WASTE MINIMIZATION TECHNOLOGY DEVELOPMENT IN THE DOE COMPLEX

W. E. Schwinkendorf and W. P. Dassing
BDM International, Inc.

ABSTRACT

Waste Minimization, to the U.S. Department of Energy (DOE), is the reduction in volume or toxicity of hazardous waste at the source of generation. There are currently five programs in progress at DOE facilities to address its waste management problems. Depleted Uranium Waste Minimization, at the Y-12 plant, has the goal to reduce the total waste generated at the site by 80%. Environmentally Conscious Manufacturing seeks to minimize waste through an integrated systems approach in the manufacturing of electronic components. DP/EM MOA is an agreement between two Department of Energy agencies to jointly assess waste problems and minimize waste production in the weapons complex. DOE/Air Force MOU is an agreement between DOE, the U.S. Air Force, and others, to evaluate waste minimization problems and to develop technologies in conjunction with each other to eliminate duplication of efforts. Nuclear Weapons Dismantlement is a newly-funded project still in the developmental stage.

INTRODUCTION

Waste Minimization is a key component in the U.S. Department of Energy (DOE) effort to solve waste management problems in the Nuclear Weapons Complex. DOE has developed a multimedia waste minimization program to comply with: the Resource Conservation and Recovery Act (RCRA) mandate to maintain structured programs to reduce the amount of waste generated at its sites, the Pollution Prevention Act, Federal Facility Agreements, and various DOE orders. As a result, all DOE program offices and field organizations have instituted pollution prevention programs that follow a hierarchy of environmental practices.

Eliminating or minimizing the generation of waste at the source is the first priority and is the subject of a departmental wide cross-cut strategic plan. Second priority is to recycle within the operating plant followed by recovery and reuse by industry. Third, all generated waste will be treated to reduce volume, toxicity, or hazardous constituent mobility prior to storage or disposal. Minimizing present and future wastes is the only way DOE can reduce the cost and liabilities associated with the toxic materials its mission generates.

DOE waste generating programs are required to identify opportunities to effect reductions in the amount of waste they generate. DOE's office of Environmental Restoration and Waste Management (EM) has responsibility for conducting technology development programs aimed at minimizing waste generation. These programs are managed by EM's Office of Technology Development (OTD).

This paper describes DOE's efforts to develop new technologies to further its ongoing waste minimization program. OTD coordinates research and development activities with DOE's Office of Defense Programs (DP) on weapons design, materials substitution, and process modification for production and dismantlement. OTD works with DP to develop selected technologies, but the demonstration and engineering for pilot scale systems and beyond is done by DP. DP has the responsibility for the reliability and maintainability of weapons and must have control of the implementation of waste minimization options. Major weapons system process changes, such as changing cutting fluids or cleaning solvents, require extensive material corrosion, adhesive bonding, and compatibility studies to assure the DOE weapons complex that product quality and long term reliability has not been compromised.

OTD is working toward a goal of reducing waste production in the weapons complex by 60-80% by the year 2000. To achieve this goal, OTD has established five Integrated Demonstrations (ID) specifically designed to solve waste generation problems at its production sites. Each ID consists of several research projects designed to test and demonstrate a process or material with the goal of reducing or eliminating hazardous waste. The IDs include *Depleted Uranium Waste Minimization, Environmentally Conscious Manufacturing, Defense Programs and Environmental Restoration and Waste Management Memorandum of Agreement (DP/EM-MOA), DOE/Air Force Memorandum of Understanding (DOE/AF-MOU) and Dismantlement.*

DEPLETED URANIUM WASTE MINIMIZATION

The Depleted Uranium Waste Minimization program began in FY 1990 with the goal of an 80% reduction in the total waste generated from the Y-12 production process by the year 1995. Research and development measures are being demonstrated at the Y-12 production facility at Oak Ridge, Tennessee, with the objective of significantly reducing the incoming material by using less raw material to create a part, and by incorporating a much larger percentage of scrap uranium metal into recycling. Benefits include reductions in the amount of primary, secondary, and tertiary materials purchased, reductions in most disposal streams leaving the facility, and reduced risk to personnel health and safety.

In FY 1990, chlorinated hydrocarbons were eliminated from the oralloy process at Y-12. In FY 1991, freon use was completely eliminated from the machining of depleted uranium, resulting in a 95% reduction in the total use of freon by Y-12. Chip cleaning, breaking, briquetting, and melting processes have been demonstrated for recycling operations and a no-carbon furnace has been demonstrated for chip remelt. Chemical purification of impure massive scrap for subsequent recycling, low-level waste monitoring equipment, and the use of an arc saw to minimize saw fines were all demonstrated in FY91. Generation of all low-level radioactive waste at Y-12 has been reduced by 20%.

Ongoing technology development efforts at this ID include the following:

1. Elimination of chlorinated hydrocarbon solvents by developing a cleaning process using water and detergent in an ultrasonic cleaning system.
2. Uranium scrap purification and reprocessing to reduce the quantity of virgin metal required and the waste volume. This project involves development and evaluation of electroslag remelting (ESR) and electron beam remelting (EBR) as methods for metallurgically upgrading scrap uranium and uranium alloys.
3. Investigation of various technologies to minimize uranium waste, including near net-shape and stock minimization through improved casting and metal forming methods, improved fabrication and cutting procedures to decrease the amount of scrap in the form of chips or fines, and material purification alternatives.

ENVIRONMENTALLY CONSCIOUS MANUFACTURING

This Integrated Demonstration (ID) was started in FY 1990 to implement a total systems approach to ECM that will lead to cost-effective elimination of waste in the manufacture of electronic and electromechanical components for nuclear weapons. System issues such as cost, materials compatibility, and balanced process integration cannot be addressed through individual technology programs. Instead, designers, production engineers, materials engineers, systems engineers, and process development engineers must be included in all phases of the design and manufacturing process. By means of the ECMID, cleaning, joining, solvent substitution, coating, metal finishing, process control, packaging, and assembly will be treated as interdependent processes to minimize the generation of hazardous wastes in electronics manufacturing.

The focus of this program is the manufacture of an electronics component using currently available ECM technologies developed at Sandia National Laboratories, Albuquerque (SNLA) and Allied Signal-Kansas City Division. This component, a programmer, will be manufactured using as many material and process substitutions as possible to eliminate hazardous waste streams and employ current, state-of-the-art ECM technologies while maintaining the required quality. Key areas, that are at a stage of development for implementation, include cleaning, polymer encapsulation, printed wiring board manufacturing, marking and stamping, and soldering.

Technologies developed in the laboratory are being transferred to the shop floor at the Kansas City Plant (KCP). Functional units will be manufactured at the KCP using state-of-the-art ECM technologies and tested against units built using conventional technologies. Other aspects being evaluated include the cost of ECM versus current manufacturing processes, benefits of ECM and overall risk associated with introducing ECM into the DOE complex. Because approximately 90% of all electronic component manufacturers have a contract with the KCP, proven technologies are being rapidly transferred to industry to support the ability of the United States electronics industry to meet regulatory requirements and international agreements.

A number of ongoing programs have contributed to the selection of ECM technologies for the manufacture of the programmer. The solvent substitution program has identified both aqueous and organic based cleaners for use in electronics manufacturing. D-limonene will be used to clean one demonstration unit and aqueous processing will be used for two other units. Fluxless soldering techniques, including reactive gas laser soldering and laser ablative soldering will be evaluated. In addition, no-clean fluxes, selected based on data developed by Allied Signal-Kansas City Division, will be evaluated for soldering connections to the programmer.

Methylene dianiline (MDA) is a human carcinogen and toluene disocyanate (TDI) is a suspect carcinogen. Both compounds are major constituents of materials used in electronics manufacture in the DOE complex. Based on a joint SNLA/KCP program to identify and characterize MDA free printed wiring board materials for DOE applications, a MDA free material was selected for the ECMID and boards have been fabricated at the KCP. Joint programs involving SNLA, KCP, EG&G Mound Applied Technologies, and the Pinellas Plant have been developed to look for alternatives to TDI containing foams and elastomers. Based on work in this area, a polymeric isocyanate (PMDI) based foam, and a polyurethane elastomer with a small amount of free TDI ($<0.05\%$), have been selected for evaluation in the programmer manufacturing project.

Other process changes include the use of UV curable epoxy to protect markings and inks, water soluble inks rather than solvent based inks, and laser marking. Additional work is being done in the plating and metal finishing area. However, the needs of the ECMID are such that the metal finishing technologies will not be developed in time for implementation in the initial manufacture of the demonstration component.

In addition to the integrated systems approach to ECM, individual projects to develop new technologies are ongoing. Solvent substitutes or alternative cleaning processes for CFCs and CHCs are continuing to be investigated. Cleaning methods being evaluated include aqueous processes, spray processes (single and multi-axis), vapor degreasing, ultrasonic cleaning, wet and dry blast, acid/caustic cleaning, laser ablation, and plasma cleaning. Real-time, intelligent, on-line instrumentation systems are being developed for characterizing and controlling process, recycling, and waste streams. Fluxless soldering technologies are being developed with a focus on controlled atmosphere soldering, metallization and inhibitor technology, and thermomechanical surface activation soldering to produce an oxide-free surface that allows wetting by the solder and elimination of the solvent waste required to remove flux residue. As these technologies are developed they will be implemented in the KCP factory environment for further evaluation in a manufacturing system.

DP/EM MEMORANDUM OF AGREEMENT

This ID seeks to reduce waste within the Defense Programs operations, since 80% of DOE's waste is generated in its nuclear weapons complex. The design laboratories and manufacturing facilities entered into a Memorandum of Agreement (MOA) in 1990 to optimize resources and coordinate funding in developing new technologies. Individual projects funded under this ID began in February 1991. DP and EM have agreed to jointly assess the opportunities to minimize waste in the weapons complex and to jointly select research, development, and demonstration projects which address those opportunities.

The MOA has established a Waste Minimization Management Group (WMMG) to evaluate proposals and coordinate waste minimization efforts. The goal is to develop and rapidly implement technology directed toward the top priority waste minimization needs within the weapons production complex. Under the WMMG, waste minimization strategies have been developed for eight waste streams -- uranium, plutonium, tritium, electroplating, solvents, polymers, mixed waste, and miscellaneous. The efforts to decrease each waste stream are coordinated and managed by a technically knowledgeable waste stream manager. The currently funded projects, selected to complement rather than duplicate on-going waste minimization initiatives, support improvements in current operations and the development of a technology base to design and permit the future weapons production complex.

Polymer Waste Stream

Current manufacturing processes for nuclear weapon components require the use of materials such as MDA as curing agents for epoxy and urethane encapsulants and in printed wiring boards, TDI polyurethane foams and elastomers as encapsulants, and mold releases that require chlorofluorocarbon solvent cleaning. These materials are either toxic, carcinogenic, or environmentally unacceptable. The goals for this waste stream program are to develop alternate chemistries to reduce or eliminate the use of these materials.

SNLA has identified candidate MDA-free printed wire board (PWB) material, an alternate TDI-free polyurethane foam, and alternate urethane elastomers. A battery of tests will be developed to determine physical properties, aging/compatibility properties, thermal and mechanical properties, and processing and machining properties to determine which systems warrant weapons qualification. In addition, new molding and cleaning processes will be investigated to allow elimination of hazardous mold release solvents.

Solvent Waste Stream

Routine cleaning, precision cleaning, and painting operations associated with electronics fabrication are the primary sources of organic solvent waste in the weapons complex. Alternatives to organic solvents have been developed for many of these processes but others still require extensive research and development efforts to qualify an alternative material or process for a cleaning operation. Implementation of these alternatives requires extensive characterization and testing for functionality, reliability, aging, corrosion and compatibility because of stringent system requirements. The goal is to eliminate, or greatly reduce, both current and future organic solvent waste streams associated with the production of nuclear weapons through design, materials substitution, recycling, and process modifications consistent with regulatory requirements and international agreements.

Potential solvent substitutes include aqueous and semi-aqueous based solvents such as d-limonene, a naturally occurring substance extracted from orange peels. Other substitutes include supercritical fluids, less volatile VOC's, and pelletized carbon dioxide. Dry process cleaning methods, such as laser ablation and plasma cleaning, are also being studied. On-line monitoring offers the ability to minimize solvent use at the source, and use of closed system recovery techniques. These methods require further development and validation for use in specific system applications.

Electroplating Waste Stream

The goal of this program is to reduce the level of hazards from waste generated by metal finishing operations and improve the performance of coating systems without compromising nuclear weapon safety and reliability. Specific waste targets identified by EPA and OSHA for regulation include hexavalent chromium; cadmium; other heavy metals including copper, nickel, and tin; cyanides; and acids and caustics. Technology development activities are concentrated in four major areas: direct substitution, process monitoring and control, process substitution, and closed loop recovery systems.

The target coating systems to be eliminated by substitution are cadmium, hexavalent chromium, cyanide, and eventually nickel. Sandia National Laboratory, Livermore, California (SNLL) has determined the electrical properties of trivalent chromium for potential replacement of hexavalent chromium, and has developed copper pyrophosphate as a replacement for copper cyanide. Cyanide has been eliminated from gold and copper plating operations in the DOE complex. Sensors are being developed for monitoring and control of plating solutions, rinse tanks and cleaning tanks to extend bath life. Easily implemented processes for reducing drag-out and waste water metal concentration are being evaluated for coating performance and part cleanliness.

Technologies emphasizing in-process separation and reuse of metal and water are being investigated to separate the hazardous component from the radioactive waste component. Process changes, process control techniques, and process substitutions are being investigated at Los Alamos National Laboratory, New Mexico (LANL) to reduce waste production at the source. The goal is to recycle the hazardous components such as metals and metal salts into the process stream and to allow the radioactive components to be classified as radioactive waste for disposal. The focus is on various chemical separation techniques such as electrochemical separation, selective precipitation, selective crystallization, ion exchange, etc.

Miscellaneous Waste Stream

The goal of this program is to develop a comprehensive pollution prevention/ hazard minimization program for miscellaneous waste streams, involving potential releases into all environmental media with an objective of 50% volume and toxicity reduction by FY 1995. Miscellaneous waste streams include lithium, explosives, uranium/beryllium, airborne emissions, classified hazardous waste, waste from weapons assembly/disassembly, and nonhazardous waste. For each miscellaneous waste stream, site specific hazards, assessment tools, worker exposure and waste characterization needs have been identified and prioritized.

Site specific issues include minimizing lithium waste and reducing exposure during extraction of molten lithium from electrolytic cells, and during casting and press operations through automation. Another project involves developing improved processes for the synthesis, purification, handling and recycling of lithium hydride and deuteride to reduce the waste streams. Specific process developments include near net-shape forming, improved handling of machine dust, and an improved dehydride/rehydride process. Automated systems for machining and inspecting uranium parts, weapon disassembly, and handling of explosive and radioactive parts are being developed.

Baseline characterization of waste streams is being achieved through process waste assessments (PWAs). Worker exposure and waste characterization methods are being developed to support the PWAs. This includes methods to enhance the identification of compounds of specific environmental concern in all media, real-time detection of airborne uranium and beryllium, and detection of airborne emission, both routine and off-normal.

Mixed Waste Stream

Currently, there is no disposal site available for mixed waste. All mixed waste that is currently generated must be stored at DOE generating sites; however, some of these sites are reaching their regulatory storage limits. Thus, the minimization or elimination of mixed waste from the nuclear weapons complex is a high priority. The goal of this program is complete elimination of mixed waste to meet the goal of the reconfigured Nuclear Weapons Complex. An intermediate goal is a 50% reduction of mixed waste by FY 1995.

The first step is to document mixed waste generation by type and volume at each site. This documentation has begun, however, the processes in which mixed wastes are generated are not well documented. The documentation will be required to identify the solutions and priorities for mixed waste issues. The focus of specific waste minimization efforts include eventual elimination of solvents in plutonium machining and assembly, elimination of large amounts of secondary and tertiary low level mixed waste (e.g., mops, wipes, gloves, etc.) associated with weapons production, minimization of mixed waste associated with weapons retirement, and source separation and process control techniques to eliminate mixed wastes during uranium and plutonium processing.

Uranium Waste Stream

In the enriched uranium oralloy waste stream, the problem stems from both the amount of the generated wastes and their associated hazards. Areas in the enriched uranium waste stream requiring attention are solid, organic, aqueous, and gaseous wastes. Goals for this program include a greater than 20% reduction in the generation of overall wastes as a result of process modifications.

There are six projects currently underway as part of the uranium waste stream minimization program. Four are directed toward source reduction, and two are directed toward a combination of source reduction and recycle capability.

The source reduction tasks include the following:

1. Reducing the amount of scrap generated by developing special near net-shape forming techniques.
2. Developing technologies to convert highly enriched uranium nitrates to uranium metal by first converting the nitrate to an oxide, and then converting the oxide to a metal by a saltless direct oxide reduction process. This technology will result in approximately 100% elimination of reduced slag solids and hydrogen fluoride scrubber solution.
3. Developing an enriched uranium recovery and purification process by new techniques for dissolution/leaching of uranium contaminated residues; replacing the current two cascade solvent extraction system with a single cascade system; and selection of alternative extractant, membrane, and membrane processing equipment for recovery of uranium process solutions.
4. Developing alternate component materials to replace the depleted uranium/alloys currently in use.

The two other combination projects include evaluating the rheocasting method of casting uranium to significantly reduce segregation, and eliminate the current multi-step method of producing uranium alloy ingots, (which generates contaminated scrap); and developing a process for cleaning and drying oralloy chips which does not require the use of freon.

Tritium Waste Stream

At this time, tritium is the only isotope other than uranium and plutonium known to be produced in sufficient quantities and with sufficient toxicity to be of concern in the nuclear weapons complex. Every modern tritium facility in the DOE complex has a system for the recovery of tritium from glovebox gases. All of these systems work by converting tritium to tritiated water. However, the toxicity of tritiated water is 10,000 to 30,000 times that of tritium gas in equivalent concentrations. This program will emphasize the reduction of tritiated water with a goal of 50% reduction by the year 2000.

Ongoing projects to minimize production of tritiated water include development of metal hydride beds to capture tritium from waste streams, and development of gas permeable membranes to separate tritium from gas mixtures. Over the past year, LANL has selected tritium getter materials for further study to allow recovery of tritium in the form of metal hydrides rather than in the more hazardous form of tritiated water. In addition, gas separation test stations using capillary membrane technology have been installed at LANL and at the University of Texas. Preliminary non-tritium permeation studies have been performed to determine the feasibility of direct separation and recovery of tritium from the air stream without formation of tritiated water.

Plutonium Waste Stream

The approach of this program is to focus on specific waste problems with projects that emphasize demonstration and implementation. Systems will be engineered to reduce and/or eliminate the impact of hazards and waste, and changes will be implemented in a production environment to demonstrate improvements. The waste minimization activities in this program were initially targeted for Rocky Flats (RFP) operations, but with the decision to cease production, the emphasis will be on developing a model plutonium handling system. The projects were selected based on priority of need with special focus on the impact on waste generation. Individual projects are described as follows:

1. System Evaluation provides a model that simulates the plutonium processing operations in terms of product flow, waste flow, and hazards flow. The model will be used to assess the impact of new technologies on the generation of waste and exposure to hazards.
2. Dry Machining To eliminate carbon tetrachloride use in the machining operations, reduce use of cutting oils which are now disposed of as mixed waste, and decrease generation of plutonium oxide resulting from

poor atmospheres in the gloveboxes. Metallurgical investigations of dry machined Pu and preliminary tests of dry machining nonactinides were completed at LANL to evaluate the dry machining processes.

3. Hydriding/Dehydriding. Hydriding is a technology used to separate plutonium metal from various materials. It will replace the acid dissolution and leaching techniques currently in use thereby eliminating the associated waste solutions and solids. A hydride/dehydride system has been installed, tested and calibrated at LANL, and an integrated hydriding/dehydriding/casting process has been cold tested at LLNL.
4. Oxide Reduction. The single largest plutonium residue is oxide generated in foundry operations. The elimination or rapid recycle of this stream will essentially eliminate the need for extensive recovery operations. The oxide reduction project will incorporate Multiple Cycle Direct Oxide Reduction (MCDOR). By incorporating the excess salt stream as a salt reagent into the salt balance of the entire plant, >85% of the waste generated under conventional Direct Oxide Reduction will be eliminated.
5. Casting. This project incorporates improvements in process parameter control, automation of equipment, and the use of reusable molds resulting in less plutonium oxide generation, reduced radiation exposure, and less secondary waste. A furnace for precision die casting of plutonium has been designed, fabricated and installed at LLNL and is being tested.
6. Electrowinning. This technology will be applied to the treatment of salt waste emerging from pyrochemical processes. The principle use will be in the decomposition of calcium chloride with the subsequent recovery and reuse of both calcium metal and chlorine gas. Alternately, it will be used in the decomposition of calcium oxide with the subsequent reuse of calcium metal and the discard of oxygen as carbon dioxide. Cold testing of an electrowinning concept for reducing plutonium oxide to plutonium metal with no net generation of waste salt or ceramic has been completed at LLNL.
7. Oxygen Sparge. This technique is used to precipitate plutonium oxide from molten salts resulting in electrorefining and molten salt extraction. The salts can then be discarded without further treatment.
8. Chloride Recovery. This task will result in recovery processes for several molten salts that cannot be directly recycled. This includes metals, oxides, and salt residues that have too much plutonium for direct disposal.
9. Nitrate Recovery. This task will improve process efficiencies, reduce waste generation, and treat waste to reduce volume and TRU content. Plutonium will be recovered from the ion exchange low level waste streams enabling reduction of liquid waste by 90% and TRU sludge waste by 95%. It will eliminate TRU plastics and organics from leaving the facility and completely recover embedded plutonium.

DOE/AIR FORCE MEMORANDUM OF UNDERSTANDING

This program, begun in FY 1990, establishes an agreement between DOE, the Air Force and several industrial partners, including Boeing Corporation, to address shared waste minimization problems including testing non-hazardous solvents and minimizing scrap during metal casting and finishing operations. The partners share information generated by coordinated research activities that are mutually beneficial, resulting in reduced duplication of effort, and reductions in cost and time for implementation of a waste minimization approach.

The primary focus of the program is to eliminate chlorinated solvents in metals preparation, paint stripping, plating, and cleaning operations by systematically evaluating alternative solvents. Solvents are evaluated by their cleaning and corrosive characteristics, safety or health hazards, and cost. The results of the study are being compiled in a Solvent Substitution Handbook which will serve as a baseline for the DOE, Air Force and private industry when alternative solvents are being investigated. The program also includes efforts in spray casting technology and zero discharge manufacturing process development.

Solvent Substitution

The objective of this program is to eliminate the use of chlorinated solvents from the DOE weapons facilities that use such solvents in metals preparation or cleaning operations. This program encompasses several tasks focused toward substitution of alternative materials or processes to minimize or eliminate the need for using traditional toxic or hazardous materials in industrial processes. These tasks include the following: identifying and measuring the potential VOC emissions from solvent substitutes; testing and selecting low toxicity, environmentally compliant solvents or techniques for paint stripping operations; identifying and testing available technologies to recover and recycle solvents; determining the feasibility of using biotechnology to reduce the metal concentration in effluent wastewater, and recovering and recycling metal from point-source discharge streams; and holding an annual workshop to exchange information and technology in the areas of solvent substitutions and alternative solvent processes.

Metal Spray Casting and Coating

The purpose of this project is to develop and demonstrate the spray casting capability of the Controlled Aspiration Process (CAP). Applications include near net-shape casting with depleted uranium for the DOE, and spray coating of metals for refurbishment of Air Force aviation parts. This coating process produces mechanical properties equivalent to or better than those obtained with conventional electroplating techniques. For near net-shape casting, this process has the potential to produce materials in a wide variety of thicknesses and shapes, and enhance metal recovery thereby reducing depleted uranium waste. Technology development includes nozzle design and nozzle materials development for long life, and development of robotics and numerical controls so that the system can predictably and reliably spray reproducible parts.

SUMMARY

DOE has designed an adaptable program to develop technologies focused on minimizing waste throughout the DOE complex now and in the future. These programs apply to waste operations and environmental restoration projects, as well as production processes used in weapons manufacture. DOE's waste minimization program provides a structured approach to preventing future environmental problems, reducing initial material and waste disposal costs, and reducing risks to personnel health and safety.

ACKNOWLEDGEMENTS

This paper was written with the support of the U.S. Department of Energy, Office of Technology Development, Germantown, MD under contract number DE-AC01-90DP48063.