ADDRESSING POLLUTION PREVENTION ISSUES IN THE DESIGN OF A NEW NUCLEAR RESEARCH FACILITY

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Abstract

The Chemistry and Metallurgical Research (CMR) Facility was designed in 1949 and built in 1952 at Los Alamos National Laboratory (LANL) to support analytical chemistry, metallurgical studies, and actinide research and development on samples of plutonium and other nuclear materials for the Atomic Energy Commission's nuclear weapons program. These primary programmatic uses of the CMR Facility have not changed significantly since it was constructed. In 1998, a seismic fault was found to the west of the CMR Facility and projected to extend beneath two wings of the building. As part of the overall Risk Management Strategy for the CMR Facility, the Department of Energy (DOE) proposed to replace it by 2010 with what is called the CMR Facility Replacement (CMRR). In an effort to make this proposed new nuclear research facility environmentally sustainable, several pollution prevention/waste minimization initiatives are being reviewed for potential incorporation during the design phase. A two-phase approach is being adopted; the facility is being designed in a manner that integrates pollution prevention efforts, and programmatic activities are being tailored to minimize waste. Processes and procedures that reduce waste generation compared to current, prevalent processes and procedures are identified. Some of these "best practices" include the following: 1) recycling opportunities for spent materials; 2) replacing lithium batteries with alternate current adaptors; 3) using launderable contamination barriers in Radiological Control Areas (RCAs); 4) substituting mercury thermometers and manometers in RCAs with mercury-free devices; 5) puncturing and recycling aerosol cans; 6) using non-hazardous low-mercury fluorescent bulbs where available; 7) characterizing low-level waste as it is being generated; and 8) utilizing lead alternatives for radiological shielding. Each of these pollution prevention initiatives are being assessed for their technical validity, relevancy, and cost effectiveness. These efforts partially fulfill expectations of the DOE, other federal agencies, and the State of New Mexico for waste minimization. If the improvements discussed here are implemented, an estimated 1.8 million dollars in cost savings is expected.

INTRODUCTION

The 550,000-square foot Chemistry & Metallurgy Research (CMR) Facility was designed in 1949 and built in 1952 at Los Alamos National Laboratory (LANL) in support of the Atomic Energy Commission's nuclear weapons program.[1] In 1959, Wing 9 was added to the CMR Facility to provide heavily shielded facilities (hot cells) for remote-handling operations. Primary programmatic uses of the CMR Facility have not changed significantly since it was constructed. These activities include analytical chemistry, physical chemistry, inorganic chemistry, and metallurgy operations using ^{235}U and ^{238}U, ^{238}Pu, and ^{239}Pu, and smaller quantities of tritium, neptunium, ^{233}U, curium, americium, and other transuranic isotopes. Other programmatic activities include waste minimization, environmental restoration and remediation, nuclear safeguards, high-temperature superconductivity, support for the Rocky Flats site, mixed waste characterization, support for the Waste Isolation Pilot Project, and Special Nuclear Material standards development. Wing 9 capabilities were used to support post-irradiation examination of nuclear fuels.

In 1998, nine closely spaced, shallow holes were drilled at the CMR Facility.[2] The purpose of the holes was to obtain soil cores and to establish the elevation at which contacts between particular layers of the underlying geologic formation, the Bandelier Tuff, are located. These elevations were then used to develop a contour map. Abrupt changes in the contours would indicate the presence of seismic activity. The goal of the investigation was to identify faults that may have the potential for earthquake-induced surface ruptures at the site.

Analysis of the data indicated that a fault is present near the CMR Facility. Its location and inferred orientation are shown in Figure 1. While the discovery of a potential fault under the building does not increase the seismic risk at CMR Facility, it does have an impact on decisions concerning upgrades and future uses of the facility. From the seismic perspective, the question that needed to be assessed was whether it is prudent to upgrade the structure to resist ground motion loads when the probability of damaging surface rupture is near the performance goal level for the facility. While it is possible to seismically upgrade the CMR Facility to resist the displacements caused by permanent ground deformation, the costs would be prohibitive. (It should be noted that this site would not be considered adequate for a new nuclear facility.) Therefore, as part of the overall Risk Management Strategy for the CMR Facility, the Department of Energy (DOE) proposed to replace this facility by 2010 with what is called the CMR Facility Replacement (CMRR).

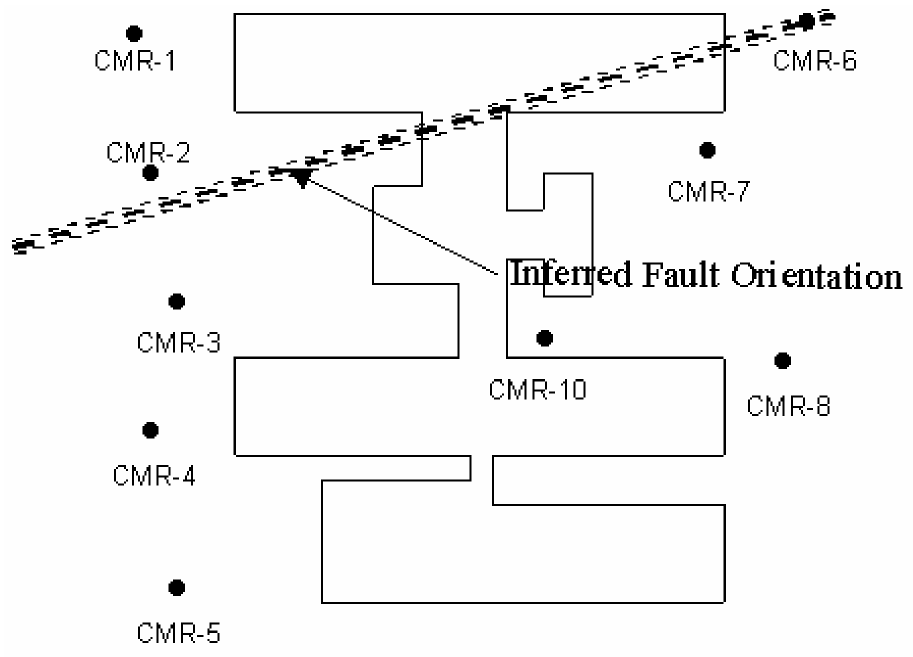

Figure 1. CMR Facility with inferred location of fault.

The current estimated cost range for building the CMRR is $420 to 955 M. Preconceptual planning focused primarily on justification of need; program requirements; project technical, environmental, safety, and cost risk; functional and operational requirements; and acquisition strategy.

Expectations from the DOE, other federal agencies, and the State of New Mexico require that appropriate consideration during design and building of the CMRR be given to Pollution Prevention/Waste Minimization (P2/WMin) objectives, including the following:

1. Reduction of volume and/or toxicity of wastes during facility operations.
2. Elimination/reduction of hazardous and pollutant materials during facility operations.
3. Proper control of hazardous and pollutant material not otherwise eliminated through substitution or alternate design.

More specifically, Executive Orders (EO) 13101,"Greening the Government thru Waste Prevention, Recycling, and Federal Acquisition," requires the practice of pollution prevention whenever feasible.

In this report, some of the environmental risks of the CMRR are discussed. An effort is under way to make this proposed new nuclear research facility environmentally sustainable. P2/WMin initiatives are being reviewed for potential incorporation during the design phase. A two-phase approach is being adopted: the facility is being designed in a manner that integrates P2/WMin efforts, and programmatic activities are being tailored to minimize waste. Finally, the ways in which these efforts partially fulfill expectations of the DOE, other federal agencies, and the State of New Mexico for waste minimization are being discussed.

POLLUTION PREVENTION OPPORTUNITIES

In the preconceptual planning stage of the CMRR design, opportunities including both administrative and engineering controls were identified that would minimize unnecessary characterization of radioactive waste, inappropriate segregation of waste, excess purchasing of chemicals, and excess storage of waste. Improved efficiency in these efforts will further support meeting P2/WMin design goals.

Unnecessary Characterization of Radwaste During the lifetime of the CMR Facility, radwaste was recharacterized repeatedly for various reasons. Through engineering and administrative controls, these costly analytical chemistry procedures can be minimized in the replacement facility.

- **Administrative Controls** Work control documents can be developed that require a waste generator to pre-certify types and amounts of waste *before* it is generated. This means that even before a given waste container is filled, its contents have been determined and pre-documented. In addition, the waste generator can be held accountable for ensuring acceptable knowledge of the waste at each step in the process.
- **Engineering Control Typically**, a glove box line contains transuranic (TRU) waste. **(**TRU is radioactive waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives of more than 20 years.) Technology is now commercially available in which the final waste container, for example, a 55-gallon drum, can be a part of the glovebox line. Radioactive materials can be transferred between glovebox line and the final shipping container without breaking containment, hindering operations, or risking the spread of contamination, typically minimizing total waste production. An example of a double-door sealed transfer system is shown in Figure 2.

Figure 2. Double-door sealed transfer system

Inappropriate Segregation of Waste In the past, wastes produced in glovebox lines may have been low-level waste (LLW), but were characterized as TRU due to interference from an external radiation-high background. (LLW is radioactive waste containing less than or equal to 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives less than or equal to 20 years.) In the CMRR, an assay room will be located in a Hazard Category III space. Only small quantities of plutonium will be allowed in this area, which will have improved shielding to reduce external radiation and hence, will increase waste characterization sensitivity. The overall effect is expected to be a reduction of waste inaccurately characterized as TRU and an increase in the proportion of waste accurately characterized as less costly LLW.

Excess Purchasing of Chemicals To minimize the disposal of unused chemicals, better administrative controls in the management of chemicals can be implemented. If waste generators know that surplus chemicals from a previous project are available, these surplus chemicals can be reused. A well-managed chemical container inventory system can address this issue.

Manually tracking hazardous material containers can quickly become a paperwork nightmare. If processes for the facile updating of storage location data are developed, the chemical container inventory system expands to serve also as a tracking system. Tracking systems are more complex to establish than simple inventories and require more effort to maintain, but their favorable impact on the economics and efficiency of chemical use in a large organization will often justify their use. Chemical inventory software programs are now commercially available.

Further improving the utility of an electronic tracking system is the use of bar codes. Bar-coding containers and container storage areas makes the tracking of chemicals more efficient.

Not only do chemical container inventory and tracking systems reduce the amount of chemicals purchased unnecessarily, but they can also assist in the storage of waste.

Excess Storage Of Waste An administrative control being considered for implementation in the CMRR addresses the storage of waste. The storage of waste costs $10,000 per square foot in a Hazard Category II nuclear facility, and so an administrative limit will be set on how much waste can be stored. Proper inventory of chemicals, equipment, and supplies will assist in keeping waste quantities lower.

Mercury-Containing Devices[3] Within the CMR Facility, mercury-containing devices were used for a variety of operations. Mercury present in these instruments does not in itself constitute a risk of contamination since the metal is contained within a closed system. However, breakage, inadequate maintenance, and disposal of such instruments can expose workers and the public to this toxic element.

To reduce the amount of mercury waste, newer commercially available instruments and tools that do not use mercury can be acquired to replace older mercury-based items.

1. Several mercury-free barometers and vacuum gauges are now available, with needle or bourdon gauges.

2. Accurate non-mercury thermometers are available that are filled with non-toxic red-dyed alcohol or with mineral spirits.
3. The replacement of mercury-containing manometers with electronic units eliminates the risk of breakage during operations or disposal. These electronic replacements are typically easier to use and provide more reliable data, as well as being safer and easier to move than the bulky mercury-containing units.
4. Another major source of mercury-laden waste is mercury containing fluorescent light bulbs. Non-hazardous fluorescent light bulbs are now available and will be recommended for implementation in the CMRR.

Spent Aerosol Cans In the past, there was no waste disposal option for aerosol cans that came from Radiological Control Areas (RCAs). Under normal conditions, spent aerosol cans represent a stored energy hazard. The potential fixed contamination on the can classifies it as a mixed waste. Employing an aerosol can puncturer eliminates the stored energy hazard. These systems are commercially available and consist of a small device that screws into the 2-inch bung on a 30-gallon or 55-gallon drum. A non-sparking tip punctures the can, and the residual liquid drains into the drum. A coalescing cartridge captures volatile organic material in the propellants. Since only the exteriors of the cans are contaminated, the liquid in the drum can be treated as normal hazardous waste. The metal can be decontaminated and sent to a recycling facility.[4] The volume of waste is reduced by 90%.

Washable Contamination Barriers Plastic sheeting has been placed on the floor in RCAs in the CMR Facility prior to almost all operations to simplify cleanup and prevent contamination from coming into contact with the floor and spreading. The used plastic sheeting is disposed as a major source of secondary LLW. Washable tarps will be considered in the CMRR. These tarps can be sent away for cleaning, returned to the site, and reused as often as feasible. The decision to use these tarps is based largely the past success of using launderable personal protective equipment. In addition, tarps tear less frequently and last longer than plastic sheeting.

Lead Substitutes[5] Many current and previous CMR operations generate large amounts of gamma radiation, primarily from various isotopes of uranium and plutonium.

In freshly purified plutonium, most of the radiation comes from *soft* (17-keV) x-rays. More penetrating (60-keV) gamma rays are emitted by ^{241}Am, which *grows in* as ^{241}Pu decays. (All grades of plutonium contain ^{241}Pu.) In plutonium more than 10 years old (since purification), these gamma rays are usually the source of most of the external radiation.

Although the major uranium isotopes decay by emission of alpha particles, they sometimes also emit gamma rays. Most of the high-energy gamma rays, which cause a deep dose (an external radiation dose that penetrates to the internal organs), arise from the daughter elements that *grow in* as the uranium ages. Important daughter elements are thorium, protactinium, radium, and radon. Gamma radiation dose rates from a large sheet of most types of uranium are generally less than 5 mrem/hour. Uranium-233, with its ^{232}U contaminant, is an exception. The daughter elements of ^{232}U and ^{233}U emit high-energy beta particles and gamma rays resulting in a dose rate of several rem/hour. As the ^{232}U decays, the concentration of daughter elements increases, causing the dose rate to increase by about a factor of 10.

A common method to measure a materials shielding efficiency is to compare the thickness of material needed to reduce the dose rate by ten-fold versus the gamma energy being shielded. The shielding efficiency of lead versus bismuth and tungsten are compared in Figure 3.[6] For gamma rays with energies over 2 MeV, tungsten is almost twice as effective as lead or bismuth. Although not shown in Figure 3, stainless steel has been found to provide effective shielding for the 60-keV gamma rays emitted from ^{241}Am.[7] Consequently, gloveboxes designed for work with old ^{239}Pu are made of stainless steel.

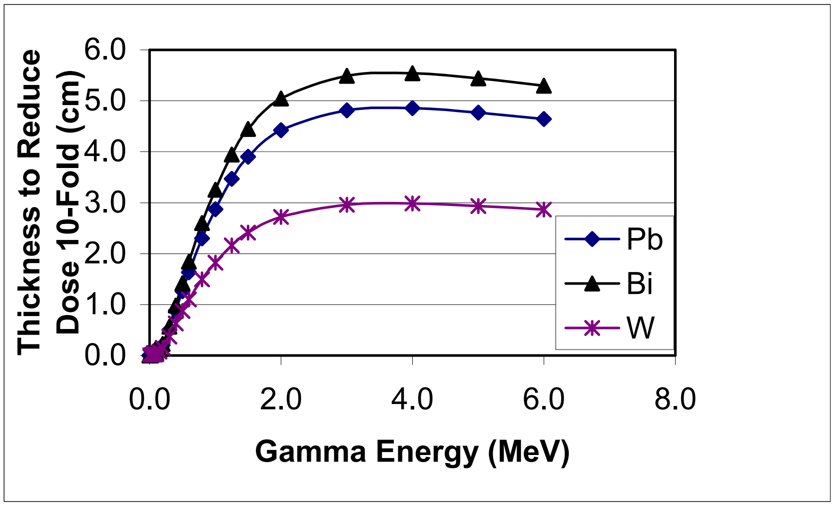

Figure 3. Comparison of Gamma Shielding Materials.

In summary, lead bricks have been used to protect workers from exposure to radiation. When practicable, complete elimination of lead in the workplace through the use of bismuth, steel, and tungsten, especially at nuclear facilities, is desired.

Other lead elimination efforts include the use of plastic crimps and lead-free aprons. Lead crimps are used as safety devices in backflow prevention maintenance operations. Replacing these with plastic crimps eliminates a hazardous waste in non-RCAs and a potential mixed waste in RCAs. Traditional x-ray and gamma photon shield aprons are constructed of lead vinyl. Lead aprons present a waste disposal concern at their end-of-life. Further, when lead aprons are used in a RCA, they have the potential to become radiologically contaminated. This presents an additional waste disposal concern, as the aprons then become a mixed low-level waste (MLLW). Commercially available lead-free aprons provide the same shield effectiveness as traditional lead aprons (0.5 mm lead equivalent at 100 keV).

Management of Chemical Spills In recent years, several potentially major chemical spills at the CMR Facility could have been avoided with more sophisticated chemical management. Because all materials released into the working environment must be considered highly toxic until proven otherwise, all liquid spills of substances that had not previously been formally identified were treated as emergencies, and clean up was done using Level A protection (positive-pressure, self-contained breathing apparatus, fully-encapsulating, vapor tight, and chemical-resistant suit). This was necessary even when workers 'knew' that the spill was, for example, simply machine oil and water. (In contrast to Level A protection, the Level D protection, appropriate for an oil and water spill, typically includes donning a lab coat, safety glasses, and gloves.)

Minimizing the number of unknown spills is now resolved through more sophisticated management of hazardous chemicals, so that in any given area, it is known before a spill occurs what chemicals may be found in that area. Thus, when a spill occurs, a level of protection appropriate to the hazard can be used.

The level of protection needed for a chemical spill in any room in the new facility should be predetermined based on the chemical inventory of the room. The predominant physical and chemical or toxic properties of the hazardous materials will dictate the type and degree of chemical protection that is required, and therefore, appropriate safety measures need not be as costly.

In a RCT, the difference in the amount waste generated and lost work hours during a major chemical spill and a minor spill is significant, as shown in Table I. A major spill cost about 20 times as much to clean up as a minor spill. Currently, an average of three chemicals spill a year occur in the CMR Facility. One of the spills typically requires the use of Level A PPE, while the rest require only Level C or D PPE.

Table I. Chemical Spill Cost Breakdown.

Criteria	Major Spill	Minor Spill
PPE	Level A or B	Level C or D
Clean-Up Effort	> 4 hours	< 1 hours
Number of Workers	4	1
Waste Generated	200 kg MLLW	20 kg MLLW
Cost	~$16000	~$800

Management of "Time Sensitive" Chemicals[8] Another area where chemical management could be improved involves the storing of "time sensitive" chemicals (materials that become unstable upon prolonged storage) and includes peroxide formers, nitrated chemicals, and perchlorates. In the past, crystals have been found in bottles of perchloric acid, concentrations of perchlorates above the action level (1.25 mg/m^3) discovered in the ductwork, and nitrated compound identified to be in an unstable form. Better management of these "time sensitive" chemicals can also minimize waste and lost work hours in the CMRR. Proper management include the following simple requirements:

- Purchases must be limited to the quantity that can be used before shelf life is reached.
- The disposal path must be determined before purchasing "time sensitive" chemicals. DOT forbidden materials must not be offered or accepted for disposal or transportation unless the material is diluted, stabilized, or incorporated into a device.
- The difference in the physical appearance between the stable and unstable form of "time sensitive" chemicals must be known before the material is ordered.
- For disposal of peroxide forming chemicals, the content must be tested with peroxide test strips and immediately placed in a less-than-90 day storage area. This limited time reduces the risk that material becomes unstable while being stored as waste.
- Reactive nitro, chlorate, and perchlorate compounds that are known to react with organic and inorganic contaminates producing highly sensitive and explosive salts (e.g., picric acid, styphnic acid and their salts with metal contaminants) must be used or disposed of in five years.

Lithium Battery Replacement Spent lithium batteries, generated by the use of electronic pipettes in gloveboxes, have been a significant source of MLLW in the CMR Facility for several years. There is now a commercially available source of electronic pipettes that run off of AC adaptors that should be used.

Pyrolysis Process Emerging processes that reduce the amount of waste generated at the CMRR should be also be considered. Thermal treatment is a process designed to destroy organic wastes by subjecting materials to oxidation at elevated temperatures. Incineration is the most common of the thermal treatment technologies. Basically, incineration is a process where organic materials are reacted with oxygen at elevated temperatures (usually between 425 °C and 1650 °C). In principle, this oxidation reaction yields carbon dioxide and water vapor as combustible products. Since hazardous waste can be complex, the resulting combustible products may be oxides, acids, ash, and/or gaseous vapors. Therefore most incinerators require a sophisticated scrubber system to minimize contaminants in gaseous by-products. Unfortunately, due predominantly to negative public sentiment, incineration is not a viable mixed waste treatment option.

The operation and maintenance of processes in the CMRR will result in the generation of a variety of cellulose materials that are contaminated with actinides. In an effort to stabilize these materials and to recover the actinides, a pyrolysis process with conversion has been developed.[9] Pyrolysis differs from incineration in that it destroys waste in the absence of oxygen and at very high temperatures. Because of the lack of oxygen, the production of oxides is reduced or eliminated. In the current process, cellulose materials are decomposed in a high-temperature chemically inert environment, and the resulting decomposition products are volatilized and removed from the actinides as an off-gas. The remaining material is reduced in both mass and volume, and is in a form suitable for the convenient recovery of the actinides. The process also incorporates a catalytic conversion step to oxidize the decomposition products. This step eliminates the formation of any potential waste streams, and effectively mitigates any flammable or combustible hazard that would compromise the safety of the process. Total mass reduction of waste is ~80%. The actinides are later recovered using conventional separation and purification processes. In addition, the process also has been ergonomically designed and optimized for glovebox operations. The process is already in use at the Plutonium Facility at Los Alamos National Laboratory. The system is displayed in Figure 3. Since pyrolysis is a form of treatment, this process is subject to the Resource Conservation and Recovery Act (RCRA).

Figure 4. Pyrolysis process with catalytic conversion

DISCUSSION

Implementation Criteria The technical validity of these pollution prevention initiatives is the most important criteria of this assessment process. All the above-discussed processes meet or exceed the requirements of the systems or processes they replace. The next criterion is relevancy. Each of these pollution prevention initiatives that has been demonstrated responds to an identified need. In addition, each of these pollution prevention initiatives has been found to be superior to existing technologies. The third issue that implementing pollution prevention initiatives raises is whether the cost is acceptable. Many emerging technologies may be technically sound and lower the risk associated with the process they seek to improve and yet may be economically unacceptable or legally challenging. From a business viewpoint, the acceptable level may be achieved when the costs of decreasing a given risk further are greater than the costs realized from the occupational exposure due to hazardous chemical operations.

Cost/Benefit Analysis Estimated volume of waste were determined using FY02 values for the CMR Facility. Rates of disposal were obtained from the current LANL waste recharge rates.[10] Assuming the expected life of the CMRR will be similar to the existing CMR Facility (~50 years), the following major cost savings from the improvement discussed in the previous sections were estimated.

- **Mercury Containing Devices** About 5 kilograms of liquid mercury has accumulated in the CMR. Cost of disposal is estimated to be $7,000.[3] By using mercury substitutes; this cost would be eliminated in the CMRR.

- **Spent Aerosol Cans** The current volume of waste generated by spent aerosol cans in the CMR Facility RCA fill 5 55-gallon drums and is classified as MLLW. The cost of disposal is $11,000 per year. By employing an aerosol can puncturer, a saving of about $495,000 should be realized over the lifetime of the CMRR Facility.
- **Plastic Sheets** About 0.25 m^3/year, ~$5,000 per year, is spent on plastic sheets in the CMR Facility. By using washable contamination barriers, a saving of about $250,000 should be realized over the lifetime of the CMRR Facility.
- **Lead** About 8300 kilograms of lead mainly in the form of shielding material has accumulated in the CMR. Cost of disposal is estimated to be $264,000. By using lead substitutes, this cost would be saved in the CMRR.
- **Chemical Spills** The majority of chemical releases are declared major spills because of the unknown identity of the material. If one assumes that ninety percent reduction of the major spills in the CMRR should occur with through more sophisticated chemical management, a saving of about $684,000 could be realized over the lifetime of the building.
- **"Time Sensitive" Chemicals** While no incidences involving the detonation of "time sensitive" chemicals have occurred in the existing CMR Facility, one incidence would cost approximately 1 million dollars. By implementing the above controls, the likelihood of this accident scenario is minimized.
- **Organic Waste** The current volume of organic waste generated in the CMR Facility RCA 8 m^3/year and is classified as LLW. The cost of disposal is ~$4,500 per year. By employing a pyrolysis process, a saving of about $142,000 could be realized over the lifetime of the CMRR Facility.

Costs are compiled on Table II. In summary, over 1.8 million dollars in saving is predicted, if these CMRR improvements are implemented.

Table II. Cost Savings from CMRR Improvements.

Waste Type	Waste Category	CMR $K/year	CMRR $K/year	TOTAL SAVINGS $K
Mercury Containing Devices	MLLW	0.1	0.0	7
Spent Aerosol Cans	MLLW	11.0	1.1	495
Plastic Sheets	LLW	5.0	0.0	250
Lead	MLLW	5.3	0.0	264
Major Chemical Spills	MLLW	16.0	2.3	684
Organic Waste	LLW	4.5	1.7	142
Total		41.9	5.1	1842

Government Expectation Several expectations from the DOE, other federal agencies and the State of New Mexico would be partially fulfilled if these improvements were implemented. All of these improvements represent either elimination of waste or reduction of waste and labor.

SUMMARY

Primary programmatic uses of the CMR Facility have not changed significantly since it was constructed. With the discovery of a potential fault under the CMR Facility, it was proposed to replace it by 2010 with the CMRR. P2/WMin will be implemented during the facility operation of the CMRR with the overall objective of minimizing raw material consumption and waste generation. Pollution prevention opportunities that reduce the use of raw material and labor, and promote material substitution and reuse have been presented. An estimated 1.8 million dollars in cost saving is expected, if these improvements are implemented.

ACKNOWLEDGEMENTS

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