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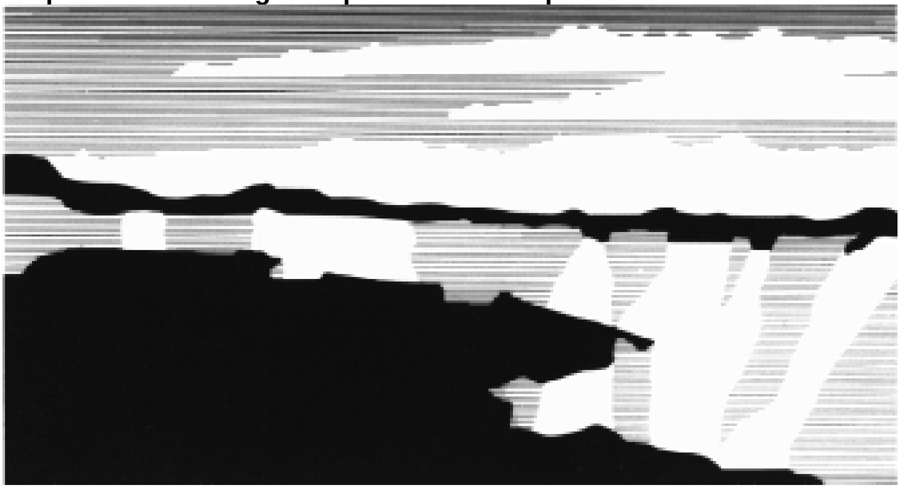

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I. Abstract

The primary emphasis of the Defense Nuclear Facility Safety Board, DNFSB, recommendation 94-1 was to quickly stabilize residues before their instability compromised safety. Most of the material covered by the recommendation has been declared surplus. Therefore, the plutonium incorporated within the residues has no programmatic use. To the contrary, there are costs associated with the storage and disposal of the residues, making the plutonium carry a negative ‘value’ or cost. At first glance, there can be no justification for plutonium separation.

Several trade-off studies, which were sponsored by DOE’s Nuclear Materials Stabilization Task Group (NMSTG) showed that plutonium separation was justified for some residue categories. Because, safeguards, transportation and safety considerations limit the amount of plutonium that can be sent per shipment to the Waste Isolation Pilot Plant (WIPP), it is less expensive to separate out the plutonium and disposition the material to the Materials Disposition Program (MD), than it is to ship the untreated residues to WIPP.

This paper incorporates the analyses from three different trade studies to show how the direct disposal/separate criteria changes as a function of plutonium content, disposal costs and processing costs. Since there differences of opinion and uncertainty about processing and disposal costs, sensitivity analyses are included. The information given in this paper will act as a general guide for disposition of residues that have not been formally studied by a trade-off study.

II. Introduction

Background

The U.S. Department of Energy (DOE) is currently storing approximately 26 metric tons of plutonium, excluding plutonium in intact nuclear weapons, spent nuclear fuel, radioactive waste and classified inventory. The plutonium materials are stored in various forms in a variety of facilities throughout the DOE complex. These facilities are located at Hanford, Washington; Lawrence Livermore, California; Rocky Flats, Colorado; Los Alamos, New Mexico; Mound, Ohio; and Savannah River, South Carolina. Many of the DOE facilities with plutonium in storage have not operated since weapons production abruptly halted in 1990. At that time, the shutdown was considered temporary, and little attempt was made either to empty the piping, tanks, or equipment or to place the plutonium in containers and packages that would provide safe storage for an extended period of time. As a result, thousands of containers of plutonium were considered vulnerable to leakage or rupture and pose a potential hazard to the DOE's workers, the public, and the environment.

These hazards prompted the Defense Nuclear Facilities Safety Board (DNFSB), a congressionally chartered organization which oversees the Department's nuclear operations, to issue Recommendation 94-1 on May 26, 1994. The essential elements of this recommendation emphasized the need to stabilize high risk material by May 1997 and the remainder by May 2002. The Defense Board also recommended that the Department employ an integrated, systems approach to stabilization efforts that would optimize the capabilities of the Department's facilities and integrate the effort across the DOE complex. The Recommendation requires attention to limiting worker exposure, minimizing generation of additional waste, and emission of effluents to the environment.

The Department of Energy accepted the Board's Recommendation on August 31, 1994. Subsequently, the Department broadened the scope of the response to Recommendation 94-1 to ensure that similar materials under similar conditions receive the same degree of management attention as those noted by the Board in its Recommendation. The Department developed an Implementation Plan which described the intensive stabilization work to occur through May 2002. This Plan was published in February 1995.

Through the development of the Implementation Plan, it became apparent that various sites with similar material intended to implement very different approaches to stabilization. Differences in stabilization approaches ranged from aqueous, glove box processing operations to recover the plutonium to disposal of the material as waste at the Waste Isolation Pilot Plant (WIPP) in New Mexico. These disparate, site specific approaches did not appear to be compatible with an integrated systems approach to stabilization.

III. Trade Studies

Methodology of Trade-Off Studies

An analysis of the various planned stabilization approaches and an identification of the technical requirements to which the stabilized material must adhere was required to understand how the different approaches interrelated. The various sites championed their approaches, exhorting the benefits in minimizing worker radiological exposure, waste generation, cost and time to implement. The Nuclear Materials Stabilization Task Group (NMSTG) created by DOE to integrate the Department's stabilization efforts, commissioned "Trade-Off" studies to investigate these differences, identify the technical objectives of stabilization and ascertain the uncertainties related to the various stabilization approaches.

“Trade-Off Study”, also known as a trade study, is a systems engineering term for a multi-variable attribute analysis. The analysis consists of identifying and defining the technical objectives and requirements at the beginning of the study. To provide a basis for comparison of alternatives, performance measures are defined to quantitatively assess the impact of each alternative. The performance measures used for the trade studies were: risk to public, risk to worker, waste generation, discharge to the environment and cost. Timeliness was a performance measure used as a screening tool. Any alternative which would not lead to completion of stabilization by May 2002 was eliminated or “screened out” of the study. These performance measures are defined later in the paper.

The Trade Study Work Group assessed each alternative with the identified performance measures. The key aspect of this analysis was to ensure the same assumptions, estimating techniques, and rigor were applied to each alternative. The purpose of this analysis was to develop a relative assessment of alternatives in each performance measure area. Utility function curves that best depict the impact of the performance factor under analysis were developed by the trade study group.

A utility function is a mathematical transformation that maps the set of outcomes of a performance measure into a numerical scale (0.0 to 0.1) to provide a methodology for comparing alternative performances. In other words, a utility function assigns a numerical value to each performance measure for each alternative. The cumulative score is the utility score for that alternative. Utility scores are then compared and reviewed by the trade study group to ensure that the scores accurately reflect the data and have a logical explanation. A “best” choice is then developed by the trade study team. The trade study results are not intended to pre-empt the decision maker's actions or calculate the answer. Their sole purpose is to aid the decision maker by ensuring that a systematic identification, assessment, and comparison of relevant technical issues occurs.

A key element to success is using the dynamics and synergy achieved by selecting the appropriate team for the job. The trade study team was carefully assembled to ensure that all stakeholders would be represented. The stakeholders included representatives from sites storing the material, scientists developing stabilization technologies, and facilities with existing treatment capabilities.

Although, members of the study team frequently had opposing viewpoints, team energy was channeled to define technical requirements and assumptions. Where consensus could not be reached, alternatives were constructed in which the impact of assumptions could be assessed. In some cases, outside specialists in niche technical areas were brought in to validate the technical basis of assumptions. The result is the development of a consistent set of technical assumptions through peer review, which are then used in the objective assessment of alternatives.

Trade Studies Focused on Plutonium-Bearing Residues

As noted, the DOE has approximately 26 metric tons of plutonium to stabilize. About 6 of the 26 metric tons are in a category called solid "residues." Residues were by-products of weapons production, which typically contained on average less than 50% plutonium by weight. Historically, the materials were stored rather than discarded because recovery of the plutonium from the matrix material was more economical than producing additional plutonium for weapons production.

Residues include impure oxides, metals, halide salts, combustibles, ash, sludges, dissolver heels, contaminated glass and metal, and other items. Although residues contain only 6 metric tons of plutonium, the plutonium and the residue matrix totals 125 metric tons in bulk, adding complexity to storage and treatment options. Because of concerns for material containment and nuclear criticality, treatment is usually limited to batches containing less than 500 grams of plutonium. The plutonium content in each batch varies widely within the different categories of material. Glove box equipment limits the amount of bulk material which can be processed at any one time.

The NMSTG selected material categories for the initial trade-off studies on residues and set up some ground rules for the trade studies. (1)The materials must have a defined end state such as WIPP or transfer to the Materials Disposition Program (MD). (2)The residues would be tracked for fifteen years, (an amount of time that should be more than sufficient to satisfy all DNFSB 94-1 issues) and (3) materials would not accrue any costs after the fifteen year window.

This paper presents the results of the trade studies for plutonium-bearing pyrochemical salts, combustibles, and sand, slag and crucible and discusses the volatile technical issues which will impact the stabilization of this material. Below is a brief description of the material and summary of trade study results.

Results of the Trade Study for the Disposition of Pyrochemical Salts

The Pyrochemical Salts Trade Study Group considered options for treating plutonium-bearing pyrochemical salt residues, about 18.2 metric tons in the DOE inventory. The bulk of the salts reside at Rocky Flats, 16 metric tons containing approximately 1 metric ton of plutonium. These salt residues resulted primarily from electrorefining plutonium metal, from direct oxide reduction of plutonium oxide to metal, and from operations to remove americium from plutonium metal. The salt matrix is either sodium chloride-potassium chloride (NaCl-KCl) or calcium chloride ($CaCl_2$). Safety concerns with these residues result from s reactive metals in the salt matrix, high radiation fields that degrade plastic packaging, and the corrosive nature of the chloride salts that can lead to container failure.

Salt residues at Los Alamos and Livermore will be processed through separations to produce plutonium metal or oxide for storage and waste with a relatively low radionuclide content. For handling the Rocky Flats salt residues, the Trade Study Group considered sixteen alternatives that fell into four general categories: (1) no action, (2) repackaging untreated salts and ship to the Waste Isolation Pilot Plant (WIPP) in New Mexico, (3) processing salts on site, and (4) shipping and process salts off site for processing. The processes considered included stabilization, separation, and immobilization technologies or combinations of these.

Of the alternatives assessed, the trade study group identified the four best alternatives for dealing with residue salts: (1) direct shipment to WIPP using a pipe component system to meet waste acceptance criteria; (2) shipment to Los Alamos National Laboratory for plutonium separation by salt distillation; (3) a combination of approaches consisting of salt distillaton at Los Alamos National Laboratory and salt scrub at Lawrence Livermore National Laboratory (with further processing of the alloy at Savannah River) with some pyro-oxidation stabilization at Rocky Flats; and (4) pyro-oxidation and distillation on site. Of the processes listed, distillation, salt scrub and alloy processing all are associated with concentrating the plutonium for transfer to MD.

This trade study revealed that each of these alternatives contain critical path items that can invalidate the alternative, if they do not eventuate. To minimize the schedule and financial risk associated with stabilizing plutonium salts, a multiple option approach should be pursued that does not prematurely exclude viable options before related critical assumptions have been validated or critical actions have been completed. The trade study identified several activities (e.g., characterization) that are common to multiple alternatives and must be pursued irrespective of the alternative selected. This approach focuses on achieving the Department's stabilization commitments listed in DNFSB Recommendation 94-1 Implementation Plan.

Results of the Trade Study for the Disposition of Sand, Slag and Crucible

The sand, slag, and crucible (SS&C) residues resulted from conversion of plutonium oxide to metal through hydrofluorination; the resulting plutonium tetrafluoride was reduced with calcium in a high temperature thermite reaction using a crucible surrounded with thermally insulating sand. The reaction yielded a pure metal button for further processing and a mixture of crucible shards, sand and a slag containing salts, metal, and oxides of plutonium, calcium, and magnesium. The safety concerns for the SS&C residues result from the presence of reactive metals (e.g. calcium and plutonium) that can generate hydrogen gas from reaction with water, high radiation fields that degrade plastic packaging, and the corrosive nature of the chloride and fluoride salts that can lead to container failure. Approximately 7.4 metric tons of SS&C containing 0.3 metric tons of plutonium are in storage. The majority of the, 3.4 metric tons material is at Rocky Flats. The DOE facility in Hanford, Washington also stores a significant quantity of SS&C, approximately 2.4 metric tons. The remainder is at Los Alamos and the Savannah River Site.

This trade study team considered twelve alternatives for the SS&C residues that fell into four general categories: (1) repackage untreated SS&C and ship to WIPP, (2) stabilize and immobilize SS&C on site for disposal at WIPP, (3) use existing SS&C separation processes on site, and (4) ship and process SS&C off site. The processes considered included stabilization, actinide separation, and immobilization technologies or combinations of these. Aqueous processing was the method of choice for concentrating the plutonium for transfer to MD.

Analysis of the Department’s stabilization plans for sand, slag and crucible resulted in the trade study team’s recommendation to cement (grout) the Hanford SS&C inventory. Rocky Flats SS&C material was recommended for aqueous processing at Savannah River. Both Los Alamos and Savannah River SS&C would aqueous process their residues in existing operations.

Results of the Trade Study for the Disposition of Combustible Residues

The combustible residues consist of a broad range of plutonium-contaminated materials that formerly were often treated by incineration to allow recovery of plutonium from the ash. These include such items as gloves, paper, tape, plastic, wood, and filter materials. The safety concerns with these residues include hydrogen gas generation from irradiation of the organic materials, flammability, and corrosion of containers for wet materials. Nearly all these residues, 21.6 of the 21.9 metric tons, reside at Rocky Flats.

Alternatives for handling the combustible residues considered by the team fell into the general categories: (1)repackaging and disposal at WIPP; (2) washing or dissolving methods to remove plutonium before disposal at WIPP; (3) removal of volatile organics before further processing; and (4) thermal or chemical processing on site or off site to destroy the organic matrix. The processes considered included aqueous washing, low temperature thermal desorption, mediated electrochemical oxidation (MEO), incineration, pyrolysis, molten salt oxidation, oxidation by relatively low temperature chemical methods, and hydrothermal destruction methods as well as combinations of these.

The major recommendations of the trade study team were to use cryogenic shredding for preparation of those combustibles requiring further processing and to implement (MEO) technology at Rocky Flats for leaching plutonium from certain residues and destroying the organic matrix in others. The MEO path generates limited amounts of transuranic (TRU) waste for disposal at WIPP and some plutonium oxide destined for long-term storage and transfer to MD. However, given the immaturity of the MEO technology, there was also a recommendation for continued development of aqueous washing and two different chemical oxidation technologies as back-up options.

Insights from the Trade Studies

Some general conclusions can be drawn from the trade study analysis. These insights are:

- The separation of plutonium from some residues is cost effective and minimizes generation of TRU waste for shipment to WIPP,

- Shipping of some Rocky Flats residues to Savannah River reduces costs, optimizes the use of existing facilities, and supports the closure of Rocky Flats by 2006,

- Plutonium separation operations can avoid multiple handling steps and produce metal or oxide for ultimate disposition,

- Because of continuing missions, Los Alamos, Lawrence Livermore, and Savannah River retain many of the plutonium processing capabilities that they had during the 1980's. Hanford and Rocky Flats have limited plutonium processing operations remaining. The differences in processing capability can lead to different approaches for stabilizing and disposing of residues at the sites. DOE's challenge is to integrate the application of these capabilities to give the greatest improvements in scope, cost, and schedule through the use of the trades study process.

- These trade studies contain important data and analyses to help the DOE field operations and contractor personnel refine the treatment methods for plutonium-bearing residues. They also identify needs for technology development. Most of these technology needs are being addressed by the research program managed by Los Alamos National Laboratory and the Nuclear Materials Stabilization Task Group. There are technical approaches and assumptions in the trade studies that still need to be validated.

IV. Disposition Paths

The NMSTG chose two potential pathways for disposal of stabilized residues in the trade studies. The first is shipment of material to WIPP as waste. Material that has been processed to meet criteria in DOE STD 3013, can be stored for the long term and ultimately transferred to the MD program. This material is comparatively rich in plutonium compared to the waste materials sent to WIPP.

These disposition options were the only two practical approaches available at the time that the NMSTG chartered the trade studies. The options were to either dispose of the waste or to process the materials into a form that is acceptable to the receiving program. A simple stabilization and repackaging to meet interim storage requirements would have met the requirements of DNFSB recommendation 94-1. However, this material would have to be processed again in the future, and there is no assurance that funding or facilities will be available. Therefore, the material has to be processed sufficiently to meet the acceptance standards of a program that will be around in the future, namely MD.

Both of these disposition paths entail packaging and transportation. The transportation requirements for WIPP are quite restrictive. In order for WIPP to be usable, material must be packaged up in a form that meets WIPP Waste Acceptance Criteria (WIPP WAC) and transported from its current location to the WIPP site. The only practical container for shipment of materials to WIPP is the TRUPACT II container. The TRUPACT II specifications restrict the amount and form of the plutonium residue that can be shipped and have a large influence on the cost structure of WIPP disposal options.

The TRUPACT II is a heavy walled, hermetically sealed, stainless steel container. Each container can hold two layers of seven standard 55- gallon drums. However, based on accident scenario criticality calculations, the fourteen drums of waste are allowed to contain a total maximum of 350g of plutonium. At an average loading of approximately 100Kg / drum, this equates to 0.025% Pu. This is one to two orders of magnitude below the plutonium concentrations present in the pretreated residues. To satisfy this criteria, the residue will have to either be diluted or the drums will only be partially filled. However, the WIPP drum charge of approximately $15K applies to partially filled drums as well as to full ones, so meeting this criteria can be very expensive. Empty drums, however, do not incur the $15K charge.

In order to increase the capacity of the TRUPACT II container, WIPP has requested permission from the Nuclear Regulatory Commission (NRC) to use a sturdy container called a pipe component. This container could hold the residues more securely from the standpoint of criticality safety. Once the NRC permission is received, a TRUPACT II will hold up to 2.8Kg of plutonium. While this is an improvement, it still necessitates dilution for residues with higher concentrations, and concentration of residues with lower percentages of plutonium in order to take full advantage of the pipe component's capacity.

The TRUPACT II specification further restricts plutonium loading in order to prevent build up of radiolytic hydrogen. The alpha field associated with plutonium decomposes hydrogenous chemicals such as moisture and organic materials. The hydrogen released from these reactions can cause a fire and/or explosion hazard, if it reaches sufficiently high concentrations. The TRUPACT II specification addresses this issue by imposing wattage limits. The practical implication of the wattage limits is to reduce the potential plutonium loading for hydrogenous materials below the amount allowed by the pipe component. Some combustible residues are restricted to approximately 15g/drum, which equates to about $1000/g of plutonium disposal cost.

The issue is further complicated by the need to safeguard the plutonium bearing material from diversion and misuse. Safeguards termination limits are expressed in DOE Order 5633.3B and the newly released Safeguards Guidance. Safeguards protection must be legally terminated on residues prior to their acceptance by WIPP. The guidelines limit the concentration of plutonium in materials, based on the difficulty of extracting the plutonium from those materials. If the plutonium is in a form that is very difficult to recover, it can be present in concentrations up to five percent. If it is in an easily recoverable form, the plutonium content must be kept below 0.2%.

Obviously, the 0.2% concentration would be incompatible with achieving the maximum achievable loading in the pipe component. Therefore, practical use of the pipe component necessitates processing of these materials to make them less attractive to recover. This processing can cost as much as processing the materials to concentrate the plutonium for transfer to MD in the STD 3013 containers.

If the plutonium concentration exceeds 50%, material may be packaged in a STD 3013 container and eventually transferred to MD. For residues that contain relatively large quantities of plutonium, this alternative is economical as compared to direct disposal. The economics derive from the smaller bulk amounts of material that have to be stored, handled and transported. An example of this reduction in material is illustrated in Fig 1 from the Sand, Slag and Crucible Trade Study.

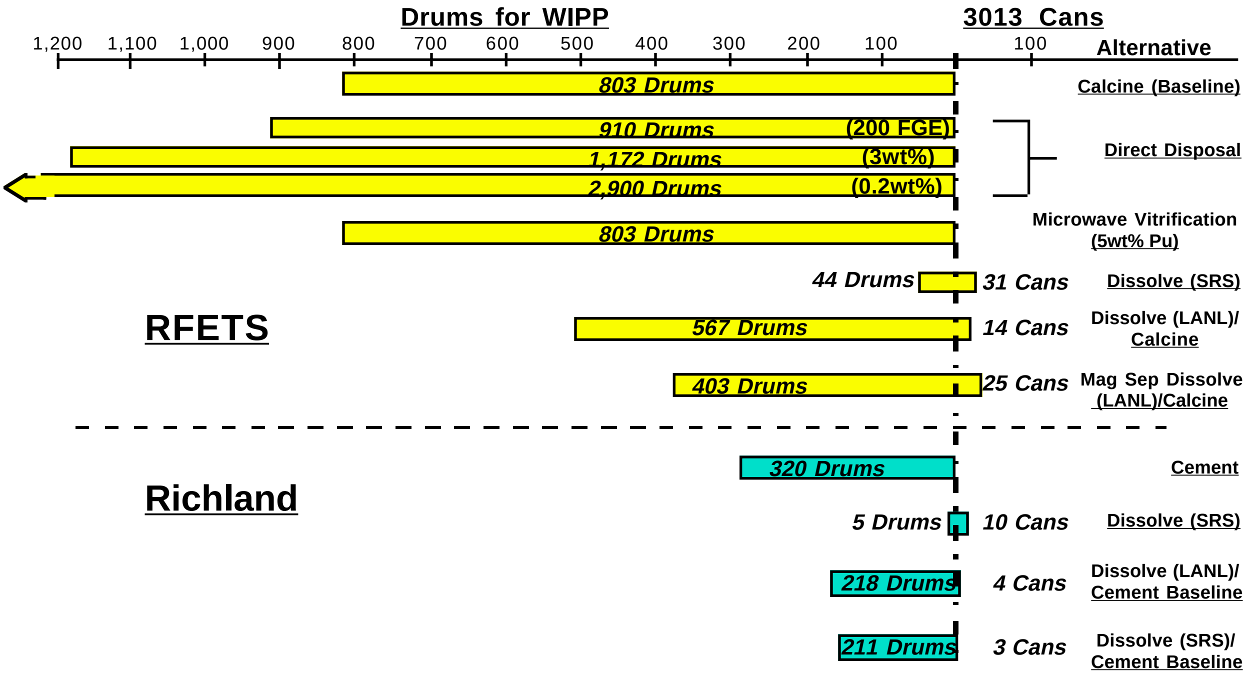

Fig. 1 A comparison of the amount of waste going to WIPP and MD for various alternatives in the SS&C Trade study.

In the trade studies, the materials packaged in the STD 3013 containers were to be stored for fifteen years and then transferred to MD without an assigned charge. The trade studies did not calculate costs associated with the ultimate disposition of these materials, because of the uncertainty associated with the scheduling and processing by MD. However, recent events have demonstrated that such cost assignments are not significant enough to change the analysis.

On January 14, 1997, DOE published the Record of Decision for the Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (ROD) for MD materials. The ROD calls for converting excess pure plutonium metal and oxides into mixed oxide fuel (MOX) and immobilizing relatively impure materials in glass or ceramic matrices. It is generally impractical to purify residues sufficiently to use their plutonium for MOX fuel. However, the immobilization process could potentially treat concentrates, derived from residues, years before the end of the fifteen year window used in the trade studies. Accelerating the schedule will reduce storage time and costs. Additionally, it is possible that immobilization can treat material that does not fully comply with STD 3013, if long term storage is not necessary. Both of these circumstances have the potential to reduce the cost associated with MD disposition. This reduction may be larger than the immobilization processing costs that must now be added into the calculation.

V. Performance Measures

Several performance measures were used to evaluate the different options being compared in the trade studies. These performance measures were treated somewhat differently in each study, because the individual study groups had the freedom to treat them as they deemed most appropriate. Additionally, the methodology evolved measurably between trade studies, so that later studies had somewhat more mature treatment than their predecessors.

Risk to Public

The primary emphasis of the trade studies is to treat materials before their instability causes undo risk to workers or the public. However, there is some risk associated with the processing of the target residues. The performance measure , risk to public, was intended to capture this processing risk. However, no absolute value of risk was determined. Since no unnecessary risk to the public was allowed, the risk to public measure had its primary impact on the cost and schedule of the alternative. In other words, if a particular process posed a risk to the public that was excessive, the process, as used in an alternative, was reengineered to mitigate that risk. This reengineering increased to cost and lengthened the schedule of the alternative, so that high risk options were eliminated from the final evaluation process.

Risk to Worker

The risk to worker was treated in much the same manner as risk to the public. However, it is much more likely to injure a worker who is near a process than a member of the public, who remains outside the plants boundary. Again, no absolute value of risk was calculated.

Therefore this performance measure had a larger impact on cost and schedule than risk to the public because even more reengineering was usually required to make the processes safe to the workers. Again, the primary impact of worker risk was to the cost and schedule of the alternative.

Worker Exposure

The presence of plutonium can cause alpha, gamma and neutron radiation fields that can be harmful to humans. Under normal circumstances, the barriers provided by glove boxes, gloves and containers are sufficient to control alpha radiation to extremely low levels. However, gamma and neutron radiation is only partially attenuated by these barriers and plutonium workers regularly receive small, but measurable exposures.

10 CFR 835 mandates that workers are not allowed to be exposed to more than 5.0rem / yr. The policy of DOE and its contractors is to not only keep exposure below the legal limit, but to maintain exposure levels as low as reasonably achievable (ALARA). The trade studies estimated the exposure levels for different treatment scenarios. These estimates were a performance measure used in the multi attribute analysis and also were used to help implement the ALARA approach.

All processing produced comparable exposures. Processes requiring more personnel or requiring the personnel to be near plutonium for a longer times produced higher exposures. Residues containing higher levels of americium also resulted in higher exposure estimates. Generally, the processing times are similar for processing to repackage for disposal and processing for plutonium partitioning so that worker exposure was not a strong discriminator between the two disposition paths.

However, the analysis did turn up one important finding. Processing material twice roughly doubles the amount of worker exposure. Therefore, alternatives that featured immediate treatment to stabilize the residues and required subsequent processing to groom the materials for disposition did not score well. Residues should be processed only once to achieve stability and meet disposition criteria in order to minimize worker exposure.

Waste and Environmental Impact

The primary disposition paths are TRU and Low Level Waste disposal in geological repositories and storing plutonium rich materials in STD 3013 packages. These rich materials will be processed and placed in geological repositories by MD. In the case of MOX fuel, geological disposal will occur after the fuel has been used in a reactor. All three of these lead to different waste forms and the cost performance measure includes their costs. Some alternatives produce secondary wastes that are not included in the cost. If these secondary wastes are very significant, then they score lower on the waste and environmental performance measure . However, most of the alternatives produced similar amounts of secondary waste and this performance measure was not a discriminator between processes.

Cost

From the above descriptions of performance measures, cost is impacted by each public and worker risk and waste and environmental impact. Thus, a low cost alternative will require a minimal amount of reengineering and produce a minimum amount of waste. Therefore, cost is not only important from a budget point of view, but also is an important indicator of risk and environmental impact. Because of this, cost is the primary emphasis of this current work.

To calculate cost for the various alternatives, a complete set of flow diagram was constructed for all of them. Costs were then assigned for each step in the flow diagram. Process locations were those that were programmatically available in existing facilities. Complete new facilities were generally eliminated from consideration because of the lengthy construction schedules.

Since detailed cost estimates were not always practical, identical estimating factors were used in all alternatives. In other words, WIPP disposal costs, packaging cost, storage costs etc. were expressed in unit volume measures and then applied uniformly to all alternatives. Therefore, the costs are a better relative measure than they are an absolute measure.

Timeliness

Timeliness was used to screen alternatives and was not evaluated like the other performance measures. DNFSB recommendation 94-1 states that urgent risks should be addressed within three years, ending in May 1997. Less urgent risks can take up to eight years to stabilize. The various sites, based on DNFSB 94-1, have developed specific processing schedules. The timeliness performance measure was used to determine whether these schedules were feasible for the various alternatives. Alternatives that could not conceivably meet the schedule, then the alternatives were screened out.

Technical Maturity

Technical maturity had a major impact on the timeliness performance measure and was assessed using a multivariable attribute analysis developed by the NMSTG's R&D committee. The process is described in the NMSTG R&D Plan. The analysis did not attempt to come up with an absolute measure of technical maturity, but rather was a measure of the time and effort that would be required to field a given technology at a DOE facility in a plutonium environment. The measure included such parameters as safety development, process development, engineering and training.

Technologies that were too immature to meet schedules or were much less mature that most other candidate technologies were eliminated. The combustibles trade study found *all* the technologies were too immature to meet the schedules, so the least mature were eliminated from consideration, and DOE was informed that, in the opinion of the trade study group, current schedules were at risk. The technologies needed for baseline and alternatives chosen by the trade study will require too much work and time to reliably meet current schedules.

Since each candidate alternative might require several technologies, the trade studied concentrated on the one or two technologies that might be rate limiting. Other technologies with higher technical maturity were not specifically addressed.

VI. Cost Elements

From a programmatic viewpoint cost is less important than risk to the public or risk to the worker. Cost is also less important than large differences in schedule, because longer schedules introduce an unacceptable risk associated with the unstabilized materials. However, the costs calculated by the trade studies incorporate the public risk and schedule elements as mentioned previously. The costs are assigned to options that have been designed to have minimal risk and to meet, or come near meeting, established processing schedules.

Each trade study evaluated two types of alternatives; those that involve stabilization and direct disposal to WIPP and those that involve processing to concentrate plutonium for disposition to the Materials Disposition Program, MD. The trade studies were primarily interested in their specific topics, Pyrochemical Salts S,S&C, and Combustibles. However, an examination of the cost elements shows that the disposition alternatives are strongly influenced by the amount of plutonium within the residues. Some alternatives used a dual approach to take advantage of cost-plutonium dependence. Plutonium rich residues were planned for reprocessing and lean residues were dispositioned to WIPP. An examination of the relevant cost elements will demonstrate this dependence on plutonium concentration.

Processing

Processing to stabilize or separate plutonium can use a wide variety of technologies and processes. However, the processing cost element is dominated by the sub-elements that are common to all processes. Most of the processing is performed in glove boxes, and the capital equipment cost for glove boxes depends on the area occupied by the boxes. Candidate alternatives were generally designed to fit into the available area, so that glove box costs were usually identical between alternatives. The cost of the processing equipment is usually small compared to the cost of manufacturing and installing the glove boxes.

In a like manner, the transfer of material into and out of glove boxes is relatively expensive when compared to processing the material within the glove boxes. These costs are applicable to processing for both disposal and separation. Thus processing a unit volume of residue is about equal cost, independent of what the processing happens to be. Storage and disposal costs become a more important discriminator than processing costs.

Pretreatment Storage

At facilities where hazardous residues reside, storage space is in short supply. Storage conditions are so congested that it is difficult or impossible to inspect items without moving containers of other residues. The hazardous nature of these materials necessitates periodic inspection. However, the process of moving the containers can cause container damage, which increases risk of exposure and contamination. Therefore, in general, pretreatment storage is more expensive than post treatment storage, where the contents are stable and require less frequent inspection.

Post Treatment Storage

Post treatment storage is generally less expensive than pretreatment storage for a given volume of residue material. Packaging is more uniform, the contents have been stabilized and inspections are less frequent. However, if the residue has been diluted to meet Safeguards and WIPP-WAC criteria, it occupies much more space. This extra space not only costs more, but is unavailable at some sites.

Processing for Long Term Storage

Materials destined for the MD program must be stored in a DOE STD 3013 container. This material must contain greater than fifty percent of plutonium by weight. The container is a double walled stainless steel container that is resistant to pressure buildup. The material in the container must be calcined to remove water and other volatile constituents that can cause container pressurization. This material package combination is designed to remain safe for fifty years with a minimum of inspection.

However, STD 3013 containers contain enough plutonium to require continuing Safeguards protection. Storage requires minimal inspection, but this continuing safeguards protection is expensive. An infrastructure of guards, gates and fences must be supported. Additionally the ROD for materials disposition indicates that most residues will have to transported to a different site for storage, which further adds to the storage cost element..

If the processing of STD 3013 containers is performed in conjunction with other processing, the costs are not affected as much as having to process, interim store and reprocess for long term storage. Rocky Flats Environmental Technology Site, RFETS, is planning for an integral residue processing / 3013 processing line that will allow the site to avoid some interim storage and packaging costs. Other sites are following suit.

Waste Isolation Pilot Plant Interment

The WIPP facility at Carlsbad New Mexico was designed to receive transuranic waste, TRU waste. Residues that meet all the TRUPACT, WIPP-WAC and Safeguards criteria qualify for disposal at WIPP. In addition to preparation of the WIPP facility, the charges include chemical and physical characterization, inspection, administration, transportation and packaging. Full costs for WIPP disposal cost between $13-$15K per drum. Packaging material in a pipe component will add and an additional $0.5-$3K per drum.

VII. Discussion

The three trade studies discussed here; the Pyrochemical Salts, the Sand, Slag and Crucible, and the Combustibles all targeted the disposition of the complete residue category, regardless of plutonium concentration. In the case of the S,S&C from Hanford, the trade study recommended partitioning the rich fraction for disposition to MD and stabilizing the dilute fraction in grout for shipment to WIPP.

All of the parameters necessary to calculate disposition cost as a function of residue plutonium content were developed. Capital and development costs do not vary as a function of plutonium content. Pretreatment storage costs do not vary with plutonium content, but post treatment storage, transportation and disposition costs are linear functions of plutonium concentration, above a certain threshold. Below this threshold value, the residue can be stabilized and shipped directly without dilution to meet Safeguards, WIPP-WAC and TRUPACT II requirements. Processing costs vary somewhat depending on the exact process and the labor involved with the processing, but do not vary greatly with plutonium concentration.

Pyrochemical Salts

Figure 2 shows the functional relationships for processing for disposal and MD storage for Pyrochemical Salts. Appendixes A and B show the processing steps that were involved with the calculations. Distillation was chosen by the trade study as a method to process salts into a form suitable for STD 3013 storage. Shipment to WIPP must be preceded by pyro-oxidation, a stabilization process. Distillation becomes economical for plutonium concentrations greater than 0.25% Pu.

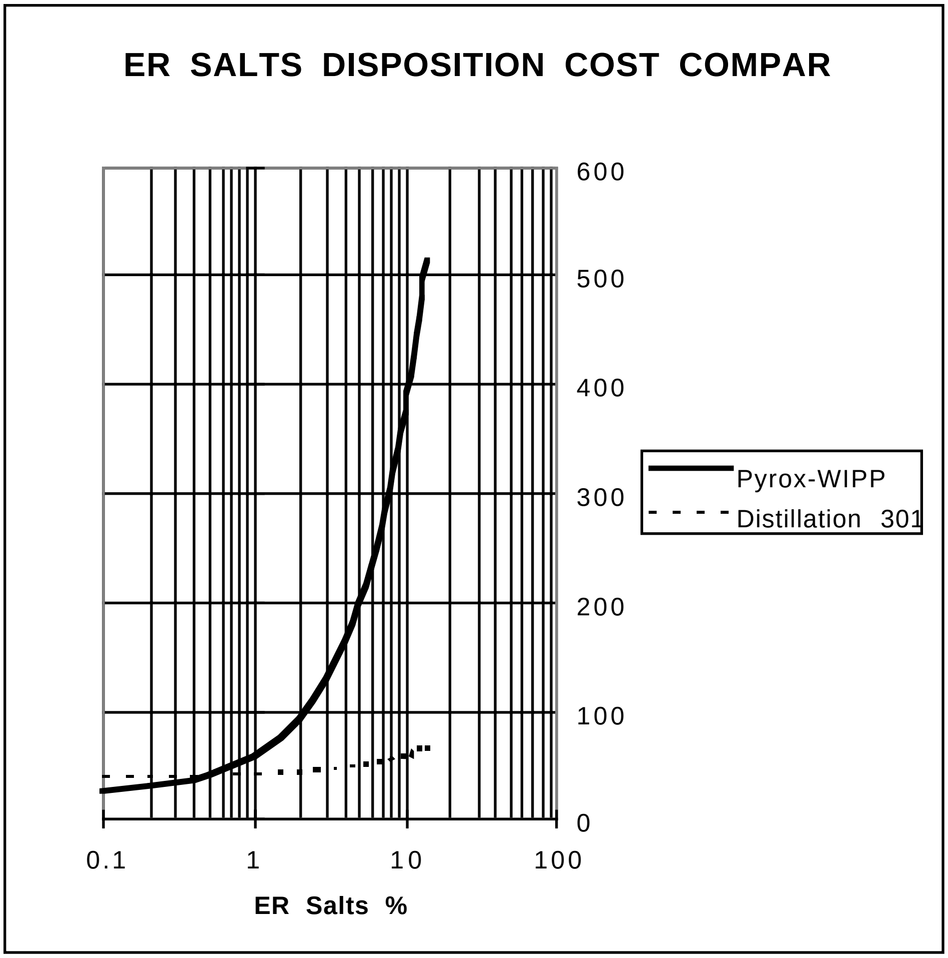

Figure 2. Costs of direct processing by pyro-oxidation and distillation for transfer to MD. (Based on data from the Pyrochemical Salts Trade Study.)

Sand, Slag and Crucible

Figure 3 shows the functional relationships for processing for disposal and MD storage for S,S&C residues. Appendixes C and D show the processing steps that were involved with the calculations. The direct disposal method for S,S&C is accomplished after the residue has been cemented or grouted. At the time of the trade study the wattage limit only allowed 67g of Pu to be in each pipe. However, Fig C shows the cost relationship for the full 167g. Actual hydrogen generation tests were performed to demonstrate that the higher plutonium loading would be acceptable. This makes processing for disposition to MD progressively less attractive as the wattage limits increase.

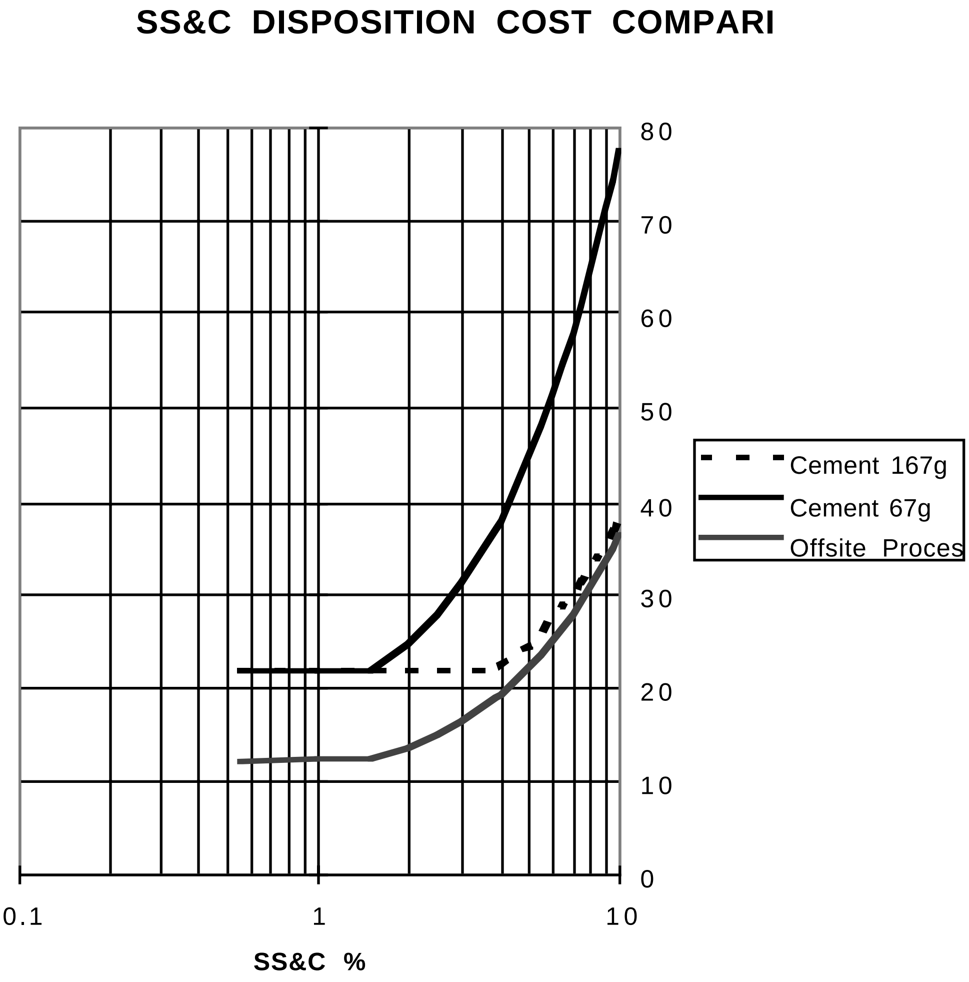

Fig. 3 Costs of direct disposal for two cement grout loadings and for off site processing for transfer to MD. (Based on data from the S,S&C Trade Study.)

Combustibles

Figure 4 shows the functional relationships for processing for disposal and MD storage for Combustible residues. Appendixes E and F show the processing steps that were involved with the calculations. The baseline involves washing and desorption treatments followed by dilution and repackaging for shipment to WIPP. The STD 3013 alternative, mediated electrochemical oxidation (MEO) dissolves the plutonium bearing compounds and oxidizes most of the combustible materials. The plutonium is recovered by precipitation from the MEO solutions. The precipitate is then calcined and packaged in a STD 3013 container.

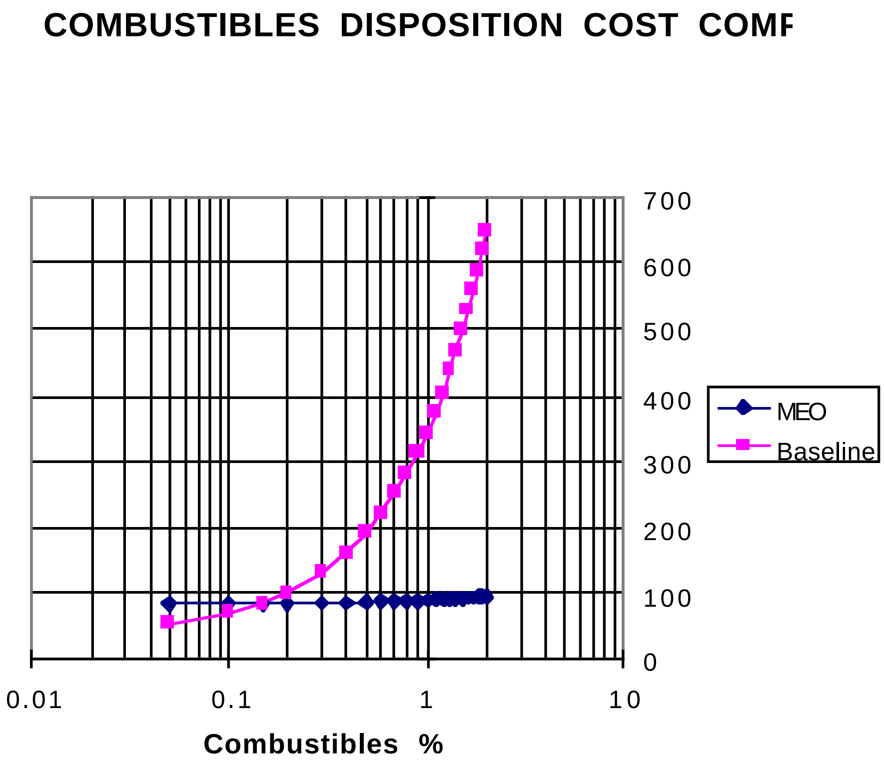

Fig. 4 Costs of the baseline, direct disposal to WIPP, and MEO, which transfers material to MD.

Rocky Flats is trying to get wattage limits increased from a limit that allows them approximately 15g per drum up as far as they are allowed. The pipe component limit of 200g equates to a useable limit of 167g, after assay measurement error is deducted to conservatively meet the TRUPACT II criticality limits. Figure 5 shows the effect of progressively raising the wattage and Safeguards limits up to 167g. Processing of the waste becomes progressively less attractive as the wattage and Safeguards limits are raised.

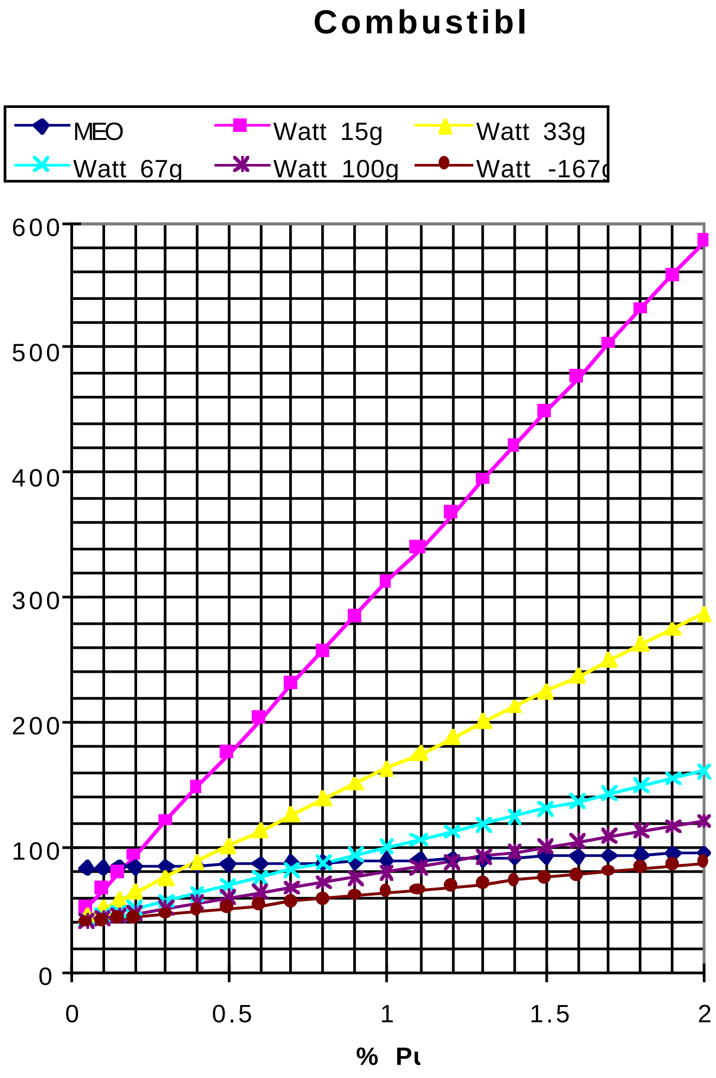

Fig. 5 Cost of processing for transfer to MD is compared to the cost of direct disposal at several different package loadings. (Based on data from the Combustibles Trade Study.)

VI. Conclusions

All of the disposition paths eventually lead to interment of surplus plutonium in geological repositories. Low level and TRU waste involve direct disposal. Materials destined for the MD program will either be incorporated in MOX fuel or immobilized in glass or ceramic. After use in a reactor MOX fuel is destined for geological disposal. The immobilized material will reside with high level waste glass destined for geological disposal. Therefore, the decision to process or direct dispose involves finding the safest, most economical route to the geological disposal.

Safeguards, transportation and waste acceptance limits all make it relatively more expensive to direct dispose of materials containing high plutonium concentrations. Above 0.1-0.5% plutonium, processing to partition for the Materials Disposition Program becomes more cost effective from a financial and a safety standpoint.

This work is intended to provide a useful guidelines that are applicable to smaller residue populations that do not warrant full trade studies. However, it must be cautioned that local conditions must be factored into any analysis. These guidelines apply if appropriate processing equipment is available at the site where the residues are located. If the equipment is not already available, transportation barriers and schedule requirements can reduce the practicality of processing.

Additionally, increases in safeguard disposal limits and the TRUPACT II wattage limits can change the economics of the equation. Direct disposal becomes more economical in comparison to processing for transfer to MD. However, the ROD for materials disposition creates an opening for changing material acceptance specification . These new specifications could reduce the cost of transferring residue concentrates to MD. DOE has initiated studies to coordinate residue disposal with MD acceptance requirements.

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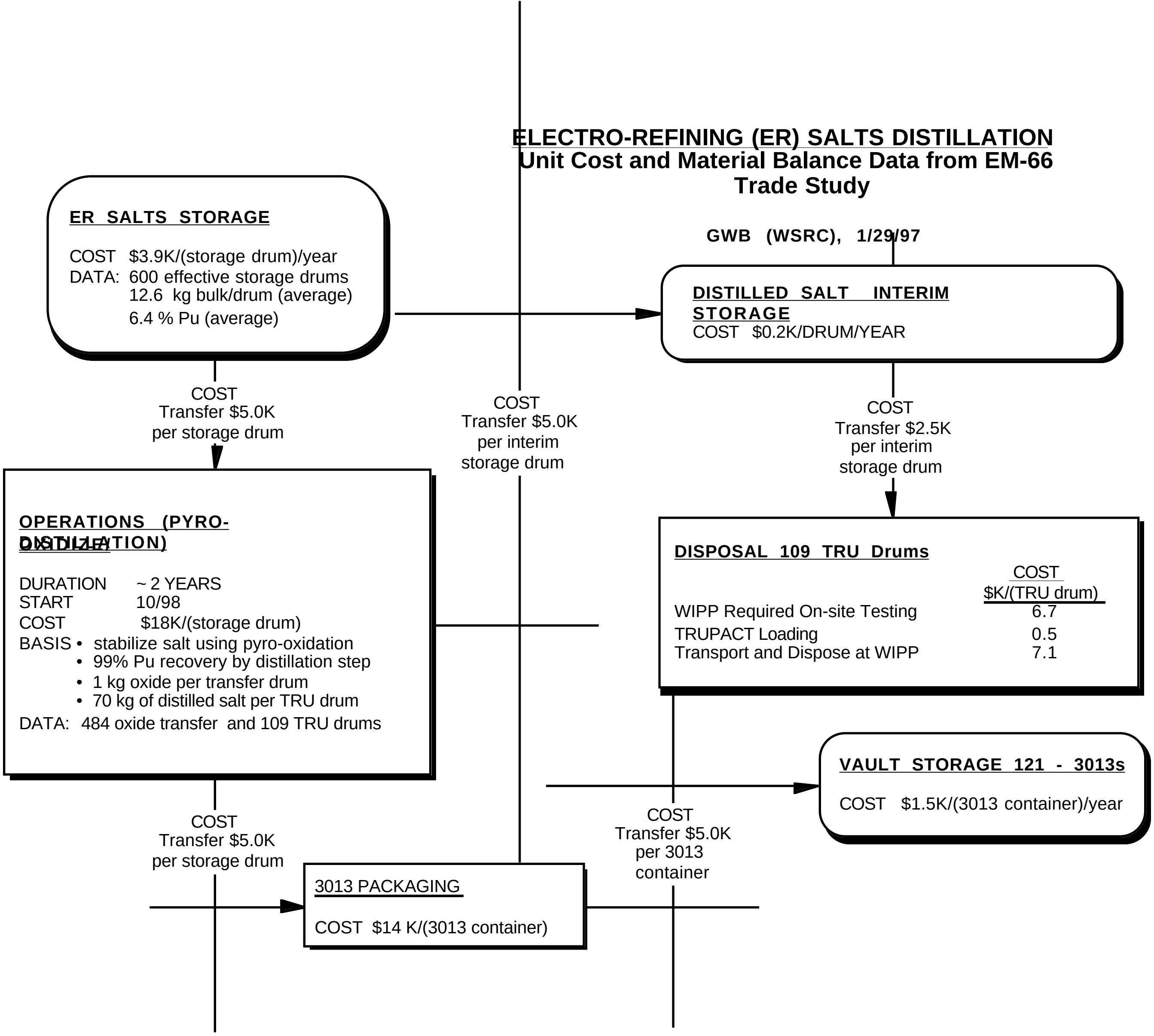
Appendix A

ELECTRO-REFINING (ER) SALTS DISTILLATION
Unit Cost and Material Balance Data from EM-66 Trade Study

GWB (WSRC), 1/29/97

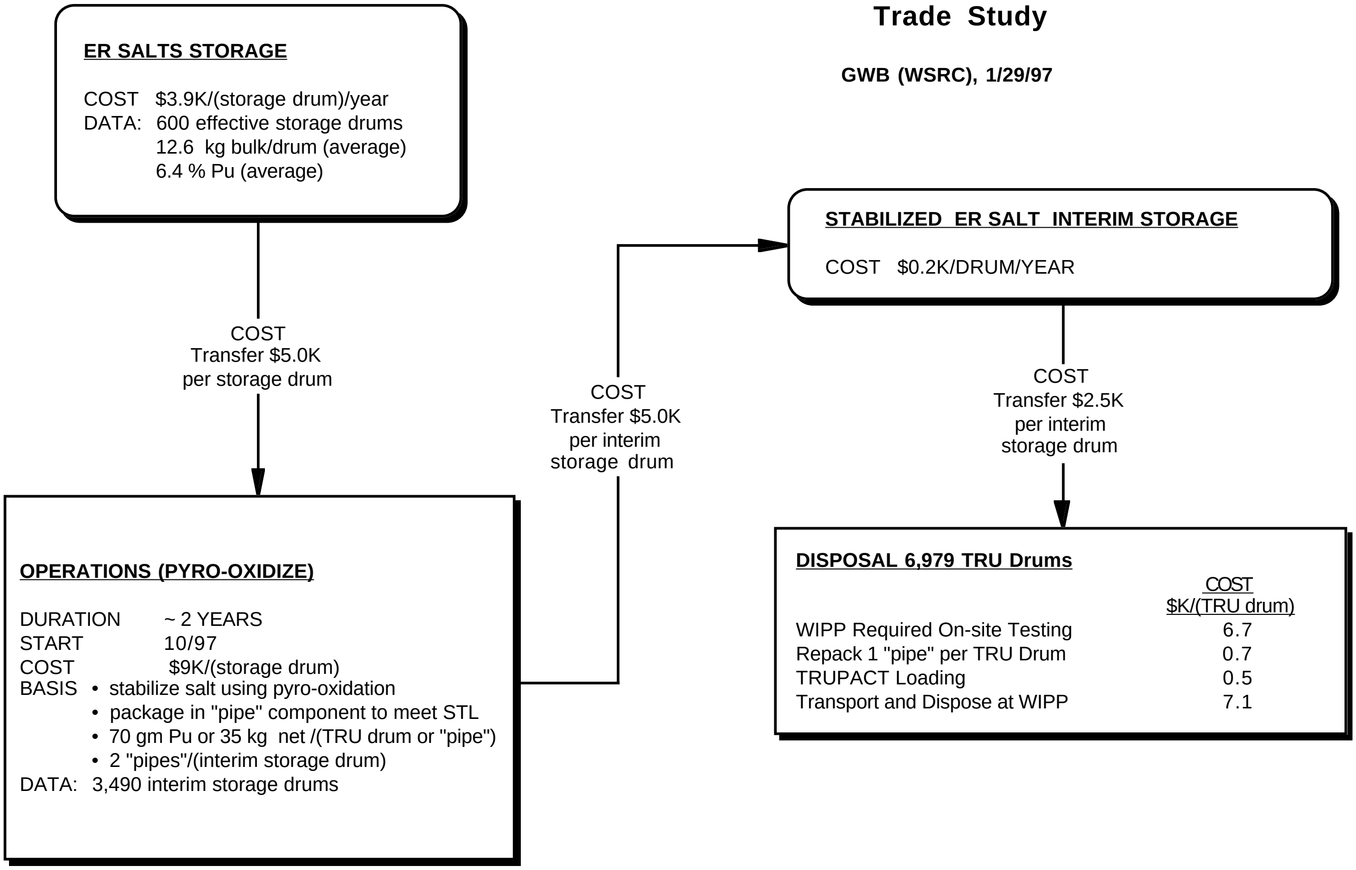


Appendix B

ELECTRO-REFINING (ER) SALTS BASE CASE

Unit Cost and Material Balance Data from EM-66 Trade Study

GWB (WSRC), 1/29/97



ER SALTS STORAGE

COST $3.9K/(storage drum)/year
DATA: 600 effective storage drums
12.6 kg bulk/drum (average)
6.4 % Pu (average)

COST
Transfer $5.0K
per storage drum

OPERATIONS (PYRO-OXIDIZE)

DURATION ~ 2 YEARS
START 10/97
COST $9K/(storage drum)
BASIS
- stabilize salt using pyro-oxidation
- package in "pipe" component to meet STL
- 70 gm Pu or 35 kg net /(TRU drum or "pipe")
- 2 "pipes"/(interim storage drum)

DATA: 3,490 interim storage drums

COST
Transfer $5.0K
per interim
storage drum

STABILIZED ER SALT INTERIM STORAGE

COST $0.2K/DRUM/YEAR

COST
Transfer $2.5K
per interim
storage drum

DISPOSAL 6,979 TRU Drums

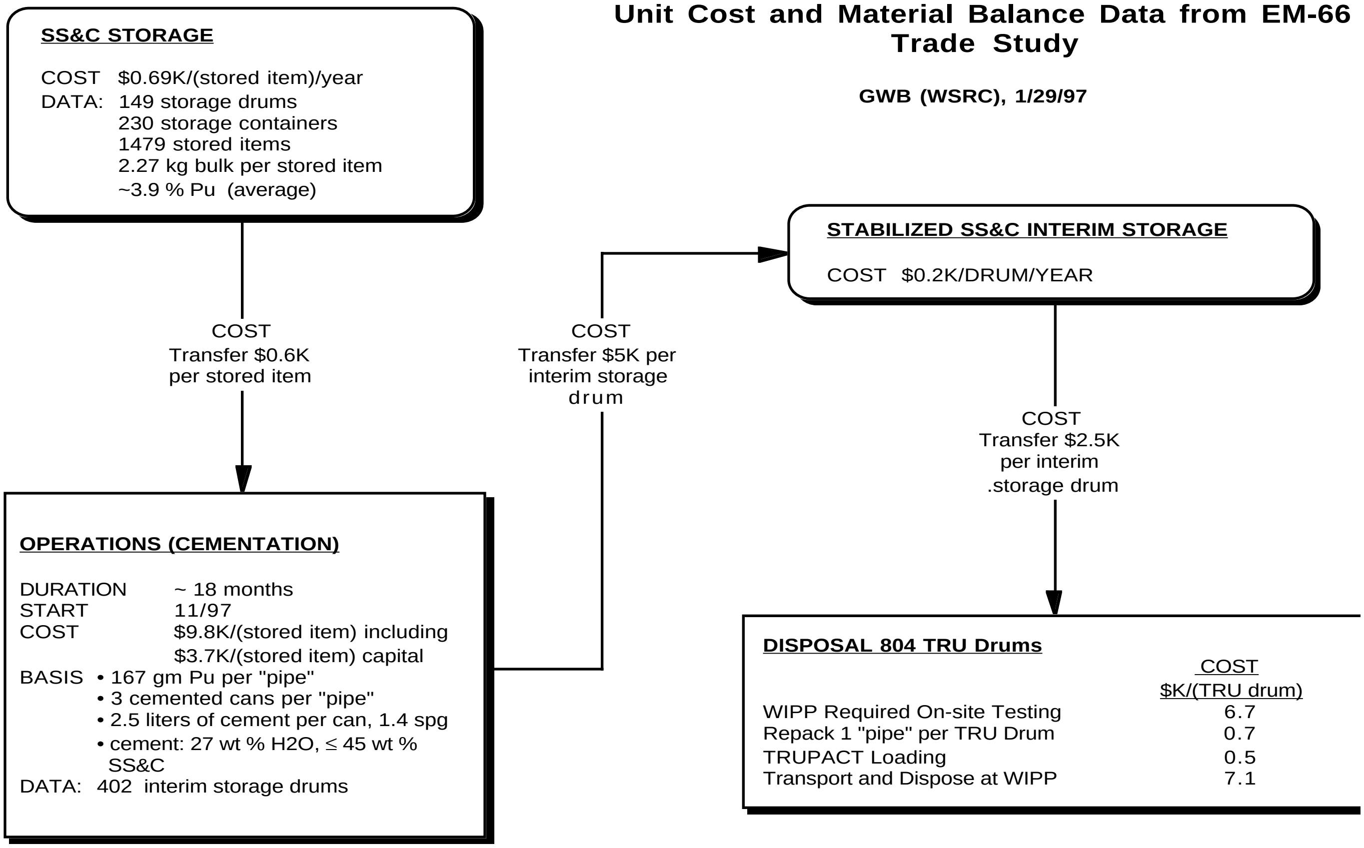
	COST $K/(TRU drum)
WIPP Required On-site Testing	6.7
Repack 1 "pipe" per TRU Drum	0.7
TRUPACT Loading	0.5
Transport and Dispose at WIPP	7.1

Appendix C

SS&C BASE CASE

Unit Cost and Material Balance Data from EM-66 Trade Study

GWB (WSRC), 1/29/97



SS&C STORAGE

COST $0.69K/(stored item)/year
DATA: 149 storage drums
230 storage containers
1479 stored items
2.27 kg bulk per stored item
~3.9 % Pu (average)

COST
Transfer $0.6K
per stored item

OPERATIONS (CEMENTATION)

DURATION ~ 18 months
START 11/97
COST $9.8K/(stored item) including $3.7K/(stored item) capital
BASIS
- 167 gm Pu per "pipe"
- 3 cemented cans per "pipe"
- 2.5 liters of cement per can, 1.4 spg
- cement: 27 wt % H2O, ≤ 45 wt % SS&C

DATA: 402 interim storage drums

COST
Transfer $5K per
interim storage
drum

STABILIZED SS&C INTERIM STORAGE

COST $0.2K/DRUM/YEAR

COST
Transfer $2.5K
per interim
.storage drum

DISPOSAL 804 TRU Drums

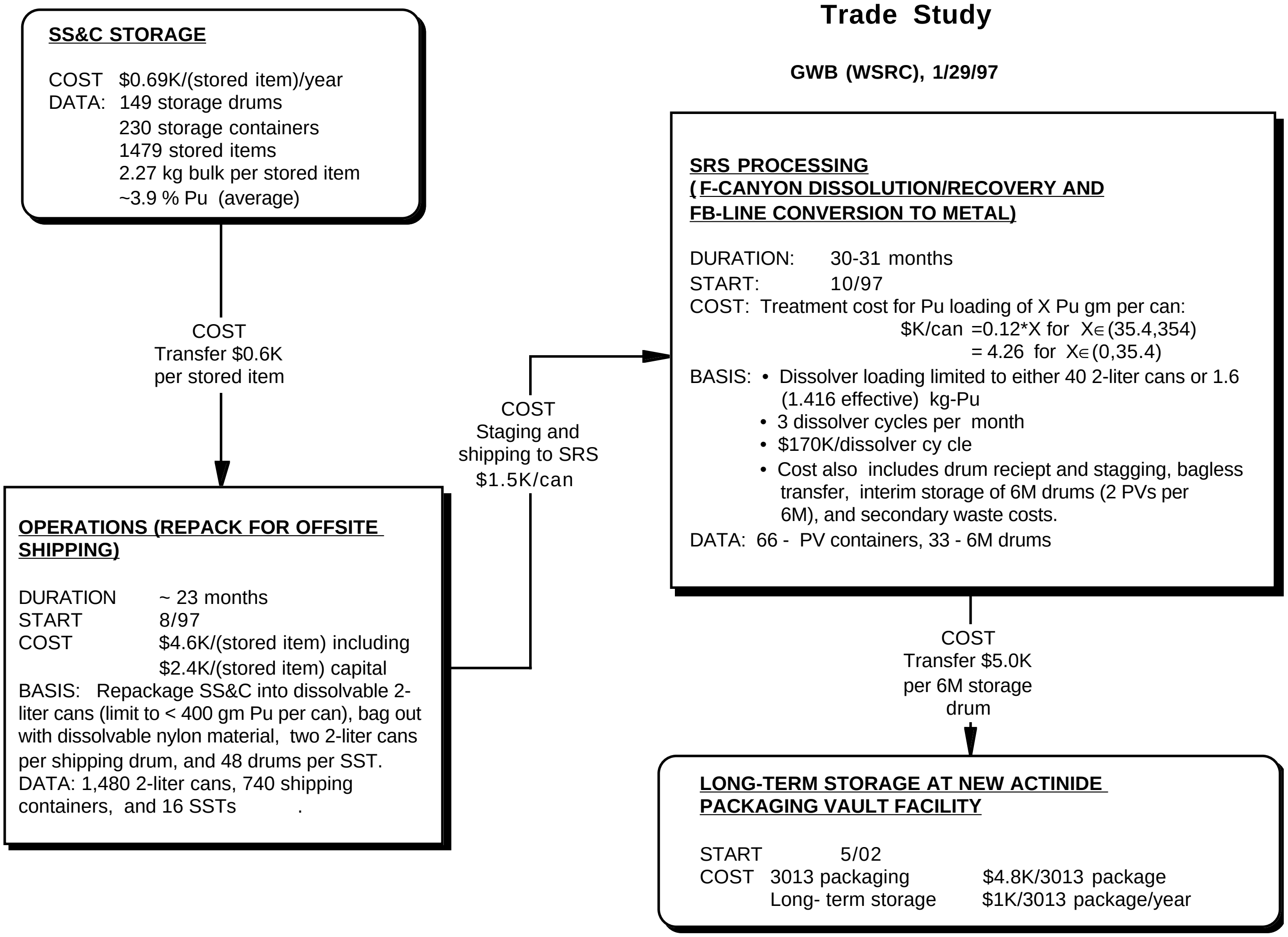
	COST $K/(TRU drum)
WIPP Required On-site Testing	6.7
Repack 1 "pipe" per TRU Drum	0.7
TRUPACT Loading	0.5
Transport and Dispose at WIPP	7.1

Appendix D

SS&C PROCESSING AT SRS

Unit Cost and Material Balance Data from EM-66 Trade Study

GWB (WSRC), 1/29/97



SS&C STORAGE

COST $0.69K/(stored item)/year
DATA: 149 storage drums
230 storage containers
1479 stored items
2.27 kg bulk per stored item
~3.9 % Pu (average)

COST
Transfer $0.6K
per stored item

OPERATIONS (REPACK FOR OFFSITE SHIPPING)

DURATION ~ 23 months
START 8/97
COST $4.6K/(stored item) including
$2.4K/(stored item) capital

BASIS: Repackage SS&C into dissolvable 2-liter cans (limit to < 400 gm Pu per can), bag out with dissolvable nylon material, two 2-liter cans per shipping drum, and 48 drums per SST.

DATA: 1,480 2-liter cans, 740 shipping containers, and 16 SSTs .

COST
Staging and
shipping to SRS
$1.5K/can

SRS PROCESSING
(F-CANYON DISSOLUTION/RECOVERY AND FB-LINE CONVERSION TO METAL)

DURATION: 30-31 months
START: 10/97
COST: Treatment cost for Pu loading of X Pu gm per can:
$K/can =0.12*X for $X \in (35.4,354)$
= 4.26 for $X \in (0,35.4)$

BASIS:
- Dissolver loading limited to either 40 2-liter cans or 1.6 (1.416 effective) kg-Pu
- 3 dissolver cycles per month
- $170K/dissolver cy cle
- Cost also includes drum reciept and stagging, bagless transfer, interim storage of 6M drums (2 PVs per 6M), and secondary waste costs.

DATA: 66 - PV containers, 33 - 6M drums

COST
Transfer $5.0K
per 6M storage
drum

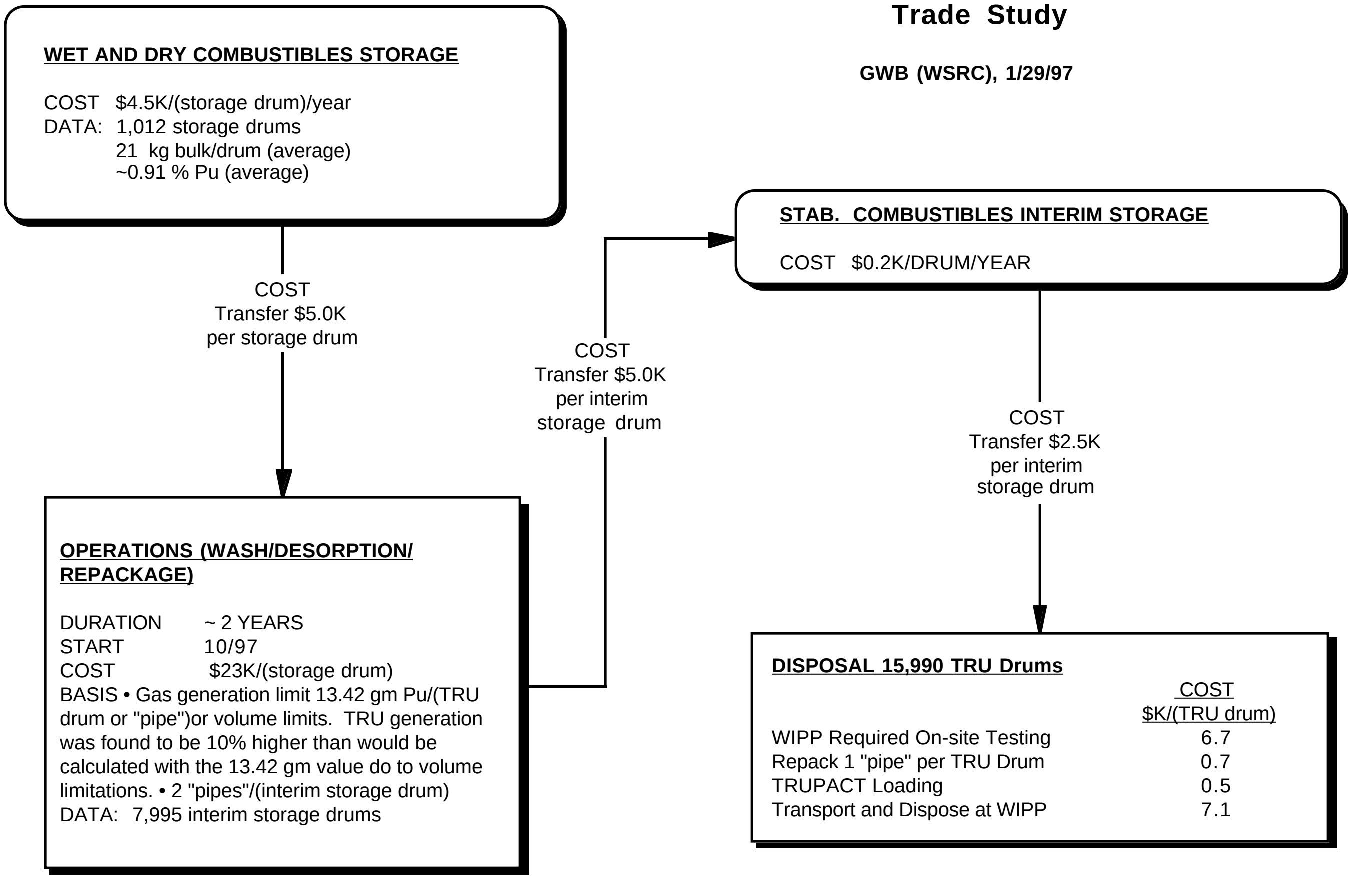
LONG-TERM STORAGE AT NEW ACTINIDE PACKAGING VAULT FACILITY

START 5/02
COST 3013 packaging $4.8K/3013 package
Long- term storage $1K/3013 package/year

Appendix E

WET AND DRY COMBUSTIBLES BASE CASE
Unit Cost and Material Balance Data from EM-66 Trade Study

GWB (WSRC), 1/29/97



WET AND DRY COMBUSTIBLES STORAGE

COST $4.5K/(storage drum)/year
DATA: 1,012 storage drums
21 kg bulk/drum (average)
~0.91 % Pu (average)

COST
Transfer $5.0K
per storage drum

OPERATIONS (WASH/DESORPTION/ REPACKAGE)

DURATION ~ 2 YEARS
START 10/97
COST $23K/(storage drum)
BASIS • Gas generation limit 13.42 gm Pu/(TRU drum or "pipe")or volume limits. TRU generation was found to be 10% higher than would be calculated with the 13.42 gm value do to volume limitations. • 2 "pipes"/(interim storage drum)
DATA: 7,995 interim storage drums

COST
Transfer $5.0K
per interim
storage drum

STAB. COMBUSTIBLES INTERIM STORAGE

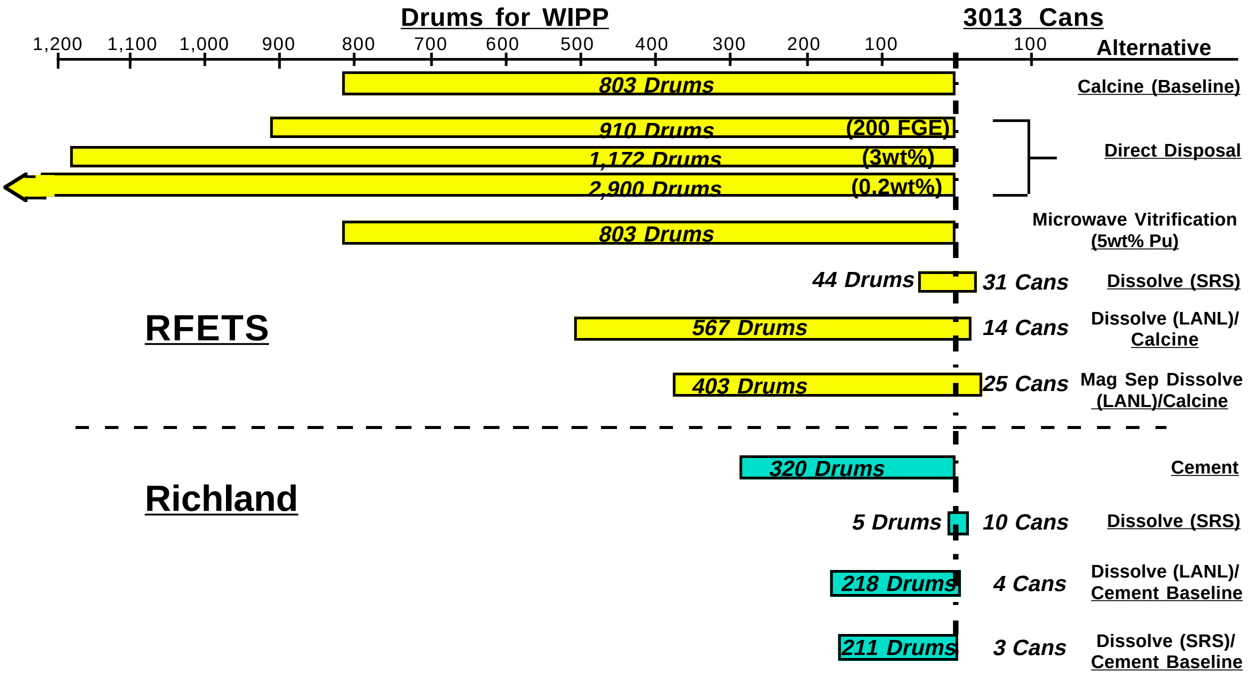
COST $0.2K/DRUM/YEAR

COST
Transfer $2.5K
per interim
storage drum

DISPOSAL 15,990 TRU Drums

	COST $K/(TRU drum)
WIPP Required On-site Testing	6.7
Repack 1 "pipe" per TRU Drum	0.7
TRUPACT Loading	0.5
Transport and Dispose at WIPP	7.1

AppendixF


Drums for WIPP
3013 Cans
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
100
Alternative
803 Drums
Calcine (Baseline)
910 Drums
(200 FGE)
1,172 Drums
(3wt%)
2,900 Drums
(0.2wt%)
Direct Disposal
803 Drums
Microwave Vitrification
(5wt% Pu)
44 Drums
31 Cans
Dissolve (SRS)
RFETS
567 Drums
14 Cans
Dissolve (LANL)/
Calcine
403 Drums
25 Cans
Mag Sep Dissolve
(LANL)/Calcine
320 Drums
Cement
Richland
5 Drums
10 Cans
Dissolve (SRS)
218 Drums
4 Cans
Dissolve (LANL)/
Cement Baseline
211 Drums
3 Cans
Dissolve (SRS)/
Cement Baseline