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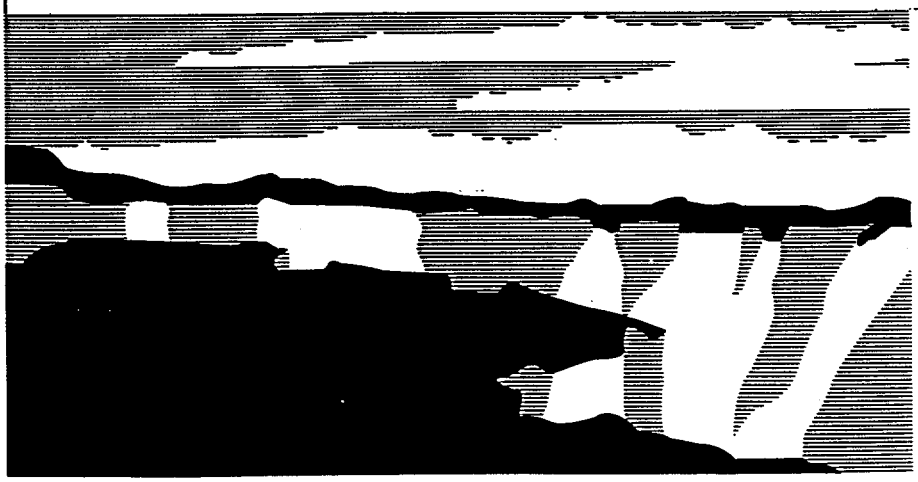

Los Alamos
NATIONAL LABORATORY

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Application Of Molten Salt Oxidation for the Minimization and Recovery of Plutonium-238 Contaminated Wastes

By
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May 1998

For
CH-NE 552
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Summary

Plutonium heat sources are used for thermal and thermal-electric power supply on spacecrafts in deep-space missions to study our solar system. The typical plutonium heat source is a ceramic cylinder of plutonium-238 oxide ($^{238}PuO_2$) shaped into pellets less than a 3 cm in length and diameter. Production of plutonium heat sources at Los Alamos National Laboratory (LANL) has created $^{238}PuO_2$ waste materials. This waste is characterized as transuranic (TRU) waste. A large portion of the waste is considered combustible waste in the form of paper towels, Kimwipes™, and cotton rags containing fine plutonium residue leftover from production facility clean-up. The TRU waste must be disposed of, and current plans call for it to be transported to the permanent underground repository known as Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Drums of ^{238}Pu contaminated waste must be prepared, packaged, certified and transported to WIPP following strict requirements on container contents. Presently, requirements allow no more than 0.26 grams of ^{238}Pu contents per drum. The Los Alamos National Laboratory inventory of 55-gallon drums includes many drums that are over this limit and thus they will have to be repackaged to meet the WIPP waste acceptance criteria. In some cases one such drum will have to be repackaged into ten or more drums. The Los Alamos legacy waste inventory includes 262 ^{238}Pu drums that meet the limit, plus the 312 drums that do not meet the 0.26 gram limit[1]. These 312 drums will require repackaging to meet the limit and represent more than 4,400 drums once repackaged. The Los Alamos total legacy inventory represents a total mass of 1167 grams of ^{238}Pu.

Plutonium – 238 was created as a by-product of the former production of weapons-grade plutonium-239 (^{239}Pu). With the end of the Cold War, the United States has discontinued production of plutonium for use in weapons. Since ^{238}Pu is no longer produced, its monetary value has increased to $2500 per gram [2].

Molten Salt Oxidation (MSO) is proposed as a ^{238}Pu waste treatment technology that should be developed for volume reduction and recovery of ^{238}Pu and as an alternative to the transport and permanent disposal of ^{238}Pu waste to the WIPP repository.

In MSO technology, molten sodium carbonate salt at 800–900°C in a reaction vessel acts as a reaction media for wastes [3]. The waste material is destroyed when injected into the molten salt, creating harmless carbon dioxide and steam and a small amount of ash in the spent salt. The spent salt can be treated using aqueous separation methods to reuse the salt and to recover 99.9% of the precious ^{238}Pu that was in the waste. Tests of MSO technology have shown that the volume of combustible TRU waste can be reduced by a factor of at least twenty. Using this factor the present inventory of 574 TRU drums of ^{238}Pu contaminated wastes is reduced to 30 drums. Further ^{238}Pu waste costs of $ 22 million are avoided from not having to repackage 312 of the 574 drums to a drum total of more than 4,600 drums. MSO combined with aqueous processing of salts will recover approximately 1.7 kilograms of precious ^{238}Pu valued at 4 million dollars (at $2500/gram). Thus, installation and use of MSO technology at LANL will result in significant cost savings compared to present plans to transport and dispose ^{238}Pu TRU waste to the WIPP site. Using a total net present value cost for the MSO project as $4.09 million over a five-year lifetime, the project can pay for itself after either

recovery of 1.6 kg of Pu or through volume reduction of 818 drums or a combination of the two. These savings show a positive return on investment.

Introduction to Plutonium

Plutonium, a silvery radioactive metal with the atomic number of 94 is an element of the actinide series in the periodic table. Plutonium is physically warm because of energy released from alpha decay. Plutonium is the most important transuranium element because of its dual role as a nuclear fuel and as a nuclear weapons material.

In 1943, the World was at war and the Manhattan Project frantically worked to produce the world's first pieces of pure plutonium metal. At that time only milligrams of the silvery metal were in existence [4]. This was scarcely enough to measure. Today, fifty-five years later, roughly 1200 metric tons of plutonium exists in the world [5].

Plutonium is a dense metallic element. Plutonium occurs rarely in nature and only in minute amounts as the result of nuclear reactions with uranium ores. Therefore, plutonium is synthetically produced most efficiently in nuclear reactors. These nuclear reactors are fueled with natural uranium enriched with uranium-235 which splits or fissions, in the presence of neutrons. This fissioning process releases thermal energy (heat) and additional neutrons. Thus, this process is exploited for its thermal energy (heat) production. The additional neutrons produce a chain reaction as more neutrons cause more fission events. The excess neutrons not only cause fission they are also absorbed or captured causing transformation of elements in the reactor. Neutron capture

transforms natural ^{238}U into ^{239}U, which decays via ^{239}Np in a few days to produce ^{239}Pu. This is the process used to produce ^{239}Pu by the kilogram in nuclear reactors. Successive neutron capture produces other plutonium isotopes with mass number up to 244. These include ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{243}Pu. However, only ^{239}Pu and ^{241}Pu are readily fissionable by thermal neutrons.

Uses of Plutonium

In the military context, the purpose for developing plutonium is for creating nuclear weapons. While all isotopes of plutonium are fissionable and thus can be turned into nuclear weapons, only mixes of ^{239}Pu and ^{241}Pu are of interest to weapons designers.

Weapons grade plutonium contains more than 90 percent ^{239}Pu. In this form, ^{239}Pu has a half-life of over 24,000 years and emits only alpha particles which do not have energy to penetrate the skin and thus can be handled with ease. Plutonium used in nuclear weapons usually contain only a small fraction of ^{241}Pu, as ^{241}Pu has a short 14 year half-life and decays to ^{241}Am which is an intense emitter of both alpha particles and gamma rays. Americium can quickly accumulate in plutonium resulting in radiation hazards that require additional shielding and making handling more difficult. While ^{241}Pu poses problems for safeguards and handling, the presence of even-numbered nuclides of plutonium present the most serious problems for weapons design. These problems include increasing the critical mass of plutonium required for a weapon. Thus, when grading plutonium for weapons use, the distinction "weapons grade" refers to plutonium containing less than seven percent (weight) ^{240}Pu [6].

In the commercial context, plutonium has economic value as it can be used as a fuel in nuclear power plants. Nuclear power reactors produce plutonium in their uranium fuel assemblies. Again the process is neutron capture as described above that transforms materials and can be expressed by the reaction:

$$^{238}U + n \rightarrow {}^{239}U \rightarrow {}^{239}Np \rightarrow {}^{239}Pu$$

Thus, uranium fueled reactors also vicariously contain plutonium that fissions in the reactor also producing heat in the process of producing power.

There is one additional nuclide of plutonium that has an important use. That nuclide is ^{238}Pu and it is used as a heat and thermal-electric power source for terrestrial, oceanographic and deep-space applications. It is available from neutron irradiation of neptunium-237 by the following reaction [7]:

$$^{237}Np\ (n, \gamma)\ ^{238}Np\ \ \beta^{-}\ 2.1\ day\ \rightarrow\ ^{238}Pu$$

Neptunium – 237 has been separated from fuel of plutonium production reactors. The primary source of which is:

$$^{238}U\ (n, 2n)\ ^{237}U\ \ \beta^{-}\ 6.7\ day \rightarrow\ ^{237}Np$$

or by the ^{235}U pathway which is as follows [8]:

$$^{235}U\ (n,\gamma)\ ^{236}U\ (n,\gamma)\ ^{237}U\ \ \beta^{-}\ 6.7\ day \rightarrow\ ^{237}Np$$

Since the beginning of the space age, plutonium-238 oxide has been used as an excellent heat and thermal-electric energy source. Plutonium-238 is a radioactive material that alpha decays with an 87 year half-life. In doing so it gives off thermal energy and thus ^{238}Pu is used as a general purpose heat source (GPHS) or radioisotope

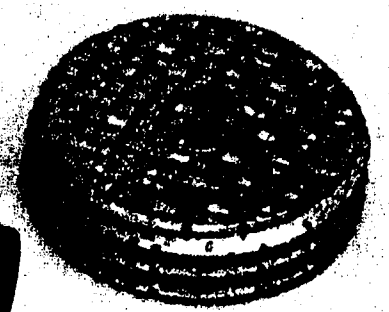
thermoelectric generator or RTG. The United States has used RTGs in space flights of satellites and deep–space probes since 1961. Spacecraft missions including Apollo, Pioneer, Viking, Voyager, Galileo, Ulysses and most recently Cassini have all employed RTGs for onboard power. The heat sources are fabricated into cylindrical pellets typically having a height and diameter of three centimeters and weigh 150 grams. A heat source this size has a power output of about 60 watts. The heat can then be converted into electricity through thermal–electric converters, typically a silicon-germanium thermopile and the electricity then powers instruments onboard the spacecraft [9]. Unlike a conventional battery, which relies on chemical action, the heat source can last up to 30 years.

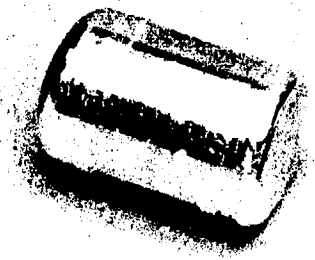
Purity specifications for ^{238}Pu heat sources are stringent as small amounts of impurities can interfere with the proper function of the heat source. This high purity ^{238}Pu has been produced in U.S. military reactors by neutron irradiation of neptunium-237. This ^{238}Pu production is in addition to the primary mission of producing ^{239}Pu for the plutonium used in the nuclear weapons program.

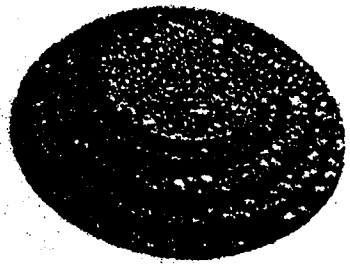
The Los Alamos National Laboratory Plutonium Facility has processed $^{238}PuO_2$ heat sources for the past couple decades and as a result has generated ^{238}Pu contaminated wastes. Unlike the other plutonium wastes, that are primarily ^{239}Pu, ^{238}Pu wastes are more difficult to dispose of than other transuranic (TRU) wastes as ^{238}Pu has a high heat load characteristic, as well as curie content of 17Ci/g compared to 0.06Ci/g of ^{239}Pu.

RADIOISOTOPE HEATER UNIT

- HEAT OUTPUT - 1 WATT
- FUEL LOADING - 33.6 CI
- WEIGHT - 1.4 OZ
- SIZE - 1 IN x 1.3 IN







Today, the nuclear arms race, or the Cold War is over. Our nation's interest in mass producing large quantities of plutonium has ceased. In 1995, President Clinton announced that 200 metric tons of fissile materials would be withdrawn from the United States' nuclear weapons stockpile. Approximately 50 metric tons of the declared excess are plutonium and must be managed or disposed of in the near future. Since 1989, all 14 of the plutonium–producing reactors in the United States have been shut down. Further, by agreement reached in September 1997 at the ninth U.S. – Russian Joint Commission on Economic and Technological Cooperation, the U.S. is prohibited from restarting any idled plutonium-producing reactors [10]. Today, as we approach the next millennium a new era exists for cooperation between the U.S and Russia for nuclear arms reduction resulting in a great surplus of weapons material. Progress and continuation of disarmament are beyond the scope of this paper, however the subject leaves a large question which is central to this paper, "where will our future supply of ^{238}Pu come from now that the U.S. has permanently stopped production of weapons-grade plutonium?"'

The answer proposed here is that some of the future supply can be recovered from that which presently exists as residue or TRU waste left over from existing or past ^{238}Pu fabricating and test activities.

This paper will examine the radioactive waste inventory at Los Alamos National Laboratory for radioactive waste containing ^{238}Pu. This will include a review of the planned disposition of this waste and assess the feasibility of recovering this ^{238}Pu for reuse.

Transuranic Waste (TRU)

Radioactive waste that contains alpha particle emitting elements of atomic number greater than 92 and a half-life of greater than 20 years are called transuranic waste or simply TRU waste. Since all plutonium isotopes are alpha emitters of atomic number 94 with half-lives longer than 20 years they are considered TRU waste. TRU materials by definition have and activity of more than 100 nCi/g and at Los Alamos National Laboratory examples include contaminated equipment, rags, paper, and protective clothing and other waste produced from routine Laboratory operations. TRU waste is classified according to the radiation dose rate at a packages surface. Contact-handled TRU waste has a surface radiation dose rate of less than 200 mrem/hr. Personnel can safely handle this waste. Remote–handled TRU waste has a radiation dose rate at a package surface of greater than 200 mrem/hr and must be handled remotely with equipment designed to distance or shield workers from the radiation.

Disposal of TRU

Since 1981 the U.S. Department of Energy has been working to develop the Waste Isolation Pilot Plant (WIPP) to demonstrate the safe disposal of TRU waste in a mined repository in a ancient salt bed 2100 feet below the earth's surface. The salt deposit is about 25 miles east of Carlsbad, New Mexico. The WIPP underground disposal project is now complete and stands ready to open with a storage capacity of 170,000 cubic meters of TRU waste. The Waste Isolation Pilot Plant (WIPP), is the U.S.'s intended repository for "defense-related" transuranic wastes and may open as early

as June 1998. When this occurs, wastes generated from research, development and production of nuclear weapons at DOE sites across the country, including LANL, will be shipped by truck to WIPP. A national campaign of approximately 38,000 shipments is expected to continue for over 35 years [11].

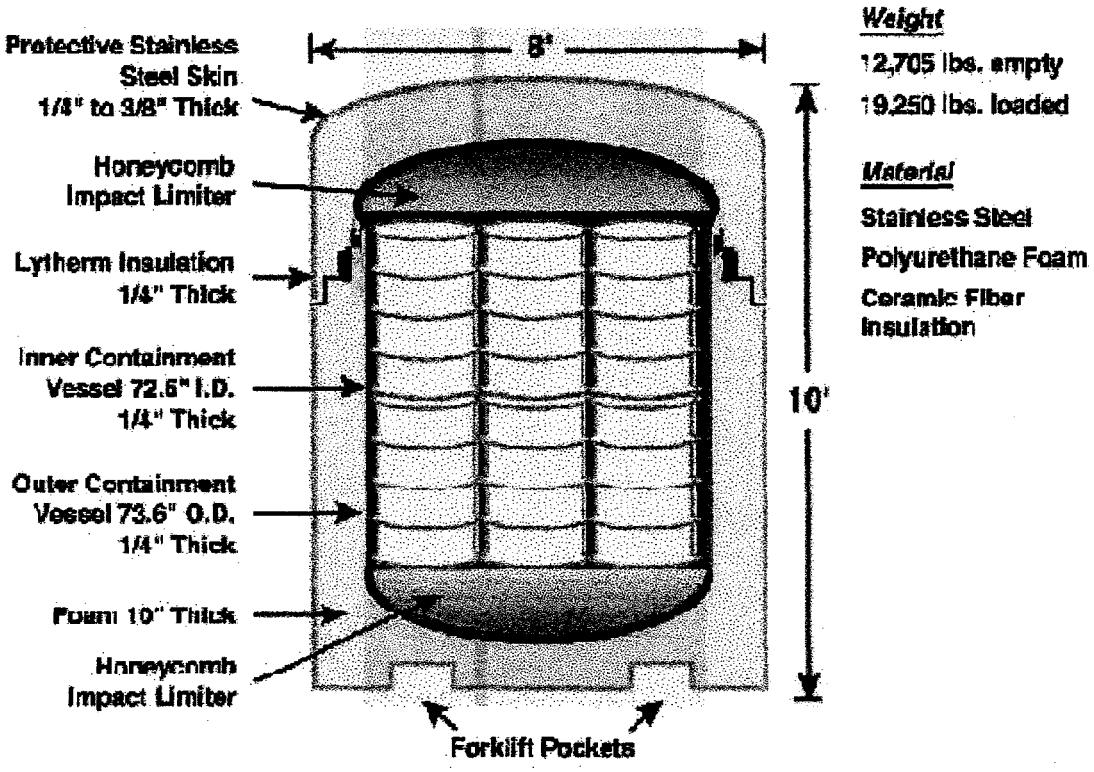
All contact-handled transuranic wastes destined for WIPP will be transported in the Transuranic Packaging Transporter (TRUPACT-II). This is a reusable shipping container or "cask," certified by the Nuclear Regulatory Commission (NRC). No more than three TRUPACTs, each holding up to fourteen 55-gallon drums of waste, will be hauled at any one time. A diagram of the TRUPACT-II is shown below [12].

TRU Waste Management Plans For Los Alamos

Before 1972, transuranic waste at LANL was disposed of in pits or trenches in shallow land burial. From 1972 to 1988, waste was retrievably stored under earthen covers in trenches for most TRU waste, while a small portion was stored in shafts for remote-handled TRU waste. Since 1988, the low level or contact-handled TRU waste has been stored in domes on pads. Presently, LANL's TRU waste is in interim storage awaiting shipment to the Waste Isolation Pilot Plant (WIPP). The Laboratory must characterize the TRU waste and certify that it meets WIPP Waste Acceptance Criteria. In September 1997, the Laboratory achieved a national milestone when it became the first Department of Energy site to attain certification authority to ship waste to WIPP. Los Alamos is planning its first shipment to WIPP in June 1998; all LANL waste is expected to be shipped to WIPP by 2015.

New Mexico's
WIPP Transportation Safety Program

TRUPACT-II



The TRUPACT-II has been certified to transport TRU waste to WIPP. The certification process includes stringent package testing.

The TRUPACT can hold up to14 55-gallon drums or 2 standard waste boxes of waste.

LANL currently generates approximately 100-200 cubic meters of TRU waste annually. Presently, more than 8,500 cubic meters of TRU waste representing more than 41,000 55-gallon drum equivalents are in retrievable storage at LANL's Technical Area - 54 Area G. The inventory will be characterized in accordance with Waste Acceptance Criteria (WAC) requirements to allow eventual shipment to the Waste Isolation Pilot Plant (WIPP).

The initial shipping campaign is based on the shipment of non-mixed TRU waste (meaning without Resource Conservation and Recovery Act (RCRA) hazardous constituents). Shipments of TRU mixed waste will begin after the state of New Mexico issues the RCRA Part B permit for the WIPP site.

A detailed inventory of LANL's TRU waste is determined from analysis of TRU storage records that span the period of 1970 to present. As of this writing the total TRU inventory at LANL is more than 11,000 cubic meters (m^3) with as indicated above more than 8,500 m^3 in retrievable storage.

The total waste volume is broken down by categories of waste. The categories are as follows: soil, remote-handled, special case/unknown, cemented sludges, non-combustibles, combustibles, and metallic scrap and equipment. Table 1 [13] shows the major waste categories by their percentages of the total.

Table 1

Category	Percent of Total
Soil	1%
Remote Handled	1%
Special case / Unknown	4%
Cemented sludges	8%
Non-combustibles	40%
Combustibles	18%
Metallic	28%

The LANL Plutonium Facility, known as Technical Area (TA) -55 generates about 97% of LANL's TRU waste. In an average year TA-55 generates about 36 kg of Pu in TRU waste forms. These wastes must be characterized and managed according to strict TRU waste disposal procedures. Acceptable knowledge documentation is created for the TRU waste showing the process that created the waste. A waste profile form (WPF) is created for each waste stream describing the chemical and physical characteristics of the waste composition. This information is used to compile a data package of characterization and certification information for all TRU waste generated at TA-55. The data package contains detailed information on the TRU waste including its matrix and packaging configuration, number designation and codes. These codes include both LANL identification codes as well as, WIPP codes known as TRUCON codes [14].

This TRU waste characterization is in accordance with the LANL TRU Waste Certification Plan and associated Quality Assurance Plan. This plan is used to meet the requirements of the WIPP WAC Revision 5 ultimately resulting in knowing complete characterization of the TRU waste for each and every container of waste destined for disposal in the WIPP. Containers vary by type. The most prevalent is the 55- gallon drum, and as shown in the diagram a TRUPACT-II can hold up to 14 55-gallon drums or two standard waste boxes. Other container types used to ship waste but not as common as the 55-gallon drums are; the standard waste boxes (SWBs) which hold (4) 55-gallon drums, and the ten-drum overpack (TDOP) which contains ten 55-gallon drums [15].

The WIPP Waste Acceptance Criteria (WAC) certification process ensures that TRU waste meets WIPP acceptance requirements and that the waste can be transported to WIPP. WIPP WAC Criteria include the following:

Container Type (55-Gallon Drum, Standard Waste Box)
Weight Limit (< 1000 lbs. / 55-gallon drum)
Flammable Constituents (< 500 ppm flammable VOC's)
Pu Fissile Gram Equivalents (< 200 g/ 55-gallon drum)
TRU Curie Limit (< 80 PE-Ci / 55 gallon drum)
EPA Constituents (limited to EPA waste codes)
Thermal Power Limit (< 40 watts / TRUPACT-II)

Limits and safety requirements are placed on all TRU waste packages containing plutonium since nuclides of plutonium exhibit several chemical and physical properties that makes them dangerous. These include the following:

Nuclear Criticality, fissile gram equivalent (FGE) - a limit on the gram amount to ensure that the Pu cannot be in a critical mass that could result in a nuclear reaction, for example < 200 g/ 55-gallon drum. FGE restrictions are given in fissile gram equivalents to equate all the Pu nuclides to ^{239}Pu which is the most fissile.

Decay Heat or Thermal power – a restriction on the thermal power density of a container, for example 3.5 watts/m^3 for a package or 40 watts total per TRUPACT-II

Plutonium Equivalent Activity – equivalent activity in curies normalized to ^{239} Pu; for example ≤ 80 PE–Ci / 55-gallon drum; ^{239}Pu equivalent activity = 80 Ci ^{239}Pu or 88 Ci ^{238}Pu per 55–gallon drum thus 88 Ci ^{238}Pu ÷ 17.1 Ci/g = 5.14 g / drum .[DOE/WIPP-060]

Of the above restrictions the most limiting requirement for the ^{238}Pu is the decay heat or thermal power restriction. In order to ship ^{238}Pu a 55-gallon container can have no more than 0.26 g of ^{238}Pu in the package.

LANL TRU Waste Storage Records

LANL has been generating TRU wastes since its inception. Since 1970 TRU waste storage records have been complied in a computer database. The database serves as tool for determining the inventory of TRU waste and as a means of determining the volumes and characteristics of wastes that comply with the WIPP WAC requirements. The thermal power ratings for the TRU waste containers in the inventory are calculated using the fissile nuclide content information from the LANL TRU waste database.

A Search For ^{238}Pu Contaminated TRU Waste

The TRU databases were searched in order to determine the inventory and waste characteristics of ^{238}Pu TRU. The TRU database consists of four parts (or generations) spanning the years from 1978 to present. The four database parts were searched for 238Pu contaminated waste in a combustible form.

The database searches determined the present ^{238}Pu inventory to be 574 containers. For these containers the thermal power distribution of drummed waste plays important role in determining whether drums will meet the WIPP WAC criteria without being repackaged. For example, if a drum contains more than 0.26 g of ^{238} Pu it exceeds the transportation requirements and must be repackaged. Of the 574 containers, 262 were determined to meet the 0.26 g/ drum requirement. The 262 containers were determined to contain 21.6 total grams of ^{238}Pu. The remaining 312 containers will have to be repackaged to the 0.26 g/drum requirement. Repackaging increases the number of drums to 4,405 containing a remaining total of 1146 grams of ^{238}Pu. In summary:

Total Waste Inventory ^{238}Pu = 1167 g

Present number of drums/containers = 574

Containers within the limit = 262

Containers requiring repackaging = 312

Containers after repackaging = 4,405

Total containers to ship = 262 + 4,405 = 4,667

Total number of TRUPACT-II shipments = 333

Average Cost per drum to Repackage = $2,500

Total Repackage Cost $2,500 x 312 = $ 0.78 M

The above data show that there is a major cost with the present LANL plans to repackage and ship the ^{238}Pu segment of its TRU wastes to WIPP. Repackaging the 312 drums so that they can meet their thermal power limits is estimated at $ 0.78 M. The additional costs associated with shipping these 4405 drums to WIPP is estimated at $22 M. Clearly, great savings can be realized if LANL is able to identify and deploy alternative TRU waste treatment technologies which will reduce the large numbers of TRU drums in the waste inventory. Presently, the LANL plan for addressing this high number of waste drums is a "wait and see" approach. ^{238}Pu TRU wastes are stored in domes or on pads awaiting the WIPP to open, or for alternative TRU waste treatment technologies to come along to reduce the waste problem.

Alternative Waste Treatment Technologies

This paper selects Molten Salt Oxidation for deployment as a technology to both reduce the volume of combustible ^{238}Pu contaminated TRU waste and to recover the ^{238}Pu from the waste stream.

Molten Salt Oxidation

As presented above, in view of arms control agreements no new plutonium will be produced from the nation's military reactors. Further, the by-product production of ^{238}Pu is no longer available. This situation has resulted in an increased value of the presently existing supply of ^{238}Pu as ^{238}Pu continues to be in demand as a heat source material for

space missions. Current monetary estimates of the worth the existing ^{238}Pu is $ 2500 per gram.

The development of Molten Salt Oxidation technology thus has the dual advantage of reducing the large amounts of ^{238}Pu contaminated TRU waste that must eventually be shipped at a high cost to the WIPP. MSO also serves as a recovery technology to reuse highly valuable ^{238}Pu.

Molten Salt Oxidation technology has been around for the last twenty five to thirty years and has been extensively studied and evaluated in pilot and full-scale systems. The chemistry and properties of molten salts have been thoroughly characterized by the Molten Salts Data Center in the early 1960's at the Rensselaer Polytechnic Institute. The primary salt of interest to this technology is sodium carbonate.

Sodium Carbonate Salt

Sodium carbonate, Na_2CO_3, is commonly known as soda ash and has a long history of use as an industrial product. The principle use of soda ash is the production of other chemicals, mainly sodium hydroxide or caustic soda. Soda ash is used as a base in the Bayer process in aluminum production. Alumina is produced using soda ash treated with lime that converts to sodium hydroxide and is used to dissolve bauxite. In glass manufacture soda ash is used to lower the melting point of sodium silicates thus reducing the cost of production. From these and other uses high temperature industrial applications of sodium carbonate are well known [16].

Soda ash can be produced synthetically by the Solvay process using salt, ammonia, carbon dioxide and lime. Today, however it is more commonly produced from refining trona ore (sodium sesquicarbonate) from abundant deposits in Green River basin of Wyoming, and the Searles Valley in California's Mojave Desert. According to the United States Geological Survey [17] the annual production in this country is about 12 million tons. Thus, sodium carbonate is readily available as a commercial product. It's high temperature (molten) applications, physical properties, product specifications and material safety is well known. The physical properties of sodium carbonate, as typically found in a Material Safety Data Sheet (MSDS) sheet, are provided in the Appendix.

Recent Study and Interest In Molten Salt Oxidation

Much of today's knowledge of the molten salt oxidation technology can be credited to the work in the 1970's performed by Atomics International (then a division of Rockwell International now the Rocketdyne Division of Boeing) in Canoga Park, CA. Atomics International investigations were performed as bench scale; pilot scale and full-scale tests using molten salts initially to scrub sulfur oxides from coal combustion flue gases, and subsequently as a catalyst for coal gasification studies. This work branched into experimentation on the molten salt oxidation processes for a host of applications including as a means of destroying hazardous chemical wastes, poison gases, pesticides, destruction of Polychlorinated Biphenyl's (PCBs) and as a recovery technique for metals including silver, antimony, aluminum and tin. These studies and tests never reached full maturation of the technology however, because at the time, the alternative treatment

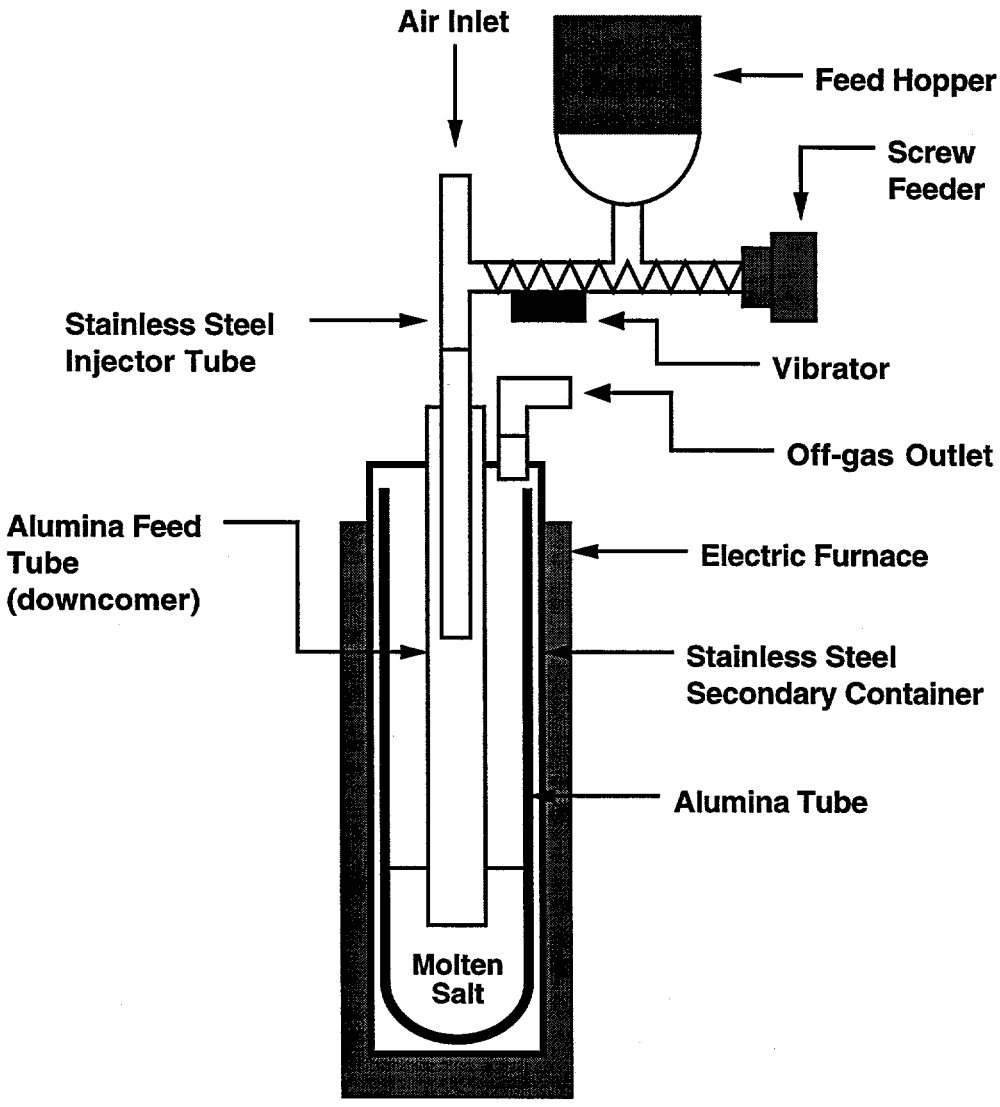
method, namely hazardous waste incineration, was less expensive. And until 1980 air pollution regulations for incinerators were almost non-existent.

Recently, molten salt has gained renewed interest. One reason is that the U.S. EPA regulations for incinerators are now extremely rigorous. Public resistance to hazardous waste incineration has grown so strong that even when trial burn and operating permits are issued to owners of incinerators rarely are they fully licensed and operated. Thus, hazardous waste incineration has become a non-option in the 1990's. For the opposite reason interest in molten salt oxidation is growing. Since the technology results in no off-gases or air emissions the EPA regulations are much less onerous.

Basic Description of the Molten Salt Oxidation Technology

Molten Salt Oxidation, or MSO for short, uses a flameless reaction to oxidize organic wastes. The reaction takes place in a molten pool of salt, usually sodium carbonate, at atmospheric pressure and at temperatures ranging from 900°C to 1000°C. Molten salt [18] in a reaction vessel acts as a heat transfer and reaction media for wastes that are injected along with air. The waste material and air are injected into the molten salt vessel causing mixing and complete oxidation of the waste. Gases generated are the result of organics reacting with oxygen producing carbon dioxide and water in the form of steam, nitrogen and any unreacted oxygen. The combustible waste is consumed in the salt melt, while the inorganics, neutralized salt and undissolved inert impurities are retained in the melt. When the concentration of undissolved impurities reaches about 20 weight percent, the spent salt is drained off and fresh salt is added to the system. The

Molten Salt Oxidation Reactor



system is preheated electrically and once up to temperature, the temperature is controlled by the feed rate of the waste and air which serve as a combustion heat source for the melt. Spent salt contains impurities, typically reaction products including sodium chloride, halide salts and ash which are disposed of as waste salt. The spent salt, salt- ash impurities mixture, can be disposed in metal containers which solidify and are then placed in 55- gallon drums. If there is anything in the waste salt worth recovering the salt can be processed (dissolved in water using filtration) to separate insolubles for recovery, and then the carbonate fraction can be reused.

Molten Salt Oxidation Technology Applied For Recovery of ^{238}Pu Contaminated Waste

The MSO process can be applied to destroy the combustible matrix of ^{238}Pu contaminated waste. LANL generates ^{238}Pu combustible waste forms in operations at the $^{238}PuO_2$ heat source production line. Plutonium contaminated scrap items are generated from milling PuO_2, use of powders, excess reagents, surface oxidation and other associated solid and liquid clean-up activities resulting in a combustible organic ^{238}Pu waste stream. The waste form typically contains cellulose such as paper towels or Kimwipes™ that are used in cleaning up operations in the process line gloveboxes. Other combustible wastes include paper and cotton rags and sometimes rubber in the form of surgeon's gloves. These wastes are assayed for their ^{238}Pu content and the wastes are characterized in accordance with the WIPP waste acceptance criteria, and placed into waste boxes or 55-gallon drums. Lists from the LANL TRU inventory databases dating

back to 1978 have been reviewed to identify ^{238}Pu content in the wastes. Waste materials typically have ^{238}Pu concentrations in the 0.01 to 0.1 weight percent range. This means that drums contain from a few tenths of a gram to several grams of ^{238}Pu typically in oxide form.

A review of the LANL TRU ^{238}Pu combustible inventory results in the following breakdown as to an estimate for recoverable ^{238}Pu waste.

Number of Containers Ready to Ship, < 0.26 grams / drum	Weight of the Waste	Grams of the ^{238}Pu
262	14,543 Lbs (6,602 kg)	21.6 g

Numbers of Containers Not Ready to Ship, (> 0.26 grams/drum)	Weight of the Waste	Grams of the ^{238}Pu
312	16,518 lbs. (7,491 kg)	1146 g

The Repackaged Number of Containers to meet < 0.26 grams/drum (from the 509 Containers Not Ready to Ship)	Weight of the Waste	Grams of the ^{238}Pu
4405	Not Applicable	1146 g

The total estimate of ^{238}Pu in the existing inventory surveyed back to 1978 is 1146 grams of ^{238}Pu. The monetary value of this waste plutonium using $2500/g is $ 2.86 million.

Treatment of Plutonium Contaminated Waste

The Molten Salt Oxidation process has been successfully demonstrated to reduce the weight and volume of plutonium contaminated TRU waste. Atomics International (AI) developed in the mid-1970's a bench-top process that was used with plutonium-contaminated combustible wastes. The AI system showed that greater than 99.9% of the plutonium was retained in the salt melt during combustion. The small amount of plutonium that was not retained in the melt (<0.1%) was captured as particulate in the prefilter to the off-gas clean-up and filtration system. The AI tests showed less than 10^{-4} % of the plutonium was found in the off-gas condensate or on the HEPA filter [19]. The AI system used molten salt consisting of natural inexpensive sodium carbonate and about 10 wt. % sodium sulfate. In the MSO system, shredded waste was fed with air to the bottom of molten salt combustion reactor. The combustion gases exited via an off-gas line to a water trap and gases were then routed though a heat exchanger system where they were cooled and passed through HEPA filters and exhausted to the atmosphere.

The feed system tested surrogate waste material of paper (Kleenex™, Kimwipes™ and magazines), plastics (polyethylene and PVC) and rubber (surgeons gloves) with a variable speed feeder system and variable flow air-feed. The tests ran with actual plutonium contaminated waste of a concentration of 9×10^{-5} g/g and 1.1×10^{-3} g/g simulating actual TRU waste. Greater than 99.9% of the plutonium was retained in the melt in all tests.

Tests were also performed to show that plutonium could be recovered from the spent salt using aqueous recovery techniques.

The spent salt, sodium carbonate with sodium sulfate and sodium chloride was dissolved in water and filtered. It was found that 98% of the plutonium in the spent salt mixture was recovered using acid leaching. This plutonium was later purified using solvent extraction and ion exchange techniques. These tests were performed in glove-boxes in a bench scale configuration. The system was sized to process 0.2 kg/hr. From the success of these bench-scale tests AI built a pilot plant called the Molten Salt Test Facility (MSTF) where 50 kg/hr combustion tests (without plutonium) were performed. The results obtained with the MSTF were consistent with the bench-scale test confirming the MSO process as an effective volume reduction method. The AI data showed a volume reduction factor of 57 when plutonium recovery was used.

Since the AI tests in the 1970's other organizations have performed similar confirmatory studies of the MSO technology. Oak Ridge National Laboratory (ORNL) reported in 1995 on use of bench-scale MSO technology to destroy hazardous wastes composed of chloroform, 111 trichlorethane (TCA) and 2,4 dichlorophenol [20].

The Naval Surface Warfare Center (NSWC) is actively examining the use of MSO technology at its Indian Head Division (IHD). In recent tests performed in 1997 they have confirmed the feasibility of using MSO to destroy propellants, oils, paints and cellulose materials. Their results have been so encouraging that NSWC/IHD has collaborated with a newly formed consortium known as Molten Salt Oxidation Corporation for the design of a prototype waste destruction system.

Presently, a technical exchange and research project has been undertaken between LANL Nuclear Materials Technology (NMT) Division's Power Source Technology Group (NMT-9) and NSWC/IHD. This summer NMT –9 plans to test a surrogate ^{238}Pu waste in the NSWC/IHD molten salt oxidation reactor based on the AI design. The purpose is to determine the effectiveness (or a volume reduction factor presently assumed to be 20:1) of the combustion process for combustible waste forms typically produced by NMT-9 in their ^{238}Pu heat source production activities.

NMT-9 is evaluating a proposal from the Molten Salt Oxidation Corporation who will supply the NSWC/IHD MSO reactor. The proposed NSWC/IHD system is priced at approximately $300,000 includes the following capabilities [21]:

Reactor vessel – 10 inch diameter x 60 inch height oxidation chamber constructed of aluminized surface on a 0.5 inch Inconel 600 steel vessel

Cooling System – a closed loop water-cooled system to remove 20K BTU/lb salt

Electric Heaters – adjustable dual electrode 30 kW VRT each

Temperature sensors – 12 in-vessel thermocouples

Salt drain valve – a phase change salt drain valve for bleed and feed

Waste Feeder - variable speed screw feeder rated up to 26 kg/hr

Sparge Air Port – feeds air for combustion reaction control

Reactor vessel exhaust air – port for exhaust to zero release filtration

The MSO system operating plan calls for operating for 2000 hours per year with a nominal feed rate of 2 kg/hr. This nominal rate equates to processing up to 4,000 kg of combustible waste each year. It would take just over 5 years to work off the LANL baseline ^{238}Pu inventory since there are 21,932 kg (14,093 kg legacy + 7845 kg future) of combustible net weight in the baseline inventory (see discussion on page 25).

Cost-Effectiveness of MSO

This section examines the feasibility of deployment of MSO technology at LANL. Based on the foregoing discussion it is clearly of interest to reduce the volume of the of LANL ^{238}Pu TRU waste destined for the WIPP site when considering the economic value of recovering this ^{238}Pu for reuse and the high cost for shipping and WIPP disposal.

The feasibility of MSO must consider both the estimated project costs for deployment of MSO technology and the existing committed costs for the WIPP disposal option.

Establishing a Baseline for Comparison

The first step is to evaluate the cost-effectiveness of the MSO technology relative to the baseline existing WIPP disposal option, and then to estimate the cost savings should MSO be deployed [22]. The baseline option is the WIPP disposal of the LANL legacy inventory of ^{238}Pu, plus the future waste stream. For this evaluation we have defined the future forecasted period to be the next five years.

The existing baseline combustible inventory of ^{238}Pu, was determined to be 1564 grams in 574 containers. This consists of 262 drums that meet WIPP criteria and 312 that will have to be repackaged in order to ship to WIPP. An estimate of future ^{238}Pu waste streams for the period of 1998 to 2003 can be made by multiplying the ^{238}Pu combustible waste inventory generated in the last two years by 2.5. In the 24

months from 5/95 to 5/97 LANL generation of ^{238}Pu combustible waste was 131 containers weighing 6916 pounds containing 159 grams of ^{238}Pu. These values were multiplied by 2.5 to produce the five-year estimate of 397 grams of combustible ^{238}Pu from 1998 to 2003. For the baseline the legacy inventory and five-year future forecast totals are summarized as shown below.

Number of Containers (using 0.26 g/container)	Grams of combustible 238Pu
Existing Inventory = 574	1,167.6
In future forecast 1998 to 2003 = 1,526	397
Total = 2100	1,564

The legacy inventory represents 31,061(14,543 +16,518) pounds of net weight and the five-year forecast weight, which is based on averages, represents 17,300 pounds (7845 kg) net weight for a total container combustible weight of 48,000 pounds (21,932 kg) containing 1,564 grams of ^{238}Pu.

The WIPP disposal baseline is further estimated using the LANL TRU Waste Management Plan to collect committed costs for work off of the ^{238}Pu legacy waste. This plan calls for work off of 5000 drums per year of all forms of TRU at a cost of $23 million per year or a per drum average cost of about $5,000 (in 1998$) for drums requiring repackaging and $2500 per drum for those that meet the WIPP criteria.

312 drums repackaged to 4400 drums @ $5000 each	$ 22.025 M
262 drums legacy waste @ $2500 each	$ 0.655 M
1526 future drums in next 5 years @ $2500	$ 3.82 M
Total baseline	$ 26.5 M

The total cost to work off the legacy and future ^{238}Pu waste to the year 2003 can be estimated to be $ 26.5 M (in 1998$). Using an accelerated work off timetable of 8 ½ years the per year committed expenditure is $ 3.12 M (in $98) or a 5 year present value of $14.6 M.

Establishing MSO Project Costs

The capital costs to establish the MSO technology, in general are the one-time costs that occur at the beginning of the project. These include all the costs to get the MSO project operational. A proposed representative list of capital costs follows:

Capital Costs

A. Facility preparation $465,000	
Clearing space to house MSO	$10,000
Painting	$10,000
HVAC preparation	$20,000
Fire protection	$100,000
Security systems	$75,000
Permits	$150,000
Hazards Analysis	$100,000
B. Structures and Equipment $ 2,170,000	
MSO 10" Reactor and Controls	$300,000
Stainless steel glovebox housing	$500,000

Analytical instrumentation	$75,000
Process piping	$75,000
Aqueous recovery system	$500,000
Tanks	$200,000
Radiation Shielding	$100,000
Storage racks	$20,000
Handling equipment	$50,000
Feeder systems	$150,000
Off-gas emissions sampling	$200,000
C. Process Equipment $30,000	
Cost of parts and supplies	
Materials	$30,000
D. Non-process Equipment $150,000	
Office and administrative equipment	$ 50,000
Computer equipment	$30,000
Safety equipment	$40,000
Vehicles (forklifts)	$30,000
E. Utilities $15,000	
Plumbing, heating, lighting, water	$15,000
F. Labor $ 350,000	
Direct labor to install and system	
960 hrs (6 man-mo.) @$50/hr	$ 50,000
Engineering (6 man-mo.) @ $150/hr	$ 150,000
Licensing permits	$150,000
G. Other $40,000	
Rental of equipment	$4,000
Start-up and testing	
720 hrs (4.5 man-mo.)@50/hr	$36,000
Total	$3,220,000

Operating Cost per year

Direct Labor $490,000	
Direct labor to operate	
2 Full Time Employee @ $120K/FTE	$240,000
Direct labor to supervise @150K/FTE	$150,000
ES&H (Rad. Prot., IH, safety)	$100,000
Direct materials $60,400	
Consumables supplies	$15,000
Process materials and chemicals	$ 8,000
Sodium carbonate 10,000 kg/yr x $0.20/ kg)	$2,000
Utilities	
Electricity	
30kW per electrode @$ 0.09/kWh x 2000 hr/yr	$ 5,400
Wastewater treatment @ $per gallon	
Spare parts	$ 30,000
Overhead $20,000	
Maintenance cost	$10,000
Equipment rental	$10,000
General and Administrative $95,000	
Administrative Labor	$50,000
Project management	$25,000
Travel expenses	$20,000
Other $ 400,000	
Waste disposal 20:1 or 6 drums/yr	$15,000
Environment Safety & Health	$ 80,000
Drum excavation and segregation	
574 drums / 5yr = 114 drums @ $2500/drum	$285,000
Site decon / decommission activities	$20,000
Total Annual Operating Costs	$1,065,000

Based on the U.S. Office of Management and Budget Circular dated January 1998 [23] the real discount interest rate for cost-effectiveness for a 5-year project is 3.5 percent. Using this value, the total net present-value 5 year life cycle cost of the MSO

project is capital cost of $3.22M plus the present value of the annual operating cost of $4.98M. Thus the 5-year MSO project total net present-value cost is $ 8.20 M. This value is off-set by $ 4.10 M for the present-value of assumed recovery of 90% of the 1954 gram of 238Pu for a final net-present value cost of the MSO project of $ 4.10 M.

Recommendations and Economic Analysis for MSO Applied at LANL

The cost comparison summary between the baseline WIPP disposal and MSO is presented in below in the Table:

Table 2

Present-value of the 5-year life cycle costs (in $000)

Category	WIPP Baseline	MSO Project
Capital		$ 3,220
Operating and maintenance	$ 14,600	$4,977
Revenue from recovery of 90% of 238 Pu		$(4,104)
Total	$14,600	$4,093

This comparison shows that it is three times more costly to repackage and ship 238 Pu TRU waste to the WIPP when compared to recovery by MSO.

Actual results of the cost effectiveness comparison depend on many factors. The cost estimates presented in this paper carry some uncertainty. This is due in large part to

a lack of detail in the baseline WIPP project assumptions that are based on committed annual budget costs, but are not broken down in detail for their capital and operational components. Further, uncertainty exists in costs for aqueous recovery of ^{238}Pu from spent salt and subsequent cost to convert it to oxide. Los Alamos facilities have recovered plutonium from salts using several processes including; chloride anion-exchange, electrorefining (ER), direct aqueous recovery and pyroredox methods [24]. These recovery operations are beyond the scope of this paper, however it is fair to report that these processing technologies need to be scaled up to handle the MSO recovery and they produce liquid and solid wastes that must be properly disposed. Caustic solutions and filtrate wastes generated from the ^{238}Pu recovery processes will be treated at the LANL Liquid Waste Facility on a cost per unit volume rate which has been left blank in the Direct materials section of the Operating Costs estimate.

Given there is some uncertainty in the above estimates a remaining exercise is to perform a sensitivity analysis and parameter studies. This will determine how sensitive MSO total project costs are to variations in aqueous recovery methods on the back-end of the MSO process.

These uncertainties are caveats in the total cost comparison between the baseline WIPP disposal option and the MSO process. These caveats can be removed as the project scope moves from conceptual phase to refined detail resulting from the completed design phase. This will result in more accurate capital costs and operating expenses for use in determining the life-cycle cost of the project.

Conclusion

Serious consideration should be given to the implementation of Molten Salt Oxidation as a process to recover highly valuable ^{238}Pu residue in LANL TRU wastes. The MSO process serves to reduce the volume of waste destined for WIPP. The baseline disposal scenario would require existing drums of combustible ^{238}Pu waste to be repackaged to meet WIPP waste acceptance criteria. Repackaging swells the existing total inventory of drums from 574 to approximately 4600 (262 + 4405) drums. MSO volume reduction factors of 20:1 result in reducing the number of drums to 29. In the next five years LANL ^{238}Pu oxide work is estimated to generate 1526 drums of waste for the WIPP.

Consider the following:

- the costs avoided from not shipping 262 legacy drums equates to $0.655M
- the costs avoided from not shipping 4405 repackaged drums equates to $22 M
- the costs avoided from not shipping future 1526 future drums of estimated ^{238}Pu wastes generated in the next five years equates to $3.82 M
- the recovery value of the ^{238}Pu mass in the 574 waste drums is estimated at $4.1 M

The sum of costs avoided totals more than $26 M in contrast to the MSO total project 5-year cost of $ 4.09 M when adjusted for the recovery value ^{238}Pu. Clearly MSO is a cost-effective option.

Acknowledgements

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Appendix

Future Value and Present Value (PV) of Operating Costs

Calculate escalating operating costs from FY99 base year, future value FV

$FV = PV(1+i)^n$ nth year

$FV_{1999} = \$1.065M(1.0) = \$1.065\ M \quad n=0$

$FV_{2000} = \$1.065M(1.035) = 1.102\ M \quad n=1$

$FV_{2001} = \$1.065M(1.0712) = 1.141\ M \quad n=2$

$FV_{2002} = \$1.065(1.1087) = 1.181\ M \quad n=3$

$FV_{2003} = \$1.065M(1.1475) = 1.222\ M \quad n=4$

$PV = \text{sum } FV/(1+i)^n = \$5.711\ M / (1.035)^4 = \$4.977\ M$

Note: Based on OMB real discount rates effective January 1998 of 3.5% for 5-year projects. The same method was used to calculate the PV of 238Pu.

Using 90% of 1954 g 238Pu = 1758 g/ 5 yr x $ 2500/g = $0.879 M/yr

$FV_{1999} = \$0.879\ M(1.0) = \$0.879\ M \quad n=0$

$FV_{2000} = \$0.879\ M(1.035) = 0.910\ M \quad n=1$

$FV_{2001} = \$0.879\ M(1.0712) = 0.941\ M \quad n=2$

$FV_{2002} = \$0.879\ M(1.1087) = 0.974M \quad n=3$

$FV_{2003} = \$0.879\ M(1.1475) = 1.006\ M \quad n=4$

$PV = \text{sum } FV/(1+i)^n = \$4.710M / (1.035)^4 = \$4.104\ M$

The same method was used to calculate the PV of the WIPP baseline cost pro rated over 8 ½ years

Legacy and future 238Pu waste to the year 2003 can be estimated to be $ 30.24M (in 1998$). Using an accelerated work off timetable of 8 ½ years the per year committed expenditure is $ 3.12 M (in $98) or a 5 year present value of $14.60 M.

$FV_{1999} = \$3.12\ M(1.0) = \$3.12\ M \quad n=0$

$FV_{2000} = \$3.12\ M(1.035) = 3.23\ M \quad n=1$

$FV_{2001} = \$3.12\ M(1.0712) = 3.34\ M \quad n=2$

FV_{2002}= \$3.12 M(1.1087) = 3.46 M n=3

FV_{2003}= \$3.12 M(1.1475) = 3.58 M n=4

PV = sum FV/ $(1+i)^n$ = \$16.73 M / $(1.035)^4$ = \$14.60 M

Soda Ash (Sodium Carbonate, Anhydrous)

Material Safety Data Sheet | Date Prepared | 5/20/96 | Supersedes Date: | 12/18/95

1. Chemical Product and Company Description

OCI Chemical Corp. One Corporate Drive Shelton, CT 06484

Emergency Phone Numbers: FOR EMERGENCIES INVOLVING A SPILL, LEAK, FIRE, EXPOSURE OR ACCIDENT CONTACT: CHEMTREC (800-424-9300) IN THE UNITED STATES OR OCI (1-203-225-3100 or 1-888-278-1657); IN CANADA CONTACT CANUTEC (1-613-996-6666).

For Product Information: (800) 865-1774

Chemical Name or Synonym: DISODIUM CARBONATE; SODA ASH; CARBONIC ACID, DISODIUM SALT

Molecular Formula: Na2CO3

2. Composition / Information on Ingredients

Component	CAS Reg Number	OSHA Hazard	Percentage
SODIUM CARBONATE	497-19-8	YES	100

3. Hazards Identification

A. Physical Appearance and Odor: White granules solid, odorless

Warning Statements:
WARNING: CAUSES EYE IRRITATION. MAY CAUSE SKIN IRRITATION

B. Potential Health Effects

Acute Eye: Causes irritation.

Acute Skin: May cause redness, swelling.

Acute Inhalation: May cause upper respiratory tract irritation, lung irritation.

Acute Ingestion: Low acute oral toxicity. May cause nausea, vomiting, diarrhea, irritation, corrosion.

Chronic Effects: This product does not contain any ingredient designated by IARC, NTP, ACGIH or OSHA as probable or suspected human carcinogens.

4. First Aid Measures

First Aid Measures for Accidental:

Eye Exposure: Hold eyelids open and flush with a steady, gentle stream of water for at least 15 minutes. Seek immediate medical attention.

Skin Exposure: In case of contact, immediately wash with plenty of soap and water for at least 5 minutes. Seek medical attention if irritation develops or persists. Remove contaminated clothing and shoes. Clean contaminated clothing and shoes before re-use.

Inhalation: Remove victim from immediate source of exposure and assure that the victim is breathing. If breathing is difficult, administer oxygen, if available. If victim is not breathing, administer CPR (cardio-pulmonary resuscitation). Seek immediate medical attention.

Ingestion: If victim is conscious and alert, give 1-2 glasses of water to drink. Do not give anything by mouth to an unconscious person. Seek immediate medical attention. Do not leave victim unattended. To prevent aspiration of swallowed product, lay victim on side with head lower than waist. Vomiting may occur spontaneously. If vomiting occurs and the victim is conscious, give water to further dilute the chemical.

MEDICAL CONDITIONS POSSIBLY AGGRAVATED BY EXPOSURE:

Inhalation of product may aggravate existing chronic respiratory problems such as asthma,

emphysema or bronchitis. Skin contact may aggravate existing skin disease.

NOTES TO PHYSICIAN:

All treatments should be based on observed signs and symptoms of distress in the patient. Consideration should be given to the possibility that overexposure to materials other than this product may have occurred.

5. Fire Fighting Measures

FIRE HAZARD DATA:

Flash Point: Not Applicable

Extinguishing Media: Not combustible. Use extinguishing method suitable for surrounding fire.

Special Fire Fighting Procedures: Firefighters should wear NIOSH/MSHA approved self-contained breathing apparatus and full protective clothing. Dike area to prevent runoff and contamination of water sources. Dispose of fire control water later.

Unusual Fire and Explosion Hazards: Not combustible.

Hazardous Decomposition Materials (Under Fire Conditions) Carbon dioxide

6. Accidential Release Measures

Evacuation Procedures and Safety: Ventilate closed spaces before entering. Wear appropriate protective gear for situation. See Personal Protection information in Section 8.

Containment of Spill: Follow procedure described below under Cleanup and Disposal of Spill.

Cleanup and Disposal of Spill: Scrape up and place in appropriate closed container (see Section 7: Handling and Storage). Collect washings for disposal. Decontaminate tools and equipment following cleanup. Clean up residual material by washing area with water. Avoid creation of dusty conditions.

Environmental and Regulatory Reporting: Do not flush to drain. If spilled on the ground, the affected area should be scraped clean placed in an appropriate container for disposal. Prevent material form entering public sewer system or any waterways. Large

spills should be handled according to a predetermined plan. For assistance in developing a plan contact with the Technical Service Department using the Product Information phone number in Section 1.

7. Handling and Storage

Minimum/Maximum Storage Temperatures: Not Available

Handling: Do not get in eyes. Do not breathe dusts. Avoid direct or prolonged contact with skin.

Storage: Store in an area that is cool, dry, well-ventilated.

8. Exposure Controls / Personal Protection

Introductory Remarks: These recommendations provide general guidance for handling this product. Because specific work environments and material handling practices vary, safety procedures should be developed for each intended application. While developing safe handling procedures, do not overlook the need to clean equipment and piping systems for maintenance and repairs. Waste resulting from these procedures should be handled in accordance with Section 13: Disposal Considerations.

Assistance with selection, use and maintenance of worker protection equipment is generally available from equipment manufacturers.

Exposure Guidelines: Exposure limits represent regulated or recommended worker breathing zone concentrations measured by validated sampling and analytical methods, meeting OSHA requirements. The following limits (AGGIH, OSHA and other) apply to this material, where, if indicated, S=skin and C=ceiling limit:

PARTICULATES NOT OTHERWISE REGULATED RESPIRABLE FRACTION

	Notes	TWA	STEL
OSHA		5 mg / cu m	

Engineering Controls: Where engineering controls are indicated by use conditions or a potential for excessive exposure exists, the following traditional exposure control techniques may be used to effectively minimize employee exposures.

Respiratory Protection: When respirators re required, select NIOSH/MSHA approved equipment based on actual or potential airborne concentrations and in accordance with the

latest OSHA standard (29 CFR 1910.134) and/or ANSI Z88.2 recommendations.

Under normal conditions, in the absence of other airborne contaminants, the following devices should provide protection from this material up to the conditions specified by OSHA / ANSI: Air-purifying (half-mask / full-face) respirator with cartridges / canister approved for use against dusts, mists and fumes.

Eye / Face Protection: Eye and face protection requirements will vary dependent upon work environment conditions and material handling practices. Appropriate ANSI Z87 approved equipment should be selected for the particular use intended for this material.

It is generally regarded as good practice to wear a minimum of safety glasses with side shields when working in industrial environments.

Skin Protection: Skin contact should be minimized through use of gloves and suitable long-sleeved clothing (i.e., shirts and pants). Consideration must be given both to durability as well as permeation resistance.

Work Practice Controls: Personal hygiene is an important work practice exposure control measure and the following general measures should be taken when working with or handling this material:

1. Do not store, use, and/or consume foods, beverages, tobacco products, or cosmetics in areas where this material is stored.
2. Wash hands and face carefully before eating, drinking, using tobacco, applying cosmetics, or using the toilet.
3. Wash exposed skin promptly to remove accidental splashes of contact with this material.

9. Physical and Chemical Properties

Physical and Chemical properties here represent typical properties of this product. Contact the business area using the Product Information phone number in Section 1 for its exact specifications.

Physical Appearance: White granules solid.

Odor: Ordorless

pH: 1. at 1 wt / wt %

Specific Gravity: 1. at 20(C (68 F)

Water Solubility: Soluble 7 Wt / Wt % at 25(C (77 F)

Melting Point Range: 851(C (1564 F)

Boiling Point Range: Not Available

Vapor Density: Not Available

Molecular Weight: 105.99

10. Stability and Reactivity

Chemical Stability: This material is stable under normal handling and storage conditions described in Section 7.

Conditions To Be Avoided: Extreme Heat

Materials / Chemicals To Be Avoided: Aluminum, Fluorine, Humid Air, Moisture, Sulfuric Acid, Acids, Magnesium, Phosphorus Pentoxide

Decomposition Temperature Range: 400(C (752 F)

The Following Hazardous Decomposition Products Might Be Expected:

Decomposition Type: Thermal Carbon Dioxide

Hazardous Polymerization Will Not Occur.

Avoid The Following To Inhibit Hazardous Polymerization: Not Applicable

11. Toxicological Information

Acute Eye Irritation: Toxicological Information and Interpretation, Eye - Eye Irritation, 50 mg, Rabbit. Severely Irritating.

Acute Skin Irritation: Toxicological Information and Interpretation, Skin - Skin Irritation, Rabbit. Mildly Irritating.

Acute Dermal Toxicity: No Test Data Found For Product.

Acute Respiratory Irritation: No Test Data Found For Product.

Acute Inhalation Toxicity: Toxicological Information and Interpretation, LC50 - Lethal Concentration. 50% Of Test Species, 2300 mg/cu m/cu m/2hr, rat.

Acute Oral Toxicity: Toxicological Information and Interpretation, LD50 - Lethal Dose 50% Of Test Species, 4090 mg/kg, rat.

Chronic Toxicity: This product does not contain any substances that are considered by OSHA, NTP, IARC or ACGIH to be "probable" or "suspected" human carcinogens.

No additional test data found for product.

12. Ecological Information

Ecotoxicological Information: No data found for product.

Chemical Fate Information: No data found for product.

13. Disposal Considerations

Waste Disposal Method: Chemical additions, processing or otherwise altering this material may make the waste management information presented in this MSDS incomplete, inaccurate or otherwise inappropriate. Please be advised that state and local requirements for waste disposal may be more restrictive or otherwise different form federal laws and regulations. Consult state and local regulations regarding the proper disposal of this material.

Container Handling and Disposal: Rinse containers before disposal.

EPA Hazardous Waste - NO

14. Transportation Information

Transportation Status: US Department of Transportation

DOT Shipping Name: NOT REGULATED

15. Regulatory Information

FEDERAL REGULATIONS:

TSCA Inventory Status: All ingredients of this product are listed on the TSCA Inventory.

SARA Title III Hazard Classes:

Fire Hazard - NO

Reactive Hazard - NO

Release of Pressure - NO

Acute Health Hazard - YES

Chronic Health Hazard - NO

STATE REGULATONS:

This product does not contain any components that are regulated under California Proposition 65.

16. Other Information

National Fire Protection Association Hazard Ratings - NFPA(R):

2 Health Hazard Rating - - Moderate

0 Flammability Rating - - Minimal

0 Reactivity Rating - - Minimal

National Paint & Coating Hazardous Materials Identification System - HMIS(R):

2 Health Hazard Rating - - Moderate

0 Flammability Rating - - Minimal

0 Reactivity Rating - - Minimal

Reason for Revisions: Change and / or addition made to Section 1.

Key Legend Information:

NAV - Not Available

NAP - Not Applicable

ND - Not Determined

ACGIH - American Conference of Governmental Industrial Hygienists

OSHA - Occupational Safety and Health Administration

TLV - Threshold Limit Value

PEL - Permissible Exposure Limit

TWA - Time Weighted Average

STEL - Short Term Exposure Limit

NTP - National Toxicology Program

IARC - International Agency for Research on Cancer

Disclaimer: *The information herein is given in good faith but no warranty, expressed or implied, is made.*

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