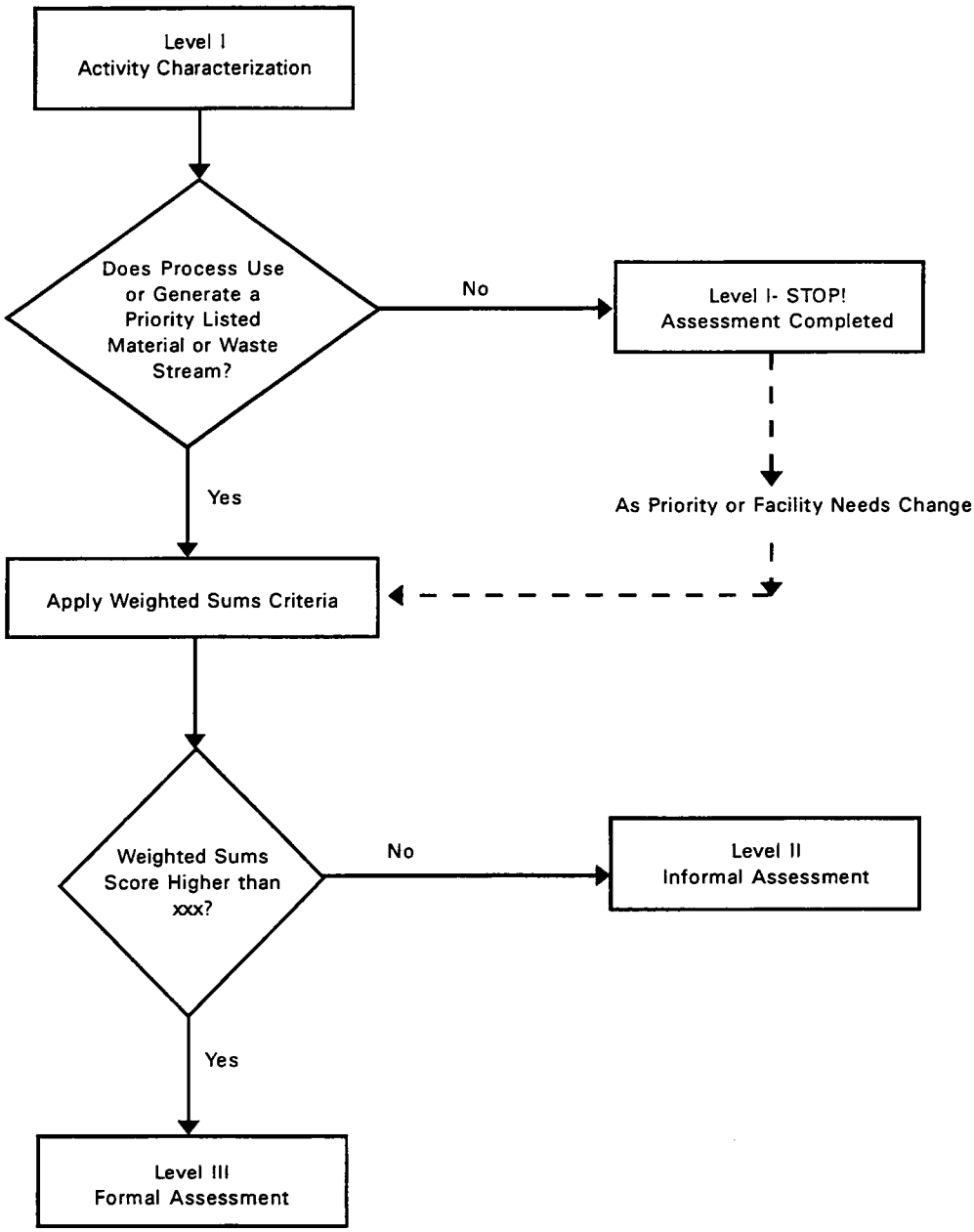


Figure A-5. Pollution Prevention Opportunity Assessment (PPOA) Logic Diagram (U.S. Department of Energy's Graded Approach)

Source: Adapted from Lockheed Martin Energy Systems, Inc. (Energy Systems). *Pollution Prevention Opportunity Assessment Training*. Oak Ridge, Tennessee: Lockheed Martin Energy Systems, Inc., Summer 1994.

APPENDIX B

Specific Metals and Ceramics Division

Waste Source- and Cost-Related Information

This appendix contains the following:

- details related to the costing methodology used to gather data (Table B-1),
- tabulated data related to materials, wastes, pollution prevention, costs, and changes in productivity (cost avoidance) (Tables B-2 through B-7),
- select figures related to avoided costs by funding sources resulting from current and potential pollution prevention and elementary neutralization (Figures B-1 through B-8), and
- text and tables (Tables B-8 and B-9) summarizing the basis and data used organized by waste types and clarifications related to this study.

Table B-1
Basis for Added Requirements and Associated Costs for Hazardous Materials and Subsequently Generated Hazardous Wastes in the Metals and Ceramics Division at the Oak Ridge National Laboratory

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Procurement Requirements	
Complete purchase requisition for hazardous material including management approval	Sources of information: (1) Interviews with 8 personnel, who complete the purchase requisitions (PR) for the 3- and 4-rated hazardous chemicals, were used to determine an estimated average number of items on a PR and the amount of time spent completing the additional requirements for 3- and 4-rated hazardous materials. (2) L. Pierce electronic mail response summarizing her investigation of potential added costs for procurement or MSDS personnel (no added costs identified) (3) HMIS used by D. Walmsley [using V. Tharpe's guidance (the HMIS Manager for Energy Systems and ORNL Hazardous Materials Manager)] to determine the total number of items of hazardous materials and total number of items of 3- and 4-rated hazardous materials that were ordered in 1992. (4) Energy Systems *Hazard Communication Program* standard ESS-IH-140 (Energy Systems 1993) and Energy Systems *Hazardous Materials Inventory Program* procedure ESP-ESH-16 (Energy Systems 1991). 3- and 4-rated hazardous materials: Materials receiving 3 or 4 ratings for health, flammability, or reactivity per Energy Systems Standard ESS-IH-140 Time per PR: 4 additional hours required on average to complete 5 PRs (can vary greatly) Average number of items per PR: 4 items on average per PR (can vary greatly) Number of items ordered in 1992: See Table B-2 (Associated with activities that generated nonradioactive RCRA hazardous wastes) Calculation basis: Cost prorated and allotted to each 3- and 4-rated hazardous material based on number of items ordered in 1992 that resulted in a nonradioactive RCRA hazardous waste; total cost allotted to total of all M&C nonradioactive RCRA hazardous wastes. Cost allocation in 1994: Direct R&D funding accounts Calculation used to estimate this added cost (annual): Direct R&D funding cost: (hourly rate) x (total number of 1992 items ordered/yr) x (1 PR/4 items) x (4 hr/5 PRs)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional General Environmental, Safety, and Health Requirements	
Maintain program for carcinogens and reproductive hazards	Sources of information: Interviews with R. Ogle, the M&C IH Manager and one of the M&C PPRs, to determine time required to simply maintain the Carcinogens and Reproductive Hazards Program, and the *ORNL Chemical Carcinogen Control Program* procedure IHP-13 (ORNL 1990). Time required: 40 hours per year (for one item or many items) Calculation basis: Total program cost allotted to each carcinogen or reproductive hazard material that resulted in a nonradioactive RCRA hazardous waste and to total of all M&C nonradioactive RCRA hazardous wastes because cost exists as long as one controlled item exists in M&C areas. Cost allocation in 1994: M&C overhead accounts Calculation used to estimate this added cost (annual): M&C overhead cost: (hourly rate) x (40 hr/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional General Environmental, Safety, and Health Requirements (continued)	
Perform carcinogen and reproductive hazards user sampling and assessment	Sources of information: Paper "Validation of the Use of Professional Judgement in Determining Potential for Exposure to Chemical Reproductive Hazards and Carcinogens in Research Laboratory Operations" (Ogle et al. 1994) by R. B. Ogle, E. E. Guy, and L. C. Hoch at the May 1994 AIHCE and additional clarification from authors concerning assessment and sampling and average cost of IH colorimetric tubes. ASO, N. M. Ferguson, cost of analysis (IR and ICP) on samples. Also referred to the ORNL Procedure, IHP-13 (ORNL Chemical Carcinogen Control Program). Scope of assessment: 110 areas surveyed and sampling performed in 19 areas Time required: R&D researcher or technician: 0.5 hr/area plus 20 hr for sampling; 75 hr total M&C IH Manager: 90 hr coordinating effort and providing technical support ORNL IH employee: 20 hr sampling 19 areas and IH student (Non-ORNL, Y-12 Plant employee): 470 hours Time frame: Reassess all areas using carcinogens and reproductive hazards every 3 yr (annualized cost of 1/3 of cost/yr) Total samples and analyses required and analytical costs: 15 IH colorimetric tubes at $5/colorimetric tube (average - can vary greatly) 1 sample requiring IR analysis at $200/IR analysis (respirable quartz) 30 samples requiring ICP analyses at $160/ICP analysis (solid material) Calculation basis: Specific cost allotted to each carcinogen or reproductive hazard material that resulted in a nonradioactive RCRA hazardous waste and total cost included in total cost of all M&C nonradioactive RCRA hazardous wastes. Cost allocation in 1994: Researcher time - Direct R&D funding accounts and M&C IH Manager time - M&C overhead accounts ORNL IH time and sampling and analysis - ORNL overhead accounts IH student time - Non-ORNL cost Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (researcher hr)/3 yr M&C overhead costs: (hourly rate) x (M&C IH Manager hr)/3 yr ORNL overhead costs: (hourly rate) x (ORNL IH hr)/3 yr + (number of IH colorimetric tubes x cost per tube + number of samples requiring IR analysis x cost of IR analysis + number of samples requiring ICP analysis x cost of ICP)/3 yr Non-ORNL costs: (hourly rate) x (IH student hr)/3 yr

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional General Environmental, Safety, and Health Requirements (continued)	
Perform industrial hygiene reviews and sampling	Sources of information: Interviews with R. Ogle, M&C IH Manager Number of IH reviews and sampling performed: 20 reviews per year Time required: 1 hr/review of researcher 12 hr/review of ORNL IH personnel Sampling and analysis required: 4 samples per review with an average cost of $100/analysis (cost for analysis can range from $25 to $200 per sample) Calculation basis: Cost prorated and allotted to each 3- and 4-rated hazardous material that resulted in a nonradioactive RCRA hazardous waste resulting in total cost allotted to total of all M&C nonradioactive RCRA hazardous wastes. Cost allocation in 1994: Researcher time - Direct R&D funding accounts ORNL IH time and sampling and analysis - ORNL overhead accounts Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (researcher hr/review) x (number of reviews/yr) ORNL overhead costs: (hourly rate) x (ORNL IH hr/review) x (number of reviews/yr) + (number of samples/review x cost of analysis) x (number of reviews/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional General Environmental, Safety, and Health Requirements (continued)	
Perform Metals and Ceramics Division special internal "New Work Reviews"	Sources of information: Interviews with R. Ogle, M&C IH Manager and use of the ORNL *Facility Authorization Basis Documentation* procedure FS-2.0 (ORNL 1994) Number of "New Work" reviews performed: 50 reviews per year Time and Personnel required: 1.5 hr/review 3 M&C ES&H Group personnel per review 1 researcher and 1 technician per review 1 ORNL QA employee per review Calculation basis: Cost prorated and allotted to each 3- and 4-rated hazardous material that resulted in a nonradioactive RCRA hazardous waste resulting in total cost allotted to total of all M&C nonradioactive RCRA hazardous wastes. Cost allocation in 1994: Researcher time - Direct R&D funding accounts M&C ES&H Group time - M&C overhead accounts ORNL QA time - ORNL overhead accounts Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (researcher hr/review) x (number of reviews/yr) M&C overhead costs: (hourly rate) x (M&C ES&H Group personnel hr/review) x (number of reviews/yr) ORNL overhead costs: (hourly rate) x (ORNL QA hr/review) x (number of reviews/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Usage and Storage Requirements	
Perform quarterly inspection of special storage cabinet and area for carcinogenic materials	Sources of information: Interviews with R. B. Ogle, M&C IH Manager and use of *ORNL Chemical Carcinogen Control Program* procedure IHP-13 (ORNL 1990) Number of inspections performed: 4 inspections of each area per year, 110 areas Time and personnel required: 0.25 hr/area per inspection (or 1 hour per area per year) 1 M&C ES&H Group employee per inspection Cost allocation in 1994: M&C ES&H Group time - M&C overhead accounts Calculation basis: Cost prorated and allotted to each 3- and 4-rated hazardous material that resulted in a nonradioactive RCRA hazardous waste resulting in total cost allotted to total of all M&C nonradioactive RCRA hazardous wastes. Calculation used to estimate this added cost (annual): M&C overhead costs: (hourly rate) x (M&C ES&H Group hr/area/yr) x (number of areas)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Usage and Storage Requirements (continued)	
Maintain and test proper hood and vent systems	Sources of information: Interviews with R. Ogle, M&C IH Manager, R. Moore in ORNL QA, C. Phillips in ORNL IH, and J. Coen, the facilities engineer for the M&C building 4508. Two costs are incurred that are associated with laboratory hoods and venting systems, (1) annual hood testing and (2) changing out the HEPA filters and smoke testing them. Use of *ORNL Program for the Control of Local Exhaust Ventilation Systems and Associated Devices* procedure IHP-15 (ORNL 1992). Number of venting systems: 296 recorded hoods in 1992 (value from ORNL QA) Labor requirements for annual hood testing: 3 hours of ORNL IH plus 1 hour ORNL QA employee per hood (from ORNL IH and ORNL QA) Costs associated with filter changes and smoke testing: Average cost for changing out a filter to M&C is $1,000 (from building 4508 facilities engineer) On average, 12 hoods are connected to a bank of filters with an average of 40 filters in a bank (average number of filters per hood is 3 1/3). However, a filter bank can have 12 to 100 filters in it. HEPA filters are changed out on an average of once every 18 months (or 1.5 years). Cost allocation in 1994: ORNL IH and ORNL QA - ORNL overhead accounts Filter change out and smoke testing - M&C overhead accounts Calculation used to estimate this added cost (annual): M&C overhead costs: (cost per filter) x (filters per hood) x (number of hoods)/1.5 yr ORNL overhead costs: (number of hoods) x (hourly rate) x (ORNL IH time/hood + ORNL QA time/hood)/yr

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal)	
Perform annual training for RCRA hazardous waste generators as a best management practice	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), and D. Walmsley (M&C EPO) and training print out from D. Walmsley to verify trend toward annual training for waste generators. Estimated length of training: 4 hours per year Number of satellite areas: 92 satellite areas in 1992 Number of personnel impacted: 2 generators per satellite area Cost allocation in 1994: Generator training - Direct R&D funding accounts Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (hr per person/yr) x (number of satellite areas) x (number of employees per satellite area)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Maintain satellite accumulation areas with proper container, label, log book, and adequate space	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), and D. Walmsley (M&C EPO). Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Labor requirements: 0.25 hr of researcher or technician time for labeling waste per item 0.25 hr of researcher or technician time for maintaining log book (13 hr/logbook/yr) Number of items: 331 nonradioactive RCRA hazardous waste items declared waste in 1992 Label cost: Average cost of $0.50 to M&C overhead per custom-made hazardous waste label; one label per item Number of satellite areas: 92 satellite areas in 1992 Average square feet per satellite area: 9 square feet per satellite area Average annual cost per square foot of laboratory area: $15/ft^2 per year (for utility cost only) Cost allocation in 1994: Researcher or technician time - Direct R&D funding accounts Label cost and square footage cost for utilities - M&C overhead accounts Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (researcher hr for labeling) x (time/label) x (1 label/item) x (number of items) + (hourly rate) x (researcher hr for log book/yr) x (1 satellite area/log book) x (number of satellite areas) M&C overhead costs: (cost per label x 1 label/item x number of items/yr) + (utility cost per square foot/yr) x (square feet/satellite area) x (number of satellite areas)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Compile and complete request for disposal (RFD) form	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), D. Walmsley (M&C EPO), and Paul Cox (M&C HP support). Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Labor requirements: 1.176 hr of researcher or technician time for compiling 1 RFD form/item (based on 120 hr spent on 102 RFD forms during laboratory cleanout; can be greater than 4 hr/RFD form) 0.25 hr of ORNL HP time for surveying item and completing section on RFD form Number of items: 331 nonradioactive RCRA hazardous waste items declared waste in 1992 Cost allocation in 1994: Researcher or technician time - Direct R&D funding accounts ORNL HP time - ORNL overhead accounts Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (researcher hr/RFD form) x (1 RFD form/item) x (number of items/yr) ORNL overhead costs: (hourly rate) x (HP hr/RFD form) x (1 RFD form/item) x (number of items/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Perform audits of satellite areas	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), D. Daugherty (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Coordinator). Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Number of audits and labor requirements for 92 satellite areas: M&C inspections: 1 8-hr inspection/month, 1 waste generator and 1 M&C ES&H Group inspector ORNL audits: 1 8-hr audit every 2 months, 1 waste generator, 1 M&C ES&H Group employee, and 1 ORNL environmental compliance auditor Energy Systems or corporate audits: 2 4-hr audits per year, 1 waste generator, 2 M&C ES&H Group employees, 2 ORNL compliance personnel, 1 Energy Systems or corporate auditor DOE audits: 1 4-hr audits per year, 1 waste generator, 2 M&C ES&H Group employees, 2 ORNL compliance personnel, 2 Energy Systems Central Environmental Compliance personnel, and 1 DOE auditor TDEC audits: 2 4-hr audits per year, 1 waste generator, 2 M&C ES&H Group employees, 2 ORNL compliance personnel, 2 Energy Systems Central Environmental Compliance personnel, 2 DOE personnel, and 1 TDEC auditor Cost allocation in 1994: Waste generator time - Direct R&D funding accounts M&C ES&H personnel time - M&C overhead accounts ORNL environmental compliance personnel time - ORNL overhead accounts Energy Systems, corporate, DOE, and TDEC personnel time - Non-ORNL cost Calculation used to estimate this added cost (annual): Direct R&D funding costs: (hourly rate) x (waste generator hr spent supporting audits/yr) M&C overhead costs: (hourly rate) x (ES&H personnel hr spent supporting audits/yr) ORNL overhead costs: (hourly rate) x (ORNL compliance personnel hr spent supporting audits/yr) Non-ORNL costs: (hourly rate) x (Energy Systems and corporate personnel hr + DOE personnel time + TDEC personnel hr spent supporting audits/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Perform waste monitoring and sampling of Metals and Ceramics wastes	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), D. Walmsley (M&C EPO), Joan Gideon (ORNL Surveillance Group in the Office of Environmental Compliance Documentation), and N. M. Ferguson (ASO). Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Labor requirements: Average of 7 hours/sample of sampler's time (highly variable, but usually ranges between 6 to 8 hr/sample) Analyses required: Every used oil container requires ICP, PCB, and alpha, beta, and gamma analyses. Rest of waste types are sampled once if requested; usually about 4 samples per year in addition to the oil. Additional sampling and analysis is likely to be required in future. Cost of sample analysis: $116/sample for ICP analysis of oil sample $110/sample for ICP analysis for water sample $160/sample for ICP analysis of solid or soil sample $339/sample for PCB analysis $132/sample for gross alpha and beta analysis $135/sample for gamma analysis Calculation basis: Cost allotted to each 3- and 4-rated hazardous material that resulted in a nonradioactive RCRA hazardous waste and known to require routine sampling; total cost allotted to total of all M&C nonradioactive RCRA hazardous wastes. Cost allocation in 1994: ORNL sampler time and analytical costs - M&C overhead accounts Calculation used to estimate this added cost (annual): M&C overhead costs: (hourly rate) x (sampler's hr/sample) x (number of items sampled/yr) + (number of samples requiring ICP analysis/yr x cost of ICP analysis + number of samples requiring PCB analysis/yr x cost of PCB analysis + number of samples requiring alpha, beta, and gamma analysis/yr x cost of alpha, beta, and gamma analyses)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Pick-up and transport RCRA hazardous waste to a permitted RCRA storage facility at ORNL	Sources of information: Interviews with R. Ogle (M&C IH Manager), J. Bain (M&C PPR), Donna Slagle (M&C Financial Officer), D. Daugherty (ORNL Waste Management), K. G. Edgemon, Jr. (ORNL Waste Management), Ruth O. McKee (ORNL Waste Management DMC) and S. Michaud (ORNL Pollution Prevention Program Coordinator), and search of the ORNL Hazardous Waste Tracking System for transportation and storage data. Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Labor requirements: Average of 0.25 hours of waste management chemist's time for reviewing 1 RFD form, 0.25 hour/RFD for DMC classification for DOT and RCRA, and average of 0.5 hr of DMC personnel time to enter the RFD into the database system. Average of 8 hours each for 20 pick ups: 2 packagers to check that waste has been properly labeled and tagged and to pack up waste for pick up, 1 P&E truck driver, 2 P&E laborers and 2 waste management transportation personnel, and 2 P&E laborers. Average of 0.5 hour each for 2 personnel from field operations to take material and forms and properly distribute waste once received at building hazardous waste management station (All labor-based values can vary greatly from one case to another.) Items-based Data: 331 nonradioactive RCRA hazardous waste items declared waste in 1992 1 item per RFD In 1992, 66 trips transported 527 items of M&C hazardous waste or an average of 7.98 items/trip Cost allocation in 1994: Pick-up and transport of M&C hazardous waste costs - Waste Management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: (hourly rate) x [(2 x 0.5 hr + 0.25 hr + 0.25 hr + 0.5 hr)/RFD x 1 RFD/item + (7 people x 8 hr/person/day x 1 day/20 trips x 66 trips/527 items)] x number of items/yr

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Store waste in permitted storage facility	Sources of information: Interviews with R. Ogle (M&C IH Manager), D. Daugherty (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Program Coordinator), and June 1994 *Indexing Cost Avoidance with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems 1994), page B-4 for mixed waste because all RCRA waste is managed as mixed waste. Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Cost Basis: Unless RCRA hazardous waste can be treated by the waste water treatment systems at ORNL, all ORNL RCRA hazardous waste is currently stored in RCRA permitted storage facilities. Therefore, RCRA waste generated in 1992 is expected to be stored for at least 3 years before being transported to an appropriate treatment facility. Unless a specific waste type such as acetone was being evaluated, 1,000 kg/m^3 (density of water) was used. Density or specific gravity data for individual materials were obtained from the *Handbook of Chemistry and Physics* (Weast 1981) and *The Condensed Chemical Dictionary* (Hawley 1981). Although the waste is stored for 3 years, all costs are assumed to be incurred during first year. The cost of storing this waste is assumed to be $450/55-gallon drum per year based on the June 1994 guidance document. Cost allocation in 1994: M&C hazardous waste storage costs - Waste management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: (cost per unit volume of waste/yr) x (yr in storage) x (density of waste) x (mass of waste/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Perform additional sampling and analysis in the future to comply with waste acceptance criteria for treatment	Sources of information: Interviews with R. Ogle (M&C IH Manager), D. Daugherty (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Program Coordinator), and June 1994 *Indexing Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems 1994). Because this sampling and analysis is an anticipated future activity, this value is presently assumed to be the same as the M&C sampling and analytical costs previously delineated. Once the sampling and analysis is actually planned based on WACs for specific treatment operations, this calculation and resulting values can be updated. Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Cost allocation in 1994: Additional sampling and analysis of waste costs - Waste management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: same as cost of initial sampling and analysis by M&C

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Transport waste to RCRA permitted off-site storage and treatment facility (to K-25 Site and in the future)	Sources of information: Interviews with R. Ogle (M&C IH Manager), D. Daugherty (ORNL Waste Management), K. G. Edgemon, Jr. (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Program Coordinator), and June 1994 *Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems 1994). Waste is currently transported to the K-25 Site for storage and will be moved from K-25 storage to a treatment facility in the future. Because the second pick-up and transport to a treatment facility is an anticipated future activity, this value is presently assumed to be the same as the initial cost for transport of this waste to a permitted storage facility at the K-25 Site. Therefore, the estimated cost of transporting waste to the K-25 Site is doubled to account for this future waste transport activity. Once the treatment facility is identified and treatment is scheduled, this calculation and resulting values can be updated. Use of procedures related to waste management including *Resource Conservation and Recovery Act (RCRA) and Mixed Waste Program Management* ESS-EP-136 (Energy Systems 1992), *Packaging for Hazardous Materials and Wastes, Including Radioactive Materials, to be Transported Off-Site* X-GP-21 (ORNL 1992), and *Off-Site Transportation of Hazardous Wastes* X-GP-28 (ORNL 1992). Labor Requirements: On average, for one shipment of waste, the equivalent of 5 people working for 1.5 weeks (60 hours) is required to perform all needed tasks, such as to compile needed data, complete forms and labeling, obtain needed reviews and signatures, load and transport wastes, unload at destination and complete paper work, and return to facility and complete paperwork. Quantity-based Data: On average, each shipment consisted of 32 drums. At ORNL, 208.45 kg/drum is assumed as a general value for RCRA hazardous wastes, which is based on the density of oil. To determine the number of drums of waste for transport, it was assumed that the mass of the M&C waste studied would equate to the mass in a drum, which meant that any lab packing material was not considered in the mass basis. Cost allocation in 1994: Transport of waste to K-25 storage and to future treatment facility - Waste management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: 2 x hourly rate x 5 people x 60 hr/person/shipment x 1 shipment/32 drums x mass of waste/yr)/(mass/drum)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Treat waste per RCRA requirements in the future	Sources of information: Interviews with R. Ogle (M&C IH Manager), D. Daugherty (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Program Coordinator), and June 1994 *Indexing Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems 1994), page B-4. Because treatment is an anticipated future activity, this value is presently based on the value for incineration of nonradioactive mixed liquid waste (including PCBs, oils, solvents, and contaminated paint waste) listed in the June 1994 costing guidance document. Also, the cost for waste water treatment published in this costing guidance document is used for specific waste types that are or can be discharged to an ORNL waste water treatment facility. Once a treatment facility is identified and treatment is scheduled, this calculation and resulting values can be updated. Cost allocation in 1994: M&C hazardous waste treatment costs - Waste management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: (cost of treatment per unit mass of waste) x (mass of waste/yr)

Table B-1 (continued)

Added Requirements Resulting in Additional Costs	Basis for Estimated Costs
Additional Waste Management Requirements (from Generation to Disposal) (continued)	
Dispose of treatment residues in the future	Sources of information: Interviews with R. Ogle (M&C IH Manager), D. Daugherty (ORNL Waste Management), and S. Michaud (ORNL Pollution Prevention Program Coordinator), June 1994 *Cost Avoidance Associated with a Pollution Prevention Option at the Oak Ridge Reservation* (Energy Systems), page B-4, *Solid Waste* (Tchobanoglous et al. 1977), and DOE's March 1994 memorandum entitled "Nationwide Mixed Waste Commercial Disposal Contract" which documented mixed waste disposal information related to sending waste for disposal to Envirocare of Utah, Inc.. Because treatment is an anticipated future activity, this value is presently based on 5 percent residue generated by treatment per estimate in *Solid Waste* for incineration of solid wastes. A density of 2,200 kg/m^3 for ash from *Solid Waste* was assumed for wastes in general; 1,000 kg/m^3 was assumed for residues from waste water treatment. Per the contract with Envirocare, a cost of \$1,585.74/yd^3 was estimated. Once a treatment facility is identified and treatment is scheduled, this calculation and resulting values can be updated based on expected residues. Mass of Waste: 10,557.8 kg of nonradioactive RCRA hazardous waste were generated in 1992 by the M&C Division Cost allocation in 1994: M&C hazardous waste treatment residue disposal - Waste management (EM) accounts Calculation used to estimate this added cost (annual): EM costs: (cost of disposal per unit volume of waste residue) x (mass of waste/year) x (mass of residue generated/mass of waste treated) x (density of residue)

Notes: (1) M&C's average fully burdened hourly rate was calculated to be \$119.19 per hour by taking the summation of the fully burdened hourly rate for each M&C cost center times the number of employees that charge their time in that cost center. This sum was then divided by the total number of personnel that charge their time. The hourly rate information as of July 1994 was obtained from M&C's financial personnel. In general, this fully burdened hourly rate was used as a basis for the cost of a person at ORNL. This basis was selected because many of the ORNL support personnel could be performing R&D activities if the support activities were not required. However, the cost of these support personnel was included in the overhead rates applied to this fully loaded hourly rate. Therefore, the resulting costs per funding source could not be added together because they were interrelated. In spite of this interrelationship, the costs associated with overhead must be captured to understand where the added costs of managing 3- and 4-rated hazardous materials and the resulting nonradioactive RCRA hazardous wastes were incurred.

(2) As with the quantifiable costs associated with added requirements, the estimated increase in productivity, represented as a reduction in these costs, was also calculated and categorized by funding source. The resulting values were not added together due to the interrelationship among the various funding sources. The estimated increase in productivity values depicted as cost avoidance data were also divided among the four categories: procurement, general ES&H, usage and storage, and waste management from generation to disposal. Additionally, the cost avoidance data were estimated based on various combinations of possibilities related to implemented options, potential options, and the level of success of potential options.

Table B-1 (continued)

Abbreviations:
AIHCE - American Industrial Hygiene Conference and Exposition
ASO - Analytical Services Organization
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
Energy Systems - Lockheed Martin Energy Systems, Inc.
EPO - Environmental Protection Officer
ES&H - environmental, safety, and health
HEPA - High Efficiency Particulate Air
HMIS - Hazardous Materials Inventory System
HP - health physics or health physicist
hr - hour
ICP - Inductively Coupled Plasma Spectroscopy
IH - industrial hygiene
IR - Infrared Spectroscopy
kg - kilogram
MSDS - Material Safety Data Sheet
M&C - Metals and Ceramics Division
ORNL - Oak Ridge National Laboratory
PCB - polychlorinated biphenyl
PPR - Pollution Prevention Representative
PR - purchase requisition
QA - Quality Assurance
RCRA - Resource Conservation and Recovery Act
TDEC - Tennessee Department of Environment and Conservation
WAC - Waste Acceptance Criteria
yr - year

Table B-2
3- and 4-Rated Hazardous Materials Procured and
Hazardous Waste Generated in 1992 by the Metals and Ceramics Division at ORNL
(by mass and by number of items)

Material and Waste Grouping Category	Quantity of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (kg)	Number of Items of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (each)	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)
All M&C 3- and 4-Rated Hazardous Materials and Wastes	6145.2	344	12802.6	578
Proportion of M&C 3- and 4-Rated Hazardous Materials and All M&C RCRA Hazardous Wastes	5542.0	208	11546.0	349
Proportion of M&C 3- and 4-Rated Hazardous Materials and M&C Nonradioactive RCRA Hazardous Wastes	5067.7	197	10557.8	331
Types of Activities				
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes	2617.9	90	5453.9	152
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes	2365.6	58	4928.5	98
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes	84.2	48	175.4	81
Types of Activities-Based Totals	5067.7	197	10557.8	331
Waste Types				
Acetic Acid	0.0	0	2.5	3
Acetone-Based [@]	448.9	24	149.4	9
Acrylamide [@]	0.0	0	1.5	4
Alumina/Aluminum Oxide	15.4	3	113.9	2
Amines Curing Agent	0.0	0	0.2	1
Ammonium Hydroxide-Based	0.0	0	46.1	4
Ammonium Persulfate	0.0	0	3.0	2
Anti-static Solution	0.0	0	0.2	2
Barium Oxide Solution (procured as barium)	0.0	0	3.0	2
Batteries (Lead Acid, Mercury, etc.)	0.0	0	49.4	7
Blue Silicone Primer Solution	0.0	0	0.7	1
Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	0.0	0	1.2	2
Carbon Tetrachloride [@]	0.0	0	3.3	1
Cement Paper and Solution	0.0	0	0.4	2
Ceramic Chrome Dinnerware Gloss Glaze [@]	0.0	0	0.2	1

Table B-2 (continued)

Material and Waste Grouping Category	Quantity of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (kg)	Number of Items of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (each)	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)
Ceramic Chrome Dinnerware Gloss Glaze [@]	0.0	0	0.2	1
Chromic Acid [@]	0.0	0	6.0	2
Chromium-Based (Solid) [@]	226.8	1	99.1	6
Coal	0.0	0	2.0	2
Copper Mixture Contaminated Solids [@]	0.5	1	4.8	1
Dichloromethane [@]	0.0	0	0.2	1
Ethanol Solution [@]	136.5	7	0.6	1
Ethylene Dichloride [@]	0.0	0	4.2	2
Ganex V-516	0.0	0	0.4	1
Glycerine Solution	0.0	0	0.1	1
Graphite/Activated Carbon	2.6	2	0.6	2
Hexane Solution [@]	16.0	1	4.5	1
Hydrochloric Acid Solution [@]	109.8	8	0.1	2
Hydrofluoric Acid [@]	31.1	8	2.2	5
Hydrogen Peroxide	16.5	7	4.3	2
Ink Solution	0.0	0	0.2	1
Isopropanol Solution [@]	72.0	4	5.8	5
Lead [@]	0.0	0	21.7	3
Lithium-Based	0.0	0	9.5	11
Magnesium Perchlorate	0.0	0	20.5	2
Magnifloc Polyacrylamide Solution	0.0	0	0.1	1
Manganese Mixture [@]	0.0	0	2.5	1
Mercury-Based [@]	5.7	1	9.2	22
Methacrylic Acid	0.0	0	0.9	1
Methanol Solution [@]	139.6	11	44.8	11
Methyl Ethyl Ketone [@]	1.6	1	34.1	4
Methyltrichlorosilane	0.0	0	15.2	1
Molybdenum	0.0	0	0.1	1
N,N,N',N'- Tetramethylethylenediamine	0.2	1	0.3	1
Nickel Mixture [@]	47.2	2	36.5	7

Table B-2 (continued)

Material and Waste Grouping Category	Quantity of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (kg)	Number of Items of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (each)	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)
Nitric Acid Solution and Solids [@]	198.5	10	338.7	7
Nitrocellulose Solution (Pyroxylin)	0.0	0	0.4	2
Oil and Oily Solids	17.0	2	1441.0	23
Oxalic Acid Solution	1.0	1	0.5	1
Paint Solution	0.0	0	1.2	1
Petroleum Ether	0.0	0	0.5	1
Phosphoric Acid	5.0	1	3.3	2
Photographic Waste [@]	791.1	36	4277.9	94
Potassium-Based	0.1	2	3.1	4
Praseodymium Oxide	0.0	0	0.02	1
Propoxylated Aliphatic Amines Solution	0.0	0	1.0	1
Resin Solution	0.0	0	0.4	1
Silicon-Based	0.0	0	11.0	4
Soap Leak Detector Solution	0.0	0	0.1	1
Sodium Cyanide	0.0	0	0.9	1
Sodium Dichromate	0.0	0	0.2	1
Sodium Hydroxide	14.0	4	4.5	4
Sodium Iodide	0.0	0	0.1	1
Sodium Metal	5.0	1	3.0	3
Sodium Silicate	0.1	1	1.0	1
Stainless Steel Powder	7.5	1	11.1	1
Stainless Steel Soldering Flux	0.0	0	0.2	1
Strontium	0.0	0	0.2	1
Sulfuric Acid	41.8	7	1.5	1
Tantalum Metal	0.0	0	0.3	1
Tetramethyl Ammonium Hydroxide	0.2	2	0.2	1
Titanium Sponge	0.0	0	1.3	1
Trichloroethane [@]	0.0	0	2.3	2
Trichloroethylene Solution [@]	0.0	0	50.6	5
Trichlorotrifluoroethane	0.0	0	59.7	3

Table B-2 (continued)

Material and Waste Grouping Category	Quantity of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (kg)	Number of Items of 3- and 4-Rated Hazardous Materials Procured in 1992 [#] (each)	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)
Trimethylolpropane Trimethacrylate	0.0	0	1.4	1
Troysol Solution	0.0	0	0.1	1
Xylene [@]	2.0	1	0.7	1
Yttrium Oxide Mixture	14.1	6	0.2	1
Zinc Bromide	0.0	0	3633.8	12
Waste Types-Based Totals	2367.9	157	10557.8	331

Notes:

[#] Procured data related to the following groupings were based on multiplying the total amount of 3- and 4-rated hazardous materials procured by a ratio of hazardous waste generated in a grouping divided by all hazardous waste:
- All M&C RCRA Hazardous Wastes,
- M&C Nonradioactive RCRA Hazardous Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes.

Procured data for the listed waste types were extracted from printouts from HMIS of M&C's 3- and 4-rated hazardous materials procured in 1992.

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:
HMIS - Hazardous Materials Inventory System
kg - kilogram
M&C - Metals and Ceramics Division
ORNL - Oak Ridge National Laboratory
RCRA - Resource Conservation and Recovery Act
R&D - research and development

Table B-3
Nonradioactive RCRA Hazardous Waste Generated in 1992 by the
Metals and Ceramics Division at ORNL Categorized by Type of Activity
(by mass and by number of items for hazardous wastes and by waste types)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes				
	Amines Curing Agent	0.2	1	Legacy
	Ammonium Hydroxide-Based	3.7	3	Legacy/Lab Cleanout
	Anti-static Solution	0.2	2	Legacy
	Barium Oxide Solution (procured as barium)	0.2	1	Legacy
	Batteries (Lead Acid, Mercury, etc.)	5.0	4	Legacy/Lab Cleanout
	Blue Silicone Primer Solution	0.7	1	Legacy
	Carbon Tetrachloride [@]	3.3	1	Excessed Chemical - Not Used Since 1987
	Cement Paper and Solution	0.4	2	Legacy/Lab Cleanout
	Ceramic Chrome Dinnerware Gloss Glaze [@]	0.2	1	Lab Cleanout
	Chromic Acid [@]	5.7	1	Lab Cleanout
	Chromium-Based (Solid) [@]	2.5	4	Legacy
	Coal	1.8	1	Lab Cleanout
	Copper Mixture Contaminated Solids [@]	4.8	1	Lab Cleanout
	Ethylene Dichloride [@]	2.5	1	Lab Cleanout
	Glycerine Solution	0.1	1	Legacy
	Hexane Solution [@]	4.5	1	Silicon Carbide Whisker Fabrication Close Down
	Ink Solution	0.2	1	Lab Cleanout
	Isopropanol Solution [@]	4.6	3	Legacy/Silicon Carbide Whisker Fabrication Close Down
	Lead [@]	21.7	3	Excessed Chemical/Lab Cleanout
	Lithium-Based	1.0	2	Legacy
	Magnifloc Polyacrylamide Solution	0.1	1	Lab Cleanout
	Manganese Mixture [@]	2.5	1	Legacy

Table B-3 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)				
	Mercury-Based [@]	4.5	11	Legacy
	Methyl Ethyl Ketone [@]	1.9	1	Silicon Carbide Whisker Fabrication Close Down
	Molybdenum	0.1	1	Legacy
	Nickel Mixture [@]	36.5	7	Legacy
	Nitrocellulose Solution (Pyroxylin)	0.4	2	Lab Cleanout
	Oil and Oily Solids	5.7	3	Legacy/Spill Cleanup/Silicon Carbide Whisker Fabrication Close Down
	Paint Solution	1.2	1	Legacy
	Phosphoric Acid	3.2	1	Lab Cleanout
	Potassium-Based	1.6	2	Lab Cleanout
	Praseodymium Oxide	0.02	1	Legacy
	Propoxylated Aliphatic Amines Solution	1.0	1	Lab Cleanout
	Silicon-Based	10.6	2	Legacy
	Sodium Cyanide	0.9	1	Excessed Chemical
	Sodium Dichromate	0.2	1	Lab Cleanout
	Sodium Hydroxide	1.4	1	Legacy
	Sodium Silicate	1.0	1	Legacy
	Stainless Steel Powder	11.1	1	Lab Cleanout
	Strontium	0.2	1	Legacy
	Tantalum Metal	0.3	1	Legacy
	Trichloroethane [@]	1.5	1	Legacy
	Trichlorotrifluoroethane	25.4	1	Lab Cleanout
	Xylene [@]	0.7	1	Legacy
	Yttrium Oxide Mixture	0.2	1	Legacy
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Total)		175.4	81	

Table B-3 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes				
	Acetic Acid	2.5	3	Stage 1 - Electropolishing solution for prepping sample for viewing under atom probe (75% acetic acid; 25% perchloric)
	Acetone-Based [@]	149.4	9	Degreasing, Cleaning, and Washing Activities (Degreasing Test Coupons and Tubing in Corrosion Research, Washing Silicon Carbide Cloth to Dissolve Binder, Cleaning Silicon Wagers for Thin-Film Deposition, and Cleaning Specimens, Equipment, and Glassware)
	Acrylamide [@]	1.5	4	Gel Casting for Production of Ceramic Shapes - Eliminated Through Substitution (MAM-BAM, MBAM, and PEG)
	Alumina/Aluminum Oxide	113.9	2	Alumina Slurry Containing Acrylamide - No Longer Hazardous - Eliminated Acrylamide Through Substitution. Aluminum Oxide Solids from Catch Basin for Sink in Gel Casting; Reclassified as non-RCRA
	Ammonium Hydroxide-Based	42.4	1	Used in Gel Casting Process as Titrant to Bring Up pH Usually - Part of Massive Cleanup of a Lab - Still Used Though
	Ammonium Persulfate	3.0	2	Used in Gel Casting Process as Free Radical Initiator - Unpublished Shelf Life; If Performs Poorly, Rest Sent for Disposal
	Barium Oxide Solution (procured as barium)	2.9	1	Used in System to Deposit Barium and Barium Oxide onto Silicon Wagers - From Cleaning of System
	Batteries (Lead Acid, Mercury, etc.)	44.4	3	Batteries for Equipment, Flashlights, and Calculators
	Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	1.2	2	Stage 2 - Electropolishing solution for prepping sample for viewing under atom probe (98% Butylcellusolve; 2% perchloric)
	Coal	0.2	1	From Completed Research Project
	Chromic Acid [@]	0.3	1	Excess/Used for Etching
	Chromium-Based (Solid) [@]	96.6	2	Used as Subarc Flux Powder in Welding (Covers Arc So That Weld Materials Will Not Oxidize. Also Used in Past to Make Chromium Coating.
	Dichloromethane [@]	0.2	1	Used to Dissolve Epoxy
	Ethanol Solution [@]	0.6	1	Sample Preparation for Atomic/Molecular Research

Table B-3 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)				
	Ethylene Dichloride [@]	1.7	1	Was Used for Analytical Work - No Longer Used
	Ganex V-516	0.4	1	Experimented With This Material as a Dispersant
	Graphite/Activated Carbon	0.6	2	Used to Purify Gases and Residue Generated from Specimen Holder
	Hydrochloric Acid Solution [@]	0.1	2	Used in Electrolyte Solutions or in Etching
	Hydrofluoric Acid [@]	2.2	5	Usually used in Electrolyte Solutions. Used Once in Family Day Demonstration to Etch Glass and Used in Past in Solution with Nitric and Sulfuric Acids to Clean Out Crucibles
	Hydrogen Peroxide	4.3	2	Used to Electropolish Steel (Clean It); Now Using Ultrasonic Water-Based System
	Isopropanol Solution [@]	1.2	2	Used in General Degreasing as Solvent and to Rinse Parts Installed into MS.
	Lithium-Based	8.5	9	Used in Past in Space Program Mass Transfer Loops. Also in Past Generated Lithium Hydride from Cleaning Lithium Specimens with Anhydrous Ammonia.
	Magnesium Perchlorate	20.5	2	Purification Agent in Gas Stream
	Mercury-Based [@]	4.8	11	Old Mercury Switches and Thermometers; Some Not Needed Anymore; Others Replaced With Electronic Systems
	Methacrylic Acid	0.9	1	Monomer Used in Gel Casting
	Methanol Solution [@]	44.8	11	Electropolishing Solution to Prepare Sample for Atom Probe Viewing, Preparing Sample for Atomic/Molecular Research, Cleaning Silicon Wagers for Thin-Film Deposition, One-Time Metal Etching, and Removing Residue from Acetone on Ceramic Samples (Tribology)
	Methyl Ethyl Ketone [@]	32.2	3	Gel Casting for Production of Ceramic Shapes - Cleanout - One-Time Statistical Testing Method
	Methyltrichlorosilane	15.2	1	Blown Through Silicon Carbide Cloth to Form Ceramic Composite
	N,N,N',N'- Tetramethylethylenediamine	0.3	1	Catalyst Used in Gel Casting - Unpublished Shelf Life; If Performs Poorly, Rest Sent For Disposal
	Nitric Acid Solution and Solids [@]	338.7	7	Iridium Etching, Preparing Sample for Atomic/Molecular Research, and Cleaning Silicon Wagers for Thin-Film Deposition

Table B-3 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)				
	Oil and Oily Solids	784.7	16	Changing Oil in Vacuum Pumps, Replacing Gasket on Vacuum Pump, Quenching Specimens After Heating, Cleaning Out Tube Reducer, Bubbler to Prevent Oxygen from Getting into a Furnace
	Oxalic Acid Solution	0.5	1	Used to Chemically Reduce the Size of a Sample
	Petroleum Ether	0.5	1	Pentane-Based Nonaqueous Solvent
	Phosphoric Acid	0.1	1	Electropolishing Copper Stub Used to Hold the Sample
	Potassium-Based	1.5	2	Ingredient Used in Research; Use of This Specific Sample of Material Was a Concern; Sent for Disposal. Also Used in Past to Electropolish Tungsten
	Resin Solution	0.4	1	Material Used to Make Mold in Gel Casting Operation
	Silicon-Based	0.4	2	Material Used to Make Composites and Gel Casting
	Soap Leak Detector Solution	0.1	1	Soak Leak Detector Solution Eliminated Because Vacuum System and Pumps Eliminated Due to Program Change
	Sodium Hydroxide	3.1	3	Material Used for pH Adjustment
	Sodium Iodide	0.1	1	Was Used in Research or for Radiographs; Sent for Disposal As Part of Lab Cleanout
	Sodium Metal	3.0	3	Used in Mass Transport Loops; Excess
	Stainless Steel Soldering Flux	0.2	1	Flux.
	Sulfuric Acid	1.5	1	Used with 10 Percent Hydrofluoric Acid in Electropolishing and Cleaning Metals
	Tetramethyl Ammonium Hydroxide	0.2	1	Base Used for Titration
	Titanium Sponge	1.3	1	Combined with Chlorine to Create Titanium Chloride
	Trichloroethane [@]	0.8	1	Polymers
	Trichloroethylene Solution [@]	50.6	5	Solvent Used to Remove Polymers in Gel Casting for Production of Ceramic Shapes, Used in Corrosion Research, and Used to Clean Silicon Wagers for Thin-Film Deposition

Table B-3 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Description of Activities
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)				
	Trichlorotrifluoroethane	34.3	2	Used as Cleaner in Turbo Pump Maintenance (Overhaul)
	Trimethylolpropane Trimethacrylate	1.4	1	Not Currently Used - But May Use in Future in Nonaqueous Gel Casting
	Troysol Solution	0.1	1	Surfactant
	Zinc Bromide	3633.8	12	Shield Window Replacement
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Total)		5453.9	152	
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes				
	Oil and Oily Solids	650.6	4	Equipment Maintenance and Spill Cleanup
	Photographic Waste [@]	4277.9	94	Photograph and Radiograph Production
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes (Total)		4928.5	98	

Note:

[#] Three Types of Activities listed in this table are as follows:

- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes.

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:

kg - kilogram

M&C - Metals and Ceramics Division

ORNL - Oak Ridge National Laboratory

RCRA - Resource Conservation and Recovery Act

R&D - research and development

Table B-4

Pollution Prevention or Waste Management Technique Applied to Nonradioactive RCRA Hazardous Waste Generated in 1992 by the Metals and Ceramics Division at ORNL Categorized by Type of Activity

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of of Waste Items Generated in 1992 (each)	Current Waste Management or Implemented Pollution Prevention Options	Waste Management or Pollution Prevention Option Category
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes					
	Amines Curing Agent	0.2	1	Storage	ST
	Ammonium Hydroxide-Based	3.7	3	Storage	ST
	Anti-static Solution	0.2	2	Storage	ST
	Barium Oxide Solution (procured as barium)	0.2	1	Storage	ST
	Batteries (Lead Acid, Mercury, etc.)	5.0	4	Storage	ST
	Blue Silicone Primer Solution	0.7	1	Storage	ST
	Carbon Tetrachloride [@]	3.3	1	Storage	ST
	Cement Paper and Solution	0.4	2	Storage	ST
	Ceramic Chrome Dinnerware Gloss Glaze [@]	0.2	1	Storage	ST
	Chromic Acid [@]	5.7	1	Storage	ST
	Chromium-Based (Solid) [@]	2.5	4	Storage	ST
	Coal	1.8	1	Storage	ST
	Copper Mixture Contaminated Solids [@]	4.8	1	Storage	ST
	Ethylene Dichloride [@]	2.5	1	Storage	ST
	Glycerine Solution	0.1	1	Storage	ST
	Hexane Solution [@]	4.5	1	Storage	ST
	Ink Solution	0.2	1	Storage	ST
	Isopropanol Solution [@]	4.6	3	Storage	ST
	Lead [@]	21.7	3	Storage for Potential Reuse/Storage	ST/RR/ST
	Lithium-Based	1.0	2	Storage	ST
	Magnifloc Polyacrylamide Solution	0.1	1	Storage	ST

Table B-4 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of of Waste Items Generated in 1992 (each)	Current Waste Management or Implemented Pollution Prevention Options	Waste Management or Pollution Prevention Option Category
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)					
	Manganese Mixture [@]	2.5	1	Storage	ST
	Mercury-Based [@]	4.5	11	Storage	ST
	Methyl Ethyl Ketone [@]	1.9	1	Storage	ST
	Molybdenum	0.1	1	Storage	ST
	Nickel Mixture [@]	36.5	7	Storage	ST
	Nitrocellulose Solution (Pyroxylin)	0.4	2	Storage	ST
	Oil and Oily Solids	5.7	3	Storage/Reclassified as Not Being a RCRA Hazardous Waste	RC/ST
	Paint Solution	1.2	1	Storage	ST
	Phosphoric Acid	3.2	1	Storage	ST
	Potassium-Based	1.6	2	Storage	ST
	Praseodymium Oxide	0.02	1	Storage	ST
	Propoxylated Aliphatic Amines Solution	1.0	1	Storage	ST
	Silicon-Based	10.6	2	Storage	ST
	Sodium Cyanide	0.9	1	Storage	ST
	Sodium Dichromate	0.2	1	Storage	ST
	Sodium Hydroxide	1.4	1	Storage	ST
	Sodium Silicate	1.0	1	Storage	ST
	Stainless Steel Powder	11.1	1	Storage	ST
	Strontium	0.2	1	Storage	ST
	Tantalum Metal	0.3	1	Storage	ST
	Trichloroethane [@]	1.5	1	Storage	ST
	Trichlorotrifluoroethane	25.4	1	Storage	ST
	Xylene [@]	0.7	1	Storage	ST
	Yttrium Oxide Mixture	0.2	1	Storage	ST
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Total)		175.4	81		

Table B-4 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of of Waste Items Generated in 1992 (each)	Current Waste Management or Implemented Pollution Prevention Options	Waste Management or Pollution Prevention Option Category
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes					
	Acetic Acid	2.5	3	On-site neutralization/Process drain	NU/C
	Acetone-Based [@]	149.4	9	Storage	ST
	Acrylamide [@]	1.5	4	Storage; Already Performed Material Substitution	SR/C
	Alumina/Aluminum Oxide	113.9	2	Storage; Already Performed Material Substitution on Part of Waste Type (1 item or 6.3 kg); Remainder of Waste Type Reclassified as Not Being a RCRA Hazardous Waste	SR/C/ ST/RC
	Ammonium Hydroxide-Based	42.4	1	Storage	ST
	Ammonium Persulfate	3.0	2	Storage	ST
	Barium Oxide Solution (procured as barium)	2.9	1	Storage	ST
	Batteries (Lead Acid, Mercury, etc.)	44.4	3	Storage	ST
	Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	1.2	2	On-site neutralization/Process drain	NU/C
	Coal	0.2	1	Storage	ST
	Chromic Acid [@]	0.3	1	Storage	ST
	Chromium-Based (Solid) [@]	96.6	2	Storage	ST
	Dichloromethane [@]	0.2	1	Storage	ST
	Ethanol Solution [@]	0.6	1	Storage	ST
	Ethylene Dichloride [@]	1.7	1	Storage	ST
	Ganex V-516	0.4	1	Storage	ST
	Graphite/Activated Carbon	0.6	2	Storage	ST
	Hydrochloric Acid Solution [@]	0.1	2	On-site neutralization/Process drain	NU/C
	Hydrofluoric Acid [@]	2.2	5	On-site neutralization/Process drain implemented for part of waste type (3 items or 0.11 kg); Remainder is in Storage	NU/C/ST

Table B-4 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of of Waste Items Generated in 1992 (each)	Current Waste Management or Implemented Pollution Prevention Options	Waste Management or Pollution Prevention Option Category
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)					
	Hydrogen Peroxide	4.3	2	Now Use Water-Based Ultrasonic Cleaner to Electropolish Steel	SR/C
	Isopropanol Solution [@]	1.2	2	Storage	ST
	Lithium-Based	8.5	9	Storage	ST
	Magnesium Perchlorate	20.5	2	Storage	ST
	Mercury-Based [@]	4.8	11	Storage/If Required Replacement - Used Electronic Systems	ST/SR/O/RR
	Methacrylic Acid	0.9	1	Storage	ST
	Methanol Solution [@]	44.8	11	Storage	ST
	Methyl Ethyl Ketone [@]	32.2	3	Storage	ST
	Methyltrichlorosilane	15.2	1	Storage	ST
	N,N,N',N'- Tetramethylethylenediamine	0.3	1	Storage	ST
	Nitric Acid Solution and Solids [@]	338.7	7	On-site neutralization/process drain implemented for part of waste type (2 items or 0.3 kg); Remainder of waste type placed in storage	NU/C/ST
	Oil and Oily Solids	784.7	16	Storage/Reclassified as Not Being a RCRA Hazardous Waste	RC/ST
	Oxalic Acid Solution	0.5	1	Substituted mechanical grinding to eliminate chemical in nonradioactive applications	SR/C
	Petroleum Ether	0.5	1	Storage	ST
	Phosphoric Acid	0.1	1	On-site neutralization/process drain	NU/C
	Potassium-Based	1.5	2	Storage	ST
	Resin Solution	0.4	1	Storage	ST
	Silicon-Based	0.4	2	Storage	ST
	Soap Leak Detector Solution	0.1	1	Storage	ST
	Sodium Hydroxide	3.1	3	Storage	ST
	Sodium Iodide	0.1	1	Storage	ST
	Sodium Metal	3.0	3	Storage	ST
	Stainless Steel Soldering Flux	0.2	1	Storage	ST

Table B-4 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of of Waste Items Generated in 1992 (each)	Current Waste Management or Implemented Pollution Prevention Options	Waste Management or Pollution Prevention Option Category
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)					
	Sulfuric Acid	1.5	1	Storage	ST
	Tetramethyl Ammonium Hydroxide	0.2	1	Storage	ST
	Titanium Sponge	1.3	1	Storage	ST
	Trichloroethane [@]	0.8	1	Storage	ST
	Trichloroethylene Solution [@]	50.6	5	Storage	ST
	Trichlorotrifluoroethane	34.3	2	Storage	ST
	Trimethylolpropane Trimethacrylate	1.4	1	Storage	ST
	Troysol Solution	0.1	1	Storage	ST
	Zinc Bromide	3633.8	12	Storage; But being generated because of material substitution with nonhazardous substitute (See Table 5-4).	ST
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Total)		5453.9	152		
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes					
	Oil and Oily Solids	650.6	4	Storage/Reclassified as Not Being a RCRA Hazardous Waste	RC/ST
	Photographic Waste [@]	4277.9	94	Implemented Digitization/Photoprocessing in one area (4 items or 139.3 kg); main technical photography area waste was sent to storage but started-up silver recovery and started piloting digitization/photoimaging (55 items or 2134.7 kg); one area eliminated and equipment removed (3 items or 126.9 kg waste sent to storage); two areas currently shut down (14 items or 614.0 kg waste sent to storage); and final area started-up silver recovery (18 items or 1263.0 kg waste sent to storage).	SR/C/RR/NU/ C/SR/O/ST
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes (Total)		4928.5	98		

Table B-4 (continued)

Note:

[#] Three Types of Activities listed in this table are as follows:
- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes.

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:
C - Completed
kg - kilogram
M&C - Metals and Ceramics Division
NU - Neutralization
O - Ongoing
ORNL - Oak Ridge National Laboratory
RC - Reclassified as Not Being a RCRA Hazardous Waste
RCRA - Resource Conservation and Recovery Act
RR - Recycle and/or Reuse
R&D - research and development
SR - Source Reduction
ST - Storage

Table B-5

Potential Pollution Prevention or Waste Management Technique to Apply to Nonradioactive RCRA Hazardous Waste Generated in 1992 by the Metals and Ceramics Division at ORNL Categorized by Type of Activity

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes						
	Amines Curing Agent	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Ammonium Hydroxide-Based	3.7	3	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Anti-static Solution	0.2	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Barium Oxide Solution (procured as barium)	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Batteries (Lead Acid, Mercury, etc.)	5.0	4	Potential Off-Site Recovery Once Examined for Condition and Contamination of Material	RR	50%
	Blue Silicone Primer Solution	0.7	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Carbon Tetrachloride [@]	3.3	1	If Still Required to be Used in ORNL, Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Cement Paper and Solution	0.4	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Ceramic Chrome Dinnerware Gloss Glaze [@]	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)						
	Chromic Acid [@]	5.7	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Chromium-Based (Solid) [@]	2.5	4	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Coal	1.8	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Copper Mixture Contaminated Solids [@]	4.8	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Ethylene Dichloride [@]	2.5	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Glycerine Solution	0.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Hexane Solution [@]	4.5	1	Potential Contamination with Silicon Carbide Whiskers - Therefore, No Potential For Reuse Due to Health Concerns	NC/ST	0%
	Ink Solution	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Isopropanol Solution [@]	4.6	3	Potential Reuse Once Examined for Condition and Contamination of Material Applied to 2 items. The Other Item (4.0653 kg) Was Potentially Contaminated with Silicon Carbide Whiskers - Therefore, No Potential For Reuse Due to Health Concerns.	RR (2 items) NC/ST (1 item)	50% (RR) and 0% (NC/ST)

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)						
	Lead [@]	21.7	3	Potential Reuse of 2 Items and Potential Recovery of the Other Item (0.04 kg) If Quantity Justifies Recovery.	RR	50%
	Lithium-Based	1.0	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Magnifloc Polyacrylamide Solution	0.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Manganese Mixture [@]	2.5	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Mercury-Based [@]	4.5	11	Potential Off-Site Recovery of Mercury Once Examined for Condition and Contamination of Material	RR	50%
	Methyl Ethyl Ketone [@]	1.9	1	Potential Contamination with Silicon Carbide Whiskers - Therefore, No Potential For Reuse Due to Health Concerns	NC/ST	0%
	Molybdenum	0.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Nickel Mixture [@]	36.5	7	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Nitrocellulose Solution (Pyroxylin)	0.4	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)						
	Oil and Oily Solids	5.7	3	Reclassified as Not Being a RCRA Hazardous Waste. Potential Off-Site Recycle for 1 Item (0.1 kg), No Potential for 1 Item (3.3 kg), Potential Silicon Carbide Whisker Contamination, and 1 Item (2.3 kg) Oil Contaminated Solids Recycle Unlikely	RC - all items (complete) RR - 1 item NC/ST - 2 items	N/A
	Paint Solution	1.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Phosphoric Acid	3.2	1	Potential Reuse Once Examined for Condition and Contamination of Material or On-Site Neutralization	RR/NU	100% (NU)
	Potassium-Based	1.6	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Praseodymium Oxide	0.02	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Propoxylated Aliphatic Amines Solution	1.0	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Silicon-Based	10.6	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Sodium Cyanide	0.9	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Sodium Dichromate	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Continued)						
	Sodium Hydroxide	1.4	1	Potential Reuse Once Examined for Condition and Contamination of Material or On-Site Neutralization	RR/NU	100% (NU)
	Sodium Silicate	1.0	1	Substitution or Recycle Unlikely - If Properly Identified, Potential Reuse Possible Once Condition/Contamination Examined	NC/ST	0%
	Stainless Steel Powder	11.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Strontium	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Tantalum Metal	0.3	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Trichloroethane [@]	1.5	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Trichlorotrifluoroethane	25.4	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Xylene [@]	0.7	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Yttrium Oxide Mixture	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes (Total)		175.4	81			

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes						
	Acetic Acid	2.5	3	Potential Future Changes Unlikely Because Neutralized On Site	NU/C	N/A
	Acetone-Based [@]	149.4	9	Potential Solvent Substitution	SR	50%
	Acrylamide [@]	1.5	4	Already Performed Material Substitution	SR/C	N/A
	Alumina/Aluminum Oxide	113.9	2	Storage; Already Performed Material Substitution on Part of Waste Type (1 item or 6.3 kg); Remainder of Waste Type Reclassified as Not Being a RCRA Hazardous Waste	SR/C/ ST/RC	N/A
	Ammonium Hydroxide-Based	42.4	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Ammonium Persulfate	3.0	2	Allow for Smaller Quantities to be Procured through AVID	SR	50%
	Barium Oxide Solution (procured as barium)	2.9	1	Potential System Redesign or Modification	SR	50%
	Batteries (Lead Acid, Mercury, etc.)	44.4	3	Potential Off-Site Recovery Once Examined for Condition and Contamination of Material	RR	50%
	Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	1.2	2	Potential Future Changes Unlikely Because Neutralized On Site	NU/C	N/A
	Coal	0.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)						
	Chromic Acid [@]	0.3	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Chromium-Based (Solid) [@]	96.6	2	Potential Substitute Unlikely for 1 Item (96.2 kg) of Subarc Flux Powder; Potential Reuse of the Other Item (0.4 kg) Once Examined for Condition and Contamination of Material.	RR - 1 item NC/ST - 1 item	50% (RR) and 0% (NC/ST)
	Dichloromethane [@]	0.2	1	Potential Solvent Substitution	SR	10%
	Ethanol Solution [@]	0.6	1	Potential Solvent Substitution	SR	50%
	Ethylene Dichloride [@]	1.7	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Ganex V-516	0.4	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Graphite/Activated Carbon	0.6	2	Potential Off-Site Recycle (Reactivation) - If Ever Performed Again for 1 Item (0.4 kg) and Potential Reuse Once Examined for Condition and Contamination of Material for Other Item (0.2 kg)	RR	50%
	Hydrochloric Acid Solution [@]	0.1	2	Potential Future Changes Unlikely Because Neutralized On Site	NU/C	N/A

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)						
	Hydrofluoric Acid [@]	2.2	5	Potential Future Changes Unlikely for 3 Items (0.11 kg) Because Neutralized On Site; Potential Material Substitution for 1 Item (1.5 kg), and Potential Reuse of 1Item (0.3 kg) Once Examined for Condition and Contamination of Material.	NU/C - 3 items SR - 1 item RR - 1 item	N/A (NU/C), 50% (SR), and 50% (RR)
	Hydrogen Peroxide	4.3	2	Already Performed Pollution Prevention with Substitution of Material with Water-Based Ultrasonic Cleaner	SR/C	N/A
	Isopropanol Solution [@]	1.2	2	Potential Solvent Substitution	SR	50%
	Lithium-Based	8.5	9	Potential Reuse Unlikely Due to Use for Cleaning for 1 Item (0.6 kg); Potential Reuse for Remainder of Items Once Examined for Condition and Contamination of Material	NC/ST - 1 item RR - 8 items	0% (NC/ST) and 50% (RR)
	Magnesium Perchlorate	20.5	2	Potential Substitution or Process Change	SR	50%
	Mercury-Based [@]	4.8	11	When Required, Replaced with Electronic Systems; May Be Able to Recover Mercury If Quantity Justifies Recovery	SR/O/RR	N/A (SR/O) and 50% (RR)

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)						
	Methacrylic Acid	0.9	1	Allow for Smaller Quantities to be Procured through AVID	SR	50%
	Methanol Solution [@]	44.8	11	Potential Solvent Substitution	SR	50%
	Methyl Ethyl Ketone [@]	32.2	3	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Methyltrichlorosilane	15.2	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	N,N,N',N'- Tetramethylethylenediamine	0.3	1	Allow for Smaller Quantities to be Procured through AVID	SR	50%
	Nitric Acid Solution and Solids [@]	338.7	7	Potential Material Substitution or On-Site Neutralization (1 Item or 2.3 kg); Potential Future Changes Unlikely Because Neutralized On Site (2 Items or 0.3 kg Implemented and 2 Items or 327.1 kg Start Up); Potential Reuse 2 Items (9.0 kg) Once Examined.	SR/NU - 1 Item NU/C - 2 Items NU/O - 2 Items RR - 2 Items	100% (NU), N/A (NU/C and NU/O), and 50% RR
	Oil and Oily Solids	784.7	16	Reclassified as Not Being a RCRA Hazardous Waste. Potential Replacement with Oil-Free Pumps, Potential Extension of Life of Oil by Filtration, or Potential for Off-Site Recycle of Oil; Future Changes Unlikely for 4 Items (702.8 kg, PCB Contaminated).	RC/NC/ST- 4 Items RC/SR/RR - Rest of Items	N/A
	Oxalic Acid Solution	0.5	1	Already Implemented Pollution Prevention Option	SR/C	N/A

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)						
	Petroleum Ether	0.5	1	Potential Substitute Unlikely Because Used as Nonaqueous Solvent in Process	NC/ST	0%
	Phosphoric Acid	0.1	1	Potential Future Changes Unlikely Because Neutralized On Site	NU/C	N/A
	Potassium-Based	1.5	2	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Resin Solution	0.4	1	Allow for Smaller Quantities to be Procured through AVID	SR	50%
	Silicon-Based	0.4	2	Potential Substitute Unlikely; Allow for Procurement of Smaller Quantities Through AVID	SR	50%
	Soap Leak Detector Solution	0.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Sodium Hydroxide	3.1	3	Potential Material Substitution Unlikely; As a Minimum, Characterization/On-Site Neutralization/Process Drain	NU	100%
	Sodium Iodide	0.1	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Sodium Metal	3.0	3	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Stainless Steel Soldering Flux	0.2	1	If Still Required to be Used in ORNL, Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Continued)						
	Sulfuric Acid	1.5	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Tetramethyl Ammonium Hydroxide	0.2	1	Potential Substitute Unlikely Because Material Is Base Used for Titration	NC/ST	0%
	Titanium Sponge	1.3	1	Potential Reuse Once Examined for Condition and Contamination of Material	RR	50%
	Trichloroethane [@]	0.8	1	Potential Solvent Substitution	SR	50%
	Trichloroethylene Solution [@]	50.6	5	Potential Solvent Substitution	SR	50%
	Trichlorotrifluoroethane	34.3	2	Potential Solvent Substitution	SR	50%
	Trimethylolpropane Trimethacrylate	1.4	1	Not Currently Used	NC/ST	0%
	Troysol Solution	0.1	1	Potential Material Substitution Unlikely Because Material Used As Surfactant in Process	NC/ST	0%
	Zinc Bromide	3633.8	12	Being Replaced with Mineral Oil/Leaded Glass Shielding; Potential Reuse of Material Unlikely Based on Characterization	SR/O	N/A
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes (Total)		5453.9	152			

Table B-5 (continued)

Type of Activity [#]	Waste Type Generated By Each Type of Activity	Quantity of Waste Generated in 1992 (kg)	Number of Waste Items Generated in 1992 (each)	Potential Waste Management or Pollution Prevention Options	Potential Waste Management or Pollution Prevention Option Category	Percentage Chance of Success of Potential Options (%)
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes						
	Oil and Oily Solids	650.6	4	Reclassified as Not Being a RCRA Hazardous Waste. Potential Replacement with Oil-Free Pumps, Potential Extension of Life of Oil by Filtration, or Potential for Off-Site Recycle of Oil; Future Changes Unlikely for 1 Item (55.4 kg, Oily Solids).	RC/NC/ST-1 Item RC/SR/RR - Rest of Items	N/A
	Photographic Waste [@]	4277.9	94	Implement Digitization/Photoimaging in remaining M&C areas if possible; if not, implement metallic replacement for silver recovery and then remaining liquid waste can be neutralized at on-site waste water treatment facility (process drain); [two areas with operations currently shut down (14 items or 614.0 kg)].	RR/NU/SR	100%
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes (Total)		4928.5	98			

Table B-5 (continued)

Note:

[#] Three Types of Activities listed in this table are as follows:
- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes.

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:
C - Completed
kg - kilogram
M&C - Metals and Ceramics Division
N/A - not applicable because option already implemented
NU - Neutralization
O - Ongoing
ORNL - Oak Ridge National Laboratory
RC - Reclassified as Not Being a RCRA Hazardous Waste
RCRA - Resource Conservation and Recovery Act
RR - Recycle and/or Reuse
R&D - research and development
SR - Source Reduction
ST - Storage

Table B-6

Estimated Quantifiable Costs Associated with Added Requirements for Managing 3- and 4-Rated Hazardous Materials and Resulting Hazardous Waste Generated in the Metals and Ceramics Division at ORNL

(by total, general activity, and waste type)[#]

Material and Waste Grouping Category	Total R&D Direct Funding Cost ($)	Total M&C Overhead Funding Cost ($)	Total ORNL Overhead Funding Cost ($)	Total Direct EM Funding Cost ($)	Total Direct Non-ORNL Funding Cost ($)
All M&C 3- and 4-Rated Hazardous Materials and Wastes	379536.72	801657.04	216863.75	669623.42	21454.20
Proportion of M&C 3- and 4-Rated Hazardous Materials and All M&C RCRA Hazardous Wastes	329464.06	523698.93	135099.25	561617.46	15787.52
Proportion of M&C 3- and 4-Rated Hazardous Materials and M&C Nonradioactive RCRA Hazardous Wastes	312471.64	500079.01	128131.38	522093.43	14973.26
Types of Activities					
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes	143491.51	244869.59	58839.79	273532.36	6875.94
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes	92514.26	146913.23	37936.18	213250.99	4433.17
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes	76465.87	117831.38	31355.41	35588.85	3664.15
Types of Activities-Based Totals	312471.64	509614.21	128131.38	522372.20	14973.26
Waste Types					
Waste Types-Based Totals	309336.43	562297.32	129000.37	452365.64	10656.23
Acetic Acid	2762.70	3931.91	1148.41	1009.31	61.47
Acetone-Based [@]	8891.25	16737.14	3465.37	7724.77	333.41
Acrylamide [@]	3714.64	10183.96	1531.21	1279.80	230.95
Alumina/Aluminum Oxide	1913.31	2621.27	765.60	4066.92	40.98
Amines Curing Agent	920.90	1310.64	382.80	315.85	20.49
Ammonium Hydroxide-Based	3683.60	5242.54	1531.21	2875.43	81.96
Ammonium Persulfate	1841.80	2621.27	765.60	710.52	40.98
Anti-static Solution	1841.80	2621.27	765.60	622.37	40.98
Barium Oxide Solution (procured as barium)	1841.80	2621.27	765.60	704.73	40.98
Batteries (Lead Acid, Mercury, etc.)	6446.30	9174.45	2679.62	3875.96	143.44
Blue Silicone Primer Solution	920.90	1310.64	382.80	331.53	20.49
Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	1872.84	7562.69	765.60	658.54	189.97
Carbon Tetrachloride [@]	951.94	6252.05	382.80	414.07	169.48

Table B-6 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost ($)	Total M&C Overhead Funding Cost ($)	Total ORNL Overhead Funding Cost ($)	Total Direct EM Funding Cost ($)	Total Direct Non-ORNL Funding Cost ($)
Cement Paper and Solution	1841.80	2621.27	765.60	628.07	40.98
Ceramic Chrome Dinnerware Gloss Glaze [@]	951.94	6252.05	382.80	314.11	169.48
Chromic Acid [@]	1872.84	7562.69	765.60	800.73	189.97
Chromium-Based (Solid) [@]	5580.28	12805.23	2799.50	4749.92	271.93
Coal	1841.80	2621.27	765.60	684.27	40.98
Copper Mixture Contaminated Solids [@]	975.78	6252.05	382.80	447.97	169.48
Dichloromethane [@]	951.94	6252.05	402.95	315.31	169.48
Ethanol Solution [@]	1118.81	6252.05	382.80	327.59	169.48
Ethylene Dichloride [@]	1872.84	7562.69	765.60	755.37	189.97
Ganex V-516	920.90	1310.64	382.80	321.39	20.49
Glycerine Solution	920.90	1310.64	382.80	310.66	20.49
Graphite/Activated Carbon	1889.48	2621.27	765.60	633.49	40.98
Hexane Solution [@]	975.78	6252.05	382.80	479.41	169.48
Hydrochloric Acid Solution [@]	2063.54	7562.69	765.60	618.00	189.97
Hydrofluoric Acid [@]	4795.20	11494.60	1934.16	1611.22	251.44
Hydrogen Peroxide	2008.67	2621.27	765.60	755.70	40.98
Ink Solution	920.90	1310.64	382.80	313.00	20.49
Isopropanol Solution [@]	4730.89	11494.60	1914.01	1751.36	251.44
Lead [@]	2793.74	8873.33	1794.72	1552.07	210.46
Lithium-Based	10129.90	14416.99	4210.83	3767.37	225.40
Magnesium Perchlorate	1841.80	2621.27	765.60	1264.40	40.98
Magnifloc Polyacrylamide Solution	920.90	1310.64	382.80	309.36	20.49
Manganese Mixture [@]	951.94	6252.05	382.80	381.11	169.48
Mercury-Based [@]	20314.68	33775.41	8421.65	7030.90	599.79
Methacrylic Acid	920.90	1310.64	382.80	338.09	20.49
Methanol Solution [@]	10423.16	19358.41	4291.41	5019.57	374.39
Methyl Ethyl Ketone [@]	3738.48	10183.96	1571.50	2475.78	230.95
Methyltrichlorosilane	920.90	1310.64	382.80	817.01	20.49
Molybdenum	920.90	1310.64	382.80	310.76	20.49
N,N,N',N'- Tetramethylethylenediamine	944.74	1310.64	382.80	318.47	20.49

Table B-6 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost ($)	Total M&C Overhead Funding Cost ($)	Total ORNL Overhead Funding Cost ($)	Total Direct EM Funding Cost ($)	Total Direct Non-ORNL Funding Cost ($)
Nickel Mixture [@]	6525.01	14115.87	3541.37	3215.63	292.43
Nitric Acid Solution and Solids [@]	6715.72	14115.87	2760.20	13252.49	292.43
Nitrocellulose Solution (Pyroxylin)	1841.80	2621.27	765.60	627.98	40.98
Oil and Oily Solids	21228.37	30144.62	8804.45	59985.18	471.30
Oxalic Acid Solution	944.74	1310.64	382.80	323.04	20.49
Paint Solution	920.90	1310.64	382.80	421.70	20.49
Petroleum Ether	920.90	1310.64	382.80	326.15	20.49
Phosphoric Acid	1865.64	2621.27	765.60	721.06	40.98
Photographic Waste [@]	87453.80	128141.18	36003.57	178408.03	2075.15
Potassium-Based	3731.28	5242.54	1531.21	1341.36	81.96
Praseodymium Oxide	920.90	1310.64	382.80	308.00	20.49
Propoxylated Aliphatic Amines Solution	920.90	1310.64	382.80	343.40	20.49
Resin Solution	920.90	1310.64	382.80	320.29	20.49
Silicon-Based	3683.60	5242.54	1531.21	1572.76	81.96
Soap Leak Detector Solution	920.90	1310.64	382.80	310.15	20.49
Sodium Cyanide	920.90	1310.64	382.80	338.65	20.49
Sodium Dichromate	920.90	1310.64	382.80	313.37	20.49
Sodium Hydroxide	3778.95	5242.54	1531.21	1371.81	81.96
Sodium Iodide	920.90	1310.64	382.80	309.15	20.49
Sodium Metal	2786.54	3931.91	1148.41	1029.44	61.47
Sodium Silicate	944.74	1310.64	382.80	337.11	20.49
Stainless Steel Powder	944.74	1310.64	382.80	633.07	20.49
Stainless Steel Soldering Flux	920.90	1310.64	382.80	313.84	20.49
Strontium	920.90	1310.64	382.80	312.66	20.49
Sulfuric Acid	1087.77	1310.64	382.80	353.91	20.49
Tantalum Metal	920.90	1310.64	382.80	317.00	20.49
Tetramethyl Ammonium Hydroxide	968.58	1310.64	382.80	314.43	20.49
Titanium Sponge	920.90	1310.64	382.80	347.42	20.49
Trichloroethane [@]	1872.84	7562.69	765.60	692.14	189.97
Trichloroethylene Solution [@]	4635.54	11494.60	1914.01	3199.33	251.44

Table B-6 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost ($)	Total M&C Overhead Funding Cost ($)	Total ORNL Overhead Funding Cost ($)	Total Direct EM Funding Cost ($)	Total Direct Non-ORNL Funding Cost ($)
Trichlorotrifluoroethane	2762.70	3931.91	1148.41	2892.18	61.47
Trimethylolpropane Trimethacrylate	920.90	1310.64	382.80	355.12	20.49
Troysol Solution	920.90	1310.64	382.80	312.37	20.49
Xylene [@]	975.78	6252.05	382.80	334.21	169.48
Yttrium Oxide Mixture	1063.93	1310.64	382.80	313.55	20.49
Zinc Bromide	11050.80	15727.63	4593.63	112505.38	245.89
Waste Types-Based Totals	309336.43	562297.32	129000.37	452365.64	10656.23

Notes:

[#] Based on data available to be applied to the costing methodology, cost data were evaluated to one significant figure. Additional numerical digits were included in the values shown in this table, however, to support verification of calculations. When the costs were totaled in this table, the total values varied because of the level of detail available for each type of material and waste grouping: waste types, types of activities, and a proportion of M&C 3- and 4-rated hazardous materials and M&C nonradioactive RCRA hazardous wastes. This variation was attributed to the assumed basis for the 3- and 4-rated hazardous materials data used to calculate the values. The waste type-based values were estimated using the actual type and amount of material procured in 1992 that corresponded with specific waste types generated in 1992. In contrast, the procured materials data and associated costs related to the following groupings were based on multiplying the total amount of 3- and 4-rated hazardous materials procured by a ratio of hazardous waste generated in a grouping divided by all hazardous waste:

- Proportion of M&C 3- and 4-Rated Hazardous Materials and All M&C RCRA Hazardous Wastes,
- Proportion of M&C 3- and 4-Rated Hazardous Materials and M&C Nonradioactive RCRA Hazardous Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes.

This proportion-based estimation was assessed to determine if the estimated cost-based values would vary significantly.

When the proportion-based cost values (activity-based and total M&C nonradioactive RCRA hazardous waste-based) were specifically compared to the waste type-based cost values, the waste type-based cost values were:

- approximately 99 percent of the proportion-based values for the direct R&D funding category,
- approximately 110 percent of the proportion-based values for the M&C overhead funding category,
- approximately 101 percent of the proportion-based values for the ORNL overhead funding category,
- approximately 87 percent of the proportion-based values for the EM funding category, and
- approximately 71 percent of the proportion-based values for the non-ORNL funding category.

Table B-6 (continued)

Prior to rounding to one significant figure, the nonradioactive RCRA hazardous waste and general activities proportion-based totals were observed to vary slightly for the M&C overhead funding and EM funding categories, within 2 percent and 1 percent, respectively. The calculation method was examined and the following reasons were identified:

- Because the time required to maintain the basic Carcinogen Control Program does not vary based on the number of items or mass of the carcinogenic materials covered by the program, the required 40 hours were assigned to the total nonradioactive RCRA hazardous waste category as well as each general type of activity for each calculation. Therefore, the total values in this table for the M&C overhead funding costs varied slightly.
- The waste residue disposal value for support activities was based on a density of water (1,000 kilogram/cubic meter) because the majority of the treatment residue within this general activity category was expected to be from wastewater treatment. However, when the waste residue disposal values for the total nonradioactive RCRA hazardous waste, the R&D-oriented waste, and the legacy or laboratory cleanout-oriented waste were calculated, the density of ash (2,200 kilograms/cubic meter) was used. This density value variation resulted in the slight difference in the total EM funding cost values in this table.

Because the cost data were rounded to one significant digit, these minor variations did not significantly impact the results of this study.

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
M&C - Metals and Ceramics Division
Non-ORNL - Other Organizations That Are Not Part of ORNL That Incur Costs Associated with These Materials and Wastes
ORNL - Oak Ridge National Laboratory
RCRA - Resource Conservation and Recovery Act
R&D - research and development

Table B-7

Estimated Reduction in Added Requirements and Quantifiable Costs Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities

Applied to ORNL Nonradioactive RCRA Hazardous Wastes in the Metals and Ceramics Division [#]

Material and Waste Grouping Category	Total R&D Direct Funding Cost Avoided ($)	Total M&C Overhead Funding Cost Avoided ($)	Total ORNL Overhead Funding Cost Avoided ($)	Total Direct EM Funding Cost Avoided ($)	Total Direct Non-ORNL Funding Cost Avoided ($)
Proportion of M&C 3- and 4-Rated Hazardous Materials and M&C Nonradioactive RCRA Hazardous Wastes	252886.46	286084.37	71245.40	426953.76	10512.16
Types of Activities					
M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes	120493.31	165502.91	38191.01	239284.01	5218.78
M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes	82609.09	106531.16	27464.09	184862.91	3641.32
M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes	49784.06	17873.44	5590.30	31080.74	1652.05
Types of Activities-Based Totals	252886.46	289907.51	71245.40	455227.66	10512.16
Waste Types					
Acetic Acid	1903.46	378.64	179.55	1009.05	61.47
Acetone-Based [@]	8891.25	16737.14	3465.37	7724.77	333.41
Acrylamide [@]	3714.64	10183.96	1531.21	1279.80	230.95
Alumina/Aluminum Oxide	1913.31	2621.27	765.60	4066.92	40.98
Amines Curing Agent	634.49	126.21	59.85	311.61	20.49
Ammonium Hydroxide-Based	2537.95	504.86	239.40	2061.63	81.96
Ammonium Persulfate	1841.80	2621.27	765.60	710.52	40.98
Anti-static Solution	1268.97	252.43	119.70	618.61	40.98
Barium Oxide Solution (procured as barium)	1555.39	1436.85	442.65	677.92	40.98
Batteries (Lead Acid, Mercury, etc.)	4441.40	883.50	418.96	3004.53	143.44
Blue Silicone Primer Solution	634.49	126.21	59.85	319.36	20.49
Butylcellusolve Solution (Ethylene glycol monobutyl ether) [@]	1268.97	252.43	119.70	658.48	40.98
Carbon Tetrachloride [@]	634.49	126.21	59.85	356.21	20.49
Cement Paper and Solution	1268.97	252.43	119.70	621.42	40.98

Table B-7 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost Avoided ($)	Total M&C Overhead Funding Cost Avoided ($)	Total ORNL Overhead Funding Cost Avoided ($)	Total Direct EM Funding Cost Avoided ($)	Total Direct Non-ORNL Funding Cost Avoided ($)
Ceramic Chrome Dinnerware Gloss Glaze [@]	634.49	126.21	59.85	310.75	20.49
Chromic Acid [@]	1268.97	252.43	119.70	694.44	40.98
Chromium-Based (Solid) [@]	3172.43	631.07	299.26	2501.81	102.46
Coal	1268.97	252.43	119.70	649.21	40.98
Copper Mixture Contaminated Solids [@]	634.49	126.21	59.85	362.89	20.49
Dichloromethane [@]	951.94	6252.05	402.95	315.31	169.48
Ethanol Solution [@]	1118.81	6252.05	382.80	327.59	169.48
Ethylene Dichloride [@]	1268.97	252.43	119.70	681.58	40.98
Ganex V-516	634.49	126.21	59.85	314.35	20.49
Glycerine Solution	634.49	126.21	59.85	308.98	20.49
Graphite/Activated Carbon	1268.97	252.43	119.70	623.49	40.98
Hexane Solution [@]	0.00	0.00	0.00	0.00	0.00
Hydrochloric Acid Solution [@]	1268.97	252.43	119.70	617.99	40.98
Hydrofluoric Acid [@]	3503.19	2803.78	626.24	1603.42	132.25
Hydrogen Peroxide	2008.67	2621.27	765.60	755.70	40.98
Ink Solution	634.49	126.21	59.85	310.20	20.49
Isopropanol Solution [@]	3161.33	4850.27	885.31	1359.88	141.56
Lead [@]	1903.46	378.64	179.55	1168.78	61.47
Lithium-Based	6344.86	1262.14	598.51	3272.52	204.91
Magnesium Perchlorate	1841.80	2621.27	765.60	1264.40	40.98
Magnifloc Polyacrylamide Solution	634.49	126.21	59.85	308.40	20.49
Manganese Mixture [@]	634.49	126.21	59.85	336.74	20.49
Mercury-Based [@]	16847.78	16867.03	4546.24	6942.06	518.53
Methacrylic Acid	920.90	1310.64	382.80	338.09	20.49
Methanol Solution [@]	10423.16	19358.41	4291.41	5019.57	374.39
Methyl Ethyl Ketone [@]	1903.46	378.64	179.55	1405.43	61.47
Methyltrichlorosilane	634.49	126.21	59.85	548.81	20.49
Molybdenum	634.49	126.21	59.85	308.76	20.49
N,N,N',N'- Tetramethylethylenediamine	944.74	1310.64	382.80	318.47	20.49
Nickel Mixture [@]	4441.40	883.50	418.96	2571.82	143.44
Nitric Acid Solution and Solids [@]	4441.40	883.50	418.96	11520.51	143.44

Table B-7 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost Avoided ($)	Total M&C Overhead Funding Cost Avoided ($)	Total ORNL Overhead Funding Cost Avoided ($)	Total Direct EM Funding Cost Avoided ($)	Total Direct Non-ORNL Funding Cost Avoided ($)
Nitrocellulose Solution (Pyroxylin)	1268.97	252.43	119.70	620.85	40.98
Oil and Oily Solids	21228.37	30144.62	8804.45	59985.18	471.30
Oxalic Acid Solution	944.74	1310.64	382.80	323.04	20.49
Paint Solution	634.49	126.21	59.85	400.09	20.49
Petroleum Ether	0.00	0.00	0.00	0.00	0.00
Phosphoric Acid	1268.97	252.43	119.70	720.72	40.98
Photographic Waste [@]	77985.86	88557.51	25662.27	152719.08	2024.43
Potassium-Based	2537.95	504.86	239.40	1286.62	81.96
Praseodymium Oxide	634.49	126.21	59.85	307.68	20.49
Propoxylated Aliphatic Amines Solution	634.49	126.21	59.85	325.23	20.49
Resin Solution	920.90	1310.64	382.80	320.29	20.49
Silicon-Based	3110.77	2873.70	885.31	1475.79	81.96
Soap Leak Detector Solution	634.49	126.21	59.85	308.79	20.49
Sodium Cyanide	634.49	126.21	59.85	322.88	20.49
Sodium Dichromate	634.49	126.21	59.85	310.01	20.49
Sodium Hydroxide	2537.95	504.86	239.40	1371.35	81.96
Sodium Iodide	634.49	126.21	59.85	308.19	20.49
Sodium Metal	1903.46	378.64	179.55	975.66	61.47
Sodium Silicate	0.00	0.00	0.00	0.00	0.00
Stainless Steel Powder	634.49	126.21	59.85	436.59	20.49
Stainless Steel Soldering Flux	634.49	126.21	59.85	310.00	20.49
Strontium	634.49	126.21	59.85	309.70	20.49
Sulfuric Acid	634.49	126.21	59.85	328.30	20.49
Tantalum Metal	634.49	126.21	59.85	311.16	20.49
Tetramethyl Ammonium Hydroxide	0.00	0.00	0.00	0.00	0.00
Titanium Sponge	634.49	126.21	59.85	323.80	20.49
Trichloroethane [@]	1570.91	3907.56	442.65	671.69	115.48
Trichloroethylene Solution [@]	4635.54	11494.60	1914.01	3199.33	251.44
Trichlorotrifluoroethane	2476.29	2747.49	825.46	2540.93	61.47
Trimethylolpropane Trimethacrylate	0.00	0.00	0.00	0.00	0.00
Troysol Solution	0.00	0.00	0.00	0.00	0.00

Table B-7 (continued)

Material and Waste Grouping Category	Total R&D Direct Funding Cost Avoided ($)	Total M&C Overhead Funding Cost Avoided ($)	Total ORNL Overhead Funding Cost Avoided ($)	Total Direct EM Funding Cost Avoided ($)	Total Direct Non-ORNL Funding Cost Avoided ($)
Xylene [@]	634.49	126.21	59.85	321.09	20.49
Yttrium Oxide Mixture	634.49	126.21	59.85	309.94	20.49
Zinc Bromide	11050.80	15727.63	4593.63	112505.38	245.89

Notes:

[#] Potential options were assumed to be completely successful.

Based on data available to be applied to the costing methodology, cost avoidance data were evaluated to one significant figure. Additional numerical digits were included in the values shown in this table, however, to support verification of calculations. When the costs were totaled in this table, the total values varied because of the level of detail available for each type of material and waste grouping: waste types, types of activities, and a proportion of M&C 3- and 4-rated hazardous materials and M&C nonradioactive RCRA hazardous wastes. This variation was attributed to the assumed basis for the 3- and 4-rated hazardous materials data used to calculate the values. The waste type-based values were estimated using the actual type and amount of material procured in 1992 that corresponded with specific waste types generated in 1992. In contrast, the procured materials data and associated costs and cost avoidance values related to the following groupings were based on multiplying the total amount of 3- and 4-rated hazardous materials procured by a ratio of hazardous waste generated in a grouping divided by all hazardous waste:

- Proportion of M&C 3- and 4-Rated Hazardous Materials and All M&C RCRA Hazardous Wastes,
- Proportion of M&C 3- and 4-Rated Hazardous Materials and M&C Nonradioactive RCRA Hazardous Wastes,
- M&C Nonradioactive RCRA Hazardous R&D-Oriented Wastes,
- M&C Nonradioactive RCRA Hazardous Support Activities-Oriented Wastes, and
- M&C Nonradioactive RCRA Hazardous Legacy or Cleanout-Oriented Wastes.

This proportion-based estimation was assessed to determine if the estimated cost avoidance values would vary significantly.

When the proportion-based cost avoidance values (activity-based and total M&C nonradioactive RCRA hazardous waste-based) were specifically compared to the waste type-based values, the waste type-based values were:

- approximately 99 percent of the proportion-based values for the direct R&D funding category,
- approximately 93 percent of the proportion-based values for the M&C overhead funding category,
- approximately 99 percent of the proportion-based values for the ORNL overhead funding category,
- approximately 97 percent of the proportion-based values for the EM funding category, and
- approximately 74 percent of the proportion-based values for the non-ORNL funding category.

Table B-7 (continued)

Prior to rounding to one significant figure, proportion-based total improved productivity values for the nonradioactive RCRA hazardous waste and general activities were observed to vary slightly for the M&C overhead funding and EM funding categories, within 1 percent and 6 percent, respectively. In addition to the variations in the costing calculation method, the improved productivity calculation was examined, and the following reasons were identified:

- In addition to the variation listed related to the cost of maintaining the basis Carcinogen Control Program, an item-based percentage was applied to the cost avoidance calculation, but this program does not vary based on the number of items or mass of the carcinogenic materials covered by the program. Therefore, the total values in this table for the M&C overhead funding cost avoidance varied slightly.
- For the total nonradioactive RCRA hazardous waste, the cost avoidance calculation related to the cost of sampling and analyzing wastes used an item-based percentage reduction based on gathered waste reduction values. For each type of general activity, the total number of samples were determined from the sum of the estimated number of samples per specific types of generated wastes. Therefore, when the item-based percentages calculated for each general type of activity were applied to this calculation, the values varied slightly for the cost avoided within M&C overhead funding as reflected in this table.
- Item-based percentages were used to calculate cost avoidance associated with current and future storage values and with future transportation, treatment, and disposal values. These values, however, were calculated on cost values that were available based on mass units or volume units, not on items. Therefore, the total values in this table for the EM funding improved productivity expressed as cost avoidance varied slightly.

Because the improved productivity data that were expressed as cost avoidance were rounded to one significant digit, these minor variations did not significantly impact the results of this stud

[@] Waste type contains at least one material deemed a carcinogen or reproductive hazard per ORNL Procedure IHP-13 (ORNL Carcinogen Control Program).

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
M&C - Metals and Ceramics Division
Non-ORNL - Other Organizations That Are Not Part of ORNL That Incur Costs Associated with These Materials and Wastes
ORNL - Oak Ridge National Laboratory
RCRA - Resource Conservation and Recovery Act
R&D - research and development

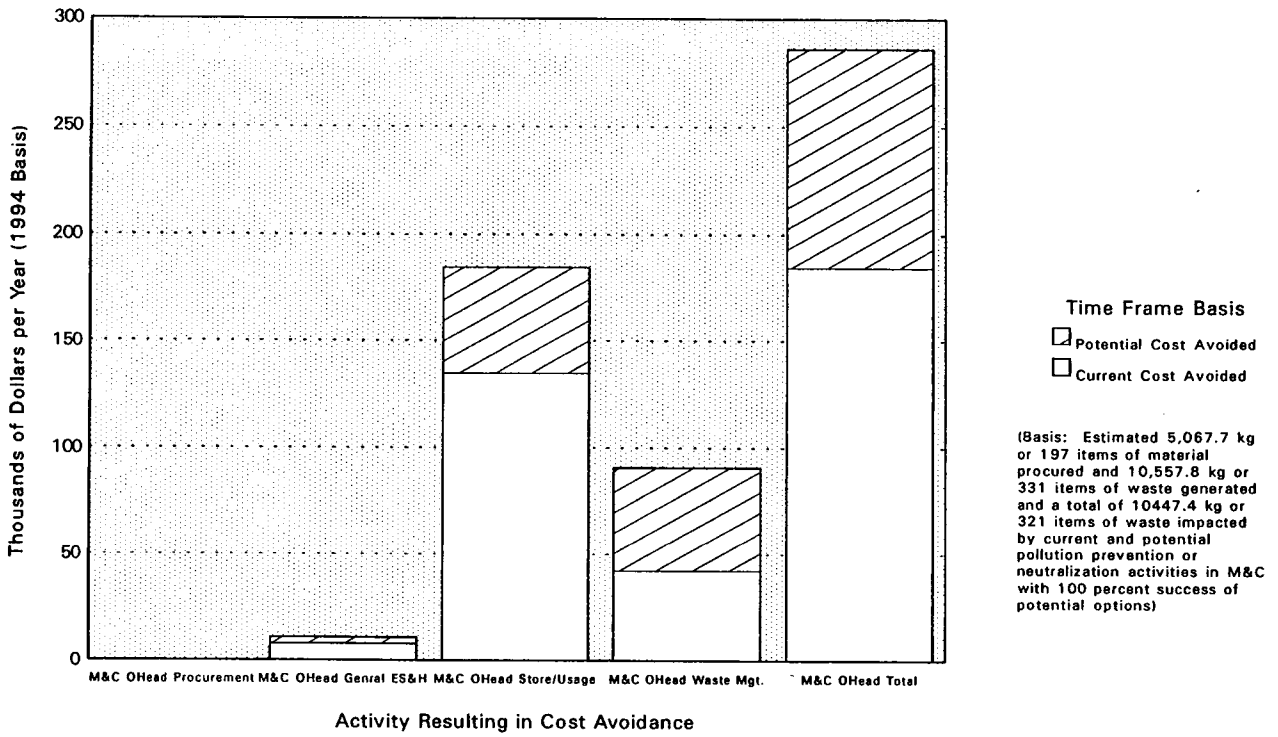


Figure B-1. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options; M&C Overhead Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
OHead - Overhead
Store/Usage - Storage/Usage

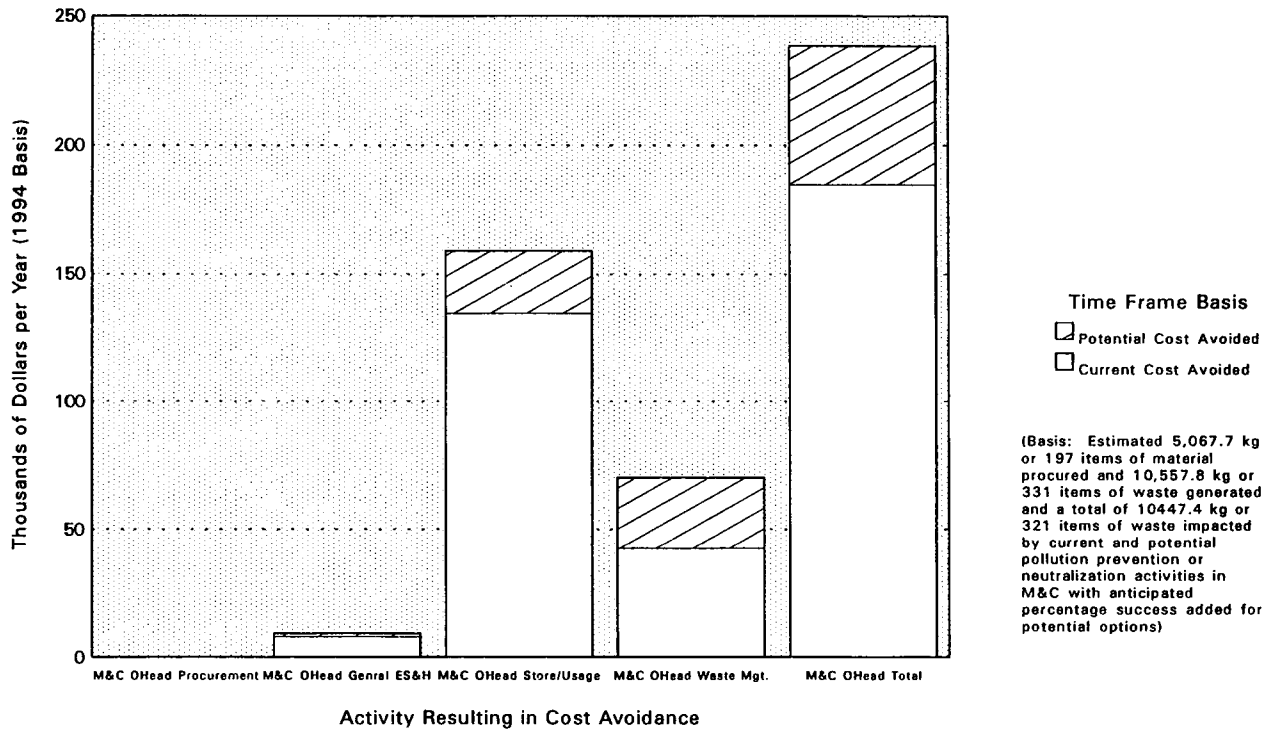


Figure B-2. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options; M&C Overhead Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
OHead - Overhead
Store/Usage - Storage/Usage

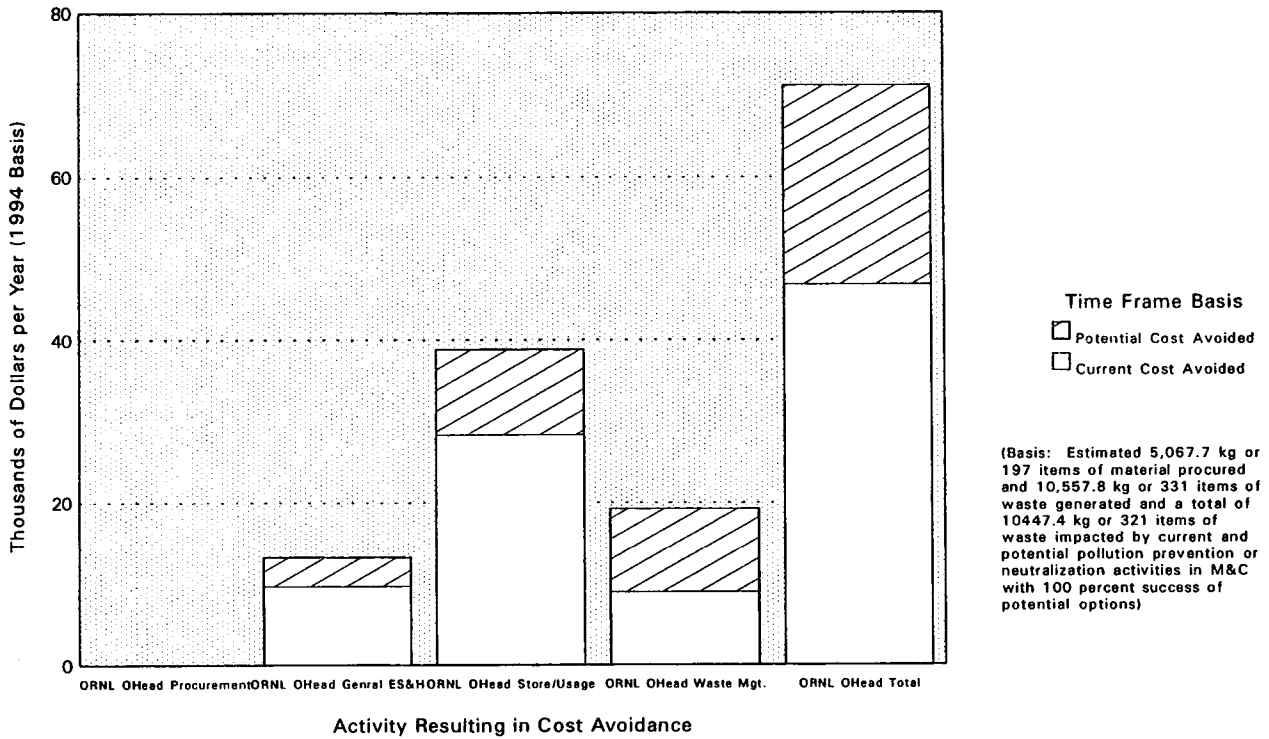


Figure B-3. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options; ORNL Overhead Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
OHead - Overhead
Store/Usage - Storage/Usage

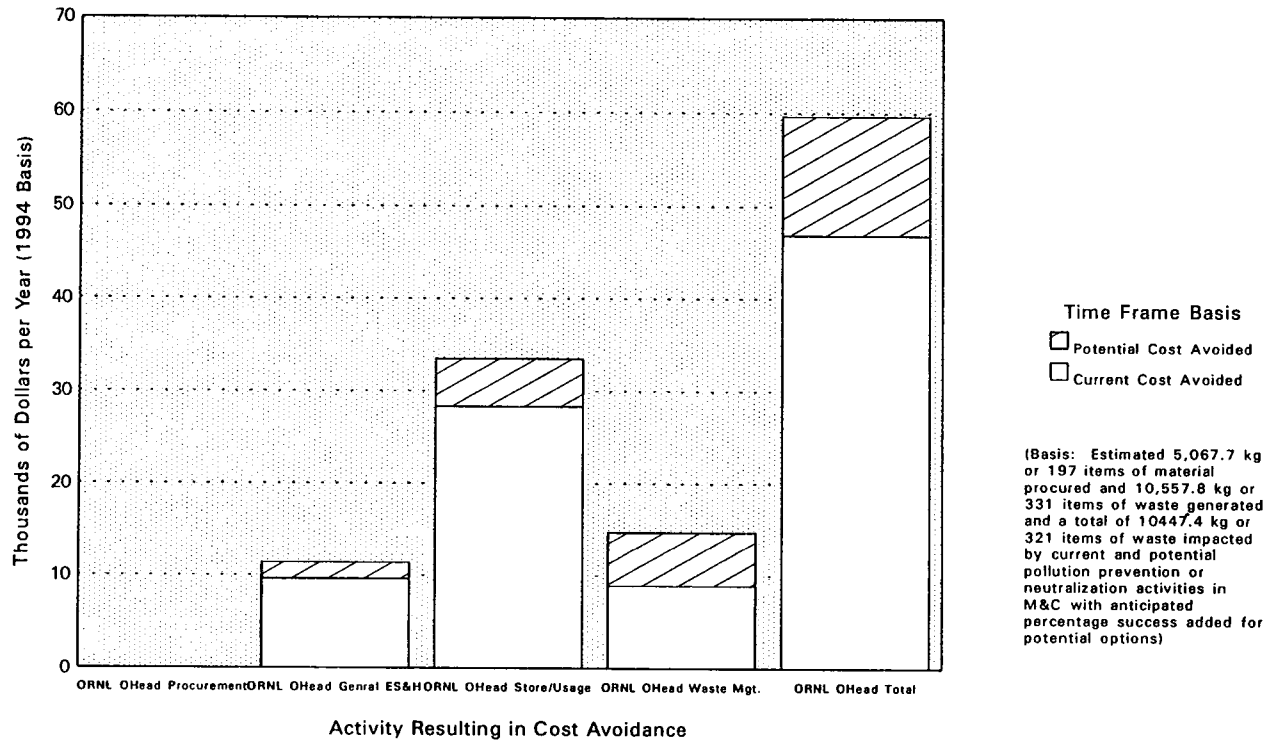


Figure B-4. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options; ORNL Overhead Funding

Abbreviations:
ES&H - environmental, safety, and health
Genral - General
kg - kilogram
Mgt. - Management
OHead - Overhead
Store/Usage - Storage/Usage

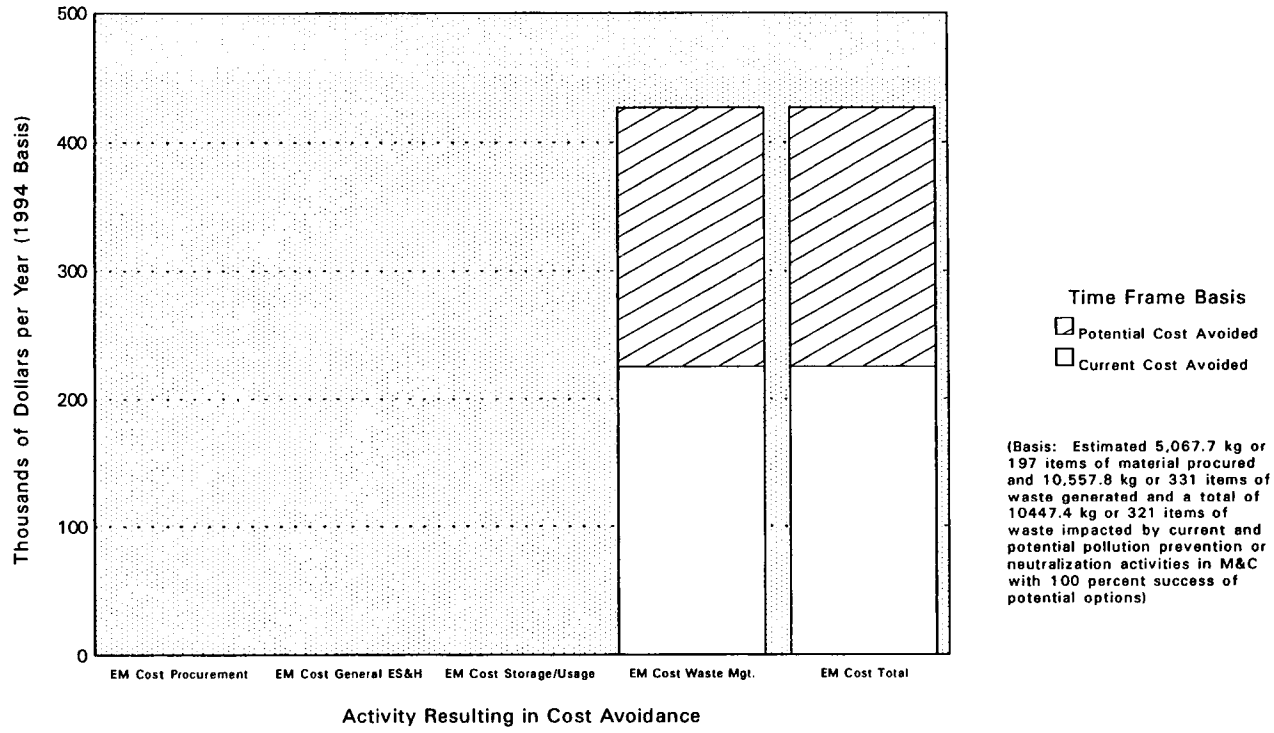


Figure B-5. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options; EM Funding

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
Mgt. - Management

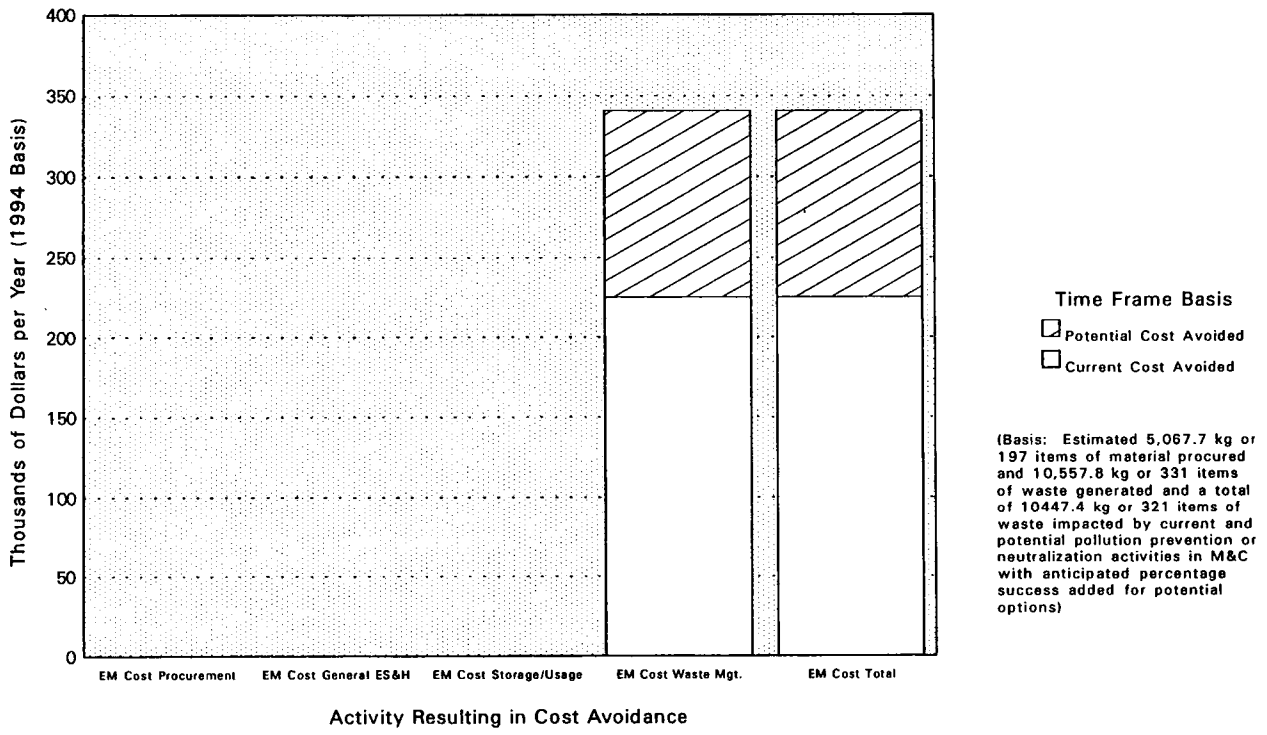


Figure B-6. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options; EM Funding

Abbreviations:
EM - U.S. Department of Energy-Headquarters Assistant Secretary for Environmental Management
ES&H - environmental, safety, and health
kg - kilogram
Mgt. - Management

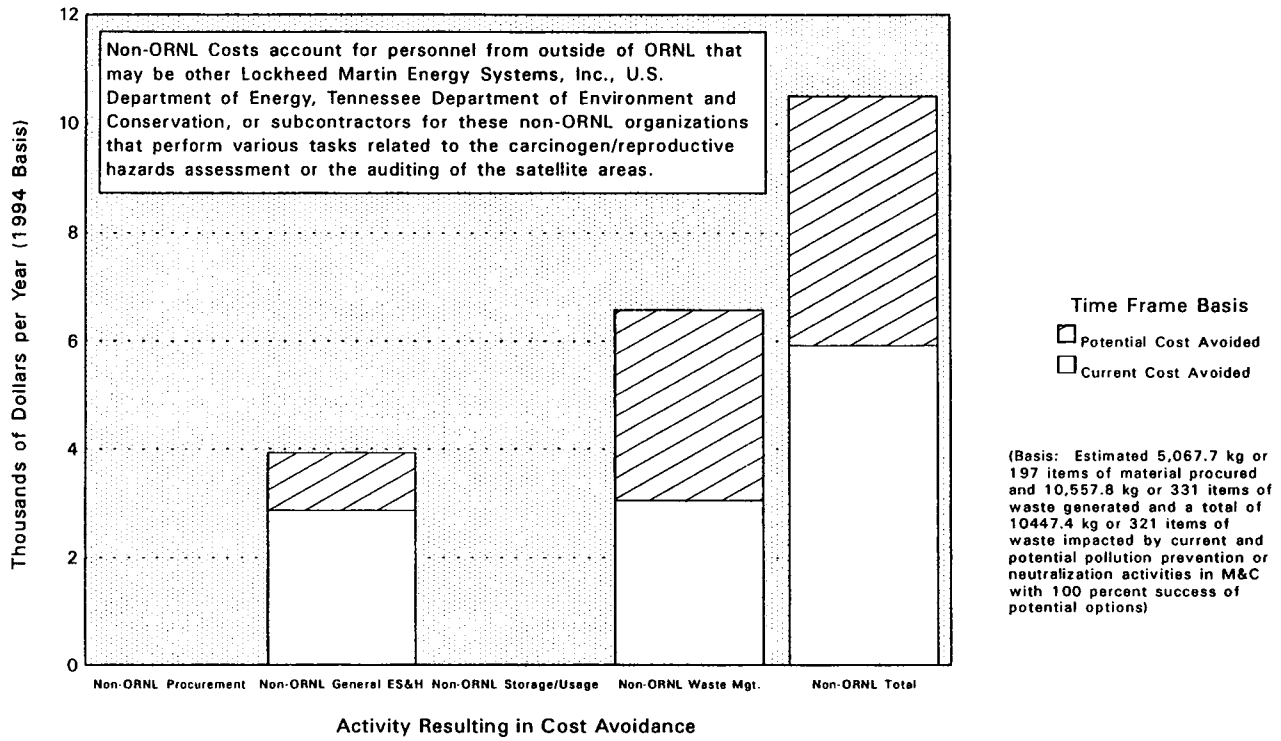


Figure B-7. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Complete Success of Potential Options; Non-ORNL Funding

Abbreviations:
ES&H - environmental, safety, and health
kg - kilogram
Mgt. - Management

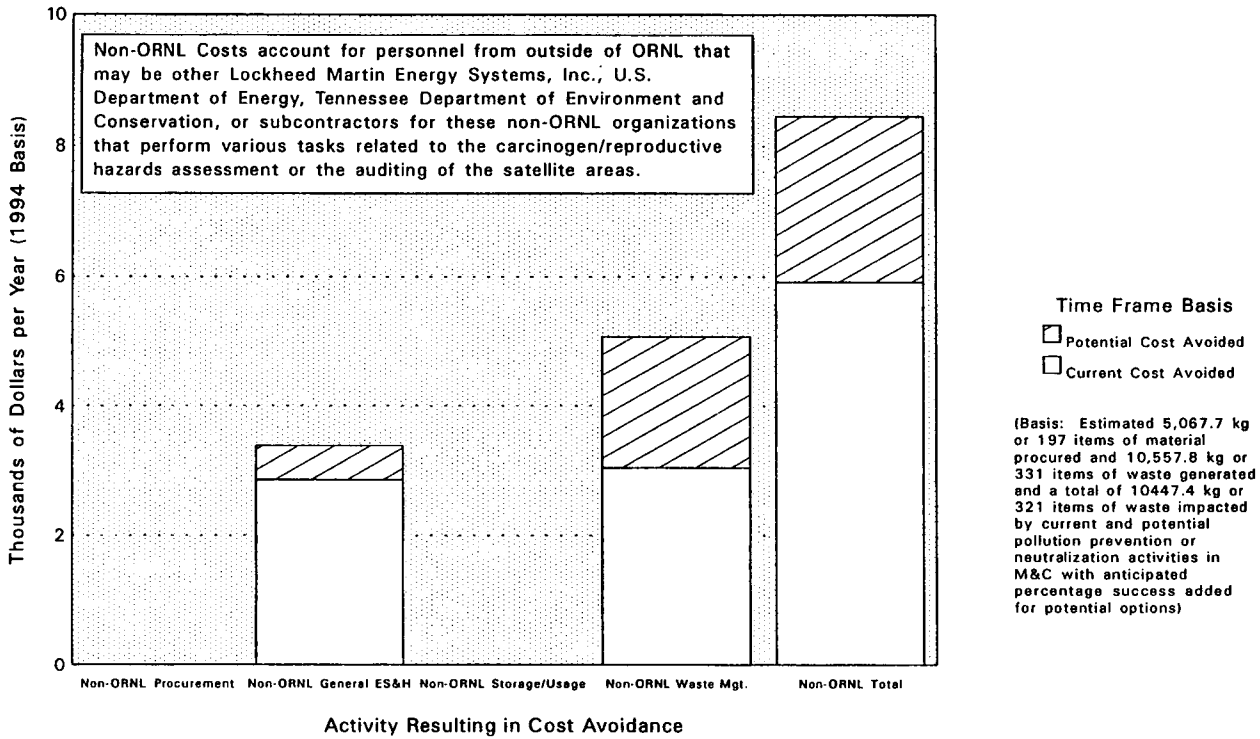


Figure B-8. Estimated Reduction in Added Requirements and Quantifiable Costs Related to 3- and 4-Rated Hazardous Materials and Resulting Nonradioactive Resource Conservation and Recovery Act (RCRA) Hazardous Wastes Generated in 1992 in the Metals and Ceramics (M&C) Division at the Oak Ridge National Laboratory (ORNL): Resulting from Current and Potential Pollution Prevention and Elementary Neutralization Activities Assuming Partial Success of Potential Options; Non-ORNL Funding

Abbreviations:
ES&H - environmental, safety, and health
kg - kilogram
Mgt. - Management

Summaries of Implemented or Potential Pollution Prevention and Elementary Neutralization Options Included in Study

The identified implemented and potential pollution prevention options and the associated Metals and Ceramics (M&C) Division processes and activities that generated nonradioactive Resource Conservation and Recovery Act (RCRA) hazardous wastes were summarized in this appendix. This summary was organized based on the type of nonradioactive RCRA hazardous waste generated in the M&C Division at the Oak Ridge National Laboratory (ORNL) in 1992. The cost values listed in this text were based on the current 1994 scenario. General options, such as those listed in Appendix A and including the use of pollution prevention-based new work reviews and the implementation of pollution prevention awareness training for M&C guest researchers, were not included in this appendix because these types of options could not be directly designated to a specific waste-generating activity.

Acetic Acid Waste

A waste mixture of 75 percent acetic acid and 25 percent perchloric was generated from one M&C area. This waste, consisting of 3 items totaling 2.5 kilograms (kg), was from the first sample preparation step, electropolishing, required for viewing a sample under an atom probe. This waste was being neutralized in the laboratory area, and the neutralized waste was then going down the process drain, which is connected to an ORNL wastewater treatment facility. This implementation had not been

documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Potential future changes were considered unlikely because the waste was being neutralized on site in the laboratory area.

Acetone-Based Waste

Acetone was used in six M&C areas as a solvent in a variety of cleaning applications including the following:

- general degreasing of test coupons, tubing, and other materials in corrosion research,
- washing silicon carbide cloth to dissolve binder in ceramic composite manufacturing,
- cleaning equipment, glassware, and ceramic specimens including specimen preparation, and
- cleaning silicon wafers for thin-film deposition.

In 1992, nine items totaling 149.4 kg of acetone waste was generated. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, binder and glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of acetone was approximately $61.44/16 liters (L) ($3.84/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately

$62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the acetone.

Acrylamide Waste

The four items totaling 1.5 kg of acrylamide-based waste were generated from gel casting used in the production of ceramic shapes. The acrylamide-based waste was eliminated through substitution with methacrylamide (MAM), n'n'-methylene bis acrylamide (MBAM), methoxy poly(ethylene glycol) methacrylamide (MPEG), and poly(ethylene glycol) 1000 dimethacrylate (PEGMA), which do not generate RCRA hazardous wastes. The cost of acrylamide was approximately $27.22/150 gram (gm) ($181.47/kg). The cost of MAM, MBAM, MPEG and PEGMA ranged from approximately $17.10/500 gm ($34.20/kg for MAM) to $43.90/100 gm ($439/kg for MPEG). Therefore, the cost values for acrylamide and MAM were comparable, with the remaining materials being more expensive, assuming approximately equal amounts of each type of material would be needed to meet the described uses. Because this substitution had already been completed, no additional pollution prevention activities would be needed for this waste stream at this time.

Alumina/Aluminum Oxide Waste

An alumina mixture, 6.3 kg or 1 item, and an aluminum oxide mixture, 107.5 kg or 1 item, were generated in two M&C areas. The alumina mixture had been contaminated with acrylamide from gel casting used in the production of ceramic shapes. This contamination made this alumina a RCRA hazardous waste. Material substitution had been implemented for the acrylamide, and this alumina mixture was no longer a RCRA hazardous waste. No additional pollution prevention activities would be needed for this waste stream at this time.

The aluminum oxide mixture were residues from the catch basin of a sink in the gel casting area. This material was tested to verify that it was not a RCRA hazardous waste and has been reclassified. Consequently, no additional pollution prevention activities would be needed for this waste stream at this time.

Amines Curing Agent Waste

One item totaling 0.2 kg of amines curing agent was generated as legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Ammonium Hydroxide Waste

In the M&C Division, ammonium hydroxide waste was generated from the gel casting process in which it was used as a titrant to increase the pH. One item of 42.4 kg was generated from a cleanup of this area. The remaining three items totaling 3.7

kg were generated from laboratory cleanout activities or as legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Ammonium Persulfate Waste

Two items totaling 3.0 kg were generated from the gel casting process. This material was used as a free radical indicator and has an unpublished shelf life. If the material performed poorly, the remainder would be sent for disposal. One potential option would be to allow smaller amounts to be procured through the Accelerated Vendor Inventory Delivery (AVID) system used by ORNL. This option would minimize the amount of material in storage in the laboratory area that would subsequently exceed its shelf life.

Anti-Static Solution Waste

Two items totaling 0.2 kg of anti-static solution was generated as legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Barium Oxide Solution Waste

Two items of barium oxide solution waste was generated by the M&C Division. One item totaling 0.2 kg was deemed a legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination. The

other item totaling 2.9 kg was generated from cleaning a system used to deposit barium and barium oxide onto silicon wafers. This waste potentially could be reduced through a procedural system design or modification to minimize waste from cleaning the system.

Waste Batteries

Seven waste items totaling 49.4 kg of waste batteries were generated by M&C areas. These waste batteries included a variety of types of batteries including lead acid batteries, mercury batteries, and nickel cadmium batteries.

One item totaling 0.6 kg of nickel cadmium batteries was eliminated by completing the related research and development (R&D) activity and subsequently eliminating the need for the various support equipment that used batteries. These batteries could potentially be sent off site for recovery once they were examined for their condition and potential contamination.

One item totaling 43.6 kg contained lead acid batteries that were used for flashlights. These batteries could potentially be sent off site for recovery once they were examined for their condition and potential contamination.

Another item totaling 0.2 kg of nickel cadmium batteries was generated from calculators. These batteries could potentially be sent off site for recovery once they were examined for their condition and potential contamination.

The four remaining items were deemed legacy waste or abandoned wastes managed by M&C. These batteries could potentially be sent off site for recovery once they were examined for their condition and potential contamination.

Blue Silicone Primer Solution

One item of blue silicone primer solution waste totaling 0.7 kg was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Butylcellusolve Solution Waste

Two items totaling 1.2 kg of butylcellusolve solution waste, also known as butoxyethanol solution waste, were generated from an electropolishing solution used during the second electropolishing step in preparing a sample for viewing under the atom probe. This solution was 98 percent butylcellusolve and 2 percent perchloric. This waste flowed through the laboratory's neutralization system into the process drain, which was connected to an ORNL wastewater treatment facility. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Potential future changes were considered unlikely because the waste was being neutralized on site in the laboratory area.

Carbon Tetrachloride Waste

One item totaling 3.3 kg of carbon tetrachloride waste was deemed excess legacy waste because this material had not been used in M&C areas since 1987. If carbon tetrachloride use would ever be required by ORNL, this material could potentially be reused once it was examined for its condition and potential contamination.

Cement Paper and Solution Waste

One item totaling 0.1 kg of cement paper waste and one item totaling 0.2 kg of cement solution waste were generated. The cement paper was deemed legacy waste, and the cement solution was from a laboratory cleanout. These materials could potentially be reused once they were examined for their condition and potential contamination.

Ceramic Chrome Dinnerware Gloss Glaze Waste

One item totaling 0.2 kg of ceramic chrome dinnerware gloss glaze waste was generated from a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Chromic Acid Waste

Two items totaling 6.0 kg of chromic acid waste were generated. One 5.7-kg item was generated from a laboratory cleanout. The other 0.3-kg item was used for etching and had been excess material. This material could potentially be reused once it was examined for its condition and potential contamination.

Solid Chromium-Based Waste

Six items totaling 99.0 kg of solid chromium-based waste were generated. One 96.2-kg item was subarc flux powder used in welding during which it covered the arc so that the weld material would not oxidize. Based on the requirements for this

welding, potential substitutes or changes in this process were not considered. Another 0.4-kg item of hexacarbonyl chromium had been used in chromium coating, but this R&D activity was no longer being performed. The remaining four items were deemed legacy or abandoned wastes. These last 5 items of chromium-based material could potentially be reused once they were examined for their condition and potential contamination.

Coal Waste

Two items of coal waste totaling 2.0 kg were generated, one item from a laboratory cleanout (1.8 kg) and the other item from a completed project (0.2 kg). This material could potentially be reused once it was examined for its condition and potential contamination.

Copper Mixture Contaminated Solids Waste

One 4.8-kg item of a copper-based mixture of contaminated solid waste was deemed a legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Dichloromethane Waste

One 0.2-kg item of dichloromethane waste was generated from dissolving epoxy. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. The potential success of a

material, such as Anisole, would depend on the material to be removed, epoxy. The cost of dichloromethane was approximately $7.06/quart ($7.46/L). The cost of Anisole was approximately $45.00/kg ($45.00/L for Anisole). The Anisole was approximately six times more expensive then the dichloromethane. However, the cost values for the solvents were within an order of magnitude of each other and were considered comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described use of the dichloromethane.

Ethanol Solution Waste

One 0.6-kg item of ethanol solution waste was generated from preparing samples for atomic and molecular research. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of ethanol was approximately $113.25/5-gallon can ($5.98/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the ethanol.

Ethylene Dichloride Waste

Two items totaling 4.2 kg of ethylene dichloride waste were generated. One 1.7-kg item was used in an area for analytical work that was no longer being performed. The other 2.5-kg item was from a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Ganex V-516 Waste

One 0.4-kg item of Ganex V-516 waste was generated from an area where it had been tested as a dispersant. This material could potentially be reused once it was examined for its condition and potential contamination.

Glycerine Solution Waste

One 0.1-kg item of glycerine solution waste was deemed abandoned waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Graphite/Activated Carbon Waste

Two items totaling 0.6 kg of graphite or activated carbon waste were generated. One 0.2-kg item of graphite was residue from a specimen holder. The other 0.4-kg item was activated carbon used to purify gases used in a completed experiment. The

graphite from the holder could potentially be reused once it was examined for its condition and potential contamination. If ever required again, the activated carbon could potentially be sent off site for reactivation and recycle.

Hexane Solution Waste

One 4.5-kg item of hexane solution waste was generated from a laboratory cleanout from the silicon carbide whisker fabrication close down. This material could potential be contaminated with silicon carbide whiskers. Therefore, no potential reuse was considered due to health concerns.

Hydrochloric Acid Solution Waste

Two items totaling 0.1 kg of hydrochloric acid solution waste were generated from electrolyte solutions and etching activities. This waste was being neutralized in the laboratory area and the neutralized waste was then going down the process drain, which is connected to an ORNL wastewater treatment facility. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Potential future changes were considered unlikely because the waste was being neutralized on site in the laboratory area.

Hydrofluoric Acid Solution Waste

Five items totaling 2.2 kg of hydrofluoric acid were generated. One 0.3-kg item was used in solution with nitric and sulfuric acids to cleanout crucibles used in an R&D

activity, which had since been completed. Another 1.5-kg item was generated from a glass etching demonstration at Family Day. Potential material substitution would be considered if demonstration was ever required again. The remaining three items were used in electrolyte solutions. This waste was being neutralized in the laboratory area and the neutralized waste was then going down the process drain, which was connected to an ORNL wastewater treatment facility. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Potential future changes were considered unlikely because the waste was being neutralized on site in the laboratory area.

Hydrogen Peroxide Waste

Two items totaling 4.3 kg of hydrogen peroxide waste were generated from electropolishing steel. The cost of this hydrogen peroxide was approximately $10.51/L. This process had been replaced with an ultrasonic water-based system, which eliminated this waste. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division.

Ink Solution Waste

One 0.2-kg item of ink solution was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Isopropanol Solution Waste

Five items totaling 5.8 kg of isopropanol solution waste were generated from laboratory cleanouts, as legacy waste, and from cleaning activities. Three items were generated from laboratory cleanouts or as legacy wastes. One 4.1-kg item was generated during a laboratory cleanout from the silicon carbide whisker fabrication close down. This material could potential be contaminated with silicon carbide whiskers. Therefore, no potential reuse was considered due to health concerns. The two other legacy or abandoned items totaling 0.5 kg could potentially be reused once they were examined for their condition and potential contamination.

The two remaining items were generated from general degreasing activities and from rinsing parts for installation into a mass spectrometry unit. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, binder and glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of isopropanol was approximately $36.25/4 L ($9.06/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the isopropanol.

Lead Waste

Three items totaling 21.7 kg of lead-based waste were generated from laboratory cleanout or deemed excess material. The lead material was being stored on site for potential reuse, and the lead contaminated solids could be examined to determine if the quantity of recoverable lead would justify recovering this material.

Lithium-Based Waste

Eleven items totaling 9.5 kg of lithium-based waste were generated. One 0.6-kg item was generated from cleaning lithium specimens with anhydrous ammonia, which produced lithium hydride. The R&D activity requiring this cleaning activity was no longer performed. No potential options were identified for this material since the R&D activity had been completed and the waste was generated from cleaning activities.

Two items totaling 1.0 kg were deemed legacy waste. The remaining eight items totaling 7.9 kg were used in completed space program R&D activities in mass transport loops. These 10 items of lithium-based material could potentially be reused once they were examined for their condition and potential contamination.

Magnesium Perchlorate Waste

Two items totaling 20.5 kg of magnesium perchlorate waste were generated after being used as a purification agent in a gas stream. This waste could be minimized through potential material substitution or a procedural process change.

Magnifloc Polyacrylamide Solution Waste

One 0.1-kg item of magnifloc polyacrylamide solution waste was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Manganese Mixture Waste

One 2.5-kg item of manganese-based waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Mercury-Based Waste

Twenty-two items totaling 9.2 kg of mercury-based waste were generated as follows:

- legacy or abandoned waste,
- from old or broken thermometers,
- from old barometers, and
- from old mercury switches.

A total of 4.5 kg from 12 items was generated from nine items deemed legacy or abandoned waste, two old barometers that were not replaced, and one broken thermometer that was not replaced because the area had one thermometer left. The mercury from these wastes potentially could be recovered off site once the wastes were examined for condition and contamination.

The remaining 10 items totaling 4.7 kg were generated from removing and replacing old mercury switches and thermometers. Some of these switches and thermometers simply were no longer needed and others were replaced with electronic systems. This replacement activity was considered source reduction. Furthermore, the mercury from these wastes potentially could be recovered off site if the quantity of recoverable mercury justified it. These implementation activities had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division.

Methacrylic Acid Waste

One 0.9 kg item of methacrylic acid waste was generated from gel casting in which it is used as a monomer. One potential option would be to allow smaller amounts to be procured through the AVID system used by ORNL. This option would minimize the amount of excess material generated in the laboratory area.

Methanol Solution Waste

Eleven items totaling 44.8 kg of methanol solution waste were generated from the following:

- ceramic composite manufacturing to remove residue left by acetone on small ceramic samples (one 3.3-kg item),
- electropolishing solution used to prepare a sample for viewing under an atom probe used in atomic and molecular research (seven items totaling 6.2 kg),

- cleaning of silicon wafers for thin-film deposition (two items totaling 35.1 kg), and
- one-time metal etching by visiting researcher (one 0.1-kg item).

The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed or to be etched. For instance, in general, glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of methanol was approximately $14.38/4 L ($3.60/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the methanol.

Methyl Ethyl Ketone Waste

Four items totaling 34.1 kg of methyl ethyl ketone waste were generated. One 1.9-kg item was legacy waste generated from the silicon carbide whisker fabrication close down. This material could potentially be contaminated with silicon carbide whiskers. Therefore, no potential reuse was considered due to health concerns.

The remaining three items were generated from a one-time statistical testing method performed in gel casting. This material could potentially be reused once it was examined for its condition and potential contamination.

Methyltrichlorosilane Waste

One 15.2-kg item of methyltrichlorosilane waste was generated from a laboratory in which it would be blown through silicon carbide cloth to form ceramic composite materials. This material could potentially be reused once it was examined for its condition and potential contamination.

Molybdenum Waste

One 0.1-kg item of molybdenum waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

N,N,N',N'-Tetramethylethylenediamine Waste

One 0.3-kg item of N,N,N',N'-tetramethylethylenediamine waste was generated from gel casting in which it would be used as a catalyst. This material has an unpublished shelf life. If the material performed poorly, the remainder would be sent for disposal. One potential option would be to allow smaller amounts to be procured through the AVID system used by ORNL. This option would minimize the amount of material in storage in the laboratory area that would subsequently exceed its shelf life.

Nickel Mixture Waste

Seven items totaling 36.5 kg of nickel-based waste were deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Nitric Acid Solution and Solids Waste

Seven items totaling 338.7 kg of nitric acid-based waste were generated. One 2.3-kg item was generated from cleaning silicon wafers for thin-film deposition. Potential material substitution may be possible and at least on-site neutralization could be considered. Two items totaling 9.0 kg were generated from deconsolidation of inert nuclear fuel particles, which was no longer performed. These two items of material could potentially be reused once they were examined for their condition and potential contamination.

Two other items totaling 327.1 kg were generated from iridium etching for which on-site neutralization was being initiated and had been documented and reported to the ORNL Pollution Prevention Program. The two remaining items totaling 0.3 kg were generated from sample preparation for atomic and molecular research and were being neutralized on site in the laboratory. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division.

Nitrocellulose Solution Waste

Two items totaling 0.4 kg of nitrocellulose solution waste, also called pyroxylin, were generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Oil and Oily Solids Waste

Twenty-three items totaling 1,441.0 kg of oil-based waste were generated and had been characterized and reclassified as not being RCRA hazardous wastes. Three items totaling 5.7 kg were deemed legacy and laboratory cleanout wastes. Sixteen items totaling 784.7 kg were generated by R&D activities including changing oil and replacing gaskets in vacuum pumps, quenching specimens after heating, cleaning out the tube reducer, and being used in a bubbler to prevent oxygen from getting into a furnace. Four items totaling 650.6 kg were generated from support activities such as equipment maintenance and spill cleanups.

Waste oil was reclassified as not being a RCRA hazardous waste and was accounted as such within this study. This reclassification had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. However, several pollution prevention options had been identified for this waste including testing oilless vacuum pumps, substituting a different lubricant with a longer life, extending the life of the oil through monitoring and with in-line filters, and extending the life of the oil using mobile filters.

Oxalic Acid Solution Waste

One 0.5-kg item of oxalic acid waste was used in atomic and molecular research to reduce the size of the sample. Mechanical grinding to reduce the size of the sample has since replaced this acid-based activity. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division.

Paint Solution Waste

One 1.2-kg item of paint solution waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Petroleum Ether Waste

One 0.5-kg item of petroleum ether waste was a pentane-based nonaqueous solvent, which was integral in the R&D activity being performed. Therefore, potential substitution was deemed unlikely based on input from M&C R&D personnel.

Phosphoric Acid Waste

Two items totaling 3.3 kg were generated. One 3.2-kg item was generated from a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination, or it could at least be neutralized on site. One 0.1-kg item was generated from electropolishing the copper stub used to hold the

sample in atomic and molecular research and was being neutralized on site in the laboratory area. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Potential future changes were considered unlikely because the waste was being neutralized on site in the laboratory area.

Photographic Waste

In 1992, photographic wastes were generated in six areas in the M&C Division. One area in the High Temperature Materials Laboratory, which generated 139.3 kg or 4 items of waste in 1992, converted to digitization and photoimaging. A second area, Technical Photography, which generated 2134.7 kg or 55 items of waste in 1992, was in the process of gradually converting from wet chemistry-based systems to digitization and photoimaging. This area had also installed metallic replacement canisters to recover any silver from the effluent from the wet chemistry-based systems. This effluent was then discharged to the process drain and was treated at an ORNL wastewater treatment facility. A third area, which generated 126.9 kg or 3 items of waste in 1992, was eliminated and the equipment removed. This elimination had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division. Two additional areas, that generated 614.0 kg or 14 items of waste in 1992, had been shut down but may start back up in the future. One area, which generated 1263.0 kg or 18 items of waste in 1992, continued to use wet chemistry and had installed metallic replacement canisters to recover the silver from the effluent from this

area. This effluent was then discharged to the process drain and was treated at an ORNL wastewater treatment facility.

In addition to digitization and photoimaging and metallic replacement, several pollution prevention options have been applied to photoprocessing wastes. Because operations across the country are different, each one would need to choose an option for their situation. The following additional options were found in the U.S. Environmental Protection Agency (EPA) *Guides to Pollution Prevention The Photoprocessing Industry* and the Brookhaven National Laboratory (BNL) *Silver-Contaminated Photographic Waste Process Waste Assessment (PWA) Report*:

- Chemical inventory control,
- Making up solutions only in quantities needed,
- Fixer reuse,
- Electrolytic silver recovery including batch, continuous, and recirculating recovery systems,
- Chemical precipitation,
- Squeegees for minimizing carryover,
- Evaporation,
- Plumbingless minilabs,
- Low flow prewash,
- Silver recovery from off-specification paper and film,
- Shutting down operations, and
- Zero silver content photographic film.

Additional details provided in these two documents concerning photoimaging and digitization and metallic replacement are paraphrased in the next two sections.

Photoimaging and Digitization

The BNL document stated that photoimaging and digital photoprocessing was relatively new and used a modified 35-millimeter (mm) camera to electronically capture an image instead of capturing the image on a film. The image would then be electronically loaded into a computer, enhanced as appropriate, and printed using specially designed printers. The image could be printed onto paper or plastic transparency material and could include black and white or color photographs, or transparencies. The resolution and quality of these prints had been high enough to satisfy many photographic and imaging applications and continued to improve over time as the technology was enhanced. The photoimaging and digital photoprocessing systems generated no chemical waste or silver-contaminated film or paper. The cost effectiveness of this type of system would depend on the specific application (BNL, 1994). The costs for the components of the M&C Technical Photography electronic imaging equipment were:

Equipment	Purchase Price
Work Station	(See cost data for each element listed below.)
Power Mac	$6,114.00
Hard Disk	$835.00
Monitor	$1,951.00

Equipment	Purchase Price
Software	$2,800.00
Digital Camera	$9,441.87
Film Scanner	$14,966.00
Flatbed Scanner	$2,300.00
Sublimation Printer	$16,159.00
Printer Software	$758.07 (Nave 1994).

The costs related to operating this system are summarized in Table B-8. In contrast, the costs related to operating the conventional wet chemistry system are outlined in Table B-9. The annual operating costs of approximately $55,000 are approximately equal.

Metallic Replacement, Silver Recovery Canisters

The dissolved silver in photographic waste, primarily in fixer and bleach/fixer, would be a thiosulfate complex. Metallic replacement could be used to recover this silver. Silver recovery canisters would allow an activated solid metal, such as iron, to come in contact with a solution containing dissolved ions of a less active metal, such as silver. The iron would dissolve into solution as an ion, and the silver would replace the iron in the solid matrix. These canisters would be used by themselves in the M&C areas and would include two steel-wool-filled plastic canisters in series with associated plumbing connections. Approximately 85 percent of the recoverable silver should be collected in a sludge in the canister. The canisters would then be sent off site for

Table B-8
Annual Cost of Operating Digital Photoprocessing System in the
Technical Photography Area in the Metals and Ceramics Division in 1994 [#]

Material	Cost Per Package	Items per Package	Items per Year	Item Units	Total
Paper (Black and White and Color)	$156.73	200	13687	sheets	$10,725.82
View Graphs (Black and White and Color)	$282.11	200	1837	sheets	$2,591.18
Printer Cartridge (for Paper)	$446.68	200	13687	sheets	$30,568.55
Printer Cartridge (for View Graphs)	$501.53	200	1837	sheets	$4,606.55
Remaining Wet Chemistry (10 Percent of Original Value Listed in Table B-9.)					$5,687.38
Annual Grand Total (1994)			31048	sheets	$54,179.48

Note: [#] The material data, number of items per year, and item units were obtained from J. Nave in Metals and Ceramics Technical Photography. J. Nave also provided a copy of the Accelerated Vendor Inventory Delivery (AVID) photography-based catalog and specified the materials used. This catalog listed the cost per package and the number of items per package. J. Nave estimated that initially 10 percent of current level of wet chemistry processing would need to continue to be performed. Based on all of this information, the total cost was calculated for 1994, as summarized in this table.

Table B-9
Annual Cost of Operating Wet Chemistry-Based Photoprocessing in the Technical Photography Area in the Metals and Ceramics Division in 1994 [#]

Material	Cost Per Package	Items per Package	Items per Year	Item Units	Total
Paper (Black and White)	$76.61	500	8830	sheets	$1,352.93
Paper (Color)	$14.82	50	4857	sheets	$1,439.61
View Graphs (Black and White)	$35.07	25	644	sheets	$903.40
View Graphs (Color)	$131.78	50	1193	sheets	$3,144.27
Cleanup Rolls	$77.12	50	600	sheets	$925.44
Chemicals Required by Processing Machine					
Black and White Royal Print Machine					
Activator	$27.42	18.9272	151	kg	$219.36
Stop Bath	$17.24	9.4636	110	kg	$199.99
Activator	$32.68	18.9272	175	kg	$302.28
Black and White Film Duraflo Line Machine					
Developer	$25.00	18.9272	76	kg	$100.00
Rapid Fixer A Solution	$27.20	18.9272	87	kg	$125.46
Rapid Fixer B Solution	$5.50	2.12931	10	kg	$25.06
Flexicolor Color Film C41 Line Machine					
Developer	$24.96	18.9272	21	kg	$27.46
Bleach	$83.37	18.9272	57	kg	$249.75
Fixer	$31.69	18.9272	19	kg	$31.69
Stabilizer	$7.76	18.9272	1	kg	$0.48
Color Paper Ektacolor RA4 Line Machine					
Developer	$17.55	10	16	kg	$27.40
Bleach/Fixer	$17.62	10	70	kg	$123.25
Additional Labor Related to Wet Chemistry	$119.19	N/A	400	hr	$47,676.00
Annual Grand Total (1994)			16124	sheets	$56,873.84

Note: [#] The operational and material data, number of items per year, and item units were obtained from J. Nave in Metals and Ceramics Technical Photography. J. Nave also provided a copy of the Accelerated Vendor Inventory Delivery (AVID) photography-based catalog and specified the materials used. This catalog listed the cost per package and the number of items per package. J. Nave also estimated that using the wet chemistry-based system required at least an additional 400 hours per year of labor when compared to the digital photoprocessing system. Based on all of this information, the total cost was calculated, as summarized in this table.

further processing to recover pure metallic silver (BNL 1994). The silver recovery cartridges cost approximately $48.31 each.

Potassium-Based Waste

Four items totaling 3.1 kg of potassium-based waste were generated. Two items totaling 1.6 kg were generated from laboratory cleanouts. One 1.0-kg item was used in the past to electropolish tungsten. The other 0.5-kg item was used in research, but a specific sample of material was a concern because of potential contamination and was sent for disposal. These materials could potentially be reused once they were examined for their condition and potential contamination.

Praseodymium Oxide Waste

One 0.02-kg item of praseodymium oxide waste was deemed a legacy waste from a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Proxylated Aliphatic Amines Solution Waste

One 1.0-kg item of proxylated aliphatic amines solution waste was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Resin Solution Waste

One 0.4-kg item of resin solution waste was generated and was usually used in making the mold in gel casting operation. One potential option would be to allow smaller amounts to be procured through the AVID system used by ORNL. This option would minimize the amount of excess material generated in the laboratory area.

Silicon-Based Waste

Four items totaling 11.0 kg of silicon-based waste were generated. Two items totaling 10.6 kg were deemed legacy wastes and could potentially be reused once they were examined for their condition and potential contamination. The other two items totaling 0.4 kg were materials usually used to make composites and in gel casting. One potential option would be to allow smaller amounts to be procured through the AVID system used by ORNL. This option would minimize the amount of excess material generated in the laboratory area.

Soap Leak Detector Solution Waste

One 0.1-kg item of soap leak detector solution waste was generated because the need for this material was eliminated due to program changes. This material could potentially be reused once it was examined for its condition and potential contamination.

Sodium Cyanide Waste

One 0.9-kg item of sodium cyanide waste was generated as excess material. This material could potentially be reused once it was examined for its condition and potential contamination.

Sodium Dichromate Waste

One 0.2-kg item of sodium dichromate waste was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Sodium Hydroxide Waste

Four items totaling 4.5 kg of sodium hydroxide waste were generated. One 1.4-kg item was deemed as a legacy waste. The remaining three items were used for pH adjustment. Identification of a substitute that would not generated a RCRA hazardous waste was unlikely based on input from M&C R&D personnel. These three items could be characterized to verify that they were RCRA hazardous wastes and at least be neutralized on site.

Sodium Iodide Waste

One 0.1-kg item of sodium iodide waste was used in the laboratory but was generated from a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Sodium Metal Waste

Three items totaling 3.0 kg of sodium metal waste were used in completed space program R&D activities in mass transport loops. This material could potentially be reused once it was examined for its condition and potential contamination.

Sodium Silicate Waste

One 1.0-kg item of sodium silicate waste was documented as generated but may have been sodium arsenate, which was put on metal to hydrogen charge the material and crack the steel apart. If it was sodium silicate, it was legacy waste. For this study, it was assumed to be sodium arsenate for which a potential substitute or recycle option was not likely. However, if this material was sodium silicate, it could potentially be reused once it was examined for its condition and potential contamination.

Stainless-Steel Powder Waste

One 11.1-kg item of stainless-steel powder waste was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination.

Stainless-Steel Soldering Flux Waste

One 0.2-kg item of stainless-steel soldering flux waste was generated but has since been eliminated. Paste flux was only being used during this study in this M&C

area. This material could potentially be reused once it was examined for its condition and potential contamination.

Strontium Waste

One 0.2-kg item of strontium waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Sulfuric Acid Waste

One 1.5-kg item of sulfuric acid waste was generated from electropolishing metals in which it was used in a mixture with 10 percent hydrofluoric acid. This material could potentially be reused once it was examined for its condition and potential contamination, or it could at least be neutralized on site.

Tantalum Metal Waste

One 0.3-kg item of tantalum metal waste was deemed a legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Tetramethyl Ammonium Hydroxide Waste

One 0.2-kg item of tetramethyl ammonium hydroxide waste was a base used for titration. Identification of a substitute that would not generated a RCRA hazardous waste was unlikely based on input from M&C R&D personnel.

Titanium Sponge Waste

One 1.3-kg item of titanium sponge waste was generated from a laboratory in which it was usually combined with chlorine to produce titanium chloride. This material could potentially be reused once it was examined for its condition and potential contamination.

Trichloroethane Waste

Two items totaling 2.3 kg were generated. One 1.5-kg item was deemed legacy. This material could potentially be reused once it was examined for its condition and potential contamination.

The other 0.8-kg item was used to remove polymers in gel casting. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of trichloroethane was approximately $5.97/L. The cost of Solvent 140, MMK Blend,

and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the trichloroethane.

Trichloroethylene Solution Waste

Five items totaling 50.6 kg of trichloroethylene solution waste were generated from the following:

- degreasing in the High Temperature Gas Reactor Program and for test coupons in corrosion research (two items or 32.0 kg),
- removing polymers in gel casting (two items or 2.7 kg), and
- cleaning silicon wafers for thin-film deposition (one 15.9-kg item).

The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of trichloroethylene was approximately $92.25/4 L ($23.06/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole).

Therefore, the cost values of the solvents were comparable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the trichloroethylene.

Trichlorotrifluoroethane Waste

Three items totaling 59.7 kg of trichlorotrifluoroethane waste were generated. One 25.4-kg item was generated during a laboratory cleanout. This material could potentially be reused once it was examined for its condition and potential contamination. The remaining two items totaling 34.3 kg were generated when this material was used as a cleaner while performing turbo pump maintenance. The potential source reduction option identified was material substitution with other solvents that would not generate RCRA hazardous wastes. These potential alternative solvents included Solvent 140, MMK Blend, and Anisole. The potential success of these materials depended on the material to be removed. For instance, in general, glue-based materials were more difficult to remove than oils and greases and fingerprints. The cost of trichlorotrifluoroethane was approximately $54.55/50 g ($1,091/kg or $1705.78/L). The cost of Solvent 140, MMK Blend, and Anisole ranged from approximately $62.10/5-gallon can ($3.28/L for Solvent 140) to $45.00/kg ($45.00/L for Anisole). Therefore, the cost values of the replacement solvents were favorable assuming approximately equal amounts of each type of solvent would be needed to meet the described uses of the trichlorotrifluoroethane.

Trimethylolpropane Trimethacrylate Waste

One 1.4-kg item of trimethylolpropane trimethacrylate waste was generated and was not being used during this study but could potentially be used in the future in nonaqueous gel casting. No options were identified because this material was not being used during this study.

Troysol Solution Waste

One 0.1-kg item of Troysol solution waste was generated and was used as a surfactant for which substitution was unlikely.

Xylene Waste

One 0.7-kg item of xylene waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Yttrium Oxide Mixture Waste

One 0.2-kg item of yttrium oxide mixture waste was deemed legacy waste. This material could potentially be reused once it was examined for its condition and potential contamination.

Zinc Bromide Waste

Zinc bromide was used in hot cell windows in the M&C Division. Because this material was corrosive, M&C knew that its use would ultimately result in the generation of a characteristically hazardous waste under RCRA. Therefore, these hot cell windows were gradually being replaced with windows that used mineral oil instead of zinc bromide. In 1992, 12 items totaling 3633.8 kg of waste were generated from this replacement activity.

M&C anticipated that this substitution would result in successful source reduction because this mineral oil initially did not display any characteristics that would result in the generation a RCRA hazardous waste. If this oil ever was removed from these windows, M&C would then verify that it still was not a hazardous waste under RCRA. This implementation had not been documented and reported to the ORNL Pollution Prevention Program by the M&C Division.

VITA

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She worked at the U.S. Department of Energy (DOE) Y-12 Plant from August 1984 to October 1990 during which time she entered The University of Tennessee, Knoxville in March, 1988. In December 1996, she received a Master of Science degree in Environmental Engineering. She is presently employed at IT Corporation in Knoxville, Tennessee.