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**ATTACHMENT 1  
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ATTACHMENT 2**

to  
ORNL/M-6625  
**Thorium Nitrate Pilot-Scale  
Demonstration and Stockpile Processing  
Option Results Report**

December 1998

**ATTACHMENT 1**

**DEMONSTRATION RESULTS REPORT:  
THORIUM DE-NITRATION PILOT PROJECT**

by

Perma-Fix Environmental Services, Inc.  
East Tennessee Materials and Energy Corporation  
Teledyne Brown Engineering  
September 25, 1998

**ATTACHMENT 2**

**PILOT DEMONSTRATION RESULTS REPORT FOR  
CONVERSION OF THORIUM NITRATE TO  
THORIUM OXIDE**

by

Recovery Dynamics Corporation  
September 1998

MANAGED AND OPERATED BY  
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION  
FOR THE UNITED STATES  
DEPARTMENT OF ENERGY

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# **DEMONSTRATION RESULTS REPORT**

**Thorium De-nitration Pilot Project**

**Rev. 1**

**Submitted by:**

**Perma-Fix Environmental Services, Inc.**

**East Tennessee Materials and Energy Corporation**

**Teledyne Brown Engineering**

**September 25, 1998**

**DEMONSTRATION RESULTS REPORT**  
**Thorium De-nitration Pilot Project**

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# DEMONSTRATION RESULTS REPORT

## Thorium De-nitration Pilot Project

### 1.0 EXECUTIVE SUMMARY

This report provides a detailed description of a project to develop and demonstrate a safe, environmentally benign, and effective means of converting thorium nitrate penta-hydrate solids stored in depots of the U.S. Army Defense Logistics Agency (DLA) to a less-voluminous, and chemically stable form for continued stockpile storage. After a bench-scale process development program was completed, approximately 2,000 pounds of thorium nitrate from the Curtis Bay, Maryland depot were shipped to the Perma-Fix of Florida pilot-scale test facility in Gainesville, Florida. These materials were split into five nominally equivalent batches for de-nitration batch testing. An experimental test plan was developed to use the five batch tests to thoroughly evaluate the de-nitration process and its reasonable permutations, and to characterize products and byproducts.

The basic de-nitration process is a simple neutralization and precipitation reaction in which thorium nitrate is dissolved in de-mineralized water and then reacted with sodium hydroxide. The result is precipitation of thorium hydroxide as a settleable and filterable solid in a sodium nitrate solution. The thorium hydroxide is settled and filtered to produce a filter cake, which is then thermally dried at low temperature (<300 °F) to produce a dry powder product which according to X-ray diffraction analysis is at least partially converted to thorium oxide. The residual thorium in the sodium nitrate byproduct is present at very low concentrations and appears to be mostly in insoluble form at the pH of the reaction end point, 11.0 or higher.

The basic de-nitration process was successfully demonstrated in Batch Tests 1 and 2. Batch Test 4 confirmed the successful results of Batch Tests 1 and 2 and demonstrated the effectiveness of demineralized water rinsing to improve product quality. Batch Test 5 evaluated the relative merits of recycling the sodium nitrate byproduct back into the de-nitration process. Batch Test 3 demonstrated that the precipitation step is sensitive to upsets, and requires close control of the rate of sodium hydroxide additions.

The test results presented and evaluated in the balance of this report lead to the following conclusions:

- All of the batch tests showed that the basic chemistry of de-nitrating thorium nitrate with sodium hydroxide is sound and reliable.
- Careful control of the reaction rate during the precipitation step is key in achieving a clean and easy separation of the thorium hydroxide solids from the sodium nitrate solution.
- If a primary goal is to minimize residual sodium nitrate in the thorium hydroxide solids, then serial demineralized water rinsing of the solids is necessary.

- The enhanced de-nitration process as demonstrated in Batch Test 4 achieved a 69.9 percent thorium yield in the filter cake solids. The serial demineralized water rinses were effective in improving cake solids quality at the expense of washing out fine thorium hydroxide particles in the rinseate. These solids were easily recovered from the rinseate by gravity settling, resulting in complete capture of thorium from the process heels.
- When the proper rate of the precipitation reaction is exceeded, the resulting thorium hydroxide solids exhibit poor settling and filtration characteristics, resulting in excessive losses of thorium into the process heels. Drying such batches and then re-suspending the dry solids appears to be an effective means of recovery. Also, back titrating with nitric acid appears to be an effective means of re-dissolving poorly settling solids to allow the precipitation process to be re-started.
- The benefits of recycling sodium nitrate solution back to the de-nitration reaction do not outweigh the problems associated with that option.
- The final packaged volume of dried thorium hydroxide was 44% of the original packaged volume.

The engineering assessment presented in Sections 7.0 and 8.0 describes the process flow and equipment envisioned for full-scale operations, and evaluates the comparative costs of siting the conversion facility on the Curtis Bay, Maryland Site or an alternate "brown-field" site in a leased building on the former K-25 Site at Oak Ridge, Tennessee. The two cases were very close in overall cost with total project costs of between \$3.16 and \$3.34 per pound of thorium nitrate feed material, with the Oak Ridge option being the lower cost option. Since the leased facility will be operated under the tenant's state issued radioactive materials license, the cost structure will be consistent with commercial treatment facilities. However, performing the full-scale treatment on an access-controlled site, within a government reservation provides the maximum protection for the public.

A market survey demonstrated that the thorium product in whatever form has limited market potential at the present time. Most of the classic industrial or consumer applications of thorium have been replaced with alternate materials, indicating that treated product will likely have to be returned to stockpile storage within the custody of DLA. The sodium nitrate byproduct can be made clean enough to be recycled for agricultural use as a fertilizer diluent, or dried for use as an ingredient in pyrotechnic materials.

## **2.0 INTRODUCTION**

Beginning in May 1997, a team composed of Perma-Fix Environmental Services, Inc., Performance Development Corporation, and Teledyne Brown Engineering planned and performed a pilot-scale demonstration of a chemical de-nitration process for possible future use in converting thorium nitrate into a more stable, reduced volume form. The work was performed for Lockheed Martin Energy Systems, Inc. under Subcontract Number 30K-HDT33V. This report describes how the pilot-scale demonstration was planned, performed and documented, and evaluates the results obtained.

### **2.1 Background**

The U. S. Army Defense Logistics Agency (DLA), Defense National Stockpile Center (DNSC) currently maintains approximately 21,000 drums of thorium nitrate hydrate (TNH), totaling approximately 7 million pounds of thorium nitrate crystals in two depot locations in the continental United States. A site at Curtis Bay, Maryland stores most of the inventory, while another site in Hammond, Indiana stores the remainder. In response to environmental, health and safety concerns of stakeholders and regulatory authorities, the DLA is investigating their options for converting the thorium nitrate crystals into a chemical and physical form which reduces environmental and health risks while reducing storage volume required to maintain the thorium in the DNSC. DLA also has the goal of consolidating all of the thorium stockpile at one of the sites. For purposes of this study, it is assumed that the final storage site will be at Curtis Bay, Maryland. However, the choice of final storage location is completely within the discretion of the DLA. Earlier pilot-scale demonstrations investigated how thermal conversion technologies might be applied to meet the DLA's goals. This project demonstrated one of the non-thermal conversion technologies which may have application.

### **2.2 Project Objectives**

The over-riding objective of the pilot demonstration project was to fully develop a safe and effective low temperature de-nitration process and demonstrate that process at a pilot scale. Other objectives for the pilot-scale demonstration included the following:

- Develop a safe and effective means of removing thorium nitrate from its original containers
- Evaluate and refine methods for control of the process
- Characterize raw materials, products, and byproducts
- Evaluate radiological control characteristics of the process
- Evaluate the market potential for products and byproducts

From the pilot-scale results described in this report, it will be possible to scale the process up to a full-scale commercial operation to address the entire 7,000,000 pound inventory in a reasonable period of time.

### **2.3 Project Plan Planning and Execution**

The project plan for this pilot-scale demonstration involved two phases; (1) preliminary bench-scale tests, and (2) pilot-scale batch tests. In the preliminary bench tests, the basic chemical and physical attributes of the process and its various feeds, intermediates and final products were evaluated. Competing control schemes of the precipitation reaction were tested, evaluated and refined. Settling and Filtration tests provided feedback for evaluating the liquid/solid separation attributes of precipitated thorium hydroxide solids. Commercial polymeric additives for liquid/solid separation and dry product binding were also evaluated during the preliminary bench-scale tests.

The lessons learned in the preliminary bench scale tests were used to develop the basic process scheme for the early pilot-scale batch tests, and to conceptualize potential process enhancements for testing in the later batch tests. The pilot-scale test facility was designed utilizing data from the bench testing, and was installed inside a quonset hut, inside a building at the Perma-Fix of Florida facility, in Gainesville, Florida.

Detailed Operating Procedures for all equipment and systems of the Pilot-scale Test Facility were developed, reviewed, and approved prior to first use. In addition, Batch Test Instruction packages were developed for each batch test. These instruction packages provided step-by-step guidance for performance of each batch test, and provided data sheets for recording of measurements performed during the test. Also, a narrative log of test activities was kept for all batch tests.

Although the DLA thorium nitrate inventory contains source material from the United States, France, and India, all of the material used in the preliminary bench tests and the pilot-scale batch tests originated in the United States. Nine (9) drums of thorium nitrate from the Curtis Bay Depot, and one (1) drum that had been in the custody of Lockheed Martin Energy Systems in Oak Ridge, were shipped to Gainesville for use in the test program. Small samples from the Oak Ridge drum were provided early by Lockheed Martin for use in the preliminary bench scale tests. The pilot-scale test program was organized into five (5) batch tests, with each batch being composed of the contents of two drums of thorium nitrate. Table 2-1 provides a summary of each batch test performed, and the experimental objective tested during each test.

This experimental scheme evaluated the basic precipitation, settling, filtration, and product rinsing operations incorporated into the process, and provided repetitive testing of the basic process.

Data collection around the process, and sampling of process streams were performed, during each batch test, to ensure that sufficient data was collected to allow calculation of material balances. Also, bench-scale tests to evaluate precipitation, settling, filtration, and serial rinsing were performed in parallel with each pilot-scale batch test using samples collected from the batch.

**Table 2-1  
Summary of Pilot-scale Batch Tests**

<b>Batch Test Number</b>	<b>Batch Size (Lbs of Thorium Nitrate)</b>	<b>Experimental Objective</b>
1	389.81	Evaluate Basic Precipitation Process
2	410.34	Evaluate Basic Precipitation Process
3	385.27	Add Serial Rinsing to the Process
4	385.52	Add Serial Rinsing to the Process
5	387.73	Add Liquid Byproduct Recycle to the Process
<b>Total</b>	<b>1,958.67</b>	—

The pilot-scale tests took thorium to a low-temperature dried product. The incremental benefits of calcining the dried product were evaluated at bench-scale using samples of dry product from the pilot-scale dryer. Section 3.0 provides more information regarding the process configuration used during the pilot-scale tests.

### 3.0 PROCESS DESCRIPTION

The thorium de-nitration process tested during this project is a variant of the sol-gel process which was used in the 1970's at the DOE Feed Materials Processing Center (FMPC) at Fernald, Ohio. Thorium nitrate hydrate crystals are dissolved in demineralized water, and the thorium nitrate is neutralized with sodium hydroxide to produce a thorium hydroxide precipitate and a sodium nitrate supernate. Liquid-solid separation and rinsing steps are used to improve the separation between the thorium hydroxide and the sodium nitrate. The thorium hydroxide is concentrated in this process, and then dried and repackaged. The steps of the process are as follows:

1. Removal of thorium nitrate crystals from packaging
2. Weighing and dissolving thorium nitrate in hot demineralized water
3. Heating and mixing while precipitating thorium using sodium hydroxide
4. Gravity separation of sodium nitrate mother liquor from the thorium hydroxide sludge
5. Optional serial rinsing of the thorium hydroxide sludge blanket
6. De-watering and rinsing of thorium hydroxide product
7. Drying of thorium hydroxide filter cake
8. Filtration and ion exchange polishing of secondary process liquid streams
9. Recovery of process heels
10. Packaging of dried product

Each of these process steps, with some minor modifications were performed during each of the five batch tests. Figure 3-1 is a Process Flow Diagram, showing the major process equipment and the flow of raw materials, reagents and products. Major process streams in Figure 3-1 are numbered. These stream numbers refer to specific columns of data in the Material Balance Spreadsheets (Tables, 6-2, 6-3, and 6-4). The steps of the process are further described below.

#### 3.1 Removal of Thorium Nitrate Crystals from Packaging

The packaging encountered during the pilot-scale batch tests typically consisted of an outer steel drum, either 55-gallons or 35-gallons in capacity. Inside the steel drum was a black plastic drum with a loose-fitting lid, completely enclosed by a sealed clear plastic bag. In some cases this bag contained a small amount (estimated at less than one gallon) of white powder, assumed to be lime. Inside the black plastic drum, was one or two concentric waxed kraft paper drums, with an internal clear plastic bag liner between the thorium nitrate crystals and the paper drums. The thorium nitrate crystals were typically fused into a solid monolith inside the container. In some cases, the inner kraft paper packages were found to be damp and deteriorated. In some cases, the internal packaging was under a slight internal pressure, which was released when the lid of the outer steel drum was unsealed.

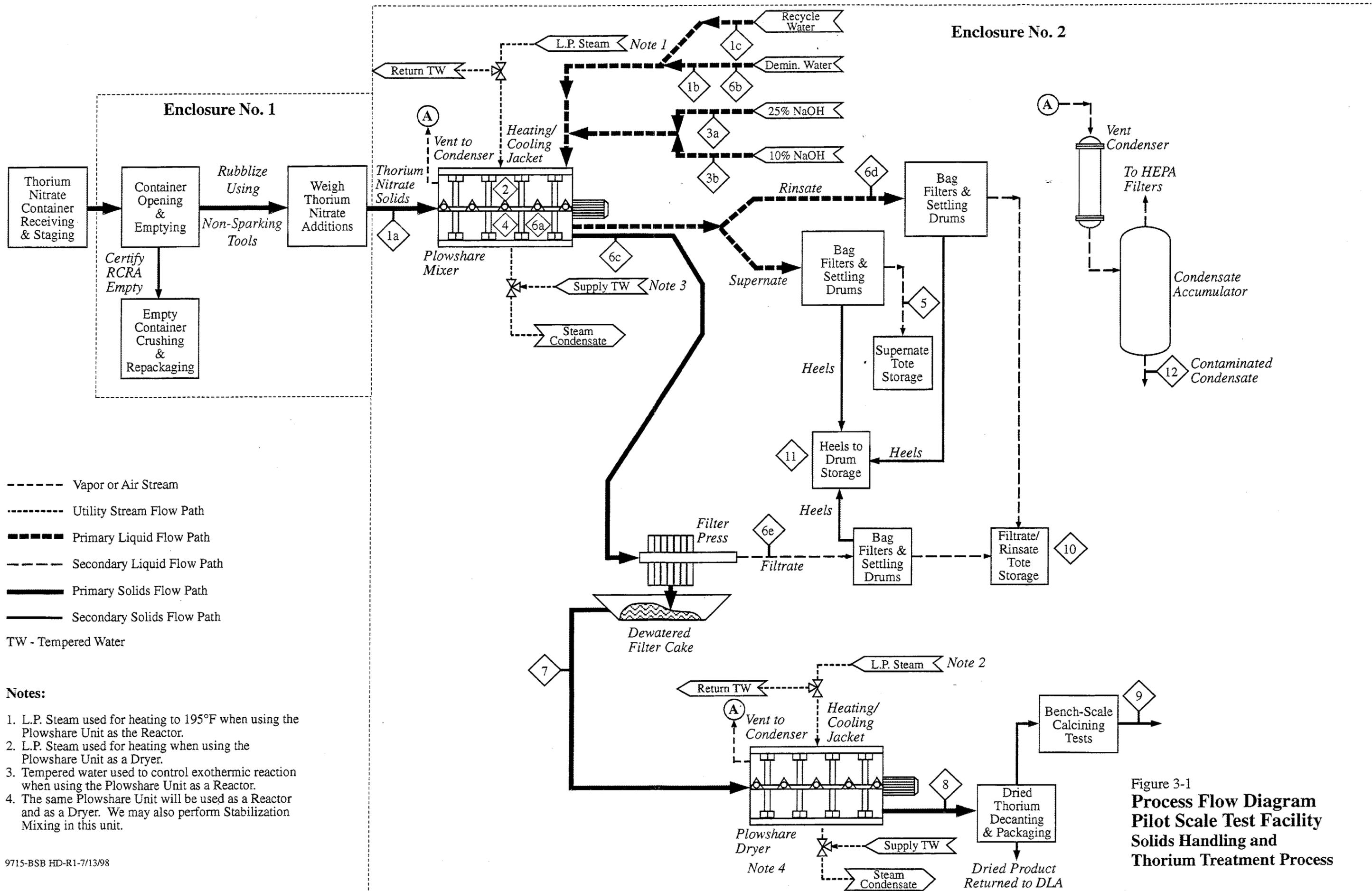


Figure 3-1  
**Process Flow Diagram**  
**Pilot Scale Test Facility**  
**Solids Handling and**  
**Thorium Treatment Process**

The drums were opened manually by two crew members dressed in anti-contamination clothing and air-line respirators. Drum opening took place inside a special enclosure with a negative pressure ventilation system. The ventilation air stream from this enclosure was filtered through pre-filters, HEPA filters, and Granular Activated Carbon filters, before being exhausted to the ambient air. A variety of manual methods were evaluated during the test program, but the most effective method was as follows:

1. Remove the lid of the outer steel container
2. Invert the entire package and lift off the steel container
3. Remove the outer steel container and its lid from the enclosure to prevent their contamination. Survey and decontaminate them as necessary to allow reuse of the steel container.
4. Return the package to its original upright position.
5. Cut away the first plastic bag
6. Remove the lid of the black plastic drum
7. Cut away the tops of the remaining plastic bags and remove the lids from the internal kraft paper drum(s)
8. Invert the black plastic drum and all its internal packages in one movement
9. Remove the outer plastic bag, the black plastic drum and any outer kraft drum encountered
10. Cut the bottom out of the inner kraft drum with a reciprocating saw
11. Lay the inner kraft drum on its side and split the side with a reciprocating saw
12. Peel away the kraft drum to expose the thorium nitrate monolith
13. Using an electric demolition hammer, break up the monolith into chunks
14. Collect and consolidate all of the thorium contaminated packaging materials and repackage for crushing as radioactively contaminated debris
15. Move the thorium nitrate chunks to the dissolving vessel.

The main advantage of this method is that all operations are done dry, thus maintaining positive control over the downstream water balance of the precipitation process. Also, secondary wastes

generated from the unpacking process remain dry, preventing the generation of acidic leachates in the waste matrix that could cause a failure of the RCRA paint filter test, and corrosive attack on secondary waste packaging.

The main disadvantage of this method is that the package must be overturned at least twice during the unpacking operation. Although two workers can manage to overturn the thorium nitrate drums, a mechanical overturning device should be incorporated into the full-scale plant design. Also, the use of a reciprocating saw to cut the kraft paper drums has the potential to create airborne thorium contamination when the thorium nitrate crystals are found to be dry. This potential problem was not observed during the pilot-scale tests because all of the thorium nitrate was fused into monoliths and was damp. Still, a better cutting tool is needed; perhaps shears. With an overturning device, and better cutting tools, the drum opening could be done in a close-fitting enclosure through glove ports, thus eliminating the need for air-line respirators and anti-contamination clothing. A further enhancement of the dry removal method described above is the elimination of the monolith demolition step and the downstream handling of the chunks (Steps 13 and 15). The dissolver vessel described in Section 7.0 will have powered choppers capable of chopping up the entire monolith. In Phase II, the monolith of thorium nitrate will be mechanically conveyed into the dissolver where the choppers will break it up.

### **3.2 Weighing and Dissolving Thorium Nitrate in Hot Demineralized Water**

It is important to weigh the thorium nitrate hydrate in each batch so that the appropriate amount of dilution water can be added to produce a starting solution strength of approximately 270 gm/L thorium. A scale accurate to at least 1.0 pounds is necessary. During the pilot-scale batch tests, a calibrated platform scale reading to 0.01 pounds accuracy was used to weigh all of the thorium feed material. The chunks of thorium nitrate hydrate were placed in tare-weighed buckets and weighed on the platform scale. After the weights had been recorded in the operating log, the buckets were emptied into the pre-heated dilution water in the reactor and then the buckets were rinsed with a small amount of demineralized water. This method was very effective in providing the necessary mass balance information from which the reaction stoichiometry could be estimated. In the full-scale system, weigh cells on the reactor or an upstream dissolving vessel will be used to obtain weights of all materials fed into the process.

### **3.3 Heating and Mixing While Precipitating Thorium Using Sodium Hydroxide**

After the thorium nitrate hydrate was dissolved, sodium hydroxide was added in two stages to precipitate the thorium and to neutralize the free nitric acid, which was imported into the process as an impurity in the thorium nitrate feed material. In the first stage, approximately 2/3 of the stoichiometric requirement was fed in the form of a 25% sodium hydroxide solution, with the first half of that increment being added quickly (essentially slug fed) and the second half being slowly metered until exhausted. In the second stage, approximately 1/3 of the stoichiometric requirement was slowly metered into the reactor in the form of a 10% sodium hydroxide solution until a final pH of 11.0 was achieved.

Before any sodium hydroxide was added, the reactor was brought up to a reaction temperature of 180 °F by non-contact heating provided by hot water circulated through the reactor jacket. A reaction temperature of between 180 and 190 °F was maintained throughout the precipitation step.

The reactor vessel was a modified plowshare dryer with a variable speed drive. The horizontal mixer shaft was used to gently agitate the reaction liquor throughout the dissolving and precipitation processes. Various mixer speeds were tried, but a speed of 10 rpm was found to be best for gentle agitation.

The five batch tests performed showed that the most critical phase of the precipitation process takes place in the pH range from 1.5 to 2.0. In Batch Test 3 and to a lesser extent in Batch Test 5, we passed through this stage too quickly, with the result being the formation of sticky, gelatinous, thorium hydroxide precipitates which had poor settling and filtering characteristics. In each of these tests, the starting pH was in the range of 0.71 to 0.92 and at the end of the slug addition of 25% caustic soda, the pH was between 2.06 and 2.08. In Batch Tests 2 and 4, starting pH was in the range of 0.41 to 0.54 and at the end of the slug addition, the pH was between 1.79 and 1.86. Batch Tests 2 and 4 produced thorium hydroxide solids (filter cake) which were much more granular in nature and much less gelatinous than the corresponding solid product from Batch Tests 1, 3 and 5. Batch Test 4 filter cake had no perceivable gelatinous characteristic. The filter cake from that test was non-sticky, and resembled table sugar which had been dampened and pressed into a block. Most of our difficulties during Batch Tests 3 and 5 were the result of over shooting the critical pH range with the slug addition of caustic soda, and that was partly due to the variability in the purity of the raw thorium nitrate received from the DLA. The variations in starting pH can be attributed only to the differences in acid content of the thorium nitrate raw material.

The titration performed in Batch Test 1 followed the optimum pH curve, but gelatinous solids were produced. This was due to an operational error in which the reactor mixer was left at high speed after the dissolving step and was not slowed down until well past the critical pH range. The problems with Batch Test 1 were the result of high mechanical shear imparted to the reactor slurry during critical phases of the titration. Because of this mistake, Batch Test 2 was a repeat of the Batch Test 1 experiment, without the mistakes.

From the titration curves of Batch Tests 2 and 4 we discovered that the rate of caustic soda addition can be increased substantially after a pH of 4.0 has been achieved. If non-gelatinous, good-settling, thorium hydroxide solids have been produced by the pH 4.0 point, the precipitation process is very resistant to production of gelatinous solids during the remainder of the titration. Our design for Phase II described in Section 7.0 of this report will eliminate the slug addition, and will use multiplexed pH sensors and a programmable logic controller to follow a prescribed titration curve, eliminating the potential for over shooting the critical precipitation pH range.

### **3.4 Gravity Separation of Sodium Nitrate Mother Liquor from the Sludge Blanket**

After the end point pH of 11.0 was reached, the mixer was shut down, and the thorium hydroxide solids were allowed to settle, forming a sludge blanket on the bottom of the reactor. Typically, the sludge blanket consisted of a relatively dense layer of milky white solids. The supernate, or mother

liquor, was crystal clear but had a yellow-green tint. The speed of settling and the relative thicknesses of the sludge blanket and the supernate layer were good indicators of how well the solids would filter in downstream separation processes. After settling was complete, the supernate layer was skimmed off to drums for intermediate storage and sampling.

### **3.5 Serial Rinsing of the Thorium Hydroxide Sludge Blanket**

In Batch Tests 3 through 5, one or more serial rinses were performed in the reactor after the mother liquor had been decanted. The goal of this activity was to wash residual nitrate and sodium out of the sludge blanket before the de-watering step. Demineralized water produced on site was used for each rinse. The desired amount of demineralized water was metered into the reactor, and the agitator was restarted to mix the rinse water with the sludge. Then, the agitator was shut down and the sludge blanket was allowed to settle again to its original volume. Then, rinsate was skimmed off and stored in drums in the same manner as the mother liquor. This process was repeated for each rinse step performed in the reactor.

### **3.6 De-watering and Rinsing of Thorium Hydroxide Product**

A standard plate and frame filter press was used to de-water the sludge blanket and provide additional rinsing. The press was fed by pumping from the reactor to the press using an air-driven double diaphragm pump. If a demineralized water rinse was performed in the filter press, it was added to the reactor to rinse down the reactor internals, the transfer hoses, and the pump as the rinse water was pumped into the press.

Press filtrate was discharged through a bag filter and into drums for settling of entrained thorium hydroxide solids. The bags used in the bag filter had 5.0, 3.0, and 1.0 micron filter ratings, but we found that none of these ratings was adequate to capture all of the solids washed out of the filter press. Filtrates and rinsates from the filter press were stored separately from the mother liquor.

Significant quantities of thorium hydroxide solids settled in the receiving drums. For test purposes, these settled solids were considered to be process heels. In our calculations of the thorium yield values quoted later in this report, we considered thorium hydroxide in the heels to be losses, and did not include this material in the calculated yield. In the full-scale process, the basic process can be improved to minimize losses of thorium solids into the heels, and the small amount of solids lost to the heels can be recovered.

At the end of the filter press run, the press was opened and the cake was dropped into a tare-weighted metal hopper. The hopper was weighed to obtain the net weight of the wet filter cake.

### **3.7 Drying of Thorium Hydroxide Filter Cake**

In the pilot-scale tests, the same plowshare dryer used earlier as a precipitation reactor was also used to dry the press filter cake. The cake was manually loaded into the dryer, and the access port was sealed. The agitator was operated at a speed in the range of 20 to 50 rpm. Low pressure saturated steam in the temperature range of 250 to 290 °F was circulated through the jacket to provide the heat for drying. Overhead vapors leaving the dryer passed through a condenser and then through an accumulator vessel before discharging through the HEPA filters to the atmosphere outside the building. Non-contact cooling water from an outdoor cooling tower was circulated through the condenser for cooling. Recovered condensate consisted of water contaminated with low concentrations of thorium, sodium and nitrate. The drying process was terminated when a visual inspection showed the thorium hydroxide solids to be an apparently dry powder.

### **3.8 Filtration and Ion Exchange Polishing of Secondary Process Liquid Streams**

Three secondary liquid streams were produced from each pilot scale batch test; (1) mother liquor, (2) filtrate/rinsate, and contaminated condensate. Mother liquor and filtrate/rinsate were bag filtered at the time of collection. Each of these streams from a batch test were combined with similar streams from earlier batch tests in stainless steel tote containers and held until all five batch tests were completed. Then, each specific liquid stream was treated in an ion exchange run, in an effort to further reduce total thorium without changing the sodium nitrate concentration.

The ion exchange resin selected for these test runs was SIR-500™, an aminophosphonic chelating resin supplied by ResinTech, Inc. This resin has a demonstrated capability to remove multi-valent cations from sodium rich brines. Manufacturer instructions for use of this resin included operation with pH over 8.0 and temperature in the range of 158 to 176 °F. All three liquid streams had initial pH over 8.0, but due to extended storage, the liquids were no longer hot. To heat these streams prior to the ion exchange run, the contents of the tote container were pumped back into the plowshare reactor and re-heated. Typically, the heated water from the reactor was slowly pumped through a cartridge filter and two ion exchange columns in series and then discharged into a tote. In a full-scale system, the liquid streams that could not be recycled back into the process would be treated while they were still hot to alleviate the need for re-heating.

### **3.9 Recovery of Process Heels**

Process heels during the pilot scale tests consisted of settled sludge blankets from the bottom of liquid receiving drums and solids collected in bag filters. The heels in the receiving drums originated from either the mother liquor, the reactor rinses, or from the press filtrate or rinsate. During the pilot scale test program, heels were recovered by drying them in the dryer. The product from this method of recovery is completely converted to thorium hydroxide, but it contains a higher concentration of residual sodium nitrate than the product resulting from serial rinsing.

Improved control of the precipitation process in the full-scale should result in a reduction in heels

produced, and they should be recoverable by recycling them back to the reactor at the end of a precipitation run. By recycling heels in this manner, the solids recovered would benefit from the rinses performed in the filter press, thus reducing their residual sodium nitrate concentrations.

### **3.10 Packaging of Dried Product**

After each dryer run was terminated, the steam supply was isolated and cooling water was pumped through the dryer jacket to cool down the thorium hydroxide solids to a temperature of less than 110 °F. Then, a trap door in the bottom of the dryer was opened and the solids were discharged into a tare-weighed, plastic-lined, 33-gallon high density polyethylene (HDPE) drum hermetically sealed to the discharge flange. The lid of the HDPE drum was placed loosely on top of the drum and the product was allowed to cool to room temperature. The drum was weighed again to determine the net weight of thorium hydroxide product in the package. When cool, the plastic bag was closed with a horse-tail closure and the drum lid was sealed. Each 33-gallon HDPE drum of product was placed in one of the original steel 55-gallon drums for shipment back to DLA's Curtis Bay, Maryland site.

## 4.0 PRELIMINARY BENCH SCALE TESTING

While design, procurement, and installation of the pilot-scale test facility were being performed, a bench-scale testing program was conducted to characterize the thorium feed material, and to develop the basic de-nitration process and the process control parameters to be used later in the pilot-scale batch tests. These tests were performed with samples from the Oak Ridge drum provided by Lockheed Martin Energy Systems, Inc. The results of these tests were used to develop the basic de-nitration process used in Pilot Batch Tests 1 and 2, and to conceptualize process improvements which were tested in Pilot Batch Tests 3, 4, and 5. Some of the specific bench tests performed were as follows:

### 4.1 Thorium Nitrate Dissolving Tests

Aliquots of thorium nitrate were dissolved in demineralized water and in mother liquor produced from earlier bench tests. These tests confirmed that thorium nitrate hydrate solubility in the anticipated dissolving liquids would not be a limiting factor in the bench-scale tests.

### 4.2 De-nitration Stoichiometry and Control Parameters

Aliquots of thorium nitrate were dissolved as in 4.1 above, and subjected to titration at temperatures of 160 and 200 °F. A titration was performed using 50% sodium hydroxide to a final pH of 11.0. Viscosity of the titrated solution was measured at pH 5.57 and 11.0. Also, temperature measurements were made to evaluate how strong the exothermic reaction would be.

A back-titration from pH 11.0 back to a pH of 1.92 was performed using thorium nitrate solution as the titrant. This was to provide data on how the pH could be brought down in the event of overshooting the sodium hydroxide reaction end point. In the pilot scale tests, back-titration with thorium nitrate solution was never attempted. In Batch Test 5 back-titration with concentrated nitric acid was performed. More details will be provided in Section 5.5 of this report.

In titrating from a starting pH of 1.32 to a final pH of 10.2, the temperature of the thorium nitrate solution rose from 76.0 °F to 113 °F. This small temperature rise showed that the exotherm could not be relied upon to raise the thorium nitrate solution to the 190 °F target established for the Fernald sol-gel process.

Experience from these tests showed that Fernald's final target pH of 6.0 would be inadequate for the purpose of maximizing precipitation of thorium. To convert essentially all of the thorium to insoluble thorium hydroxide, it proved necessary to establish an end point for the reaction at pH= 11.0. These tests also showed that the degree of control when using 50 % sodium hydroxide was poor, resulting in wide pH swings. Subsequent bench tests showed that a two-stage titration with 25 % sodium hydroxide initially, and 10 % later was optimum.

### **4.3 Gravity Thickening Tests**

The precipitation methods developed in 4.2 above were used to produce precipitate slurries at the two reaction temperatures previously discussed and with mother liquor recycled as dissolving solution. Aliquots of precipitate slurry from each of these tests were subjected to gravity settling with and without cationic polyelectrolyte settling aids. Settling curves were developed and evaluated. The results indicated that the temperature difference between 160 and 200 °F is insignificant as a process control parameter. The main factors in producing a settleable precipitate are end point pH and the rate of pH rise. Settling aids had no perceptible effect.

### **4.4 Vacuum Filtration Tests**

The settled solids produced in 4.3 above were subjected to bench scale vacuum filtration to evaluate how well filtration would effect a separation between the sodium nitrate and thorium hydroxide reaction products. The same pH and temperature ranges were used, and filtration aids were evaluated. Once again, end point pH and the rate of pH rise appeared to be the only factors having a significant effect upon filtrate thorium content. Filtering rate seemed to be strongly influenced by the rate of pH rise and the degree of fine control during the precipitation step.

### **4.5 Oven Drying Tests**

Filtered solids from 4.4 above were subjected to low temperature drying in a laboratory oven to evaluate the relative drying characteristics of the thorium hydroxide product from the various earlier test combinations. The results of these tests showed no perceptible difference in the drying performance of thorium hydroxide solids produced at differing temperatures, solids produced after recycling mother liquor, or solids treated with settling or filter aids.

## 5.0 PILOT DEMONSTRATION BATCH TESTS

The pilot-scale testing was performed as 5 discrete batch tests which were designed to demonstrate the basic de-nitration process and further investigate process enhancements. These enhancements were designed to improve the quality of the thorium product and the sodium nitrate byproduct. Each batch test is described in detail below.

### 5.1 Batch Test No. 1 - Evaluation of the Basic Precipitation Process

The results of the Preliminary Bench-Scale Tests were used to develop the Batch Test Instructions for use in Batch Test No. 1. The main goals for this batch test were to demonstrate the precipitation, thickening, filtration and drying steps of the process on approximately 400 pounds of thorium nitrate feed material.

#### 5.1.1 Test Narrative

The recoverable thorium nitrate from two randomly selected drums were removed from their original packaging on November 18, 1997, and transferred to buckets for weighing. The recovered thorium nitrate used in Batch Test No. 1 totaled 389.81 pounds. A grab sample of the raw material was collected and split into three aliquots given the sample designations BT1-001a, b, and c. These samples were submitted for analysis of total metals, % nitrate, gross alpha and beta, alpha spectroscopy, gamma spectroscopy, X-ray diffraction, and the DOT oxidizer Test. The data from these samples was used to characterize the feed thorium nitrate for all 5 Batch Tests.

Beginning early on the morning of November 19, 1997, the thorium nitrate feed material was dissolved in the reactor in 52.8 gallons of demineralized water at a temperature of approximately 145 °F. The agitator speed was set at 103 rpm. The dissolving step produced a thorium nitrate solution with a 17.3 % thorium concentration (Sample No. BT1-002b) and a nitrate concentration of 16.6 % (Sample No. BT1-002a). In anticipation of the exothermic reaction, the initial stages of the sodium hydroxide addition were performed at lower than target temperatures. Over a period of 9 minutes, 30.6 gallons of 25 % sodium hydroxide were added to the thorium nitrate solution in the reactor. During this period, the agitator speed was inadvertently left at 103 rpm. During the initial phase of sodium hydroxide addition, the solution pH increased from an instrumentally measured reading of -0.13 @ 93°C to 1.90 @ 89°C. A hot plate was used to heat all pH grab samples to approximately the same temperature before readings were taken and recorded.

Over the next hour, the temperature of the hot water circulated through the reactor jacket was increased until the reactant temperature had increased to 177 °F. The agitator speed problem was discovered and the speed was reduced from 103 rpm down to the range of 10 to 20 rpm. At this stage, injection of 10 % sodium hydroxide was begun using a small air-driven double-diaphragm pump. Control of pumping rate at the low end of the pump's speed range was difficult, and as a result the rate of addition was significantly below target. A total of 37.0 gallons of 10 % sodium hydroxide was added over the next four and one-half hours, while reactant temperature was maintained in the range of 181 to 197 °F. Final pH of the reacted slurry was 11.03.

Periodically during the precipitation reaction, grab samples of the reactant mixture were collected and observed to evaluate the settling characteristics of the solids. All of these samples showed finely dispersed small white particles of precipitate which did not settle well. Settling rates were comparable to the worst settling rates experienced during the preliminary batch tests. Vacuum filter tests showed filtration to be slightly better than settling rates. A sample of the reaction product slurry was collected and split into aliquots designated Sample Nos. BT1-004a, b and c. These samples were analyzed for sodium, nitrate, total thorium, gross alpha and beta, and gamma spectroscopy.

Because of poor settling characteristics but marginally better filtration characteristics, it was decided to bypass the gravity thickening step and feed the reactor slurry directly to the filter press, attempting to separate the solids and liquids in the press. The entire inventory of the reactor was pumped through the filter press over a period of approximately 30 minutes. Afterward, approximately 8.5 gallons of demineralized water was used to rinse down the inside of the reactor and flush the hoses and pump. This rinse water was also pumped through the filter press. Filtrate leaving the filter press was pumped through a 5.0 micron bag filter and discharged into three holding drums. The filtrate accumulated in the drums was milky white in color and had a high solids content, but was not as thick as the feed material. The filtrate in the receiving drums was allowed to settle overnight.

In the morning of November 20, 1997, the filtrate drums were each found to have developed a clear layer of yellow-green tinted water above a thickened white sludge blanket. The percentage of original water column height represented by the clear layers varied from 32 to 40 percent. Samples of the clear supernate were collected and designated Samples BT1-007a, b, and c. These samples were analyzed for sodium, nitrate, and total thorium. The sludge layers in the bottom of the drums were designated process heels and transferred to a tank for storage until they could be processed for recovery.

The filter press was opened and the filter cake discharged into a plastic-lined, tare-weighted hopper. A well-formed white filter cake was found in all of the plate cavities. However, the cake was wet and sticky, like a heavy lard. It was necessary to use a plastic paddle to scrape the cake off of the fabric and into the hopper. The hopper was weighed to determine the net weight of the wet cake, which was 218.3 pounds. Samples of the wet cake were collected from the hopper and designated Sample Nos. BT1-006a, b, c, d, and e. These samples were analyzed for sodium, nitrate, moisture, thorium, gross alpha and beta, and gamma spectroscopy.

The cake was manually shoveled from the hopper into the dryer and the agitator was started and run at a speed of 20 rpm. Low pressure steam at an inlet temperature ranging between 262 and 290 °F was circulated through the dryer jacket, resulting in an internal temperature between 195 and 240 °F. It took approximately 3 hours of drying to bring the thorium product to apparent dryness. The steam flow was shut off and cooling water was pumped through the jacket to cool down the product. It took approximately 20 minutes to cool the thorium hydroxide solids down to a temperature of 110 °F. The dried thorium hydroxide was discharged into a drum and the drum was weighed. The net weight of dried thorium hydroxide product produced was 82.5 pounds. Samples were collected from the drum and designated BT1-008a, b, c, d, e, and f. These samples were analyzed for sodium, nitrate, thorium, UTS metals, moisture, X-ray Diffraction, gross alpha and beta, gamma

spectroscopy, and the DOT oxidizer Test. An additional set of samples, designated BT1-009a, b, c, d, and e, were collected and stored for later use in bench-scale calcining tests. After calcining tests, samples of the calcined material with the same sample designation were submitted for analysis of thorium, nitrate, and UTS metals.

Contaminated condensate water from the accumulator was sampled prior to being transferred into a stainless steel tote container for storage. The samples, designated BT1-005a and b, were analyzed for sodium, nitrate, and thorium concentration.

### **5.1.2 Results Evaluation**

Overall, Batch Test No. 1 was a learning experience in which most of the lessons learned were from the mistakes made during the precipitation stage of the process. Taking credit for only the thorium hydroxide captured as filter cake and dried, the thorium yield was only 24.71 %. The remainder of the thorium came to reside in the process heels, from which it was later recovered. The nitrate content of the dried thorium hydroxide product was 14.96 %. The low yield and low product quality is a direct result of the poor settling and filtration characteristics of the thorium hydroxide solids produced in the precipitation step. The mistakes leading to these undesirable characteristics are listed in decreasing order of importance, as follows:

- Leaving the agitator at 103 rpm during the first stages of sodium hydroxide addition. This exposed the fine precipitates of thorium hydroxide to high mechanical shear during in the critical pH range of 1.5 to 2.0 units.
- Erratic metering of sodium hydroxide. The metering pump was over-sized, resulting in poor control of metered feed rates.

Batch Test No. 1 was judged to have been a failure, requiring that the test parameters be repeated in Batch Test No. 2, with process changes to address the mistakes of the first test.

Table 5-1 summarizes the time increments required for various steps of the de-nitration process during Batch Test No. 1 and estimated times for the process steps carried to Phase II, and corrected to eliminate the mistakes of Batch Test 1. The time intervals shown for Batch Test No. 1 include only the described activity, and do not include time consumed investigating problems, collecting data, sampling materials, and deciding upon the next action. The batch size in Batch Test No. 1 was 2 drums. In the Phase II column, the batch size is assumed to be 16 drums. Although it takes 22.25 hours for the batch to be processed, it moves through the process in three stages on three successive days as follows:

- Stage 1 - 8.25 hours, unpacking and dissolving of thorium nitrate
- Stage 2 - 8.5 hours, precipitation, decanting and dewatering of thorium hydroxide
- Stage 3 - 5.5 hours, drying, cool down and product packaging

As soon as a batch moves from Stage 1 to Stage 2, the next batch can begin Stage 1, and so on through the three stages.

**Table 5-1  
Summary of De-nitration Process Steps  
Based on Batch Test No. 1 Results**

<b>Process Step Description</b>	<b>Batch Test No. 1 Time for 2 Drum Batch *</b>	<b>Projected Phase II Time for 16 Drum Batch</b>
Unpack TNH Drums	3.5 hours	8.0 hours
Dissolve Thorium Nitrate	0.75 hours	0.25 hours
Add Slug of 25 % NaOH	0.15 hours	Not Applicable
Slow Addition of 25 % NaOH	Not Applicable	2.0 hours
Slow Addition of 10 % NaOH	2.5 hours	4.0 hours
Solids Settling	Not Applicable	1.0 hours
Supernate Decanting	Not Applicable	0.5 hours
Sludge Dewatering	0.5 hours	1.0 hours
Filter Cake Transfer to Dryer	1.0 hours	0.50 hours
Sludge Drying	3.0 hours	4.0 hours
Dryer Cool Down & Discharge to Packaging	0.33 hours	1.0 hours
<b>Total Processing Time</b>	<b>11.73 hours</b>	<b>22.25 hours</b>

\* Time intervals do not include investigative and operations development activities, only the time required to actually perform the described task.

## 5.2 Batch Test No. 2 - Evaluation of the Basic Precipitation Process

The results of the Preliminary Bench-Scale Tests and Batch Test No. 1 were used to develop the Batch Test Instructions for use in Batch Test No. 2. The main goals for this batch test were to incorporate the lessons learned into a demonstration of the precipitation, thickening, filtration and drying steps of the process on approximately 400 pounds of thorium nitrate feed material.

### 5.2.1 Test Narrative

The recoverable thorium nitrate from two randomly selected drums were removed from their original packaging on December 1, 1997, and transferred to buckets for weighing. The recovered thorium nitrate used in Batch Test No. 3 totaled 410.34 pounds.

Beginning early on the morning of December 2, 1997, the thorium nitrate feed material was dissolved in the reactor in 52.8 gallons of demineralized water at a temperature of approximately 130 °F. The agitator speed was set at 50 rpm. Hot water temperature in the reactor jacket was increased to 180 °F over the next 2 ½ hours. The dissolving step produced a thorium nitrate solution with 17.8 % thorium concentration (Sample No. BT2-001b) and a nitrate concentration of 20.4 % (Sample No. BT2-001a). Table 6-2 presents validated analytical results and material balance calculations in the same tabular format. The agitator speed was reset to 10 rpm. Over a period of 10 minutes, 32.6 gallons of 25 % sodium hydroxide were added to the thorium nitrate solution in the reactor. During the initial phase of sodium hydroxide addition, the solution pH increased from an instrumentally measured reading of 0.41 @ 95°C to 1.80 @ 95°C. A hot plate was used to heat all pH grab samples to approximately the same temperature before readings were taken and recorded.

Over the next hour, the temperature inside the reactor was maintained steadily in the 191 to 192 °F range, while pH increased from 1.80 to 1.86 @ 95 °C, due to addition of approximately 7.0 gallons of 10 % sodium hydroxide. The agitator speed was maintained at 10 rpm. The injection rates were considerably steadier than in Batch Test No. 1, but there were still some control difficulties. Over the next 3 ¼ hours, approximately 47.0 gallons of 10 % sodium hydroxide were added, to reach a total of 54.0 gallons added and a final pH of 10.94 @ 94.5 °C.

Periodically during the precipitation reaction, grab samples of the reactant mixture were collected and observed to evaluate the settling characteristics of the solids. Precipitated solids were first observed at a pH of approximately 1.86, very early in the addition of 10 % sodium hydroxide. From this time until the final pH of 10.94 was reached, all grab samples showed good settling rates, and clear yellow-green tinted supernates. A sample of the clear supernate analyzed at an on-site laboratory indicated that the supernate retained only 0.04 % of the original thorium.

After the final pH was reached, the agitator was shut down, and the solids were allowed to settle in the reactor for approximately 1 hour. Gravity thickening of the reactor product resulted in approximately 45 % of the batch volume being recovered as clear yellow-green supernate (mother liquor), and 55 % as a thick milky white sludge blanket. A sample of the clear supernate was collected and split into aliquots designated BT2-004a and b. These samples were analyzed for sodium, nitrate, chloride, and thorium concentration. The supernate was pumped off through a 5.0 micron bag filter and into holding drums.

The sludge blanket was rinsed by adding 50 gallons of demineralized water to the reactor and gently mixing with the agitator for 10 minutes at a speed of 10 rpm. The agitator was shut down and the sludge blanket was allowed to settle overnight.

In the morning of December 3, 1997, the sludge blanket thickness had returned to slightly less than

its original volume. The agitator was restarted at a speed of 10 rpm to stir up the sludge blanket and prepare it for filtration in the plate and frame filter press. Samples of the filter press feed slurry were collected and designated BT2-003a, b, and c. These samples were analyzed for sodium, nitrate, moisture, thorium gross alpha and beta, and gamma spectroscopy. Over a seven minute period the entire sludge blanket was pumped into the press and the filtrate was discharged into holding drums. The filtrate was a thin milky suspension with a slight yellow-green tint. The solids in the filtrate settled quickly to the bottom of the holding drums. The supernate and settled solids from the holding drums was pumped back into the reactor, and for a period of 10 minutes, the supernate was circulated from the reactor through the press and back to the reactor. This was done in an effort to maximize the solids capture efficiency of the filter press. Finally, the filtrate was discharged back into holding drums. After entrained solids settled out of the filtrate, the clear layer was pumped through a 1.0 micron bag filter and into clean drums. Only trace solids were left in the filtrate at this stage. These solids settled to form a thin non-continuous layer on the bottoms of the holding drums. Samples of the clear layer from the filtrate holding drums were collected and designated BT2-006a, b and c. These samples were analyzed for sodium, nitrate, chlorides, and thorium.

The sludge layers in the bottom of the mother liquor and filtrate holding drums were designated process heels, consolidated, and transferred to a drum for storage until they could be processed for recovery.

The filter press was opened and the filter cake discharged into a plastic-lined, tare-weighed hopper. A well-formed white filter cake was found in all of the plate cavities. Although this cake retained the color and texture of lard, it was much dryer, much denser, and much less sticky than the cake produced in Batch Test No. 1. Most of the cake fell off the fabric in one large piece, with very little need for scraping of the fabric with the plastic paddle. The large pieces of cake broke into smaller chunks in the hopper, further demonstrating the overall dryness of the cake. The hopper was weighed to determine the net weight of the wet cake, which was 312.4 pounds. Samples of the wet cake were collected from the hopper and designated Sample Nos. BT2-005a, b, c, d, and e. These samples were analyzed for sodium, nitrate, moisture, thorium, gross alpha and beta, and gamma spectroscopy.

The cake was manually shoveled from the hopper into the dryer and the agitator was started and run at a speed of 50 rpm. Low pressure steam at an inlet temperature ranging between 225 and 235 °F was circulated through the dryer jacket, resulting in an internal temperature between 209 and 211 °F. It took approximately 2 hours and 40 minutes of drying to bring the thorium product to apparent dryness. The steam flow was shut off and cooling water was pumped through the jacket to cool down the product. It took approximately 27 minutes to cool the thorium hydroxide solids down to a temperature of 105 °F. The dried thorium hydroxide was discharged into a drum and the drum was weighed. The net weight of dried thorium hydroxide product was 194.5 pounds.

Samples of the dried product were collected from the drum and designated BT2-007a, b, c, d, e, and f. These samples were analyzed for sodium, chloride, nitrate, moisture, thorium, UTS metals, X-ray diffraction, gross alpha and beta, gamma spectroscopy, and the DOT oxidizer test. An additional set of samples, designated BT2-008a, b, c, d, and e, were collected and stored for later use in bench-

scale calcining tests. After calcining tests, samples of the calcined material with the same sample designations were submitted for analysis of thorium, nitrate, moisture, UTS metals, and X-ray diffraction.

Contaminated condensate water from the accumulator was sampled prior to being transferred into a stainless steel tote container for storage. The samples, designated BT2-009a, b and c, were analyzed for sodium, chloride, and thorium concentration.

### **5.2.2 Results Evaluation**

Batch Test No. 2 was a success, finally accomplishing the goal of demonstrating the precipitation, gravity thickening, press filtration, and drying operations of the basic de-nitration process. Taking credit for only the thorium hydroxide captured as filter cake and dried, the thorium yield was 62.1 %. The remainder of the thorium came to reside in the process heels, from which it was later recovered. The nitrate content of the dried thorium hydroxide product was 4.5 %. This test showed that slow mixing speeds, and better control of the rate of sodium hydroxide additions result in a thorium hydroxide precipitate that settles and filters well. The fates of thorium, sodium, and nitrates in Batch Test No. 2 are presented in tabular form in the material balance of Table 6-2.

The results of Batch Test No. 2 were evaluated and found to have successfully demonstrated the basic de-nitration processes, but resulted in a dried thorium hydroxide product which still contained 4.5 % nitrate content. At the time of the pilot-scale tests, it was not known whether the presence of this much free nitrate would cause the product to be classified as a DOT oxidizer. Testing of the Batch Test No. 2 dried product according to 49 CFR 173 Appendix F later showed that it was not a DOT Division 5.1 oxidizer.

With the basic process demonstrated, the next batch tests were focused on improving product quality by serial rinsing of the precipitated thorium hydroxide solids. Rinsing in the reactor and in the filter press were incorporated into the Batch Test Instructions for all subsequent tests, to evaluate how pure the dried product could be made.

Table 5-2 summarizes the time increments required for various steps of the de-nitration process during Batch Test No. 2 and estimated times for the process steps carried to Phase II, and adjusted for lessons learned in Batch Test No. 2. The time intervals shown for Batch Test No. 2 include only the described activity, and do not include time consumed investigating problems, collecting data, sampling materials, and deciding upon the next action. The batch size in Batch Test No. 2 was 2 drums. In the Phase II column, the batch size is assumed to be 16 drums. Although it takes 22.75 hours for the batch to be processed, it moves through the process in three stages on three successive days as follows:

- Stage 1 - 8.25 hours, unpacking and dissolving of thorium nitrate
- Stage 2 - 9.0 hours, precipitation, decanting, rinsing and dewatering of thorium hydroxide
- Stage 3 - 5.5 hours, drying, cool down and product packaging

As soon as a batch moves from Stage 1 to Stage 2, the next batch can begin Stage 1, and so on through the three stages.

**Table 5-2  
Summary of De-nitration Process Steps  
Based on Batch Test No. 1 Results**

<b>Process Step Description</b>	<b>Batch Test No. 2 Time for 2 Drum Batch *</b>	<b>Projected Phase II Time for 16 Drum Batch</b>
Unpack TNH Drums	3.5 hours	8.0 hours
Dissolve Thorium Nitrate	0.75 hours	0.25 hours
Add Slug of 25 % NaOH	0.15 hours	Not Applicable
Slow Addition of 25 % NaOH	Not Applicable	2.0 hours
Slow Addition of 10 % NaOH	3.25 hours	4.0 hours
Solids Settling	1.0 hours	1.0 hours
Rinsing, Settling, & Decanting	1.0 hours	1.0 hours
Sludge Dewatering	0.5 hours	1.0 hours
Filter Cake Transfer to Dryer	1.0 hours	0.50 hours
Sludge Drying	2.67 hours	4.0 hours
Dryer Cool Down & Discharge to Packaging	0.50 hours	1.0 hours
<b>Total Processing Time</b>	<b>14.32 hours</b>	<b>22.75 hours</b>

\* Time intervals do not include investigative and operations development activities, only the time required to actually perform the described task.

### 5.3 Batch Test No. 3 - First Attempt at Serial Product Rinsing

The successful process control methods demonstrated in Batch Test No. 2, and serial rinsing steps were incorporated into the Batch Test Instructions for Batch Test No. 3.

### 5.3.1 Test Narrative

The recoverable thorium nitrate from two randomly selected drums were removed from their original packaging on December 3, 1997, and transferred to buckets for weighing. The recovered thorium nitrate used in Batch Test No. 3 totaled 385.27 pounds.

Beginning early on the morning of December 4, 1997, the thorium nitrate feed material was dissolved in the reactor in 52.8 gallons of demineralized water at a temperature of approximately 110 °F. The agitator speed was set at 50 rpm. Hot water temperature in the reactor jacket was increased to 190 °F over the next 2 ¼ hours, resulting in a final temperature of 183 °F inside the reactor.

The precipitation reaction was started in the same manner that had been used in Batch Test 2, but the early sampling during the precipitation step indicated that the settling and filtration characteristics were poor. In fact, the Batch Test 3 solids were worse than the Batch Test 1 solids. Although, sampling of the various process streams was performed in the same manner as in the previous two Batch Tests, these samples were archived, but never were sent out for analysis. The remainder of this test narrative is presented below in qualitative terms to describe the lessons learned in Batch Test No. 3. In terms of the original goals set for Batch Test 3, the test would have to be judged as a failure. However, the lessons learned in response to the process upset provide valuable insight for modification of the basic process.

At the beginning of the precipitation process, the agitator speed was reset to 10 rpm. Over a period of 15 minutes, 31.6 gallons of 23.4 % sodium hydroxide were added to the thorium nitrate solution in the reactor. During the initial phase of sodium hydroxide addition, the solution pH increased from an instrumentally measured reading of 0.92 @ 93°C to 2.06 @ 95°C. A hot plate was used to heat all pH grab samples to approximately the same temperature before readings were taken and recorded.

Over the next 6 ½ hours, the temperature inside the reactor was maintained in the 185 to 210 °F range, while pH increased from 2.06 to 11.02 @ 94 °C, due to addition of approximately 35.5 gallons of 9.2 % sodium hydroxide. The agitator speed was maintained at 10 rpm, except for times when the agitator was shut down for inspection or sampling of the reactant mixture in the reactor. The injection rates were as steady as in Batch Test No. 2, except for the times when injection was discontinued for inspection or sampling.

Periodically during the precipitation reaction, grab samples of the reactant mixture were collected and observed to evaluate the settling characteristics of the solids. Precipitated solids were first observed at the conclusion of the 23.4 % sodium hydroxide addition, at a pH of approximately 2.06. In Batch Test No. 2, the pH at the end of the slug addition of 25 % sodium hydroxide was 1.80 and precipitation was not observed until a pH of 1.86. Batch Test No. 3 started with a much higher initial pH than was observed in the two previous tests. These variations in starting pH are attributable only to variations in the quality of the thorium nitrate feed materials. A likely explanation is that individual drums of thorium nitrate contain differing concentrations of residual nitric acid. If this is true, the feed materials used in Batches 1 and 2 had substantially more free nitric acid than the drums used in Batch Test No. 3. The initial slug addition of 23.4 % sodium hydroxide

in Batch Test No. 3 appears to have overshot a critical initialization point of the precipitation/pH control curve. As the precipitation process continued, periodic grab samples showed settling rates that were apparently better than Batch Test No. 1, but were worse than Batch Test No. 2. After the final pH was reached, the agitator was shut down, and the solids were allowed to settle in the reactor overnight.

Early on the morning of December 5, 1997, strap measurements of the contents of the reactor showed that approximately 60 % of the batch volume was composed of a clear yellow-green supernate (mother liquor), and 40 % as a thick milky white sludge blanket. The supernate was pumped off through a 1.0 micron bag filter and into holding drums.

The sludge blanket was rinsed by adding 35 gallons of demineralized water to the reactor and gently mixing with the agitator for 10 minutes at a speed of 10 rpm. The agitator was shut down and the sludge blanket was allowed to settle. Over the next 3 hours, several attempts were made to filter out clear liquids using a pump suction wand covered with a bag filter element. The goal of this decanting method was to remove some of the interstitial liquid in the sludge blanket as well as the decantable supernate layer. These attempts failed. The bag filter attachment was removed and the wand was used to pump down the recoverable clear rinse layer. Very little liquid was removed by this method.

Finally, the entire sludge blanket was pumped through the filter press with some degree of success, if judged based upon recovered liquid. Approximately 50 gallons of liquid were recovered, which suggests that 15 gallons of that was interstitial liquid from the sludge blanket. However, the back-pressure acting against the pump built up rapidly, indicating filter cloth blinding. When the filter press was opened, only half of the cavities had cake, and that was very wet and sticky. The rest of the cavities contained unconcentrated feed sludge, which drained into the cake hopper. There was some loss of liquids to the floor, requiring some extensive cleanup. By the time the cleanup was done, it was too late in the day to do any further processing. The metal lid was placed over the cake hopper, and all equipment was shut down and the quonset hut locked up for the weekend.

It was decided that thermal conditioning of these gelatinous solids might improve our ability to rinse and de-water the thorium hydroxide. Early on December 8, 1997, all of the gelatinous filter cake and milky filtrate heels were transferred into the dryer, and these solids were dried to the point of apparent dryness. This dryer run took all day.

On December 9, 1997, two more demineralized water rinses were performed on the dryer product in the dryer. These were designated Rinses 2 and 3. Rinse 1 was the one performed before the sludge was fed to the filter press on December 5, 1997. In Rinse 2, a volume of 25.0 gallons of demineralized water was added, and 12.4 gallons were recovered when the clear layer was decanted. In Rinse 3, a volume of 29.0 gallons of demineralized water were added, and 27.2 gallons of clear liquid were recovered. In both rinses, the recovered liquid was clear except for a slight turbidity due to white colloidal solids. The lack of yellow-green tint indicated that most of the attributes of the mother liquor had been removed.

After the Rinse 3 clear liquid was recovered, the remaining sludge blanket was dried in the dryer by the same methods used in Batch Tests 1 and 2. The dry thorium hydroxide solids discharged to the drum had a net weight of 213.2 pounds. This concluded Batch Test 3.

### **5.3.2 Results Evaluation**

Batch Test No. 3 was a failure from the viewpoint of further demonstrating the basic de-nitration process, but it did provide useful information and experience in recovery from process upsets. The value of thermal digestion by drying and subsequent re-slurrying and rinse steps was demonstrated. Batch Test No. 3 also revealed the unexpected variability in the quality of the thorium nitrate feed materials, and the sensitivity of the precipitation process to variations in free nitric acid content and starting pH. In cases where the starting pH is above 0.5, great care should be taken with the early sodium hydroxide additions. Between pH 0.5 and 1.8, extra time for precipitation of desirable solids is needed. Haste at this stage of the precipitation process, assures downstream problems with liquid/solid separation. In Batch Test 3, the initial slug of 23.4 % sodium hydroxide overshot the critical pH range.

As a result of Batch Test No. 3, it was decided that only half of the 25 % sodium hydroxide solution should be added in the initial slug and that the other half should be metered in over an extended period of time. This modification was incorporated into Batch Test No. 4.

## **5.4 Batch Test No. 4 - Second Attempt at Serial Product Rinsing**

The results of the previous three batch tests were reviewed and the lessons learned were incorporated into the Batch Test Instructions for use in Batch Test No. 4. The main goals for Batch Test No. 4 were the same as the pre-test goals for Batch Test No. 3, namely, to repeat the precipitation success of Batch Test No. 2 with the added process enhancement of serial rinsing of the thorium hydroxide product.

### **5.4.1 Test Narrative**

The recoverable thorium nitrate from two of the remaining drums of feed material were removed from their original packaging on December 9, 1997, and transferred to buckets for weighing. The recovered thorium nitrate used in Batch Test No. 3 totaled 385.52 pounds.

Beginning early on the morning of December 10, 1997, the thorium nitrate feed material was dissolved in the reactor in 52.8 gallons of demineralized water at a temperature of approximately 145 °F. The agitator speed was set at 50 rpm. Hot water temperature in the reactor jacket was increased to 180 °F over the next 2 ½ hours. The dissolving step produced a thorium nitrate solution with 16.8 % thorium concentration (Sample No. BT4-001b) and a nitrate concentration of 27.5 % (Sample No. BT4-001a). Table 6-3 presents validated analytical results and material balance calculations in the same tabular format. The agitator speed was reset to 10 rpm. Over a period of 30 minutes, 15.6

gallons of 25 % sodium hydroxide were metered into the thorium nitrate solution in the reactor. During the initial phase of sodium hydroxide addition, the solution pH increased from an instrumentally measured reading of 0.54 @ 95°C to 1.79 @ 95°C. Over the next hour, another 15.0 gallons of 25 % sodium hydroxide solution were metered in, and the pH remained steady in the range of 1.70 to 1.87, with no clear upward or downward trend. A hot plate was used to heat all pH grab samples to approximately the same temperature before readings were taken and recorded.

Over the next six hours, the temperature inside the reactor was maintained steadily in the 185 to 198 °F range, while pH increased from 1.74 to 11.02 @ 95 °C, due to addition of approximately 32.8 gallons of 10 % sodium hydroxide. A new bellows pump for feeding sodium hydroxide resulted in much better control than in any of the earlier tests. The agitator speed was maintained at 10 rpm.

Periodically during the precipitation reaction, grab samples of the reactant mixture were collected and observed to evaluate the settling characteristics of the solids. Precipitated solids were first observed at a pH of approximately 2.04, very early in the addition of 10 % sodium hydroxide. From this time until the final pH of 11.02 was reached, all grab samples showed good settling rates, and clear yellow-green tinted supernates.

After the final pH was reached, the agitator was shut down, and the solids were allowed to settle in the reactor. Although settling rates were good, due to the late hour it was decided to let the solids settle overnight. On the morning of December 11, 1997, the sludge blanket and supernate ( mother liquor) were observed and their volumes calculated. Gravity thickening of the reactor product resulted in approximately 67 % of the batch volume being recovered as clear yellow-green supernate, and 33 % as a thick milky white sludge blanket. A sample of the clear supernate was collected and split into aliquots designated BT4-004a and b. These samples were analyzed for sodium, nitrate, and thorium concentration. The supernate was pumped off through a 1.0 micron bag filter and into holding drums. A skimmer attachment on the decant hose was used to help minimize the amount of sludge blanket solids lost to the holding drums during the decanting operation.

A series of demineralized water rinses were performed to demonstrate the product quality benefits of serial rinsing. Each of the first three rinses were performed by decanting any free liquid layers above the sludge blanket, and then adding 25 gallons of demineralized water to the reactor and gently mixing with the agitator for 10 minutes at a speed of 10 rpm. Then, the sludge blanket was allowed to settle to its original volume, and the next rinse was performed by the same methods. The fourth rinse was performed in the same manner, except that the sludge blanket and rinse water were separated in the filter press. Then, a fifth rinse was performed by pumping 25 gallons of demineralized water into the reactor, to rinse down the reactor internals, the pipes, hoses and transfer pumps, and then pumping the rinse water through the filter press.

All rinsates and filtrates were discharged into marked holding drums. Table 5-3 below summarizes the volumes of rinse water recovered versus the amounts added at each rinse stage.

**Table 5-3  
Summary of Batch 4 Rinses**

Rinse Stage	Start Time	End Time	Volume (Gal.) Added	Volume (Gal.) Recovered
1	09:59	11:24	25.0	27.89
2	11:39	13:26	25.0	24.90
3	13:48	15:05	25.0	30.39
4	15:26	17:44	25.0	36.99
5 (Press Rinse)	18:00	18:26	25.0	21.30
Totals	—	—	125.0	141.47

The fact that more water was recovered than was added is compelling evidence that interstitial water from the sludge blanket was first replaced by rinse waters, and then the rinse waters were effectively separated from the solids in the filter press.

The solids in each of the rinsate holding drums were allowed to settle and the clear supernates were sampled and analyzed for nitrate concentration in the host site's laboratory. Each rinse was shown to reduce the nitrate concentration to approximately half of the starting concentration. Nitrate in the thorium hydroxide solids were reduced from a starting concentration of 8.4 % to a final concentration of 0.21 %. Since the press rinse occurred after the other four rinses, its effectiveness was somewhat masked by the low starting concentration. Optimization tests at some future date may show that two press rinses using between 30 and 40 gallons each may produce as much benefit as the five rinses tested here. Not only would the total volume of rinsate for downstream disposition be reduced by a factor of 30 %, but the time required for rinsing would be cut by a factor of 4.

When the sludge blanket and rinse water from Rinse 4 were fed into the filter press, samples of the filter press feed slurry were collected and designated BT4-003a, b, and c. These samples were analyzed for sodium, nitrate, moisture, and thorium. Over an eighteen minute period the entire sludge blanket was pumped into the press, the filtrate was recirculated back to the reactor for ten minutes of that time, and then the filtrate was discharged through 1.0 micron bag filters into holding drums. The filtrate was a thin milky suspension with no perceptible yellow-green tint. Only trace solids were left in the filtrate at this stage. These solids settled to form a thin non-continuous layer on the bottoms of the holding drums. Samples of the clear layer from the filtrate holding drums containing Rinse 5 were collected and designated BT4-006a, b and c. These samples were analyzed for sodium, nitrate, chlorides, and thorium.

The sludge layers in the bottom of the mother liquor and filtrate holding drums were designated process heels, consolidated, and transferred to a drum for storage until they could be processed for recovery.

The filter press was opened and the filter cake discharged into a tare-weighted hopper. A well-formed white filter cake was found in all of the plate cavities. This cake was dry and crumbly, with none of the stickiness seen in the earlier batch tests. All of the individual cakes separated easily from the fabric and fell into the hopper from their own weight, leaving a clean filter cloth behind. The large pieces of cake could be easily broken by hand into smaller chunks, with the cleavage planes showing a consistently dry and granular structure. No portion of the cake had a gelatinous texture. The hopper was weighed to determine the net weight of the wet cake, which was 302.11 pounds. Samples of the wet cake were collected from the hopper and designated Sample Nos. BT4-005a, b, c, d, and e. These samples were analyzed for sodium, nitrate, moisture, and thorium.

The cake was manually shoveled from the hopper into the dryer and the agitator was started and run at a speed of 50 rpm. Low pressure steam at an inlet temperature ranging between 228 and 273 °F was circulated through the dryer jacket, resulting in an internal temperature between 200 and 218 °F. It took approximately 2 hours and 20 minutes of drying to bring the thorium product to apparent dryness. The steam flow was shut off and cooling water was pumped through the jacket to cool down the product. It took approximately 26 minutes to cool the thorium hydroxide solids down to a temperature of 105 °F. The dried thorium hydroxide was discharged into a drum and the drum was weighed. The net weight of dried thorium hydroxide product was 169.14 pounds.

Samples of the dried product were collected from the drum and designated BT4-007a, b, c, d, e, and f. These samples were analyzed for sodium, nitrate, thorium, and UTS metals. An additional set of samples, designated BT4-008a, b, c, d, and e, were collected and stored for later use in bench-scale calcining tests. After calcining tests, samples of the calcined material with the same sample designations were submitted for analysis of thorium, nitrate, moisture, and UTS metals.

Contaminated condensate water from the accumulator was sampled prior to being transferred into a stainless steel tote container for storage. The samples, designated BT4-009a, b and c, were analyzed for sodium, nitrate, and thorium concentration.

#### **5.4.2 Results Evaluation**

Batch Test No. 4 was an unqualified success, accomplishing the goal of demonstrating repeatability of the basic de-nitration process demonstrated in Batch Test No. 2, further enhanced by serial rinsing to improve thorium product quality. Taking credit for only the thorium hydroxide captured as filter cake and dried, the thorium yield was 69.9 %. The remainder of the thorium came to reside in the process heels, from which it was later recovered. The nitrate content of the dried thorium hydroxide product was 1.6 %. This test showed that careful control of the early stages of the precipitation process resulted in granular thorium hydroxide solids that settle quickly and filter well, to produce a very high quality granular filter cake. The fates of thorium, sodium, and nitrates in Batch Test No. 4 are presented in tabular form in the material balance of Table 6-3.

With the basic process and demineralized water rinsing demonstrated, it was decided that the next batch test would be planned to add internal recycle loops to the Batch Test No. 4 process to recycle condensate and mother liquor in the early stages of the process. If successful, these secondary byproduct recycle options would help to close the material balance and minimize the overall volume of liquid byproducts.

Table 5-4 summarizes the time increments required for various steps of the de-nitration process during Batch Test No. 4 and estimated times for the process steps carried to Phase II, and adjusted to incorporate lessons learned from Batch Test No. 4. The time intervals shown for Batch Test No. 4 include only the described activity, and do not include time consumed investigating problems, collecting data, sampling materials, and deciding upon the next action. The batch size in Batch Test No. 4 was 2 drums. In the Phase II column, the batch size is assumed to be 16 drums. Although it takes 22.25 hours for the batch to be processed, it moves through the process in three stages on three successive days as follows:

- Stage 1 - 8.25 hours, unpacking and dissolving of thorium nitrate
- Stage 2 - 9.5 hours, precipitation, decanting and dewatering of thorium hydroxide
- Stage 3 - 4.5 hours, drying, cool down and product packaging

As soon as a batch moves from Stage 1 to Stage 2, the next batch can begin Stage 1, and so on through the three stages.

**Table 5-4**  
**Summary of De-nitration Process Steps**  
**Based on Batch Test No. 1 Results**

<b>Process Step Description</b>	<b>Batch Test No. 4 Time for 2 Drum Batch *</b>	<b>Projected Phase II Time for 16 Drum Batch</b>
Unpack TNH Drums	3.5 hours	8.0 hours
Dissolve Thorium Nitrate	0.75 hours	0.25 hours
Add Slug of 25 % NaOH	0.50 hours	Not Applicable
Slow Addition of 25 % NaOH	1.0 hour	2.0 hours
Slow Addition of 10 % NaOH	5.0 hours	4.0 hours
Solids Settling	1.0 hours	1.0 hours
Supernate Decanting	0.33 hours	0.5 hours
Rinsing in the Reactor (3 rinses)	5.5 hours	Not Applicable
Sludge Dewatering	0.5 hours	1.0 hours
Rinsing in the Filter Press (2 rinses)	2.0 hours	1.0 hours
Filter Cake Transfer to Dryer	1.0 hours	0.50 hours
Sludge Drying	2.33 hours	3.0 hours
Dryer Cool Down & Discharge to Packaging	0.50 hours	1.0 hours
<b>Total Processing Time</b>	<b>23.91 hours</b>	<b>22.25 hours</b>

\* Time intervals do not include investigative and operations development activities, only the time required to actually perform the described task.

### 5.5 Batch Test No. 5 - Byproduct Recycle Test

The results of Batch Test No. 4 were reviewed and the lessons learned were incorporated into the Batch Test Instructions for use in Batch Test No. 5. All aspects of Batch Test No. 4 were incorporated for Batch Test No. 5. In addition, contaminated condensate from the condensate accumulator was to be used to dilute the sodium hydroxide, and mother liquor from storage was to be used in place of demineralized water for dissolving thorium nitrate. If successful, recycling

condensate and mother liquor would help to minimize the volume of secondary byproduct liquids and boost their nitrate content to make commercial recycle more attractive.

### 5.5.1 Test Narrative

The recoverable thorium nitrate from the last two drums of feed material were removed from their original packaging on December 10, 1997, and transferred to buckets for weighing. The recovered thorium nitrate used in Batch Test No. 5 totaled 387.73 pounds.

On December 15, 1997, the sodium hydroxide solutions for use during the precipitation step were prepared using contaminated condensate from the condensate accumulator. Late in the afternoon of December 15, 1997, the thorium nitrate feed material was dissolved in the reactor in 52.8 gallons of mother liquor (sodium nitrate solution) at a temperature of approximately 145 °F. The agitator speed was set at 50 rpm. Due to the late hour, the reactor was shut down and the thorium nitrate solution was allowed to cool overnight.

Beginning early in the morning of December 16, 1997, preparations were made for the precipitation step. Hot water was circulated through the reactor jacket to bring the thorium nitrate solution back up to operating temperature. It took approximately one hour and 50 minutes to bring the temperature back to 180 °F. The dissolving step produced a thorium nitrate solution with 19.0 % thorium concentration (Sample No. BT5-001b) and a nitrate concentration of 24.6 % (Sample No. BT5-001a). Table 6-3 presents validated analytical results and material balance calculations in the same tabular format. The agitator speed was reset to 10 rpm. Over a period of 23 minutes, 10.0 gallons of 24.6 % sodium hydroxide were metered into the thorium nitrate solution in the reactor. During the initial phase of sodium hydroxide addition, the solution pH increased from an instrumentally measured reading of 0.71 @ 93°C to 1.75 @ 93°C. Over the next 5 minutes, another 3.0 gallons of 24.6 % sodium hydroxide solution were metered in, and the pH rose to 1.83 @ 93 °C. The injection rate was reduced and another 20 gallons of 24.6 % sodium hydroxide was added over a period of 1 hour and 50 minutes. The pH at the end of the 24.6 % sodium hydroxide addition was 2.09 @ 93 °C. A hot plate was used to heat all pH grab samples to approximately the same temperature before readings were taken and recorded. Up to this time, the reactor internal temperature was maintained in the range of 175 to 182 °F. A few small white lumps of solids began to appear at the mid-point of the last increment of 24.6 % sodium hydroxide addition.

Over the next one hour and ten minutes, the temperature inside the reactor was maintained steadily in the 182 to 190 °F range, while pH increased from 2.09 to 6.96, due to addition of approximately 4.8 gallons of 11.7 % sodium hydroxide. The new bellows pump was used for control of sodium hydroxide injections. The agitator speed was maintained at 10 rpm. Grab samples from this period showed that the solids forming in the reactor had poor settling characteristics such as those produced in Batch Test No. 3. Rechecking the pump calibration revealed that sodium hydroxide had been fed at approximately 3 times the planned feed rate. This appears to have been caused by calibration error or air-locking of the pump at the time the stroke of the pump was set.

Injection of sodium hydroxide was suspended, and the decision was made to attempt to re-dissolve the precipitates by back-titrating with concentrated nitric acid obtained from the host site's

laboratory. A total of 6.0 liters of nitric acid were added over a period of one hour and 10 minutes, which reduced pH from 6.96 to 2.08 @ 93 °C. This operation appeared to re-dissolve all of the visible solids in the reactant mixture. During the back-titration, a fairly voluminous foam developed on the liquid surface, but dissipated after pH dropped below 3.0.

Injection of 11.7 % sodium hydroxide was resumed and continued over the next 5 hours. At the end of that time, another 26.3 gallons of 11.7 % sodium hydroxide had been added and the pH had been raised from 2.08 to approximately 11.0 @ 93 °C. Settling tests conducted on grab samples collected periodically from the batch in process showed that a small degree of settle-ability had been restored due to the re-dissolving and re-precipitation operations. After the final pH was reached, the reactor was shut down, and the sludge blanket was allowed to settle in the reactor overnight.

On the morning of December 17, 1997, the sludge blanket and supernate ( mother liquor) were observed and their volumes calculated. Gravity thickening of the reactor product resulted in approximately 23.8 % of the batch volume being recovered as clear yellow-green supernate, and 76.3 % as a thick milky white sludge blanket. A sample of the clear supernate was collected and split into aliquots designated BT5-004a and b. These samples were analyzed for sodium, nitrate, and thorium concentration. The supernate was pumped off through a 1.0 micron bag filter and into holding drums. A skimmer attachment on the decant hose was used to help minimize the amount of sludge blanket solids lost to the holding drums during the decanting operation.

A series of demineralized water rinses were performed to evaluate the effectiveness of serial rinsing in reducing the relatively high nitrate concentration in the sludge blanket resulting from recycle of mother liquor in the precipitation step. Each of the first two rinses were performed by decanting any free liquid layers above the sludge blanket, and then adding 50 gallons of demineralized water to the reactor and gently mixing with the agitator for 10 minutes at a speed of 10 rpm. Then, the sludge blanket was allowed to settle to its original volume, the supernate was skimmed and pumped to a holding drum, and the next rinse was performed by the same methods. After decanting the rinse water from the second rinse, the sludge blanket was pumped into the filter press in its densest form. Then, the third and fourth rinses were performed in the filter press using 25.0 gallons for each rinse.

All rinsates and filtrates were discharged into marked holding drums. Table 5-5 below summarizes the volumes of rinse water recovered versus the amounts added at each rinse stage.

The fact that approximately the same volume of rinse water was recovered as was added indicates that compaction of the sludge layer in the filter press did not occur to any great degree. Also, the large amount of solids in the various holding drums indicated wash out of significant thorium hydroxide solids from the press. These solids did not settle well in the holding drums, resulting in losses of this material into the process heels.

The solids in each of the rinsate holding drums were allowed to settle and the clear supernates were sampled and analyzed for nitrate concentration in the host site's laboratory. Each rinse was shown to reduce the nitrate concentration to approximately half of the starting concentration. Nitrate in the thorium hydroxide solids were reduced to a final concentration of 2.7 % in the wet filter cake.

**Table 5-5  
Summary of Batch 5 Rinses**

Rinse Stage	Start Time	End Time	Volume (Gal.) Added	Volume (Gal.) Recovered
1	09:38	14:27	50.0	47.10
2	14:50	17:44	50.0	47.30
3	18:32	18:53	25.0	30.14
4	19:05	19:12	25.0	28.33
Totals	—	—	150.0	152.87

When the sludge blanket remaining after Rinse 2 was decanted from the reactor, and was fed into the filter press, samples of the filter press feed slurry were collected and designated BT5-003a, b, and c. These samples were analyzed for sodium, nitrate, thorium and moisture.

Press filtrates from the end of Rinse 2, and from Rinses 3 and 4 were discharged through 1.0 micron bag filters into holding drums. The filtrate was a thin milky white suspension with no perceptible yellow-green tint. The solids in all of the holding drums were allowed to settle overnight.

On the morning of December 18, 1997, thickness measurements of the supernate and sludge layers in the holding drums were performed. These measurements showed that the solids in the drums holding mother liquor, and Rinses 1 and 2 (performed in the reactor) settled well. However, the supernates in the holding drums from Rinses 3 and 4 (performed in the filter press) had finely dispersed colloidal solids in the form of a general turbidity. This turbidity made it impossible to detect the true thickness of the sludge layer in these drums. Samples of the clear layer from the holding drum containing Rinse 2 were collected and designated BT5-006a, b and c. These samples were analyzed for sodium, nitrate, and thorium.

The sludge layers in the bottom of the mother liquor, rinsate, and filtrate holding drums were designated process heels, consolidated, and transferred to a drum for storage until they could be processed for recovery.

The filter press was opened and the filter cake discharged into a tare-weighted hopper. A well-formed white filter cake was found in all of the plate cavities. However, this cake was wet and sticky, similar to the filter cake characteristics from Batch Test No. 1. The dryness of the filter cake was better in the first plate cavities than in the last. The hopper was weighed to determine the net weight of the wet cake, which was 233.92 pounds. Samples of the wet cake were collected from the hopper and designated Sample Nos. BT5-005a, b, c, d, and e. These samples were analyzed for sodium, nitrate, moisture, and thorium.

The cake was manually shoveled from the hopper into the dryer and the agitator was started and run at a speed of 30 rpm. Low pressure steam at an inlet temperature ranging between 250 and 272 °F was circulated through the dryer jacket, resulting in an internal temperature between 214 and 216 °F. It took approximately 4 hours of drying to bring the thorium product to apparent dryness. The steam flow was shut off and cooling water was pumped through the jacket to cool down the product. It took approximately 30 minutes to cool the thorium hydroxide solids down to a temperature of 100 °F. The dried thorium hydroxide was discharged into a drum and the drum was weighed. The net weight of dried thorium hydroxide product was 108.98 pounds.

Samples of the dried product were collected from the drum and designated BT5-007a, b, c, d, e, and f. These samples were analyzed for sodium, chloride, nitrate, thorium, and UTS metals. An additional set of samples, designated BT5-008a, b, c, d, and e, were collected and stored for later use in bench-scale calcining tests. After calcining tests, samples of the calcined material with the same sample designations were submitted for analysis of thorium, nitrate, moisture, and UTS metals.

Contaminated condensate water from the accumulator was sampled prior to being transferred into a stainless steel tote container for storage. The samples, designated BT5-009a, b and c, were analyzed for sodium, nitrate, and thorium concentration.

### **5.5.2 Results Evaluation**

Batch Test No. 5 was successful in answering some basic questions regarding recycle of mother liquor, but the precipitation difficulties and the low yield make it an unprofitable option for the full-scale process. Taking credit for only the thorium hydroxide captured as filter cake and dried, the thorium yield was 37.2 %. The remainder of the thorium came to reside in the process heels, from which it was later recovered. The nitrate content of the dried thorium hydroxide product was 1.33 %. The fates of thorium, sodium, and nitrates in Batch Test No. 5 are presented in tabular form in the material balance of Table 6-4.

Once again, difficulties were encountered in the precipitation step. Early in the precipitation step, gelatinous solids were produced which exhibited poor settling characteristics. An attempt was made to reverse the precipitation process by re-dissolving the solids with concentrated nitric acid. This attempt was probably terminated prematurely. The nitric acid appeared to re-dissolve the visible solids, but the pH was only reduced to 2.08, which is still above the precipitation initialization point observed in earlier tests. Although the re-dissolving operation should be viewed as a qualified success, it probably would have been better to add an additional 1.0 to 2.0 liters of concentrated nitric acid to obtain a re-start pH of less than 1.5.

Serial rinsing was successful in removing the extra nitrate from the sludge blanket. Liquid phase nitrate concentrations were reduced from 14.9 % in the reactor product before mother liquor separation to 2.1 % at the end of Rinse 4. The wet filter cake had 2.7 % nitrate and the dried thorium product had 1.3 % nitrate.

Although a high quality thorium product was produced, the problems posed by recycle of mother liquor far outweigh the benefits.

Table 5-6 summarizes the time increments required for various steps of the de-nitration process during Batch Test No. 5 and estimated times for the process steps carried to Phase II, and adjusted to incorporate lessons learned from Batch Test No. 5. The time intervals shown for Batch Test No. 5 include only the described activity, and do not include time consumed investigating problems, collecting data, sampling materials, and deciding upon the next action. The batch size in Batch Test No. 5 was 2 drums. In the Phase II column, the batch size is assumed to be 16 drums. Although it takes 22.25 hours for the batch to be processed, it moves through the process in three stages on three successive days as follows:

- Stage 1 - 8.25 hours, unpacking and dissolving of thorium nitrate
- Stage 2 - 9.5 hours, precipitation, decanting, rinsing, and dewatering of thorium hydroxide
- Stage 3 - 4.5 hours, drying, cool down and product packaging

As soon as a batch moves from Stage 1 to Stage 2, the next batch can begin Stage 1, and so on through the three stages.

**Table 5-6  
Summary of De-nitration Process Steps  
Based on Batch Test No. 1 Results**

<b>Process Step Description</b>	<b>Batch Test No. 5 Time for 2 Drum Batch *</b>	<b>Projected Phase II Time for 16 Drum Batch</b>
Unpack TNH Drums	3.5 hours	8.0 hours
Dissolve Thorium Nitrate	0.83 hours	0.25 hours
Add Slug of 25 % NaOH	0.58 hours	Not Applicable
Slow Addition of 25 % NaOH	1.33 hour	2.0 hours
Slow Addition of 10 % NaOH	1.17 hours	4.0 hours
Stop at pH 6.96 & Back-titrate to pH 2.08	1.0 hours	Not Applicable
Slow Addition of 10 % NaOH	5.17 hours	Not Applicable
Solids Settling	10.0 hours	1.0 hours
Supernate Decanting	0.17 hours	0.5 hours
Rinsing in the Reactor (2 rinses)	5.5 hours	Not Applicable
Sludge Dewatering	0.5 hours	1.0 hours
Rinsing in the Filter Press (2 rinses)	0.67 hours	1.0 hours
Filter Cake Transfer to Dryer	1.33 hours	0.50 hours
Sludge Drying	4.0 hours	3.0 hours
Dryer Cool Down & Discharge to Packaging	0.5 hours	1.0 hours
<b>Total Processing Time</b>	<b>36.25 hours</b>	<b>22.25 hours</b>

\* Time intervals do not include investigative and operations development activities, only the time required to actually perform the described task.

### 5.6 Comparative Evaluation of Serial Rinsing

Serial rinsing was performed in Batch Test No. 4 and in Batch Test No. 5, and it was simulated on the bench using materials sampled from Batch Test No. 2. Each of these batch tests used essentially the same serial rinsing methods, with the only difference being the number of rinses, and the filtration

characteristics of the solids produced by the de-nitration process. Figure 5-1 presents graphs of the nitrate content of the solid phases and the rinsate for the simulated serial rinsing of Batch Test No. 2 and the pilot scale rinsing of Batch Test No. 4. Batch Test No. 5 data is not presented in graphical form, because it does not represent the de-nitration process in a process configuration which is meaningful for Phase II operations. The serial rinses generally show a factor of 2 reduction in solids phase nitrate content for each rinse step, whether the rinsing was performed in the plowshare reactor by the wash, settle and decant method, or by flush rinsing in the filter press. This is shown in the graph for Batch Test No. 4. In this test, Rinses 1, 2, and 3 were performed in the reactor. Rinse 4 was started in the reactor, but was finished in the filter press. Rinse 5 was performed entirely in the filter press. What is not shown by the graphs is that Rinses 1, 2 and 3 required an average of 90 minutes each to complete, whereas the filter press rinses of Rinse 4 and 5 required only 30 minutes total. Based on these results, it appears that three serial rinses, all performed in the filter press will provide the best balance of rinse performance versus processing cost.

### **5.7 Comparative Evaluation of Low Temperature Drying and Calcining**

Low temperature drying as it was applied during the pilot demonstration batch tests did not consistently produce a low moisture thorium hydroxide product. Final moisture of the dried thorium product varied between 9.2 % and 23.5 %. This wide range was due to the nature of the pilot scale equipment and the methods used to dry the thorium hydroxide filter cake. Filter cake was manually loaded into the dryer, and then the vessel was sealed and heated with non-contact steam at temperatures between 240 and 280 °F, and pressures between 10 and 20 PSIG. There was no instrumental method of measuring the moisture removed. When it was suspected that the product was dry, the mixer shaft was halted, and an access port was opened. The solids were visually observed and evaluated on a tactile basis. If the product did not appear dry, the port was closed and further drying was performed. The inspection and drying activities were repeated until the product appeared to be dry based upon visual and tactile evaluations. Then, the steam generator was shut down and cooling water was pumped through the jacket to cool the product. Finally, the batch was discharged from the bottom of the dryer into a plastic lined polyethylene drum. An instrumental means of measuring humidity in the vent pipe of the dryer would have provided a better means of deciding when to halt drying operations.

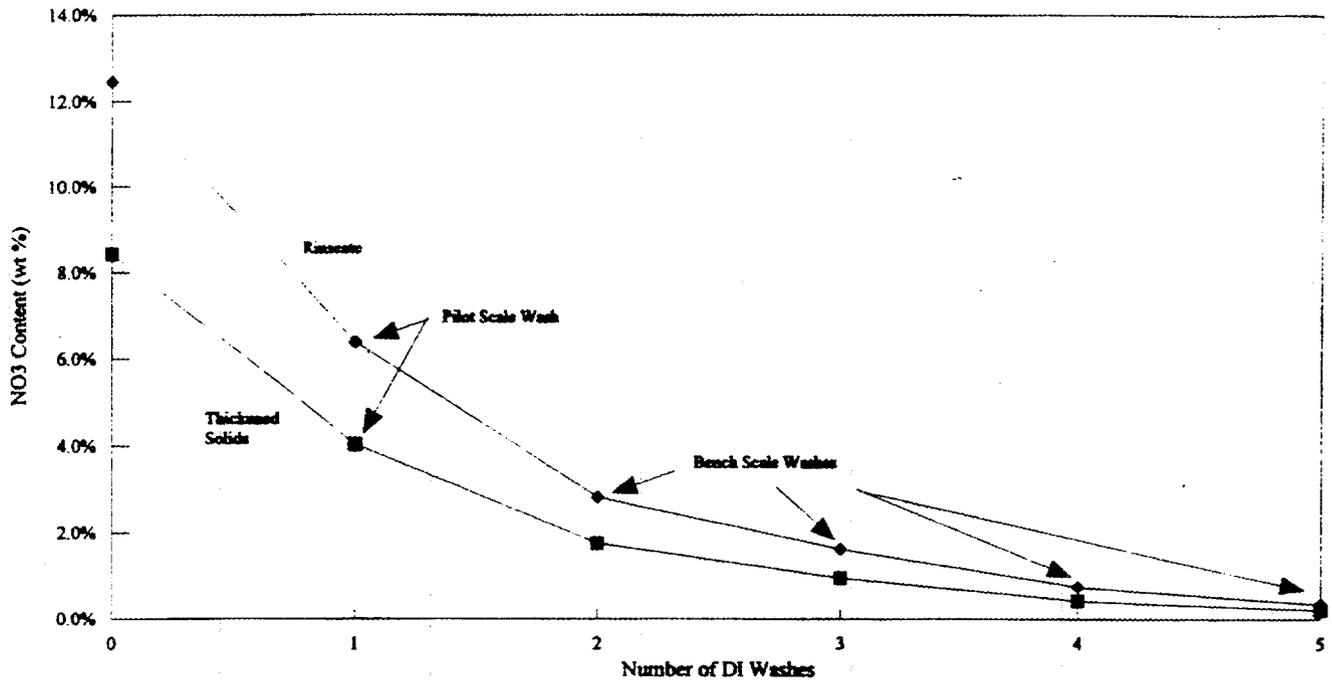
Another problem contributing to the erratic dryer performance was the lack of a dry carrier gas to augment transport of the water vapor out of the head space of the dryer and into the downstream condenser. This condition forced us to rely on the vapor pressure of the moisture to provide mass transport to the water vapor. By injecting a small flow of nitrogen or dry air into the dryer to carry away the water vapor, dryer performance could have been greatly improved. Also, the dryer manufacturer suggests that a partial vacuum be applied to the dryer to further augment the drying process.

The design for Phase II will include a dryer operating at approximately 0.5 atmospheres absolute, with a 10 CFM purge stream of dry compressed air injected into the dryer through its shaft seals. Also, a humidity sensor in the vent line between the dryer and the vent condenser will be used to determine when drying is complete.

**Figure 5-1**  
**Graphs of Serial Rinsing Performance**

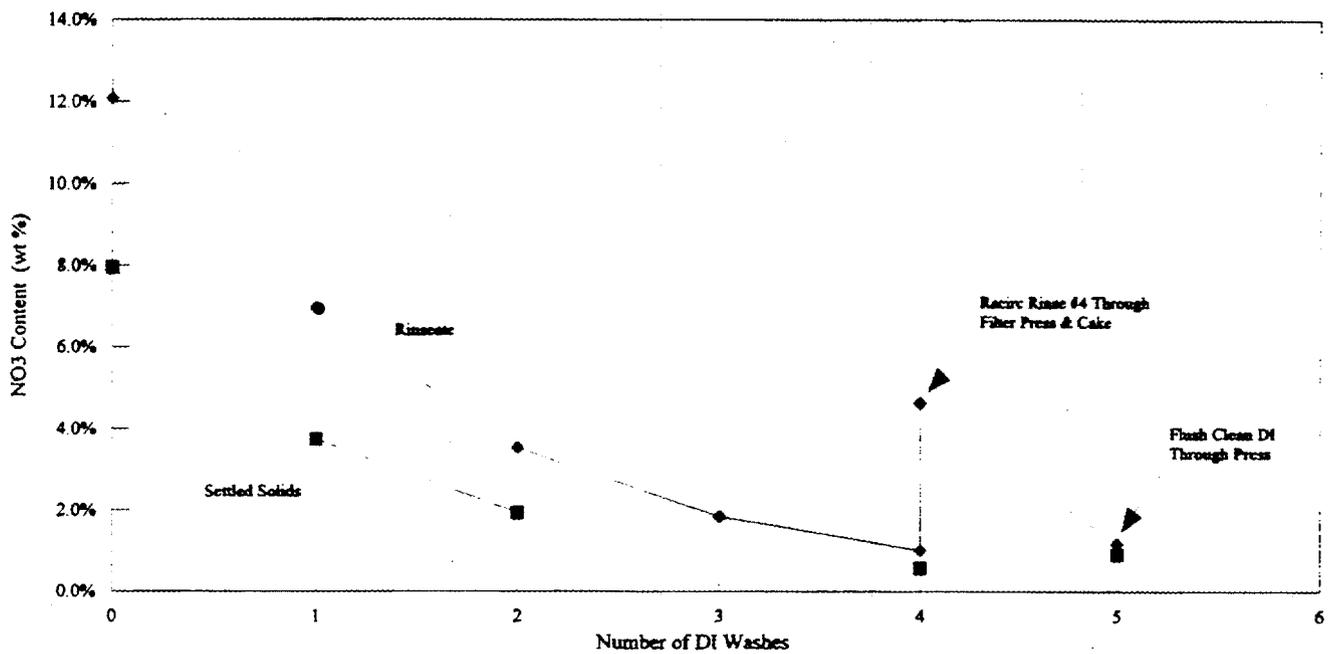
**Pilot Batch 2 - Solids Washing**

Solids Washed With Approximately Equal Volume of DI Water



**Pilot Batch 4 Solids Washing - Average NO3 Reduction Factor = 1.9**

25 gal DI Added per Wash to about 43 gal Settled Solids



The X-ray diffraction analyses performed during the pilot test program reveal useful information regarding the thorium product quality options that should be considered for Phase II. Four samples of thorium material were analyzed by Southwest Research Institute. The following discussion summarizes the results, which can also be found in their April 15, 1998 report located in Appendix A of this report.

- **Thorium Nitrate Raw Material (Sample No. BT1-001C):** "This sample is about 95% crystalline. The only identifiable crystalline species in the sample was  $\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$ . Please note that there were several unidentifiable peaks in the powder pattern."
- **Batch Test No. 1 Dried Thorium Hydroxide Product (Sample No. BT1-008C):** "This sample is about 80 % crystalline. The sample appears to be poorly crystalline as shown by the wide peaks. The crystalline portion of the sample consists of 50% thorianite ( $\text{ThO}_2$ ), 45 % nitratine ( $\text{NaNO}_3$ ), and about 5%  $\text{Na}_3\text{NO}_3$ ."
- **Batch Test No. 2 Dried Thorium Hydroxide Product (Sample No. BT2-007D):** "This sample is about 75% crystalline. The sample is poorly crystalline as indicated by the wide peaks. The only identifiable crystalline species in the sample was thorianite ( $\text{ThO}_2$ )."
- **Batch Test No. 2 Simulated Calcined Thorium Product (Sample No. BT2-008C):** "This sample is about 90% crystalline. The sample appears to be poorly crystalline as shown by the wide peaks. The crystalline portion of the sample consists of 85% thorianite ( $\text{ThO}_2$ ) and 15% nitratine ( $\text{NaNO}_3$ )."

Comparing the dried and calcined samples from Batch Test No.2 , it can be concluded that calcining will improve the crystalline integrity of the product and drive off some nitrates and additional water. However, Batch Test No. 4 showed that good filtering thorium hydroxide solids followed by effective drying can reduce both residual nitrate and moisture. The drying process improvements described above will serve to reduce residual moisture to approximately the same as the calciner. The only incremental improvement that calcining will produce is breakdown of hydroxides to oxides, and evolution of nitrates in the form of nitrogen dioxide. It is our opinion that the small improvements in moisture and nitrate content afforded by calcining do not offset the greater permitting and NEPA costs, operating costs, safety hazards and environmental insult caused by calcining, and therefore we do not recommend it for Phase II.

## 5.8 Heels Recovery

During the week of January 4, 1998, the process heels that had been accumulated during the pilot-scale batch test program were recovered by direct drying in the plowshare dryer. These heels include thorium hydroxide sludges stored in drums or tanks, and the contents of bag filter socks that had been stored in buckets. In the heels recovery effort, the heels were divided into three batches designated as Batch Tests 6, 7 and 8. Each of these batches were dried in the dryer using the same

methods as were used for drying filter cake in the previous 5 pilot-scale batch tests. When holding drums or tanks were emptied, they were rinsed down with demineralized water and the rinsate was added to the appropriate batch in the dryer.

### **5.8.1 Test Narrative**

In Batch Test 6, 168.81 pounds of wet solids from bag filter socks were dried, producing 78.57 pounds of dry thorium hydroxide solids. These solids were package for return to DLA. Approximately 6.9 gallons of contaminated condensate was recovered from the condensate accumulator.

In Batch Test 7, 5 drums of liquid heels were pumped into the dryer. The pH of the slurry was checked and found to be approximately 6.0. The remaining 10 % sodium hydroxide (12.2 gallons) and an additional 3 gallons of 50 % sodium hydroxide were needed to increase the pH to 10.0. This was done to ensure that the de-nitration reaction went to completion. Then the batch was dried to produce 158.06 pounds of thorium hydroxide solids which were packaged for return to DLA.

In Batch Test No. 8, seven drums of liquids were inspected and found to have clear supernate layers. This clear liquid was pumped to the appropriate stainless steel tote for storage. The remaining heels were pumped into the dryer and dried to produce 329.17 pounds of recovered thorium hydroxide solids.

During the week of January 19, 1998, decontamination of equipment was completed, and decontamination water and mop water from floor cleaning were consolidated into a dryer run designated Batch Test No. 9. Unused samples from the laboratory were returned and combined in this batch. The pH of the combined liquids in the batch was above 10.0, so drying was begun without any pH adjustments. It took 28.5 hours over a three day period to take this batch from a very wet state to dryness. The solids resulting from this dryer run were packaged for return to DLA as a low quality thorium hydroxide product.

### **5.8.2 Results Evaluation**

These batch test had no research or development value, but were performed to recover thorium hydroxide heels into a dry packaged form for return to DLA and log term storage at the Curtis Bay, Maryland depot.

## **5.9 Cation Exchange Batch Tests**

After all batch tests of the de-nitration process were completed, the clear liquid byproduct streams were consolidated into 3 specific types and stored separately in stainless steel totes. These three liquid byproduct streams were:

- Supernate (Mother Liquor)
- Filtrate/Rinsate
- Contaminated Condensate

During each of these cation exchange runs, the liquid feed stream was treated through two ion exchange columns piped in series, each containing SIR-500™ aminophosphonic chelating resin supplied by ResinTech, Inc. At the beginning of each test run, the liquid stream to be treated was pumped from tote storage into the plowshare dryer and heated to the temperature range specified by the resin manufacturer, 158 to 176 °F. The pH was checked to make sure that it was above 8.0, and adjusted if necessary.

### 5.9.1 Test Narrative

In Liquid Batch Test No. 1, the entire inventory of contaminated condensate from the condensate accumulator was pumped into the plowshare dryer, mixed and sampled. These samples were designated CLB1-001a, b and c, and were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. After sampling, the batch of condensate in the dryer was heated to feed temperature and then pumped at a controlled rate (within the manufacturer's loading specifications) through the cartridge filter and the two cation exchange units plumbed in series. Samples of effluent from each column were collected at approximate 15 minute intervals and analyzed in the Perma-Fix Laboratory to compare feed and effluent quality. The thorium concentrations for these samples are summarized in Table 5-7. By comparing the thorium concentrations of accumulator condensate with those for condensate in the dryer, it can be seen that insoluble thorium particulate matter was washed from the internal surfaces of the pump, the hoses or the dryer into the condensate. A sample of the mixed condensate in the dryer was subjected to laboratory filtration using a 0.7 µm filter. This filtration test was effective in removing 88.84 % of the thorium present, indicating that it was mostly in an insoluble form. The cation polishing removed enough residual thorium from the condensate to bring the overall removal efficiency of the filtration/ion exchange polishing process into the range of 89.5 to 95.5 %. At the end of the ion exchange run, the effluent from Cation Unit No. 2 was sampled and designated as CLB1-002a, b and c. These samples were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. The analytical results for the samples designated CLB1-001 and CLB1-002 are summarized in Table 5-10.

In Liquid Batch Test No. 2, the entire inventory of filtrates and rinsates from the storage tote was pumped into the plowshare dryer, mixed and sampled. These samples were designated CLB2-001a, b and c, and were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. After sampling, the batch of condensate in the dryer was heated to feed temperature and then pumped at a controlled rate (within the manufacturer's loading specifications) through the cartridge filter and the two cation exchange units plumbed in series. Samples of effluent from each column were collected at approximate 15 minute intervals and compared to samples of feed materials. The thorium concentrations for these samples are summarized in Table 5-8. Comparing the various feed streams shows that the filtrates and rinsates were not contaminated with particulate matter during transfer to the dryer. A sample of the feed liquid in the dryer was subjected to laboratory filtration using a 0.7 µm filter. This filtration test was effective in removing 45.2 % of the thorium present, indicating that a substantial portion was in an insoluble form. The cation polishing removed enough

residual thorium from the filtrate/rinsate feed liquid to bring the overall removal efficiency into the range of 99.7 to 99.9 %. At the end of the ion exchange run, the effluent from Cation Unit No. 2 was sampled and designated as CLB2-002a, b and c. These samples were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. The analytical results for the samples designated CLB2-001 and CLB2-002 are summarized in Table 5-10.

In Liquid Batch Test No. 3, the entire inventory of supernate (Mother Liquor) from the storage tote was pumped into the dryer, mixed and sampled. These samples were designated CLB3-001a, b and c, and were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. After sampling, the batch of condensate in the dryer was heated to feed temperature and then pumped at a controlled rate (within the manufacturer's loading specifications) through the cartridge filter and the two cation exchange units plumbed in series. Samples of effluent from each column were collected at approximate 15 minute intervals and compared to samples of feed materials. The thorium concentrations for these samples are summarized in Table 5-9. Comparing the various feed streams shows that the supernate was not contaminated with particulate matter during transfer to the dryer. A sample of the feed liquid in the dryer was subjected to laboratory filtration using a 0.7  $\mu\text{m}$  filter. This filtration test was effective in removing 35.8 % of the thorium present, indicating that a substantial portion was in an insoluble form. The cation polishing removed enough residual thorium from the supernate feed liquid to bring the overall removal efficiency into the range of 76.9 to 82.8 %. At the end of the ion exchange run, the effluent from Cation Unit No. 2 was sampled and designated as CLB3-002a, b and c. These samples were analyzed at an off-site laboratory for sodium, nitrate, and thorium concentrations. The analytical results for the samples designated CLB3-001 and CLB3-002 are summarized in Table 5-10.

One factor that may have impacted the performance of the cation exchangers in Liquid Batch Test No. 3 was contamination of the storage tote with oily residues. Due to a communication problem, a dirty tote was used to store supernate. This problem was first noticed when an oil slick was observed on top of the supernate in the tote. Absorbent diapers were used to absorb the floating oil, but there was no other treatment performed in advance of the cation exchange run.

Initially, the effluent from Cation Unit No. 2 showed a great reduction in the yellow-green tint of the supernate. However after about 30 minutes into the run, the strength of the yellow-green tint of the effluent returned to its original feed condition. This was interpreted as evidence of exhaustion of the cation units. The run was halted and Cation Unit No. 1 was taken out of service. Cation Unit No. 2 was moved to the original location of Cation Unit No. 1, and the spare cation column was installed in place of Cation Unit No. 2. The treated supernate was pumped back into the dryer and the run was started again. Once again, the color of the effluent was significantly reduce in the resin beds. After 50 minutes however, the yellow-green color again broke through the resin beds, indicating probable breakthrough of thorium as well. The run was continued to completion, because there were no more spare cation exchanger columns.

The cartridge filtration and cation polishing combined to remove enough residual thorium from the condensate to bring the overall removal efficiency into the range of 78.1 to 82.8 %. The data indicates that early in the treatment run, Cation Unit No. 2 became exhausted and therefore provided negligible removal efficiency. It is suspected that exhaustion of the resin was due to surface fouling

due to the oil contamination arising from the dirty tote used for storage. Overall, the cartridge filter and cation units still accounted for a 78 to 83 % removal efficiency. If they had not become fouled, it appears that the overall removal efficiency would have been well over 90 %.

All removal efficiencies referenced in this section are calculate by dividing the effluent thorium concentration by the thorium concentration in the unfiltered sample collected from the plowshare dryer, multiplied by 100.

### **5.9.2 Results Evaluation**

The results of the cation exchange tests show that the SIR-500<sup>TM</sup> aminophosphonic chelating resin is effective in polishing soluble thorium from the liquid byproduct streams produced during the de-nitration and thorium drying processes. Also, a string-wound cartridge filter was found to be effective in removing insoluble thorium from these liquid streams. In Liquid Batch Test 1 (contaminated condensate) and Liquid Batch Test 2 (filtrate/rinsate), the product purity was consistently in the range of 0.29 to 0.64 pCi/ml. Variability in the percent removal efficiency was due mainly to the starting thorium concentration of the feed liquids. In Liquid Batch Test 3, the results were inconclusive due to apparent fouling of the resin by oily contaminants. This would not be a problem in a full-scale treatment project.

Theoretically, all of the thorium should be in insoluble form. Perhaps an ultra-filter operation would be as effective in polishing liquid byproducts to remove thorium as the cartridge filter and cation exchange units were in combination.

**Table 5-7  
Summary of Liquid Batch Test No. 1 Results.**

Feed Stream Descriptions		Feed Liquid Concentration & Activity		Removal Efficiency	
		Th (ppm)	Th (pCi/ml)	(%)	
Accumulator Condensate		11.4	1.3	N/A	
Condensate in Dryer		59.1	6.4	N/A	
Lab Filtered Condensate (0.7 µm)		6.9	0.7	88.84	
Effluent Thorium Concentration & Activity versus Time					
Sample Elapse Time	Column 1 Effluent Concentrations		Column 2 Effluent Concentrations		Total Removal Efficiency
	Th (ppm)	Th (pCi/ml)	Th (ppm)	Th (pCi/ml)	(%)
0 min.	9.6	1.1	5.8	0.64	89.9
15 min.	8.4	0.93	3.7	0.41	93.6
30 min.	6.1	0.67	—	—	89.5
41 min.	6.6	0.73	5.8	0.63	90.1
56 min.	<3.5	<0.38	5.2	0.57	91.0
71 min.	3.7	0.41	2.6	0.29	95.5
86 min.	5.9	0.65	<3.5	<0.38	>94.0
101 min.	5.0	0.55	4.7	0.52	91.9
116 min.	5.6	0.62	4.8	0.52	91.8

**Table 5-8  
Summary of Liquid Batch Test No. 2 Results.**

Feed Stream Descriptions		Feed Liquid Concentrations		Removal Efficiency	
		Th (ppm)	Th (pCi/ml)	(%)	
Filtrate/Rinseate from Tote Container		3,193	383	N/A	
Filtrate/Rinseate from Dryer		2,911	340	N/A	
Lab Filtered Feed Liquid (0.7 $\mu$ m)		1,603	186	45.2	
Effluent Thorium Concentration & Activity versus Time					
Sample Elapse Time	Column 1 Effluent Concentrations		Column 2 Effluent Concentrations		Total Removal Efficiency
	Th (ppm)	Th (pCi/ml)	Th (ppm)	Th (pCi/ml)	(%)
0 min.	<3.7	<0.41	<3.7	<0.41	>99.9
15 min.	<3.7	<0.41	<3.7	<0.41	>99.9
30 min.	<3.7	<0.41	<3.7	<0.41	>99.9
45 min.	<3.7	<0.41	<3.7	<0.41	>99.9
60 min.	<3.7	<0.41	8.4	0.97	99.7
75 min.	<3.7	<0.41	<3.7	<0.41	>99.9
90 min.	<3.7	<0.41	<3.7	<0.41	>99.9
105 min.	<3.7	<0.41	<3.7	<0.41	>99.9
120 min.	<3.7	<0.41	<3.7	<0.41	>99.9
135 min.	<3.7	<0.41	<3.7	<0.41	>99.9
150 min.	<3.7	<0.41	<3.7	<0.41	>99.9
165 min.	<3.7	<0.41	<3.7	<0.41	>99.9
180 min.	<3.7	<0.41	<3.7	<0.41	>99.9
195 min.	<3.7	<0.41	<3.7	<0.41	>99.9
210 min.	<3.7	<0.41	<3.7	<0.41	>99.9
255 min.	<3.7	<0.41	<3.7	<0.41	>99.9

**Table 5-9  
Summary of Liquid Batch Test No. 3 Results.**

Feed Stream Descriptions		Feed Liquid Concentrations		Removal Efficiency	
		Th (ppm)	Th (pCi/ml)	(%)	
Supernate (Mother Liquor) from Tote Container		79.2	9.7	N/A	
Supernate from Dryer		49.9	6.1	N/A	
Lab Filtered Supernate (0.7 $\mu$ m)		33.3	3.9	35.8	
Effluent Thorium Concentration & Activity versus Time					
Sample Elapse Time	Column 1 Effluent Concentrations		Column 2 Effluent Concentrations		Total Removal Efficiency
	Th (ppm)	Th (pCi/ml)	Th (ppm)	Th (pCi/ml)	(%)
0 min.	9.8	1.2	3.0	0.3	94.3
15 min.	11.7	1.4	10.7	1.3	78.7
30 min.	12.8	1.5	11.7	1.4	76.9
45 min.	11.0	1.3	8.7	1.0	82.8
60 min.	10.8	1.3	9.8	1.2	81.0
75 min.	12.1	1.5	10.4	1.2	79.6
90 min.	10.9	1.3	11.0	1.3	78.1
105 min.	11.2	1.3	10.5	1.2	79.6
120 min.	10.2	1.2	10.8	1.3	78.6
135 min.	12.2	1.5	11.5	1.4	77.5
150 min.	10.9	1.3	11.7	1.4	77.1
165 min.	11.4	1.4	10.6	1.3	79.1
180 min.	11.5	1.4	9.6	1.1	81.3
198 min.	<11.3	1.4	11.3	1.3	77.9

**Table 5-10**  
**Summary of Off-site Laboratory Analyses**  
**Cation Exchange Tests**

Sample Analyzed	Thorium (mg/Kg)	Sodium (mg/L)	Nitrate (mg/L)	Total Activity (pCi/L)	Total Radium Alpha (pCi/L)
<b>Cation Exchange Test of Contaminated Condensate</b>					
Feed Condensate (CLB1-001)	85.40	24.80	60.67	----	----
Product Condensate (CLB1-002)	4.66	30.00	40.26	2.60 E03	220
<b>Cation Exchange Test of Filtrate/Rinsate</b>					
Feed Filtrate/Rinsate (CLB2-001)	6.36	25,500	82,371	----	----
Product Filtrate/Rinsate (CLB2-002)	<0.50	25,700	193,086	6.87 E03	400
<b>Cation Exchange Test of Supernate</b>					
Feed Supernate (CLB3-001)	2.32	38,000	138,614	----	----
Product Supernate (CLB3-002)	<0.50	40,800	121,786	9.84 E03	900

## **5.10 Radiological Control Summary**

The demonstration project was performed at the Perma-Fix of Florida facility located in Gainesville, Florida and was performed under their Florida State Radioactive Materials License 2589-1. Project radiological engineering, radiological training and field radiological controls were provided by Teledyne Brown Engineering. The host organization provided support radiological administrative functions applicable to license control. These functions included Radiological Work Permits, dosimetry, internal dose assessment, smear counting and site access control.

### **5.10.1 In-Processing Requirements**

Personnel in-processing was controlled by the host facility and Teledyne Brown Engineering. In-processing included site access, i.e., drug screening and individual company employment requirements, Hazardous Waste Operator (HAZWOPER) 29 CFR 1910.120 training, Radworker II training, initial bioassay, respirator training, respirator fit testing, project operations training, and radiation work permit briefing. All personnel were required to have successfully completed all of the above requirements prior to entry into the controlled work area. Also, periodic safety briefings were performed during the course of field operations.

### **5.10.2 Area Setup and Engineering Controls**

The project was conducted within the Nelson Building at the Perma-Fix of Florida facility, and was confined to a metal quonset hut set up inside the Nelson Building. Within the quonset hut, individual tents were constructed around areas of potentially high contamination and high airborne activity areas. All walls of the quonset hut, the floor and specific equipment were covered with Herculite™ or shrink wrap to minimize contamination of these surfaces during operations. A worker undress and entry/exit area was built within the quonset hut to ensure workers were away from the work area during undress and exit at the step-off pad. Three individual HEPA ventilation systems were used during operations which were flow balanced to ensure ventilation air flow into the hut. These units not only provided general area ventilation but were also used to provide negative pressure at specific potentially high airborne activity areas during operations. This specific ventilation was provided for the thorium material removal/packaging tent, filter press tent, and for the plowshare unit feed hopper and vent condenser/accumulator areas. The ventilation system for the thorium material removal/packaging tent contained a granular activated carbon (GAC) absorption system for capture of radon during drum opening operations. This ventilation design provided an overall negative pressure condition inside the quonset hut and also ensured that any high airborne activity that might be generated during operations would be contained within the quonset hut.

### **5.10.3 Project-Specific Radiological Operating Data**

Initial radiological control conditions for the quonset hut were established and workers were given a pre-job briefing by radiological personnel prior to signing the Radiation Work Permit. Work commenced with the opening of drums of thorium nitrate inside the thorium material removal/packaging tent.

Separate ventilation suction systems were strategically positioned at the potentially high airborne activity work areas. This specialized ventilation and tent arrangement allowed workers to wear air purifying respirators in the common areas of the quonset hut while airline respirators were worn inside the thorium material removal/packaging tent and the filter press tent only. By using this engineering controlled ventilation arrangement and establishing specific area requirements for respiratory protection, work was allowed to progress at a good pace while minimizing potential for internal radioactivity deposition. This is documented by the fact that there were no personnel skin or clothing contamination incidents during operations nor was there any internal dose as indicated by bio-assay results of the work force.

Personnel working inside the thorium material removal/packaging tent were dressed in double layered protective clothing and airline respirators. Workers outside this tent were dressed in single layer protective clothing and air purifying respirators. The drums were opened inside the tent next to a ventilation intake hood which was positioned at the open face of the drum. Air samples and swipes were taken during this activity to monitor radiological levels and to ensure high levels of contamination were not spread outside the tent.

During the demonstration operations, the work force provided as a minimum, a daily cleanup of the work area to maintain radioactive contamination levels low. Thus radioactive airborne activity was also maintained low. The highest radioactive contamination that was encountered during the demonstration operations was 20,000 dpm/100cm<sup>2</sup> α inside the thorium materials removal/packaging tent with an average radioactive contamination level of 2,000 dpm/100cm<sup>2</sup> α. The average radioactive contamination level inside the main work area of the quonset hut was <100 dpm/100cm<sup>2</sup> α and was normally maintained at <Minimal Detectable Activity (MDA) which was 10 dpm/100cm<sup>2</sup> α by Liquid Scintillation Counter (LSC) analysis which was specifically calibrated for natural thorium. Due to the large amount of dry thorium nitrate powder that was handled during the demonstration, cleanup of the work area was a vital activity in maintaining radioactive contamination and airborne activity levels low. These housekeeping activities were instrumental in preventing the workers from receiving any internal dose or from having any skin or clothing contamination or radioactive release incidents. The exit area of the quonset hut was maintained at <MDA α levels of radioactive contamination and all material exiting the areas was surveyed for clean release or covered with protective bags at the step-off pad. All personnel exiting the quonset hut were surveyed by hand held instruments for contamination. The release criteria established for the demonstration project was <MDA α contamination release.

The highest radiation levels that were encountered during the project was a dose rate of 50 millirem/hr γ on contact with a drum of final thorium hydroxide product. The highest general area dose rate inside the thorium materials removal/packaging tent during material removal operations were 10 millirem/hr γ with an average general area dose rate in the main work area of the quonset hut <2 millirem/hr γ. All areas outside the radiation area boundary of the quonset hut were maintained at <2 millirem/hr γ.

After completion of the process operations, the work area was demobilized and returned to pre-existing conditions. Major materials and capital equipment were decontaminated and surveyed for disposition per the Perma-Fix of Florida Radioactive Materials License limits. Some were

decontaminated to unrestricted use levels. Others which could not be decontaminated to unrestricted use levels were disposed of as radioactive waste or packaged in accordance with the host facility's procedures and stored for future use or disposition. All waste materials were shipped to a licensed radioactive waste processing facility for ultimate disposal at a radioactive disposal site.

#### **5.10.4 Results Evaluation**

Good radiological engineering, and aggressive radiological controls, with a allowance for worker's comfort and ease of job performance resulted in a highly desirable radiological outcome. This fact is best demonstrated by reviewing the final radiological project data. The project Man-Rem dose was 0.350 Rem with the highest individual worker dose of 100 millirem over a three month period. There was zero internal dose received by the work force, no skin or clothing contamination incidents, and no release incidents of radioactive contamination. Furthermore, the greater automation to be incorporated in full-scale process designs should reduce the above referenced exposure rates by a factor of 2 or 3. Much of the dose documented during the pilot-scale demonstration was due to direct handling of thorium materials and long hours of operation due to the research and development nature of the project.

## 6.0 LABORATORY ANALYTICAL RESULTS AND MATERIAL BALANCES

The samples collected from each pilot-scale batch test were stored at the Perma-Fix of Florida facility until a preliminary evaluation of the test's process success was performed. Based upon the preliminary evaluation, a decision was made whether or not to send the samples out for laboratory analysis. Through this decision process, it was decided not to analyze any of the samples from Batch Test No. 3. Also, as an economy measure, the slate of requested analyses was tailored to the data needs for that test. For instance, analytical questions that were answered adequately in Batch Tests No. 1 or No. 2, were not repeated in later tests. The analytical laboratories involved in this project and their contributions are summarized in Table 6-1. Overall coordination and technical guidance of the laboratory analytical program was performed by Teledyne Brown Engineering.

**Table 6-1**  
**Summary of Laboratory Analytical Services**

Laboratory	Analytical Parameters	Methods
Teledyne Brown Engineering Environmental Services 50 Van Buren Ave. P.O. Box 1235 Westwood, NJ 07675-1235	Gross alpha, Gross beta gamma isotope activity alpha isotopes activity	Direct count alpha and beta gamma spectroscopy alpha spectroscopy
Southwest Research Institute 6220 Culebra Road P.O. Drawer 28510 San Antonio, TX 78228-0510	Thorium Ignitability (D001) Crystalline Structure	Radiochemical Thorium DOT Oxidizer Test X-ray Diffraction Analysis X-ray Fluorescence Analysis
QST Environmental P.O. Box 1703 Gainesville, FL 32602-1703	RCRA metals (UTS list) sodium nitrate/nitrite-N chloride	TCLP extraction, ICP-MS wet chemical wet chemical wet chemical
Perma-Fix Environmental Services, Inc. Laboratory 2010 N.W. 67 <sup>th</sup> Place Gainesville, FL 32653	Thorium 232 Nitrate Moisture	Liquid Scintillation Count UV/Vis Spectro-photometry gravimetric

Laboratory analytical reports for all designated samples from the pilot-scale batch tests are presented in Appendix A. Appendix B contains analysis reports of sample splits provided to Lockheed Martin Energy Systems, Inc. and analyzed by their contract laboratories. Material balances were calculated for Batch Test Nos. 2, 4 and 5, and the results are presented in Tables 6-2, 6-3 and 6-4, respectively. Each column in these tables is referenced to a stream number and description in Figure 3-1. The

upper rows of data in the table are calculated flows and concentrations based upon a combination of analytical data, stoichiometric assumptions and calculations. Available analytical data for comparison to these calculated values are listed for each column in the lower rows of each table. Of the three mass balances presented, the data for Batch Test No. 4 is closest to the process that would be carried forward into full-scale thorium de-nitration in Phase II. Data for this test is summarized in Table 6-3.

To answer the question of whether the raw thorium nitrate or any of the thorium hydroxide products would be ignitable (D001) as defined by RCRA and Department of Transportation (DOT) Division 5.1, samples were analyzed by the DOT Oxidizer Test, prescribed in 49 CFR 173, Appendix F. This test evaluates the degree to which a material will propagate combustion of a combustible material (sawdust) when thoroughly mixed and ignited. The intensity of combustion is judged by comparison with standards composed of mixtures of sawdust with potassium bromate (Packing Group I), potassium perchlorate (Packing Group II), and ammonium persulfate (Packing Group III). Samples of raw thorium nitrate (BT1-001C), dried thorium hydroxide from Batch Test No. 1 (BT1-008C) and dried thorium hydroxide from Batch Test No. 2 (BT2-007D) were tested by Southwest Research Institute. They found that the thorium nitrate raw material and sawdust blend would not ignite, and that neither of the thorium hydroxide/sawdust blends burned more strongly than the standard mixtures. Therefore, neither the thorium nitrate nor its thorium hydroxide conversion products with nitrate residuals as high as 14.1 % are classified as Division 5.1 DOT oxidizers. Therefore, none of these materials would be considered ignitable (D001) under RCRA. Table 6-5 summarizes these test results in comparison to the residual nitrate content of the samples. Since the Batch Test No. 4 dried product had only 1.6 % residual nitrate, that product would not be classified as a DOT oxidizer or a RCRA D001 ignitable material, if it were to become a solid waste. As a stockpile material, RCRA definitions do not apply to either the thorium nitrate or the thorium hydroxide. Since a calcined product (thorium oxide) would have slightly lower residual nitrate content, it can be concluded that the oxide would not be classified as a DOT oxidizer or a RCRA D001 material either.

Table 6-6 is a summary of the chemical composition of primary feed and product materials and secondary byproduct materials based upon the demonstrated process from Batch Test No. 4. Table 6-7 is a summary of the radiochemical composition of these streams.

Table 6-3  
Batch Test 4 Material Balance Summary

Stream Number	1a	1b	2	3a	3b	4	5	6a	6b-1 Rinse 1	6c-1 Rinse 1	6d-1 Rinse 1	6b-2 Rinse 2	6c-2 Rinse 2	6d-2 Rinse 2	6b-3 Rinse 3	6c-3 Rinse 3	6d-3 Rinse 3	6b-4 Rinse 4	Rinse 4	6c-4 Rinse 4	6e-4 Rinse 4	6b-5 Rinse 5	6e-5 Rinse 5	7 Rinse 5	8	9	10	11	12	
Stream Description	Dry Thorium Nitrate	Demin. Water	Thorium Nitrate Solution	25% Caustic	10% Caustic	Reactor Product	Filtered Thickener Supernate	Sludge Blanket Prior To Rinse	Rinse Water Added	Rinsed Solids	Rinse Water Recovered	Rinse Water Added	Rinsed Solids	Rinse Water Recovered	Rinse Water Added	Rinsed Solids	Rinse Water Recovered	Rinse Water Added	Filter Press Feed	Rinsed Solids	Rinse Water Recovered	Rinse Water Added	Rinse Water Recovered	Rinsed Dewatered Sludge	Dried Thorium Product	Calcined Thorium Product	Supernate From Settling Filtrate (Rinses 4 & 5)	Process Heels From Various Sources	Contaminated Process Condensate	
Parameter (Units)																														
<b>Theoretical Mass Balance Based Upon Volume and Mass of Reactants</b>																														
Mass Flow Rate (lbm/batch)	385.5	437.1	822.6	309.0	286.0	1,417.6	812.8	537.1	208.3	535.3	210.1	208.3	514.4	218.4	208.3	489.3	242.2	208.3	677.6	340.3	308.1	208.3	230.2	302.1	169.1	138.0	538.3	173.85	109.0	
Volume Flow Rate (ACFM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Volume Flow Rate (GPM)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Volume Flow Rate (Gal./batch)	est. 40	52.8	66.6	30.7	32.8	130.1	87.1	35.7	25.0	32.8	27.9	25.0	32.9	24.9	25.0	27.5	30.4	25.0	52.5	25.5	37.0	25.0	21.3	29.2	13.8	-	64.6	Est. 17.5	13.1	
Solids Concentration (%)	100.0	0.0	0.0	0.0	0.0	-	<0.05	34.6	0.0	34.0	<1	0.0	34.7	<1	0.0	37.3	<1	0.0	25.8	46.5	<1	0.0	<1	46.9	85.2	>99	-	35.2	<0.1	
Water Content (lbm)	60.9	437.1	500.7	227.4	254.7	982.8	647.2	296.5	208.3	329.0	189.7	208.3	321.7	208.5	208.3	286.8	236.2	208.3	495.1	179.3	288.5	208.3	226.0	156.8	23.8	9.7	514.5	85.7	-	
Water Content (%)	15.8	100.0	60.9	75.0	90.0	69.3	88.0	55.2	100.0	61.5	90.3	100.0	62.5	95.5	100.0	57.3	97.5	100.0	73.1	52.7	93.8	100.0	1.0	51.9	14.1	<1	95.6	49.3	99+	
Thorium Content (lbm)	156.9	0.0	156.9	0.0	0.0	156.9	-	143.8	0.0	140.9	0.0	0.0	138.1	0.0	0.0	135.2	0.0	0.0	135.2	122.4	0.0	0.0	0.0	109.6	109.6	109.6	-	47.31	-	
Thorium Concentration (%)	40.7	0.0	19.0	0.0	0.0	11.8	-	26.8	0.0	26.3	0.0	0.0	26.9	0.0	0.0	28.8	0.0	0.0	20.0	36.0	0.0	0.0	0.0	36.3	64.8	79.4	-	27.2	-	
Thorium Concentration (ppm)	-	-	-	-	-	-	10.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	234.0	-	<50	
Nitrate Content (lbm)	167.7	0.0	167.7	0.0	0.0	167.7	117.7	43.0	0.0	19.0	16.0	0.0	10.2	7.3	0.0	5.6	4.4	0.0	5.6	2.0	14.3	0.0	0.0	3.1	2.7	2.7	2.7	17.4	18.8	-
Nitrate Concentration (%)	43.5	0.0	20.3	0.0	0.0	-	-	8.0	0.0	3.6	7.6	0.0	2.0	3.3	0.0	1.2	1.8	0.0	0.8	0.6	4.6	0.0	0.0	1.4	0.9	1.6	1.9	3.2	10.8	<0.2
Nitrate Concentration (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<2000
Sodium Content (lbm)	0.0	0.0	0.0	44.6	11.1	63.4	35.5	11.7	0.0	5.2	4.4	0.0	3.8	2.7	0.0	2.1	1.6	0.0	2.1	0.8	5.3	0.0	0.0	1.1	1.0	1.0	1.0	6.4	8.2	-
Sodium Concentration (%)	0.0	0.0	0.0	14.4	5.8	4.2	4.7	2.2	0.0	1.0	2.1	0.0	0.7	1.2	0.0	0.5	0.7	0.0	0.3	0.2	1.7	0.0	0.0	0.5	0.3	0.6	0.7	1.2	4.7	<0.1
Sodium Concentration (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1000
<b>Analytical Data From Samples Collected During the Pilot Test</b>																														
Sample Identification Number	BT1-001	-	BT4-001	-	-	-	BT4-004	-	-	PF Lab	PF Lab	-	PF Lab	PF Lab	-	PF Lab	PF Lab	-	BT4-003	PF Lab	PF Lab	-	PF Lab	BT4-005	BT2-007 + PF Lab	BT2-008 + PF Lab	BT2-006	-	BT2-009	
Thorium Concentration (%)	38.0	-	16.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.6	-	-	-	36.0	64.8	79.4	-	-	-	-	
Thorium Concentration (ppm)	380,000.0	-	-	-	-	-	10.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	648,000.0	794,000.0	234.0	-	1,120.0		
Nitrate Concentration (%)	42.3	-	27.5	-	-	-	14.8	8.0	-	3.7	6.9	-	1.9	3.5	-	-	1.8	-	2.7	0.6	1.02/4.64	-	1.2	0.9	1.6	2.6	11.2	-	-	
Nitrate Concentration (ppm)	423,000.0	-	274,900.0	-	-	-	147,700.0	-	-	-	-	-	-	-	-	-	-	-	26,749.0	0.6	-	-	9,034.0	16,341.0	26,439.0	112,000.0	-	66.9		
Nitrate Concentration (mg/L)	-	-	310,886.0	-	-	-	165,186.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11,204.0	-	66.9		
Sodium Concentration (%)	-	-	-	-	-	-	5.2	-	-	-	-	-	-	-	-	-	-	-	0.9	-	-	-	0.8	1.2	-	3.2	-	-		
Sodium Concentration (ppm)	-	-	-	-	-	-	52,000.0	-	-	-	-	-	-	-	-	-	-	-	26,749.0	-	-	-	7,510.0	12,400.0	-	31,800.0	-	35.3		
Sodium Concentration (mg/L)	-	-	-	-	-	-	58,100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31,700.0	-	35.3		





**Table 6-5**  
**Comparison of DOT Oxidizer Test Results**  
**(49 CFR 173, Appendix F)**

Sample Designation	Burn Time (Min./sec)	Residual Nitrate (%)	DOT/RCRA Classification
Thorium Nitrate ( Sample BT1-001C)	Did Not Burn	43.5	N/C
Batch Test 1 Dried Thorium Hydroxide (Sample BT1-008C)	23:00	14.96	N/C
	25:19	14.96	N/C
Batch Test 2 Dried Thorium Hydroxide (Sample BT2-007D)	40:56	4.5	N/C
	43:42	4.5	N/C

N/C Means not classified as a Division 5.1 Oxidizer. -- The sample mixture did not burn as intensely as any of the standard mixtures.

Table 6-6

Chemical Characterization of Primary and Secondary Material Streams

Primary Thorium Materials				
Constituent Concentrations	Feed Thorium Nitrate (%)	Dry Thorium Product (%)	Calcined Thorium Product (%)	Process Heels Before Recovery (%)
Thorium	38.0	64.8	79.4	27.2
Sodium	----	1.2	2.0	4.7
Nitrate	42.3	1.6	2.6	10.8
Water	15.8	14.1	<1.0	49.3

Secondary Byproduct Materials						
Constituent Concentrations	Raw Supernate (Mother Liquor)	Polished Supernate (Mother Liquor)	Raw Filtrate/Rinseate	Polished Filtrate/Rinseate	Raw Condensate	Polished Condensate
Thorium	10.4 ppm	<0.5 ppm	234.0 ppm	<0.5 ppm	85.4 ppm	4.7 ppm
Sodium	4.7 %	4.7 %	1.2 %	1.2 %	35.3 ppm	35.3 ppm
Nitrate	14.5 %	14.5 %	3.2 %	3.2 %	13.7 ppm	9.1 ppm
Water	88.0 %	88.0 %	95.6 %	95.6 %	99.9%	99.9%

**Table 6-7**  
**Radiochemical Characterization of Primary and Secondary Material Streams**

<b>Sample Number</b>	<b>BT1-001d</b>	<b>BT1-004a</b>	<b>BT2-003a</b>	<b>BT2-005a</b>	<b>BT2-007a</b>
<b>Constituent Activity</b>	<b>Feed Thorium Nitrate (μCi/gm)</b>	<b>Reactor Slurry (μCi/gm dry)</b>	<b>Rinsed Filter Press Feed Slurry (μCi/gm dry)</b>	<b>Wet Filter Cake (μCi/gm dry)</b>	<b>Dried Thorium Product (μCi/gm dry)</b>
Gross alpha	1.7 ± 0.1 E-01 dry	1.2 ± 0.1 E-01	2.9 ± 0.1 E-01	3.1 ± 0.1 E-01	2.6 ± 0.1 E-01
Gross beta	1.3 ± 0.1 E-01 dry	0.6 ± 0.2 E-02	1.2 ± 0.1 E-01	1.5 ± 0.1 E-01	1.1 ± 0.1 E-01
Ac-220	3.2 ± 0.3 E-02 dry	3.4 ± 0.5 E-02	6.3 ± 0.6 E-02	3.5 ± 0.4 E-02	4.0 ± 0.5 E-02
Cd-109	----	----	----	2.05 E-02	3.77 E-03
Pb-212	2.9 ± 0.3 E-02 dry	3.4 ± 0.3 E-02	5.8 ± 0.6 E-02	3.3 ± 0.3 E-02	4.0 ± 0.4 E-02
Tl-209	1.0 ± 0.1 E-02 dry	1.1 ± 0.1 E-02	1.9 ± 0.2 E-02	1.1 ± 0.1 E-02	1.3 ± 0.1 E-02
U-234	<9.5 E-07 wet	----	----	----	----
Th-230	3.1 ± 0.6 E-03 wet	----	----	----	----
Th-232	5.3 ± 0.5 E-02 wet	----	----	----	----
Th-234	----	----	----	5.01 E-03	7.33 E-03
Th-228	5.4 ± 0.5 E-02 wet	----	----	----	----

## 7.0 FULL SCALE DE-NITRATION PROCESS

The full-scale thorium de-nitration process proposed for Phase II operations conforms to the process flow described for Batch Test No. 4, except that all demineralized water rinsing will take place in the plate and frame filter press. The process flow diagram is shown in Figure 7-1. The full-scale facility is envisioned to provide a nominal treatment capacity of 5,640 pounds/day, allowing the 7,000,000 pound inventory to be processed over a 5-year period. The process is divided administratively into six separate trains or process units, as listed below.

- Feed Preparation Train
- Reagent Preparation Train
- De-nitration Train No. 1
- De-nitration Train No. 2
- Product/Byproduct Shipping Train
- Facility Support Train

Considering the flow path of thorium through the facility, it first passes through the Feed Preparation Train and the splits between two parallel de-nitration trains. Each of these trains are discussed in detail in the remainder of this section. The estimated costs of process equipment are summarized in Table 9-1.

### 7.1 Feed Preparation Train

The Feed Preparation Train is the point where containers of thorium nitrate will be received, opened, emptied, and readied for reuse or disposal. The thorium nitrate will be removed from the containers using a dry process, as described in the following step-wise presentation.

#### Steps of Drum Opening

1. Drums will enter the drum opening booth via a conveyor.
2. Remove the lid of the outer steel container.
3. Invert the drum using a hydraulic drum inverter.
4. Remove the outer steel container using a hydraulic drum grapple.
5. Remove the black plastic drum using the hydraulic drum grapple.
6. Remove the outer steel container and its lid along with the black plastic drum from the enclosure to prevent their contamination. Survey and decontaminate them as necessary to allow reuse of the steel container.
7. Invert the package to its original upright position using the hydraulic drum inverter.

8. Remove the lid from the black plastic drum from the enclosure to prevent contamination.
9. Cut away the plastic bag from the outer kraft drum.
10. Remove the lid to the outer kraft drum.
11. Invert the kraft drum using the hydraulic drum inverter.
12. Remove the kraft drum using the hydraulic drum grapple.
13. Rotate the inner kraft drum 90° using the hydraulic drum inverter, placing the drum on its side.
14. Split the sides of the kraft drum using a reciprocating saw or power shears.
15. Peel away the kraft drum to expose the thorium nitrate monolith.
16. The thorium nitrate monolith will be transferred into the dissolver vessel by an engineered conveyance.
17. Collect and consolidate all of the dry thorium contaminated packaging material and convey it to the secondary waste processing system.

The removal will take place in a drum opening booth which will be divided into two sections separated by a plastic strip curtain. The first section will be a low contamination zone in which the outer steel container will be removed to prevent external contamination. These clean reusable containers will be closed, removed from the booth, surveyed, and staged for reuse in overpacking dried thorium hydroxide product containers.

Since the pilot-scale analytical results show that none of the feed materials, products or byproducts of the process exhibit a RCRA hazardous characteristic, the inner packaging materials will be classified as debris, subject only to regulation as a low-level radioactive solid waste. Therefore, these packaging materials will be separated from the thorium nitrate solids in the second, high-contamination zone of the drum opening booth, shredded in a knife shredder, granulated in a granulator, and discharged into surplus original steel drums. These drums will be closed, sealed, and then crushed in a hydraulic-powered drum crusher to minimize their disposal volumes. A single 55-gallon drum should hold the granulated debris from 8 original packages. The compacted drum pucks will be overpacked in appropriate containers for land-disposal in a licensed LLRW repository. The volumetric compaction ratio anticipated for a steel drum filled with shredded container debris from 8 original packages is expected to be approximately 50 %.

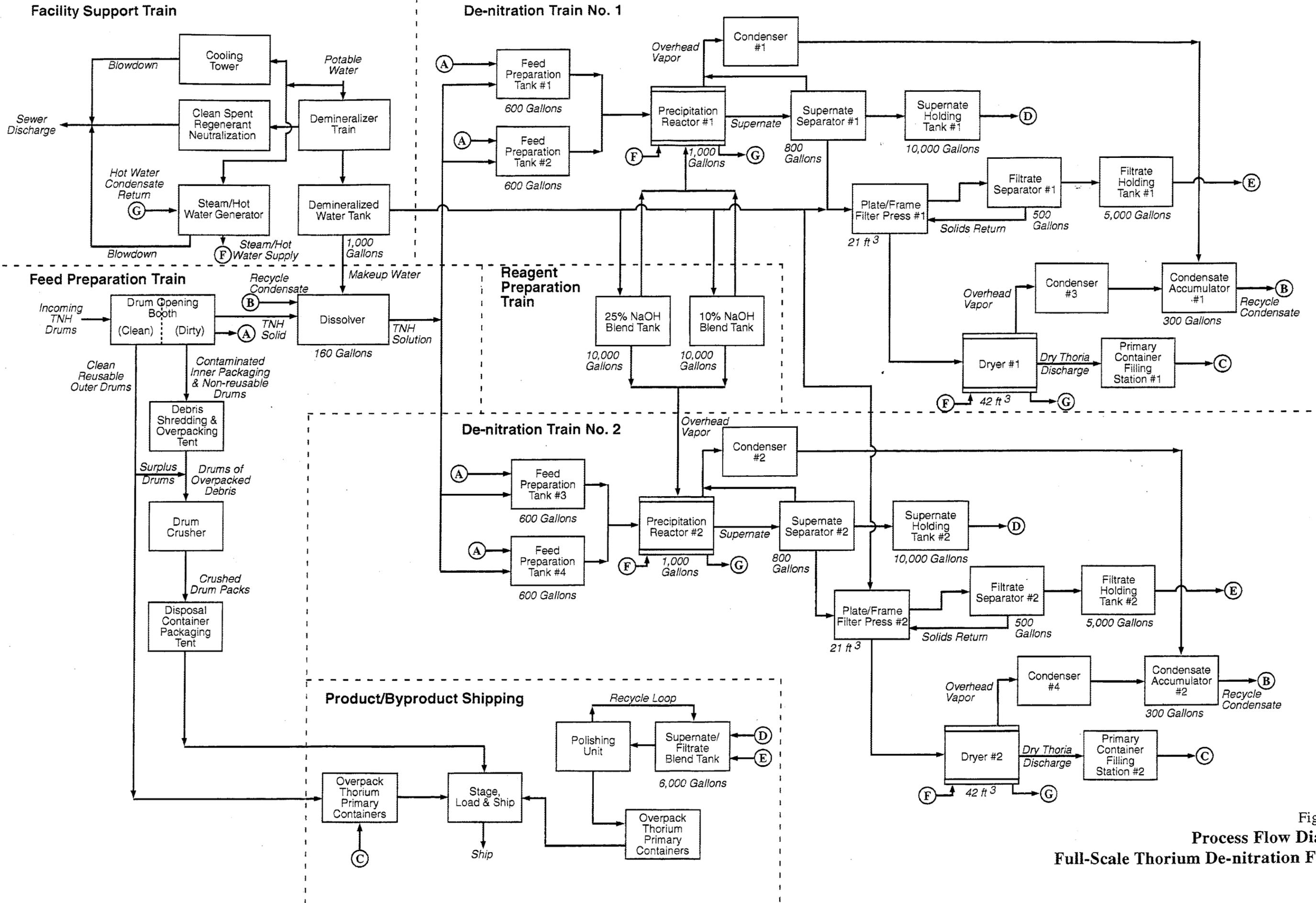


Figure 7-1  
**Process Flow Diagram**  
**Full-Scale Thorium De-nitration Facility**

The fused monolith of thorium nitrate will be conveyed directly from the drum opening enclosure into the dissolver vessel by way of an engineered conveyance, probably a shrouded weigh belt conveyor discharging by gravity through a feed hopper into the top of the dissolver. The monolith will drop into the dissolver, where the appropriate amount of dilution water will be added, and mechanical choppers incorporated into the dissolver design will chop the monolith into small chunks which dissolve quickly. The main agitator of the dissolver will be used to complete the dissolving process.

Inside the dissolver vessel, the thorium nitrate solids will be dissolved in dilution water, either demineralized water or recycled condensate. A priority will be placed upon reusing condensate and only adding demineralized water to make up any shortfall. At a target concentration of 270 gm/L thorium in the dissolver product solution, 4 drums TNH will be dissolved in 879.8 pounds (105.5 gallons) of water, producing a final volume of the dissolver product of approximately 134.4 gallons.

## **7.2 De-nitration Train No. 1**

Each batch of dissolver product solution will be pumped through dedicated piping to one of two identical de-nitration trains. It will be stored in one of two 600-gallon feed preparation tanks. It will require approximately four dissolver batches (16 TNH drum equivalents) to make one batch in a feed preparation tank. Since dissolving progresses quickly, one feed preparation tank batch in each de-nitration train can be produced per day, for a total daily production rate of 32 TNH drum equivalents. The sizing basis for each train is 16 TNH drum equivalents per day of operation. While one feed preparation tank is being filled, the other is feeding its batch into the precipitation reactor. In the feed preparation tank, the batch is held, mixed and brought up to reaction temperature. Samples of each batch will be taken and analyzed for pH and thorium concentration. If necessary, dry thorium nitrate will be taken directly from the drum opening booth to the feed preparation tank to make adjustments of these critical control parameters. Additions of water or nitric acid may also be made as necessary.

When a batch of thorium nitrate feed solution is properly adjusted, it will be pumped into the precipitation reactor where the de-nitration reaction will take place. In this reactor, the batch will be gently mixed and maintained at reaction temperature while thorium is precipitated by reaction with sodium hydroxide. The precipitation reactors will be of the conical type which are agitated by a tapered helical auger which rotates at variable speed in forward or reverse and moves along an orbital path around the inside of the cone. This mixing action gives rapid mixing and turnover of the reactor contents with low mechanical shear. The screw flights will be notched to provide safe clearance for three pH analyzers inserted into each reactor vessel. These three analyzers will be multiplexed to a programmable logic pH controller which will be programmed to follow an optimum pH curve to produce large precipitate particles with good settling and filtering characteristics.

The precipitation reaction will take place over a full operating shift, and part of another shift as necessary. This is the only process operation which may require more time than one shift per day. The precipitation reaction will be halted when the pH of the batch has reached 11.0. Then, the batch will be transferred into a cone-bottom supernate separation tank in which the thorium hydroxide

solids will form a dense sludge blanket in the cone bottom of the separator. The clear supernate will be skimmed off and pumped to a supernate holding tank.

The sludge blanket will be pumped from the bottom of the supernate separator directly into a plate and frame filter press. Filtrate discharging from the filter press will accumulate in a cone-bottom filtrate separator tank where solids will be allowed to settle. After the thorium hydroxide solids have been de-watered to separate filtrate from the solids, one or more rinses with demineralized water will be performed to wash residual sodium nitrate from the filter cake. The rinsate will also be discharged to the filtrate separator tank. After settling, the clear filtrate/rinsate layer will be skimmed off and pumped to a Filtrate Holding Tank.

After the filter cake has been washed, the press will be automatically opened and the cake will be dropped onto an enclosed conveyor belt which will transport the cake directly into a low temperature thermal dryer. This dryer will operate under a partial vacuum and will be purged with a small stream of dry compressed air to aid in the transfer of water vapor out of the head space of the dryer and into a vapor condenser. A humidity sensor in the exhaust air line between the dryer and the vapor condenser will be used to indicate when the thorium hydroxide solids have been sufficiently dried. With this system, residual moisture contents of less than 0.5 % should be achievable. This dryer will be operated in batch mode to ensure that residual moisture targets are met. When the batch in the dryer has reached desired dryness, the dry thorium hydroxide solids will be discharged into a plastic-lined high density polyethylene primary container by way of a cooling screw. A seal flange at the end of the cooling screw will prevent loss of airborne contaminants while the primary container is being filled. The cooling will prevent heat damage to the container and plastic liner. When full, the internal plastic liner will be gathered into a "horse-tail" and sealed with tape. Then, the lid will be placed loosely on the container until the contents have cooled to ambient temperature. The lid will be sealed and the container will be moved to the product/byproduct shipping unit.

Overhead vapors from the supernate separator and the precipitation reactor will pass through a water-cooled non-contact condenser. The overhead vapors from the dryer will pass through another condenser of the same type. The two-phase flow exiting each of these condensers will discharge into a single condensate accumulator tank where condensate droplets will fall out of the non-condensable air stream. This recovered condensate will be recycled to the dissolver tank for reuse in dissolving feed TNH.

### **7.3 De-nitration Train No. 2**

De-nitration Train No. 2 is an exact duplicate of De-nitration Train No. 1.

#### **7.4 Product/Byproduct Shipping**

In the product/byproduct shipping unit, product and byproduct shipments are staged, documented, loaded and shipped. Any additional overpacking of containers is performed in this unit. At a minimum, sealed high-density polyethylene primary containers of thorium hydroxide product will be overpacked in appropriately sized steel outer containers.

Clear supernate and filtrate/rinseate streams will be pumped from the holding tanks in de-nitration units 1 and 2 into a blend tank in the product/byproduct shipping unit. The blending of these liquid byproduct streams will be performed based upon samples taken from the upstream tankage and the byproduct specifications required by the outside recyclers.

A polishing unit will be used to reduce the trace thorium concentrations of the blended byproduct stream, at the time of tanker loading. Although cartridge filtration and cation exchange were successful in the pilot-scale demonstration, it is likely that most of the quality improvement was provided by filtration processes. Use of an ultra-filtration unit to remove thorium particles to 0.01 microns without producing spent regenerant streams appears to be the best polishing approach.

#### **7.5 Reagent Preparation Train**

In this process stream, low-chloride 50 % sodium hydroxide solution will be received and diluted in two tanks. One tank will be used to make and store 25 % sodium hydroxide. The other tank will be used for 10 % sodium hydroxide. These solutions will be metered into the precipitation reactor under pH control.

#### **7.6 Facility Support Train**

The facility support train consists of the potable water system and the demineralizer system used to produce demineralized water for dissolving sodium hydroxide and feed TNH, and for rinsing in the filter press. The demineralizer system will consist of a standard acid regenerated cation unit, a sodium hydroxide regenerated anion unit, a demineralized water tank, and a neutralization system for spent regenerant solutions. Because potable water will be used, and because this system will be located outside the radiation control area, the neutralized spent regenerants and any discarded ion exchange resins will be regulated as non-radiological, non-hazardous wastes.

One or more HEPA-based negative pressure ventilation systems will provide ventilation control of process equipment, the drum opening booth and the building where the facility is located. The ventilation system serving the drum opening booth will be equipped with a granular activated carbon (GAC) filtration units for capture of radon gas. It is envisioned that GAC units will be checked daily for evidence of radon breakthrough. When a GAC unit becomes exhausted, it will be taken out of service and allowed to decay in storage before being returned to service. Any GAC media that must be discarded, will be stabilized with a cement grout and poured into appropriate containers for off-site disposal at a LLRW repository.

## 7.7 Facility Siting

Siting for the thorium de-nitration facility will be considered on the basis of two separate cases; on-site at the Curtis Bay, Maryland depot, and off-site. Any off-site facility must have a radioactive materials (RAM) license issued by the Nuclear Regulatory Commission (NRC) or an agreement state. It is possible that a mobile RAM license could be used at either site.

For the purposes of the life-cycle cost estimates in Section 8.0, the off-site location is assumed to be a facility operated under lease at the former K-25 Site in Oak Ridge, Tennessee. That site is now known as the East Tennessee Technology Park (ETTP).

## **8.0 LIFE CYCLE COST OF FULL SCALE TREATMENT**

The costs of full scale treatment have been estimated for the two facility siting cases described in Section 7.7. These cost estimates include capital, operating labor, utilities, material packaging, transportation and disposal. In this section of the report, the base case will be treatment at Curtis Bay in a purpose-built building, and the alternative will be treatment at the ETTP at Oak Ridge, Tennessee.

### **8.1 Capital and Siting Cost Estimate**

Table 8-1 provides a summary of the capital costs estimated for the base case and any cost differentials associated with the alternative. Items 1 through 34 of the table are the capital and equipment costs which are the same for the base case and the alternative. Items 35 through 43 are the capital and siting costs which differ for the two siting cases. Although siting the Phase II project in a purpose-built building on the Curtis Bay Site appears to have a small capital cost, the other siting costs of the base case option make it appear to be approximately \$1,237,500 more expensive than the alternative. Most of this cost differential is in the pre-project NEPA process and the post-project decontamination and decommissioning of the purpose-built building at the Curtis Bay site. The alternative case has significantly lower NEPA process costs because the East Tennessee Technology Park has already been through the NEPA process under the Re-industrialization Initiative. That initiative considered that a tenant would establish a commercial waste treatment operation on the site and would receive shipments of waste for treatment, and that the treated materials would be shipped off-site for final disposition. The NEPA Process for the origin sites would be fairly easy and inexpensive for the alternative case, because shipping risks and socioeconomic impacts for waste shipping operations are well understood and accepted by communities hoping to eliminate local stockpiles of objectionable materials. A finding of no significant impact (FONSI) or a categorical exemption will likely be applicable. However, the base case for on-site treatment at one of the DLA sites will be much less acceptable to the local stakeholders, thus resulting in higher NEPA costs. The transportation costs are the only other costs which are significantly impacted by choice of project site. As can be seen in Section 8.5, the alternative case has only about \$229,456 additional shipping costs above the base case. Based on cost trade-offs between siting and transportation costs favoring the alternative case, the alternative case appears to be the overall lowest cost option.

### **8.2 Labor Costs**

The labor costs for the project are based upon the same crew makeup in both the base case and the alternative. The project staffing approach is summarized in Table 8-2. Assuming 5 years of activity with one 10 hour/day shift and 5 days per week, there will be 13,000 man-hours per equivalent person. The total labor costs for the staffing level shown in Table 3-2 is approximately \$10,968,800. The labor costs are expected to be the same for both cases.

### 8.3 Reagent and Utility Costs

The only reagents required for the thorium de-nitration process are demineralized water and 50% sodium hydroxide solution. The demineralized water will be consumed in the reactions at a rate of approximately 0.50 gallons per pound of TNH feed material (approximately 3,200 gallons per day). Also, up to 800 gallons per day of demineralized water will be used for equipment and area decontamination, bringing the total usage to approximately 4,000 gallons per day. Demineralized water will be produced at the treatment site from site utility water, using ion exchange columns leased from a supplier like Culligan Water Services. Regeneration of the resin most likely will be performed by the supplier at an off-site location. In this scenario, the supplier will maintain a supply of regenerated resin columns at the site, and take exhausted columns to their own site for regeneration. With this approach, no spent regenerant streams will be sent to the sewer. At an estimated cost of \$25 per 1,000 gallons, the total costs for demineralized water will be approximately \$130,000.

Sodium hydroxide will be brought to the facility in 22,500 lb tanker loads. The total anticipated usage of 50 % sodium hydroxide solution is 3,277,848 lbs (268,500 gallons). On a dry weight basis, the usage will be 1,638,924 lbs. At a price of \$ 420 per dry ton, the total cost of 50 % sodium hydroxide will be approximately \$345,000.

The utilities to be used will include potable water/sanitary sewer, propane, and electric power. Potable water usage for the facility will include the 4,000 gallons per day fed to the demineralizers, and approximately 80 gallons per day per crew member for potable purposes and showers (1,040 gallons per day), resulting in a total usage of 5,040 gallons per day. At a rate of \$10/1,000 gallons for water and sewer, the utility water cost is expected to be less than \$50/day or \$65,000 for the duration of the project.

Propane or natural gas will be used as fuel for a 150 BHP packaged boiler to generate low pressure saturated steam. This cost estimate is based upon propane as a fuel. Approximately 120 gallons of liquified propane were used in processing approximately 1,959 pounds of TNH during the five pilot-scale batch runs. We estimate that another 60 gallons of propane were used in drying the process heels. At a heating value of 91,500 BTU/gallon, a total of 16,470,000 BTU of fuel were expended, or 8,407 BTU/lb of TNH. At a price of \$10.50 per million BTU, the total fuel cost for the project is expected to be approximately \$60,200.

The electrical power load for the building and process equipment is summarized in Table 8-3. The total load is estimated at 3,572 megawatt-hour. At a price of \$67.50 per megawatt-hr, the total power cost is estimated at \$241,000.

### 8.4 Packaging

Table 8-4 compares the volumes of the inner containers of the original packaging and the final packaging demonstrated during the pilot-scale tests. The original inner containers were 30 gallon waxed kraft paper drums. The final inner containers were tapered high density polyethylene drums

of 33-gallon capacity. At the conclusion of the pilot-scale demonstration, the contents of 10 original drums were converted to thorium hydroxide with an average residual moisture content of 17.4 percent. This product was repackaged in 4 of the polyethylene drums, resulting in a demonstrated bulk density of approximately 68.9 lbs/cubic foot. Final storage volume was 44 % of the original volume. It is believed that bulk densities of between 80 and 90 lbs/cubic foot could be achieved by producing a dried product that is consistently less than 10 percent moisture, and by vibrating the container as it is being filled. Also, containers that have been filled can be placed in accessible staging areas, overnight for additional settling. Then these containers can be brought back to the dryer discharge to have more material place in them.

The four product containers from the pilot-scale demonstration were actually filled with multiple horse-tailed bags containing the dry powder product from the nine dryer runs. The air trapped in the bags certainly reduced the demonstrated bulk density. In Phase II, only one liner per container would be used, and vibrating the container would reduce the interstitial void spaces, making densities of 80 to 90 lbs/cubic foot achievable, without adding a binder that would compromise product quality.

For Phase II, the final storage volume assuming drum packaging is expected to be approximately 33 percent of the original. Box packaging may make it possible to have a final volume of approximately 25 percent of the original volume. The advantage of drum storage is that the outer steel drums from the original packaging could be used, thus reducing original packaging waste sent to disposal and alleviating the need to purchase outer containers. If boxes are used, they would all have to be purchased, and all of the original packaging would become secondary waste for disposal.

#### **8.4.1 Drum Option Costing**

For the drum option, it is assumed that no new steel outer drums would have to be purchased, but 7,824 high density polyethylene 33-gallon drums and plastic bag liners would have to be purchased. The total cost per package is estimated at approximately \$40, resulting in a total packaging cost of approximately \$312,960.

#### **8.4.2 Box Option Costing**

For the box option, it is assumed that all boxes will be 820 newly purchased B-12 boxes with a nominal holding capacity of 42 cubic feet. Bag liners conforming to the dimensions of the box will be used. At an estimated cost per package of \$550 each, the resulting total packaging cost is estimated to be \$451,000.

### **8.5 Transportation Costs**

Transportation Costs for the base case and the alternative are summarized in Table 8-5. In the base case, shipping of TNH from Curtis Bay storage to the treatment facility and the shipping of TOH back into storage would be done as an on-site transfer. Therefore, no additional shipping cost is

included for these activities in the base case. The Hammond, Indiana inventory would be shipped to Curtis Bay for treatment and the product would remain in storage on the Curtis Bay site.

In the alternative case the TNH from both DLA sites would be shipped to a treatment facility to be located in an existing radiologically contaminated building on the K-25 Site near Oak Ridge, Tennessee. All thorium product would be shipped from Oak Ridge to the Curtis Bay depot for long term storage.

In both cases, the liquid sodium nitrate byproduct will be shipped for recycle use as fertilizer. Specific outlets have not been identified for both cases. In the alternative case, an outlet has been identified in the Ohio River Basin. This company is agreeable to pay a price of \$0.10/pound of nitrogen for the sodium nitrate byproduct. Subsequent inquiries may identify other outlets and provide some limited price improvement. In the base case, alternative outlets closer to Curtis Bay must be identified. If the sodium nitrate was dried to a moisture content of no more than 10 %, another division within the U.S. Army could be an outlet. The current process scheme does not include byproduct drying.

The disposal options are the same in both cases, with the only difference being the mileage between the treatment site and the disposal site. The secondary wastes from this project will be low-level radioactive waste only, and will not be regulated under RCRA. The three candidate disposal sites considered in Table 8-5 are the Chem-Nuclear Landfill at Barnwell, South Carolina, the Waste Control Specialists Landfill near Andrews, Texas, and the Envirocare of Utah facility near Clive, Utah.

Assuming that secondary waste disposal is performed at Envirocare, the total transportation costs are \$654,371 for the base case and \$979,412 for the alternative case. The cost difference is \$325,041.

## 8.6 Secondary Waste Disposal

In both cases, approximately 2,933,500 pounds of compacted secondary waste having a volume of 41,900 cubic feet will be generated and shipped for disposal. Although the Chem-Nuclear facility at Barnwell is closest to the candidate treatment sites, their disposal rates per cubic foot are approximately 10 times the disposal rates at Envirocare of Utah or Waste Control Specialists. For comparison purposes, the estimated rates for incineration of rad-trash at the GTS-Duratek incinerator at Oak Ridge were considered. The cost ranking based on estimated rates are shown below.

Waste Control Specialists, Andrews, Texas	\$1,047,500
Envirocare of Utah, Clive, Utah	\$1,046,500
Chem-Nuclear, Barnwell, South Carolina	\$10,475,000
GTS-Duratek, Oak Ridge, Tennessee	\$24,934,800

## 8.7 Cost Summary

Table 8-6 provides a cost roll-up for the two siting cases. This summary assumes that all secondary waste is compacted and shipped to Envirocare of Utah for disposal. The Alternative is nearly \$1,237,500 less expensive than the base case. At a total project cost of \$22,110,572, the unit cost per pound of TNH fed to the process will be approximately \$3.16 per pound, which compares well with the current commercial value of thorium nitrate of approximately \$12.50 per pound.

**Table 8-1  
Summary of Estimated Capital Costs**

Base Case Estimated Capital & Siting Costs				
Item	Quantity	Equipment Description	Unit Cost (\$)	Total Cost (\$)
1	1	Granulator equipped with motor, sound enclosure and air discharge system	25,000	25,000
2	1	Shredder equipped with motor and sound enclosure	25,000	25,000
3	1	55/85 gallon drum compactor with motor, control and optional packer head	15,000	15,000
4	1	Drum Opening Booth equipped with glove ports and 2 hydraulic drum inverters	40,000	40,000
5	2	10,000 gal. Polyethylene storage tanks with agitator for reagents	10,000	20,000
6	1	Stainless steel dissolver	142,000	142,000
7	4	600 gal. Stainless steel feed tank, jacketed with agitator	5,000	20,000
8	2	Precipitation reactors, stainless steel with motor and controls	335,000	670,000
9	2	100 Ft <sup>3</sup> stainless steel condenser for condensate from the precipitators	5,000	10,000
10	2	300 Ft <sup>3</sup> stainless steel condenser for condensate from the dryer	15,000	30,000
11	2	500 Gal. stainless steel condensate accumulator	2,500	5,000
12	4	Accumulator transfer pumps	2,000	8,000
13	2	800 Gal. stainless steel supernate separation tank	4,000	8,000
14	2	Supernate transfer pumps	2,000	4,000
15	2	10,000 Gal. Supernate holding tanks, polyethylene	10,000	20,000
16	2	Filter press with controls	58,000	116,000
17	2	500 Gal. Filtrate Separation Tanks	2,500	5,000
18	2	5,000 Gal. Filtrate Holding Tanks	5,000	10,000
19	2	Filtrate Transfer Pumps	2,000	4,000
20	2	Filter Press Feed Pumps	5,000	10,000
21	2	Dryer, stainless steel, jacketed with choppers	210,000	420,000

22	2	Cooling Screw and packaging station	25,000	50,000
23	1	6,000 Gal. Blend tank, polyethylene	6,000	6,000
24	1	Blend Transfer Pump	2,000	2,000
25	2	Bag Filter Housings	3,100	6,200
26	1	Ultrafilter Unit	250,000	250,000
27	3	12,000 Gal. Nitrate Byproduct Storage Tanks	12,000	36,000
28	1	Byproduct Transfer Pump	2,000	2,000
29	1	Air compressor and dryer	15,000	15,000
30	1	Packaged cooling tower	10,000	10,000
31	1	Steam generator package unit, 150 BHP	50,000	50,000
32	2	4,000 CFM Pre-filter/HEPA ventilators	20,000	40,000
33	2	1,600 pound GAC Filters for Radon Capture	10,000	20,000
34	1 lot	Interconnecting piping, valves & fittings	30,000	30,000
<b>Subtotal Process Equipment</b>				<b>2,124,200</b>
35	1	10,000 sf Butler Building with incoming electrical power supply, and HVAC.	500,000	500,000
36	1 lot	End-of-Project Building Decommissioning & Demolition	420,000	420,000
37	80 tons	Off-site smelting of Contaminated Building Metal	9,000	720,000
38	12,000 cu. ft.	Envirocare disposal of Contaminated Concrete Debris Transport and Disposal	30	360,000
39	6 years	Costs to obtain permits and licenses and interface with regulators and stakeholders	300,000	1,800,000
40	1 lot	Origin Site NEPA Activities	100,000	100,000
41	1 lot	Treatment Site NEPA Activities	300,000	300,000
42	6 years	Liability Insurance & Bonding	100,000	600,000
43	6 years	DLA costs to Provide Site Support	250,000	1,500,000
<b>Subtotal Base Case Siting Costs</b>				<b>6,300,000</b>
<b>Total Base Case Capital and Siting Costs</b>				<b>8,424,200</b>

<b>Alternative Estimated Capital &amp; Siting Costs (Replacement for Items 35 through 41 above)</b>				
<b>Item</b>	<b>Quantity</b>	<b>Equipment Description</b>	<b>Unit Cost (\$)</b>	<b>Total Cost (\$)</b>
35	60 months	Use charges for 15,000 square feet of permitted, licensed, insured, and closure bonded off-site building space @ \$5/sq. ft./month	75,000	4,500,000
36	1 lot	End-of-Project Building Decommissioning & Demolition (Floor scabbling & dust stabilization only)	100,000	100,000
37	1 lot	Off-site smelting of Contaminated Building Metal (Covered by Item 35 and facility's closure bond)	0	0
38	250 cu. ft.	Envirocare disposal of Stabilized Contaminated Concrete Dust from Floor Scabbling (Transport and Disposal)	30	7,500
39	6 years	Costs to obtain permits and licenses and interface with regulators and stakeholders (Covered by Item 35)	0	0
40	1 lot	Origin Site NEPA Activities	100,000	100,000
41	1 lot	Treatment Site NEPA Activities	30,000	30,000
42	6 years	Liability Insurance & Bonding (Covered by Item 35)	0	0
43	6 years	DLA costs to Provide Site Support (Not Applicable)	0	0
<b>Subtotal Alternative Case Siting Costs</b>				<b>4,737,500</b>
<b>Total Alternative Case Capital and Siting Costs</b>				<b>6,861,700</b>

**Table 8-2  
Project Staffing Basis**

<b>Labor Category</b>	<b>Number of Equivalent Persons</b>
Project Manager	1
Project Engineer	1.25
Senior Technical Advisor	1
Shipping Coordinator	1
Operations Supervisor	1
Senior Operations Technicians	2
Operations Technicians	6
Warehousemen	2
Secretarial Support	2
<b>Total Equivalent Persons</b>	<b>17.2</b>

**Table 8-3  
Summary of Electrical Power Usage  
(Load Basis: 480 volt, 3-phase, 60 Hertz)**

<b>Service</b>	<b>Total HP/KVA</b>	<b>Running Amps</b>
Dissolver Motor	20 HP	27
Precipitator Motors (Main)	50 HP	68
Precipitator Motors (Auxilliary)	6 HP	9.6
Dryer Motors (Main)	100 HP	130
Dryer Motors (Chopper)	30 HP	40
Process Area HVAC	50 HP	65
Drum Opening Booth HVAC	30 HP	40
Main Exhaust Fan	30 HP	40
Lighting	20 KVA	24
Building Services	60 KVA	75

**Table 8-4  
Summary of Packaging Options**

<b>Pilot-Scale Demonstration</b>			
<b>Inner Packaging Description</b>	<b>Capacity of Packages</b>	<b>Number of Packages</b>	<b>Total Demonstrated Volumes</b>
Original - waxed Kraft paper drums	30 Gallons	10	300 Gallons 40.1 Cubic Feet
Final - tapered high density polyethylene drums	33 Gallons	4	132 Gallons 17.6 Cubic Feet
<b>Demonstrated Final Storage Volume (% of Original Volume)</b>			<b>44 %</b>
<b>Projections for Phase II Project (Based on Final Product Volume of 33% of Original)</b>			
<b>Inner Packaging Option</b>	<b>Capacity of Packages</b>	<b>Number of Packages</b>	<b>Total Projected Volumes</b>
Tapered high density polyethylene drums	33 Gallons 4.4 Cu. Ft.	7,824	34,427 Cu. Ft. TOH 66,675 Cu. Ft. Storage
B-12 Box	42 Cu. Ft.	820	34,427 Cu. Ft. TOH 45,920 Cu. Ft. Storage

**Table 8-5  
Comparison of Transportation Options**

<b>Thorium Nitrate Hydrate Shipping</b>				
<b>From/To</b>	<b>Base Case</b>		<b>Alternative</b>	
	<b>Total Wt.</b>	<b>Cost</b>	<b>Total Wt.</b>	<b>Cost</b>
Curtis Bay/Curtis Bay	7,459,550	\$0	-----	-----
Hammond/Curtis Bay	2,520,336	\$78,908	-----	-----
Curtis Bay/Oak Ridge	-----	-----	7,459,550	\$256,776
Hammond/Oak Ridge	-----	-----	2,520,336	\$87,238
<b>Subtotal TNH Shipping</b>	<b>9,979,886</b>	<b>\$78,908</b>	<b>9,979,886</b>	<b>\$344,014</b>
<b>Thorium Hydroxide Product Shipping</b>				
<b>From/To</b>	<b>Base Case</b>		<b>Alternative</b>	
	<b>Total Wt.</b>	<b>Cost</b>	<b>Total Wt.</b>	<b>Cost</b>
Curtis Bay/Curtis Bay	4,654,572	\$0	-----	-----
Oak Ridge/Curtis Bay	-----	-----	4,654,572	<b>\$159,613</b>
<b>Subtotal TOH Shipping</b>	<b>4,654,572</b>	<b>\$0</b>	<b>4,654,572</b>	<b>\$159,613</b>
<b>Liquid Sodium Nitrate Byproduct Shipping</b>				
<b>From/To</b>	<b>Base Case</b>		<b>Alternative</b>	
	<b>Total Wt.</b>	<b>Cost</b>	<b>Total Wt.</b>	<b>Cost</b>
Curtis Bay/350 mile radius	29,574,434	\$164,100	-----	-----
Oak Ridge/350 mile radius	-----	-----	29,574,434	\$164,100
<b>Subtotal Byproduct Shipping</b>	<b>29,574,434</b>	<b>\$164,100</b>	<b>29,574,434</b>	<b>\$164,100</b>

**Table 8-5 (Continued)**  
**Comparison of Transportation Options**

<b>Thorium Nitrate Hydrate Shipping</b>				
<b>From/To</b>	<b>Base Case</b>		<b>Alternative</b>	
	<b>Total Wt.</b>	<b>Cost</b>	<b>Total Wt.</b>	<b>Cost</b>
Curtis Bay/Barnwell, SC	2,933,506	\$108,417	-----	-----
Curtis Bay/Andrews, TX	2,933,506	\$303,129	-----	-----
Curtis Bay/Clive, UT	2,933,506	\$411,363	-----	-----
Oak Ridge/Barnwell, SC	-----	-----	2,933,506	\$61,115
Oak Ridge/Andrews, TX	-----	-----	2,933,506	\$207,790
Oak Ridge/Clive, UT	-----	-----	2,933,506	\$311,685

**Table 8-6**  
**Summary of Total Projected Costs for Phase II**

<b>Cost Description</b>	<b>Base Case Costs</b>	<b>Alternative Costs</b>
Siting	\$6,300,000	\$4,737,500
Capital Equipment	\$2,124,200	\$2,124,200
Labor	\$10,968,800	\$10,968,800
Reagents	\$475,000	\$475,000
Utilities	\$366,200	\$366,200
Sampling & Analysis	\$1,000,000	\$1,000,000
Packaging (Drum Basis)	\$312,960	\$312,960
Origin Site Drum Preparation	\$100,000	\$100,000
Transportation	\$654,371	\$979,412
Disposal (Envirocare)	\$1,046,500	\$1,046,500
<b>Phase II Projected Total</b>	<b>\$23,348,031</b>	<b>\$22,110,572</b>

## 9.0 ENVIRONMENTAL IMPACT CONSIDERATIONS

The thorium de-nitration process demonstrated in this project is an environmentally benign approach featuring the following attributes.

- Zero-Discharge of liquid wastes to surface waters or publicly owned treatment works (POTWs).
- Thorium product converted to a low-volume, low-hazard form and repackaged into compatible double containers for long-term storage or safe shipment.
- A total of approximately 41,900 cubic feet, 2,933,506 pounds of secondary waste generated, which is over 97 percent composed of original packaging debris. Only 3 percent of the secondary waste volume is generated from processing operations.
- The liquid sodium nitrate generated as a byproduct of the de-nitration process can be polished by ultra-filtration to allow unrestricted recycle as a fertilizer additive. Another potential recycle use is as an ingredient in pyrotechnic materials used by the U.S. Army.
- The process operates at low temperature and ambient pressure, thus preventing the development of airborne oxides of nitrogen. The nitrates stay in the liquid phase, thus alleviating the need for re-capture in a wet scrubber, which typically has only an 85% capture efficiency.
- HEPA filtration and activated carbon absorption hold particulate and radon gas emissions from the facility to a minimum.
- Radiation dose to workers will be well below established regulatory guidelines and will be kept as low as reasonably achievable (ALARA) through engineering controls, procedures and administrative controls.
- Because the nitrate materials are not exposed to high heat, the potential for fires or explosions is very low.
- Shipping of raw materials, byproducts, and secondary wastes in either case is low. In the base case, total one-way shipments are estimated at 278 over a 5 year period, for less than 5 loads per month. The alternative requires 530 one-way shipments over a 5 year period for less than 9 loads per month.

## 10.0 MARKET SURVEY REPORT

As part of this pilot-scale demonstration project, Teledyne Brown Engineering, Inc. conducted a thorough market survey which had two primary objectives; (1), to identify potential commercial outlets for thorium product, either in nitrate, hydroxide, or oxide form and (2), to identify potential recycle outlets for the sodium nitrate byproduct. A copy of the market survey report is included in Appendix C. The investigations conducted by Teledyne Brown showed that today's recycle market for thorium in any of its chemical forms is extremely limited. The commercial value of thorium sold in the existing domestic market is approximately \$12.50/pound. Based upon these findings, it is assumed that most of the thorium converted in the Phase II project will have to be returned to storage at one of the DLA depots, assumed to be Curtis Bay, Maryland.

Teledyne Brown was able to identify one potential user of the sodium nitrate byproduct within the contractor network supporting the U.S. Army. This application is as a dry oxidizing agent in pyrotechnic formulations. A copy of MIL-S-322C, the army's specification for sodium nitrate has been obtained and can be found in Appendix C. They also confirmed that agricultural applications of recycled sodium nitrate appeared viable.

Since Teledyne Brown completed the market survey, additional inquiries have been made to further evaluate the potential for agricultural recycle of polished sodium nitrate solution. A fertilizer blender in the Ohio River Valley has reviewed the quality data for the polished sodium nitrate solution from the pilot-scale demonstration and has offered to buy it for approximately \$0.10 per pound of nitrogen. He plans to use it as a diluent for blending down higher concentration nitrate fertilizer solutions. This supplier should be viewed as a benchmark for the feasibility of agricultural reuse. Other outlets may be identified which are geographically closer to the treatment site, and may offer better pricing scenarios.

**Appendix A**  
**Laboratory Analysis Reports**  
**Subcontracted Laboratories**

**Appendix B**

**Laboratory Analytical Reports**

**Split Samples Analyzed by Lockheed Martin Energy Systems, Inc.**

**Appendix C**

**Thorium Materials Market Survey**





TELEDYNE BROWN ENGINEERING ENVIRONMENTAL SERVICES

REPORT OF ANALYSIS

RUN DATE 01/13/98

WORK ORDER NUMBER      CUSTOMER P.O. NUMBER      DATE RECEIVED      DELIVERY DATE      PAGE 2

T HENKE MS 25      3-0065      RFP # HOT 33-30      12/10/97      12/24/97

TELEDYNE BROWN ENGINEERING  
CUMMINGS RESEARCH PARK  
300 SPARKMAN DRIVE NW  
MUNTSVILLE AL      33805-1912

S O L I D S

TELEDYNE SAMPLE NUMBER	CUSTOMER'S IDENTIFICATION	STA NUM	COLLECTION-DATE		NUCLIDE	ACTIVITY (UCI/GM DRY)	NUCL-UNIT-X U/M #	HID-COUNT		VOLUME - UNITS ASH-WGHT-X #	LAB.
			START DATE TIME	STOP DATE TIME				DATE	TIME		
64838	BT2-003A		12/03		GR-A	2.9 ±0.1 E-01		12/23		3	
					GR-B	1.2 ±0.1 E-01		12/23		3	
					AC-228	6.3 ±0.6 E-02		12/23		4	
					PB-212	5.8 ±0.6 E-02		12/23		4	
					TL-208	1.9 ±0.2 E-02		12/23		4	
64839	BT2-005A		12/03		GR-A	3.1 ±0.1 E-01		12/23		3	
					GR-B	1.5 ±0.1 E-01		12/23		3	
					AC-228	3.3 ±0.4 E-02		12/23		4	
					PB-212	3.3 ±0.3 E-02		12/23		4	
					TL-208	1.1 ±0.1 E-02		12/23		4	
64840	BT2-007A		12/03		GR-A	2.6 ±0.1 E-01		12/23		3	
					GR-B	1.1 ±0.1 E-01		12/23		3	
					AC-228	4.8 ±0.5 E-02		12/23		4	
					PB-212	4.0 ±0.4 E-02		12/23		4	
					TL-208	1.3 ±0.1 E-02		12/23		4	

LAST PAGE OF REPORT

APPROVED BY J. GUENTHER 01/13/98

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2 - GAS LAB.      3 - RADIO CHEMISTRY LAB.      4 - GE(LI) GAMMA SPEC LAB.      5 - TRITIUM GAS/L.S. LAB.      6 - ALPHA SPEC LAB.

# SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846  
Chemistry and Chemical Engineering  
Department of Analytical and Environmental Chemistry

February 18, 1998

Mr. Rocky Foster  
Teledyne Brown Engineering  
Cummings Research Park  
300 Sparkman Drive NW  
Huntsville, Alabama 35805-1912

Subject: Results of Analysis for Samples Received 02/02/98  
SwRI Project 01-1143-001 Work Order #12956

Dear Mr. Foster:

Enclosed please find the results for the six samples received on the above mentioned date for the analysis of total thorium.

Should you have any questions, please feel free to contact me at (210) 522-5428 or by fax at (210) 522-5938.

Best Regards,



Mike Dammann  
Inorganic Manager

Quality Assurance Unit



Jo Ann Boyd  
Manager

cc: Mr. Tom Yarbough, Permafix Environmental  
Mr. Ben Crocker, Performance Development Corporation

MJD: cjm



SAN ANTONIO, TEXAS

HOUSTON, TEXAS • DETROIT, MICHIGAN • WASHINGTON, DC

**CLIENT: TELEDYNE BROWN ENGINEERING**  
**SDG: 101920 (CLB3-002B)**

# **THORIUM (Th) ANALYSIS**

# ***SOUTHWEST RESEARCH INSTITUTE***

## **SAMPLE ANALYSIS FOR TOTAL THORIUM**

Lab Name: Southwest Research Institute

Client: Teledyne Brown Engineering

Lab Code: SwRI

Date Received: 02/02/98

Matrix: Solid

Project No.: 01-1143-001

Sample ID	Lab System ID	Sample Result (mg\Kg)
PBW	----	<0.50
CLB3-002B	101920	<0.50
Duplicate	101920	<0.50
RPD	101920	0.00%
CLB3-001B	101921	2.32
CLB2-002B	101922	<0.50
CLB2-001B	101923	6.36
CLB1-002B	101924	4.66
CLB1-001B	101925	85.40

Detection Limit: 0.5 mg/Kg

# SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846  
Chemistry and Chemical Engineering  
Department of Analytical and Environmental Chemistry

February 6, 1998

Mr. Rocky Foster  
Teledyne Brown Engineering  
Cummings Research Park  
300 Sparkman Drive NW  
Huntsville, Alabama 35805-1912

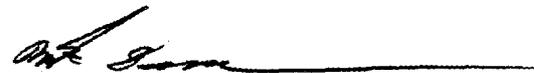
Subject: Results of Analysis for Samples Received 12/23/97  
SwRI Project 01-1143-001 Work Order #12771

Dear Mr. Foster:

Enclosed please find the results for the fourteen samples received on the above mentioned date for the analysis of total thorium.

Should you have any questions, please feel free to contact me at (210) 522-5428 or by fax at (210) 522-5938.

Best Regards,



Mike Dammann  
Inorganic Manager

Quality Assurance Unit



Jo Ann Boyd  
Manager

cc: Mr. Tom Yarbough, Permafix Environmental  
Mr. Ben Crocker, Performance Development Corporation

MJD: cjm



SAN ANTONIO, TEXAS

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# ***SOUTHWEST RESEARCH INSTITUTE***

## **SAMPLE ANALYSIS FOR TOTAL THORIUM**

Lab Name: Southwest Research Institute

Client: Teledyne Brown Engineer.

Lab Code: SwRI

Date Received: 12/23/97

Matrix: Liquid

Project No.: 01-1143-001

Sample ID	Lab System ID	Sample Result (mg/Kg)	
PBW	----	<0.5	
BT4-001B	100565	16.8%	✓
BT4-003C	100566	18.6%	✓
Duplicate	100566	19.0%	
RPD	100566	2.1%	
BT4-004B	100567	10.4	✓
BT4-005C	100568	36.0%	✓
BT4-006B	100569	234	✓
BT4-007D	100570	64.8%	✓
BT4-009B	100571	1120	✓
BT5-001B	100572	19.0%	✓
BT5-003C	100573	13.8%	✓
BT5-004B	100574	48.5	✓
BT5-005C	100575	27.2%	✓
BT5-006B	100576	8.85	✓
BT5-007D	100577	53.8%	✓
BT5-009B	100578	47.5	✓

Detection Limit: 0.5 mg/Kg

# SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846

Chemistry and Chemical Engineering  
Department of Analytical and Environmental Chemistry

April 15, 1998

Mr. Rocky Foster  
Teledyne Brown Engineering  
Cummings Research Park  
300 Sparkman Drive NW  
Huntsville, Alabama 35805-1912

Subject: Results of Analysis for Samples Received 12/10/97, 03/20/98  
SwRI Project 01-1143-001 Work Order #12681, 13246

Dear Mr. Foster:

Enclosed please find the results for the twenty samples received on the above mentioned dates for the analysis of total thorium and XRD. X-ray diffraction (XRD) was done on all requested samples. Any detectable crystalline species are reported, if a library pattern match was obtained. A small amount of each sample was carefully ground to a nominal 100 mesh particle size and run utilizing a random mount orientation. Please note that XRD will only pick up compounds that are crystalline in nature and that quantitation is very crude. A discussion of each sample is presented below. The samples were also run for major elemental determinations using energy dispersive spectrometry (EDS) in a scanning electron microscope, to determine the major constituents allowing the exclusion of phases that do not exist due to a lack of one or more major components.

## XRD INTERPRETATION:

### **BT1-001C, SWRI SYSTEM ID 99786**

This sample is about 95% crystalline. The only identifiable crystalline species in the sample was  $\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$ . Please note that there were several unidentifiable peaks in the powder pattern.

### **BT1-08C, SWRI SYSTEM ID 99792**

This sample is about 80% crystalline. The sample appears to be poorly crystalline as shown by the wide peaks. The crystalline portion of the sample consists of 50% thorianite ( $\text{ThO}_2$ ), 45% nitratine ( $\text{NaNO}_3$ ), and about 5%  $\text{Na}_3\text{NO}_3$ .

### **BT2-007D, SWRI SYSTEM ID 99800**

This sample is about 75% crystalline. The sample is poorly crystalline as indicated by the wide peaks. The only identifiable crystalline species in the sample was thorianite ( $\text{ThO}_2$ ).



SAN ANTONIO, TEXAS

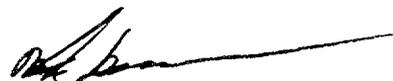
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**BT2-008C, SWRI SYSTEM ID 104141**

This sample is about 90% crystalline. The sample appears to be poorly crystalline as shown by the wide peaks. The crystalline portion of the sample consists of 85% thorianite ( $\text{ThO}_2$ ) and 15% nitratine ( $\text{NaNO}_3$ ).

Should you have any questions, please feel free to contact me at (210) 522-5428 or by fax at (210) 522-5938. We do not have a purchase order at this time, so we will invoice without one.

Best Regards,



Mike Dammann  
Inorganic Manager

Quality Assurance Unit



Jo Ann Boyd  
Manager

cc: Mr. Tom Yarbough, Permafix Environmental  
Mr. Ben Crocker, Performance Development Corporation

MJD: vtl

# **TOTAL THORIUM ANALYSIS**

# SOUTHWEST RESEARCH INSTITUTE

## SAMPLE ANALYSIS FOR TOTAL THORIUM

Lab Name: Southwest Research Institute

Client: Teledyne Brown Engineering

Lab Code: SwRI

Dates Received: 12/10/97, 03/20/98

Matrix: Liquid

Project No.: 01-1143-001

Sample ID	Lab System ID	Sample Result (mg/Kg)
PBW	---	<0.5
BT1-001C	99786	38.0%
Duplicate	99786	36.4%
RPD	99786	4.3%
BT1-002B	99787	17.3%
BT1-004C	99788	8.78%
BT1-005A	99789	23.4
BT1-006C	99790	23.2%
BT1-007B	99791	10.9
BT1-008C	99792	47.5%
BT1-0010B	99793	34.4
Duplicate	99793	26.4
RPD	99793	26.3%
BT1-0010D	99794	10.9%
BT2-001B	99795	17.8%
BT2-003C	99796	12.1%
BT2-004B	99797	17.9
BT2-005C	99798	33.2%
BT2-006B	99799	7.51
BT2-007D	99800	54.2%
BT2-009B	99801	30.1
PBW	---	<100
BT5-008C	104139	72.5%
Duplicate	104139	72.4%
RPD	104139	0.1%
BT4-008C	104140	79.4%
BT2-008C	104141	73.3%
BT1-009A	104142	57.9%

**CLASSIFICATION AND  
PACKING GROUP  
ASSIGNMENT OF DIV.  
5.1 MATERIALS**

***SOUTHWEST RESEARCH INSTITUTE***  
**SAMPLE DATA SHEET FOR THE**  
**CLASSIFICATION AND PACKING GROUP**  
**ASSIGNMENT OF DIVISION 5.1 MATERIALS**

Lab Name: Southwest Research Institute

Client: Teledyne Brown Engineering

Lab Code: SwRI

Date Received: 12/10/97

Matrix: Liquid

Project No.: 01-1143-001

Sample ID	Lab System ID	Burn Time (min/sec)	Classification
BT2-007D	99800	40:56	N/C
	99800	43:42	N/C
BT1-001C	99786	Did Not Burn	N/C
BT1-008C	99792	23:00	N/C
	99792	25:19	N/C

N/C= not classified as a Division 5.1 substance

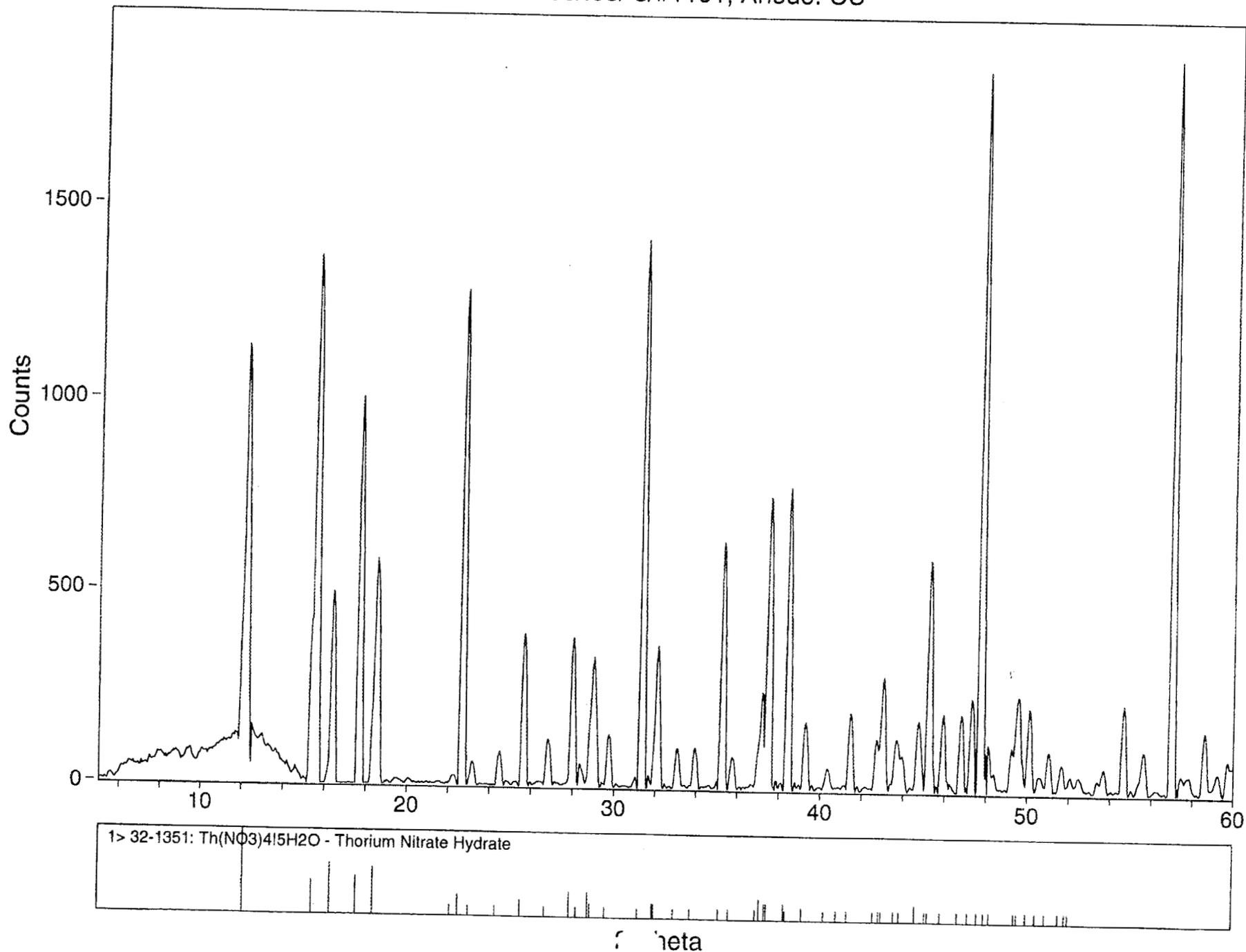
# **X-RAY DIFFRACTION ANALYSIS**

ID: #99786 - 1/7/98 - 01-1143-001

CLIENT ID: BT1-001C

File: FLASH717.MDI

Scan: 5-60/.05/ 3/#1101, Anode: CU



```

----- Scan Parameters: ----- Search Parameters: -----
Radiation = CU_1.54059           | Filter length(pts) = 9
Scan Range = 5- 60              | Noise level(sigmas) = 1.0
Step Size = .05                 | Intensity cutoff(%) = 2-100
Count Time = 3 sec.            | 2-Theta Zero (degs) = 0
-----
    
```

#	Peak-Position		Centroid-Position		Peak & Area are without Bkgrd					
	2Theta	d	2Theta	d	Bkgrd	Peak	I%	Area	I%	FWHM*
1:	7.907	11.1726	7.924	11.1482	36	40	2.2	58	13.9	1.305
2:	8.797	10.0440	8.771	10.0738	51	29	1.6	11	2.6	0.341
3:	9.489	9.3129	9.457	9.3440	55	31	1.7	9	2.2	0.261
4:	12.159	7.2733	12.164	7.2702	63	1073	58.4	333	79.9	0.279
5:	15.553	5.6928	15.542	5.6968	55	1316	71.6	385	92.3	0.263
6:	16.399	5.4010	16.392	5.4032	2	498	27.1	125	30.0	0.226
7:	17.697	5.0078	17.694	5.0086	100	907	49.4	204	48.9	0.202
8:	18.507	4.7905	18.508	4.7901	7	578	31.5	175	42.0	0.272
9:	22.696	3.9148	22.691	3.9156	116	1170	63.7	262	62.8	0.202
10:	24.492	3.6316	24.484	3.6328	5	82	4.5	19	4.6	0.209
11:	25.654	3.4697	25.661	3.4687	16	379	20.6	88	21.1	0.209
12:	26.810	3.3226	26.826	3.3208	10	110	6.0	27	6.5	0.221
13:	27.999	3.1842	27.997	3.1844	7	380	20.7	93	22.3	0.220
14:	29.000	3.0765	28.988	3.0778	12	325	17.7	103	24.7	0.285
15:	29.753	3.0004	29.756	3.0001	4	130	7.1	31	7.4	0.215
16:	31.349	2.8512	31.349	2.8511	119	1302	70.9	291	69.8	0.201
17:	32.097	2.7864	32.088	2.7872	14	355	19.3	91	21.8	0.231
18:	33.092	2.7048	33.084	2.7055	4	98	5.3	24	5.8	0.220
19:	33.946	2.6387	33.944	2.6389	9	95	5.2	22	5.3	0.208
20:	35.259	2.5434	35.271	2.5426	29	612	33.3	142	34.1	0.209
21:	35.755	2.5093	35.760	2.5089	7	76	4.1	19	4.6	0.225
22:	37.169	2.4170	37.164	2.4173	8	210	11.4	70	16.8	0.300
23:	37.506	2.3960	37.503	2.3962	10	750	40.8	197	47.2	0.236
24:	38.452	2.3392	38.455	2.3390	72	715	38.9	160	38.4	0.201
25:	39.296	2.2909	39.293	2.2911	4	172	9.4	42	10.1	0.220
26:	40.350	2.2335	40.350	2.2335	7	51	2.8	13	3.1	0.229
27:	41.455	2.1765	41.463	2.1761	8	193	10.5	46	11.0	0.215
28:	42.710	2.1154	42.728	2.1145	3	130	7.1	33	7.9	0.228
29:	43.043	2.0998	42.998	2.1019	3	292	15.9	85	20.4	0.262
30:	43.697	2.0698	43.741	2.0678	4	129	7.0	58	13.9	0.405
31:	43.942	2.0589	43.943	2.0588	5	87	4.7	22	5.3	0.228
32:	44.748	2.0237	44.754	2.0234	11	170	9.3	46	11.0	0.244
33:	45.257	2.0020	45.264	2.0018	17	583	31.7	146	35.0	0.225
34:	45.943	1.9737	45.935	1.9741	15	186	10.1	44	10.6	0.213
35:	46.805	1.9394	46.808	1.9393	23	177	9.6	40	9.6	0.203
36:	47.308	1.9199	47.318	1.9195	36	205	11.2	45	10.8	0.198
37:	47.748	1.9033	47.741	1.9035	57	1805	98.3	413	99.0	0.206
38:	49.270	1.8480	49.270	1.8480	52	63	3.4	11	2.6	0.157
39:	49.554	1.8380	49.547	1.8383	46	202	11.0	62	14.9	0.276
40:	50.106	1.8191	50.109	1.8190	15	203	11.1	47	11.3	0.208
41:	50.598	1.8025	50.608	1.8022	13	32	1.7	9	2.2	0.253
42:	51.045	1.7878	51.038	1.7880	14	92	5.0	22	5.3	0.215
43:	51.654	1.7681	51.665	1.7678	8	66	3.6	17	4.1	0.232

#	2Theta	d	2Theta	d	Bkgrd	Peak	I%	Area	I%	FWHM*
44:	52.088	1.7544	52.091	1.7543	7	37	2.0	12	2.9	0.292
45:	52.494	1.7418	52.483	1.7421	6	37	2.0	13	3.1	0.316
46:	53.690	1.7058	53.671	1.7064	11	54	2.9	12	2.9	0.200
47:	54.647	1.6781	54.646	1.6782	19	210	11.4	47	11.3	0.200
48:	55.604	1.6515	55.585	1.6520	5	105	5.7	31	7.4	0.260
49:	56.997	1.6144	56.988	1.6147	59	1837	100.0	417	100.0	0.204
50:	57.456	1.6026	57.474	1.6022	17	33	1.8	8	1.9	0.218
51:	57.838	1.5929	57.786	1.5942	11	38	2.1	12	2.9	0.284
52:	58.600	1.5740	58.606	1.5739	4	158	8.6	40	9.6	0.228
53:	59.242	1.5585	59.220	1.5590	5	52	2.8	14	3.4	0.242

\* Intensity values are based on total raw counts.

Jade: Hit List from Search/Match

Fri Apr 10 1998 @3:01pm

FLASH717.MDI> #99786 - 1/7/98 - 01-1143-001 CLIENT ID: BT1-001C

Estimated %Unknown Matched by the List = 62%

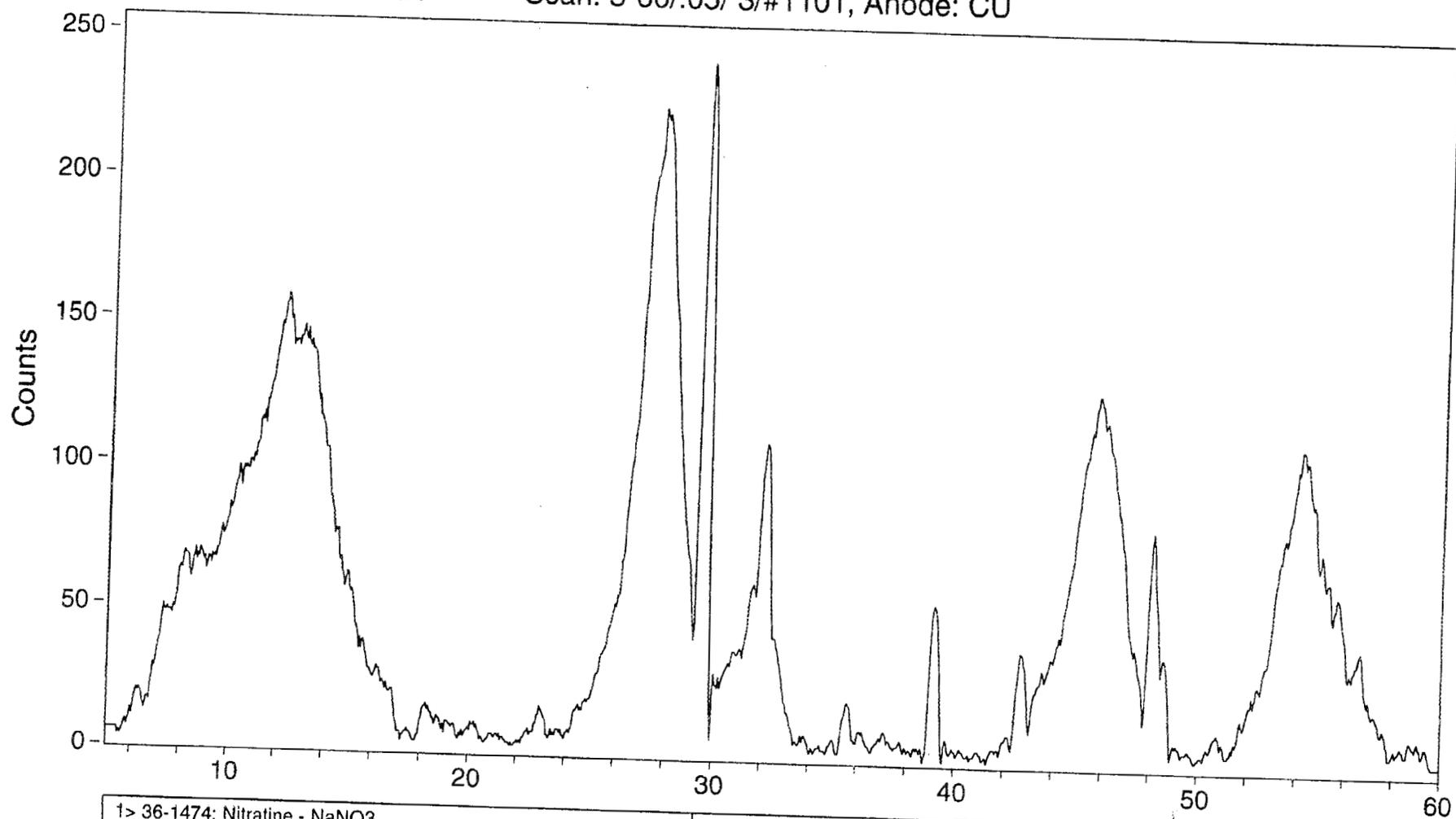
1 Hits Sorted on Tagged-Hit(s)	QM*	PDF-#	FOM	I%	OFF	RIR	Space-Group	a	b	c	Vol*	Z	Dx*
1 Th(NO3)4!5H2O - Thorium Nitrate	+	32-1351	3.7	59	0.02		Fdd2 (43)	11.20	22.90	10.59	679	8	2.788

\* QM - ? for Doubtful Quality or Non-ambient patterns; + for Indexed patterns with Space-Group, Unit Cell & Density.  
 \* vol - reduced-cell volume; dx - measured density if calculated is not available.

Current S/M parameters:

PDF Subfile to Search .....	INORGANS	2-Theta Error Window .....	.12
Chemistry Filter .....	MIKE.CHM (No)	Sensitivity to Matching Intensity ....	5
Search Focus on .....	Major Phase(s)	Sensitivity to Matching 2-Theta .....	5
Preferred Orientation in Sample .....	No	Maximum Number of Hits to Save .....	40
Search only High Quality Phases .....	No	Rubber-Ruler Search - %Elasticity ....	0
Exclude Questionable Phases .....	No	Required 100% Line in Srched Range ...	No
Exclude METALLICS from INORGANS .....	No		

ID: #99792 - 1/8/98 - 01-1143-001 CLIENT ID: BT1-008C  
File: FLASH718.MDI Scan: 5-60/.05/ 3/#1101, Anode: CU



1> 36-1474: Nitratine - NaNO3
2> 42-1462: Thorianite, syn - ThO2
3> 34-0743: Na3NO3 - Sodium Nitrate

2 Theta

Jade: Peak Listing

Fri Apr 10 1998 @2:42pm

File: FLASH718.MDI> #99792 - 1/8/98 - 01-1143-001 CLIENT ID: BT1-008C

```

----- Scan Parameters: ----- Search Parameters: -----
Radiation = CU_1.54059           || Filter length(pts) = 9
Scan Range = 5- 60                || Noise level(sigmas) = 1.0
Step Size = .05                    || Intensity cutoff(%) = 2-100
Count Time = 3 sec.                || 2-Theta Zero (degs) = 0
-----
    
```

#	Peak-Position		Centroid-Position		Peak & Area are without Bkgrd					
	2Theta	d	2Theta	d	Bkgrd	Peak	I%	Area	I%	FWHM*
1:	8.594	10.2809	8.599	10.2746	56	14	6.7	6	1.9	0.386
2:	11.954	7.3978	11.982	7.3806	94	52	24.8	109	34.3	1.887
3:	12.248	7.2204	12.245	7.2224	93	66	31.4	111	34.9	1.514
4:	13.349	6.6272	13.340	6.6321	81	59	28.1	125	39.3	1.907
5:	18.160	4.8811	18.224	4.8641	4	12	5.7	6	1.9	0.450
6:	27.252	3.2698	27.270	3.2676	38	161	76.7	318	100.0	1.778
7:	27.602	3.2291	27.606	3.2287	42	184	87.6	301	94.7	1.472
8:	27.799	3.2067	27.787	3.2080	46	174	82.9	282	88.7	1.459
9:	29.551	3.0204	29.563	3.0192	32	210	100.0	85	26.7	0.364
10:	31.602	2.8289	31.602	2.8289	12	49	23.3	73	23.0	1.341
11:	32.101	2.7861	32.093	2.7867	16	95	45.2	86	27.0	0.815
12:	35.558	2.5227	35.588	2.5206	3	17	8.1	7	2.2	0.371
13:	39.150	2.2991	39.153	2.2989	2	54	25.7	22	6.9	0.367
14:	42.657	2.1179	42.696	2.1160	11	29	13.8	11	3.5	0.341
15:	45.056	2.0105	45.086	2.0092	34	63	30.0	166	52.2	2.371
16:	45.700	1.9837	45.704	1.9835	26	104	49.5	205	64.5	1.774
17:	46.745	1.9417	46.707	1.9432	37	46	21.9	81	25.5	1.585
18:	48.099	1.8902	48.131	1.8890	17	66	31.4	27	8.5	0.368
19:	48.598	1.8719	48.596	1.8720	13	26	12.4	9	2.8	0.312
20:	53.206	1.7202	53.260	1.7185	35	32	15.2	83	26.1	2.334
21:	54.102	1.6938	54.107	1.6936	29	84	40.0	146	45.9	1.564
22:	54.647	1.6782	54.610	1.6792	34	60	28.6	132	41.5	1.980

\* Intensity values are based on total raw counts.

Jade: Hit List from Search/Match

Fri Apr 10 1998 @2:42

FLASH718.MDI> #99792 - 1/8/98 - 01-1143-001 CLIENT ID: BT1-008C

Estimated %Unknown Matched by the List = 32%

3 Hits Sorted on Most-Likelihood	QM*	PDF-#	FOM	I%	OFF	RIR	Space-Group	a	b	c	Vol*	Z	Dx*
1>[X] Nitratine - NaNO3	+	36-1474	5.5	100	0.10		R-3c (167)	5.07	5.07	16.82	125	6	60
2>[X] Thorianite, syn - ThO2	+	42-1462	6.3	100	0.02	7.5	Fm3m (225)	5.60	5.60	5.60	44	4	1.002
3>[X] Na3NO3 - Sodium Nitrate	+	34-743	24.5	12	0.08		Pm3m (221)	4.61	4.61	4.61	98	1	2.227

\* QM - ? for Doubtful Quality or Non-ambient patterns; + for Indexed patterns with Space-Group, Unit Cell & Density.  
 \* vol - reduced-cell volume; dx - measured density if calculated is not available.

Current S/M parameters:

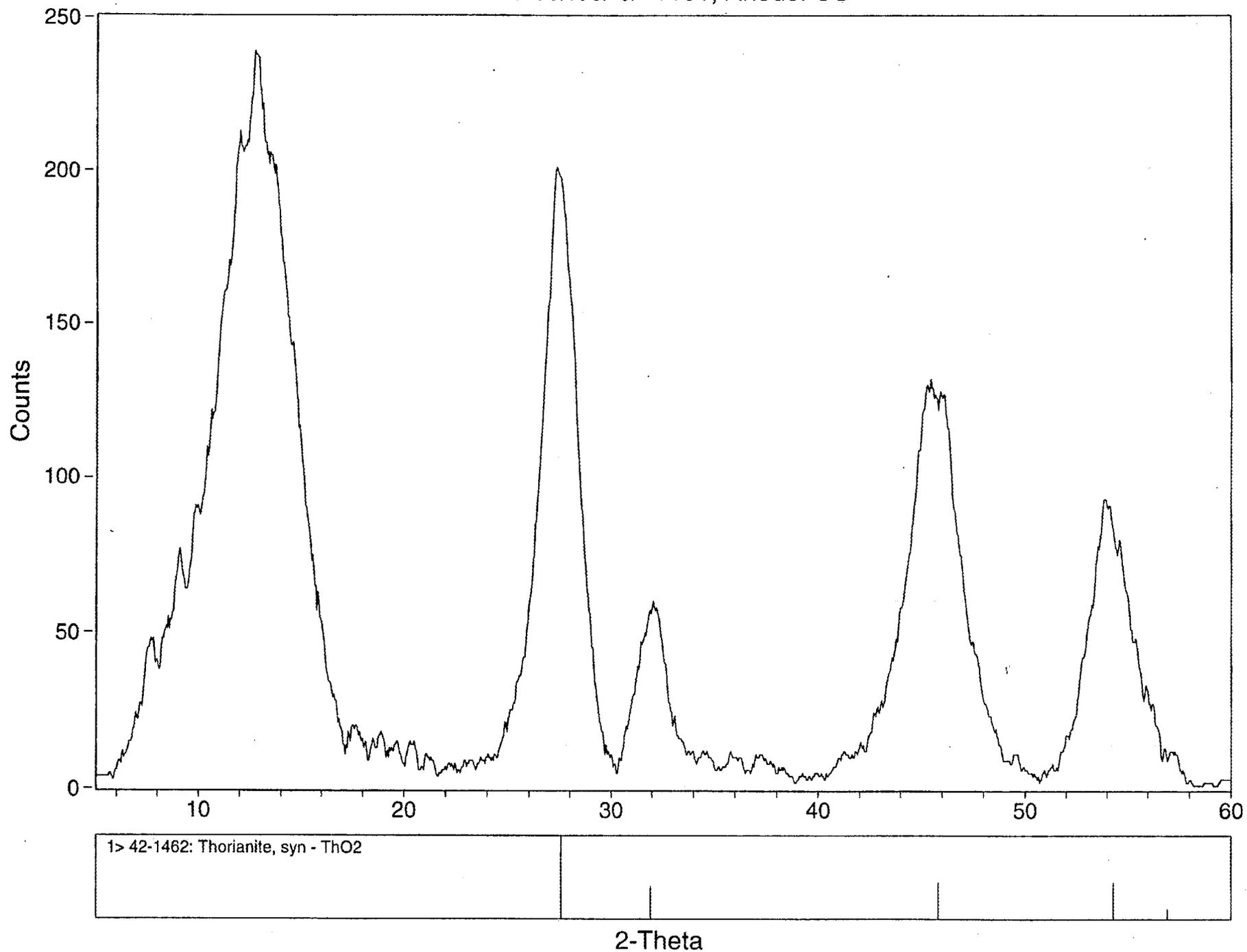
PDF Subfile to Search .....	INORGANS	2-Theta Error Window .....	12
Chemistry Filter .....	MIKE.CHEM (Yes)	Sensitivity to Matching Intensity ....	5
Search Focus on .....	Major Phase(s)	Sensitivity to Matching 2-Theta .....	5
Preferred Orientation in Sample .....	No	Maximum Number of Hits to Save .....	40
Search only High Quality Phases .....	No	Rubber-Ruler Search - %Elasticity ....	0
Exclude Questionable Phases .....	No	Required 100% Line in Srched Range ...	No
Exclude METALLICS from INORGANS .....	No		

ID: #99800 - 01-1143-001 - 1/8/98

CLIENT : BT2-007D

File: FLASH719.MDI

Scan: 5-60/.05/ 3/#1101, Anode: CU



```

----- Scan Parameters: ----- Search Parameters: -----
Radiation = CU_1.54059           || Filter length(pts) = 9
Scan Range = 5- 60              || Noise level(sigmas) = 1.0
Step Size = .05                 || Intensity cutoff(%) = 2-100
Count Time = 3 sec.            || 2-Theta Zero (degs) = 0
-----
    
```

#	Peak-Position		Centroid-Position		Peak & Area are without Bkgrd					
	2Theta	d	2Theta	d	Bkgrd	Peak	I%	Area	I%	FWHM*
1:	7.506	11.7676	7.558	11.6871	29	15	8.7	6	1.9	0.360
2:	11.951	7.3995	11.960	7.3940	134	74	43.0	165	51.7	2.007
3:	12.800	6.9107	12.800	6.9105	123	115	66.9	253	79.3	1.980
4:	13.549	6.5300	13.550	6.5298	122	83	48.3	165	51.7	1.789
5:	26.855	3.3172	26.887	3.3133	40	106	61.6	250	78.4	2.123
6:	27.302	3.2639	27.313	3.2626	28	172	100.0	319	100.0	1.669
7:	27.598	3.2295	27.589	3.2306	27	168	97.7	319	100.0	1.709
8:	28.046	3.1789	28.021	3.1818	35	121	70.3	265	83.1	1.971
9:	31.457	2.8416	31.482	2.8394	9	38	22.1	69	21.6	1.634
10:	32.199	2.7778	32.187	2.7788	6	52	30.2	91	28.5	1.575
11:	44.903	2.0170	44.933	2.0157	50	59	34.3	135	42.3	2.059
12:	45.202	2.0044	45.213	2.0039	41	87	50.6	188	58.9	1.945
13:	45.951	1.9734	45.948	1.9735	42	85	49.4	185	58.0	1.959
14:	46.296	1.9595	46.268	1.9606	46	70	40.7	155	48.6	1.993
15:	53.553	1.7098	53.584	1.7089	23	55	32.0	118	37.0	1.931
16:	53.852	1.7010	53.861	1.7008	21	72	41.9	135	42.3	1.681
17:	54.600	1.6795	54.585	1.6799	22	58	33.7	135	42.3	2.095

\* Intensity values are based on total raw counts.

Jade: Hit List from Search/Match

Fri Apr 10 1998 @2:36pm

FLASH719.MDI> #99800 - 01-1143-001 - 1/8/98 CLIENT ID: BT2-007D

Estimated %Unknown Matched by the List = 32%

1 Hits Sorted on Most-Likelihood	QM*	PDF-#	FOM	I%	OFF	RIR	Space-Group	a	b	c	Vol*	Z	Dx*
] Thorianite, syn - ThO2	+	42-1462	7.9	100	0.00	7.5	Fm3m (225)	5.60	5.60	5.60	44	4	10.002

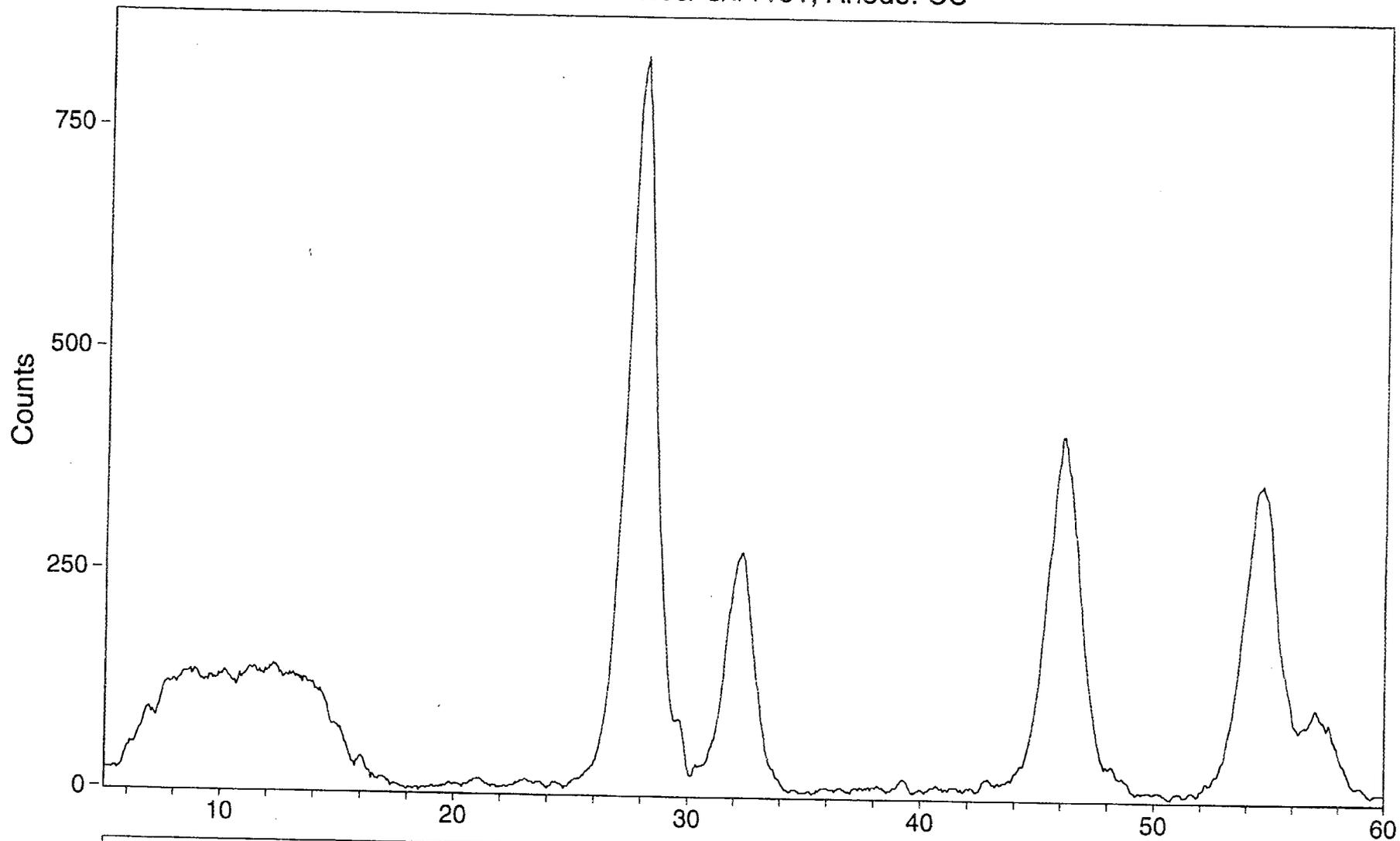
\* QM - ? for Doubtful Quality or Non-ambient patterns; + for Indexed patterns with Space-Group, Unit Cell & Density.  
 \* vol - reduced-cell volume; dx - measured density if calculated is not available.

Current S/M parameters:

PDF Subfile to Search .....	INORGANS	2-Theta Error Window .....	.12
Chemistry Filter .....	MIKE.CHEM (Yes)	Sensitivity to Matching Intensity ....	5
Search Focus on .....	Major Phase(s)	Sensitivity to Matching 2-Theta .....	5
Preferred Orientation in Sample .....	No	Maximum Number of Hits to Save .....	40
Search only High Quality Phases .....	No	Rubber-Ruler Search - %Elasticity ....	0
Exclude Questionable Phases .....	No	Required 100% Line in Srched Range ...	No
Exclude METALLICS from INORGANS .....	No		

ID: #104141 - W.O.13246 - 01-1143-001 C NT ID: BT2-008C

File: FLASH797.MDI Scan: 5-60/.05/ 5/#1101, Anode: CU



1> 42-1462: Thorianite, syn - ThO <sub>2</sub>	
2> 36-1474: Nitratine - NaNO <sub>3</sub>	

2-Theta

Jade: Hit List from Search/Match

Fri Apr 10 1998 @2:46p

FLASH797.MDI> #104141 - W.O.13246 - 01-1143-001 CLIENT ID: BT2-008C Estimated %Unknown Matched by the List = 34%

2 Hits Sorted on Most-Likelihood	QM*	PDF-#	FOM	I%	OFF	RIR	Space-Group	a	b	c	Vol*	Z	Dx*
[ ] Thorianite, syn - ThO2	+	42-1462	90.0	100	0.24	7.5	Fm3m (225)	5.60	5.60	5.60	44	4	10.002
[x] Nitratine - NaNO3	+	36-1474	90.0	18	-.22		R-3c (167)	5.07	5.07	16.82	125	6	2.260

\* QM - ? for Doubtful Quality or Non-ambient patterns; + for Indexed patterns with Space-Group, Unit Cell & Density.  
 • vol - reduced-cell volume; dx - measured density if calculated is not available.

Current S/M parameters:

PDF Subfile to Search .....	INORGANS	2-Theta Error Window .....	.12
Chemistry Filter .....	MIKE.CHEM (Yes)	Sensitivity to Matching Intensity ....	5
Search Focus on .....	Major Phase(s)	Sensitivity to Matching 2-Theta .....	5
Preferred Orientation in Sample .....	No	Maximum Number of Hits to Save .....	40
Search only High Quality Phases .....	No	Rubber-Ruler Search - %Elasticity ....	0
Exclude Questionable Phases .....	No	Required 100% Line in Srchd Range ...	No
Exclude METALLICS from INORGANS .....	No		

Jade: Peak Listing

Fri Apr 10 1998 @2:46pm

=====

File: FLASH797.MDI> #104141 - W.O.13246 - 01-1143-001 CLIENT ID: BT2-008C

```

----- Scan Parameters: ----- Search Parameters: -----
Radiation = CU_1.54059           || Filter length(pts) = 9
Scan Range = 5- 60              || Noise level(sigmas) = 1.0
Step Size = .05                 || Intensity cutoff(%) = 2-100
Count Time = 5 sec.            || 2-Theta Zero (degs) = 0
-----
    
```

Peak-Position		Centroid-Position		Peak & Area are without Bkgrd						
#	2Theta	d	2Theta	d	Bkgrd	Peak	I%	Area	I%	FWHM*
1:	8.400	10.5173	8.401	10.5166	103	29	3.6	33	2.8	1.024
2:	8.897	9.9307	8.897	9.9317	101	33	4.1	54	4.6	1.473
3:	12.345	7.1639	12.329	7.1734	114	27	3.4	52	4.4	1.733
4:	27.451	3.2465	27.451	3.2465	51	574	71.8	567	48.3	0.889
5:	27.752	3.2120	27.763	3.2107	48	750	93.9	1111	94.6	1.333
6:	27.949	3.1898	27.940	3.1907	34	799	100.0	1175	100.0	1.324
7:	28.145	3.1680	28.144	3.1681	34	688	86.1	788	67.1	1.031
8:	31.707	2.8198	31.750	2.8160	25	172	21.5	341	29.0	1.784
9:	32.053	2.7901	32.068	2.7889	17	244	30.5	380	32.3	1.402
10:	32.201	2.7776	32.204	2.7774	16	255	31.9	381	32.4	1.345
11:	32.300	2.7694	32.293	2.7699	19	257	32.2	365	31.1	1.278
12:	45.455	1.9938	45.457	1.9937	47	223	27.9	201	17.1	0.811
13:	45.853	1.9774	45.871	1.9767	28	351	43.9	619	52.7	1.587
14:	46.001	1.9714	46.004	1.9713	33	380	47.6	603	51.3	1.428
15:	46.396	1.9555	46.374	1.9564	34	316	39.5	603	51.3	1.717
16:	54.401	1.6852	54.413	1.6848	50	302	37.8	488	41.5	1.45
17:	54.847	1.6725	54.825	1.6731	63	276	34.5	431	36.7	1.405
18:	56.955	1.6155	56.984	1.6147	61	43	5.4	34	2.9	0.712
19:	57.554	1.6001	57.528	1.6008	49	39	4.9	44	3.7	1.015

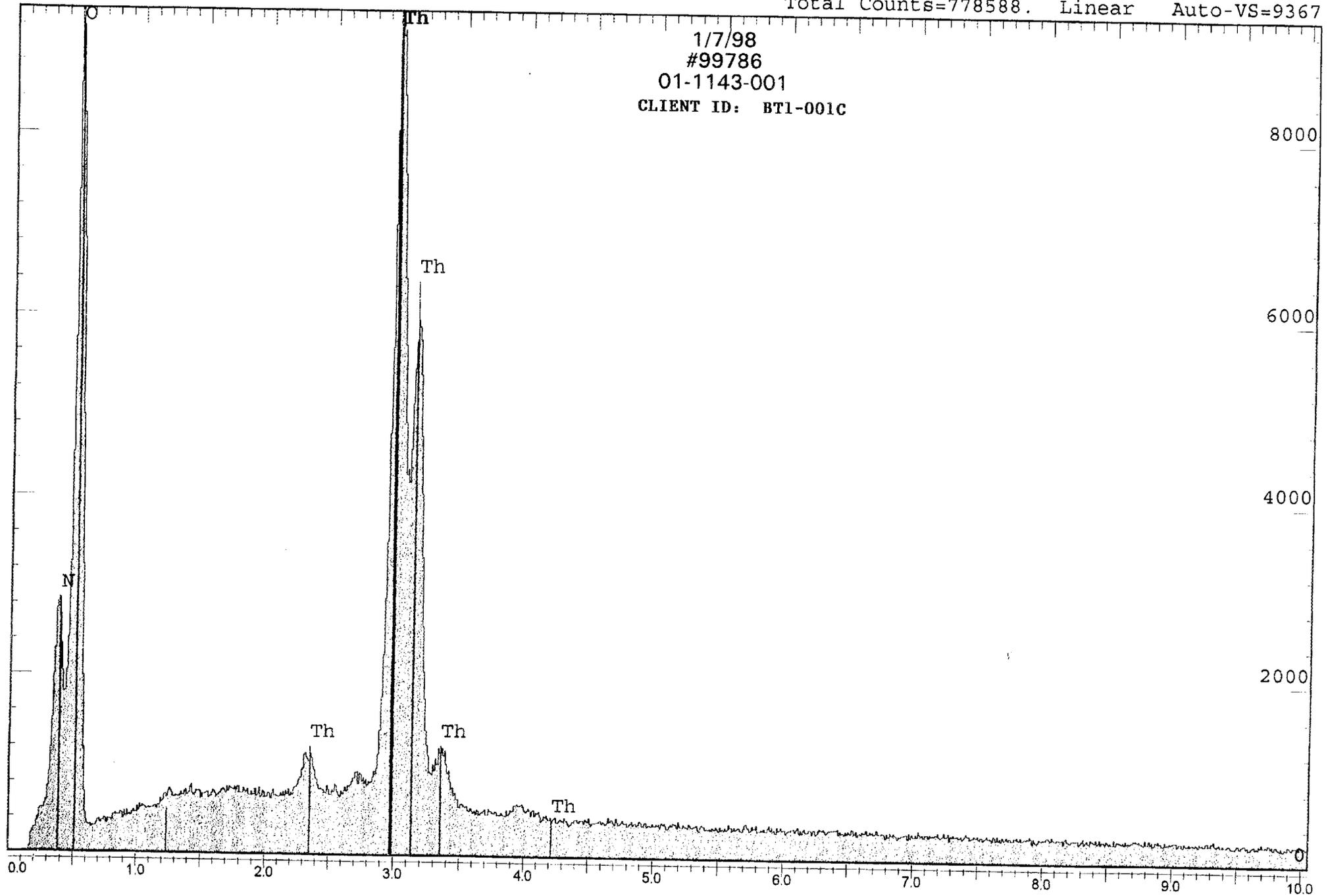
\* Intensity values are based on total raw counts.

# **X-RAY FLUORESCENCE ANALYSIS**

Spectrum: JFS570

Range: 20 keV

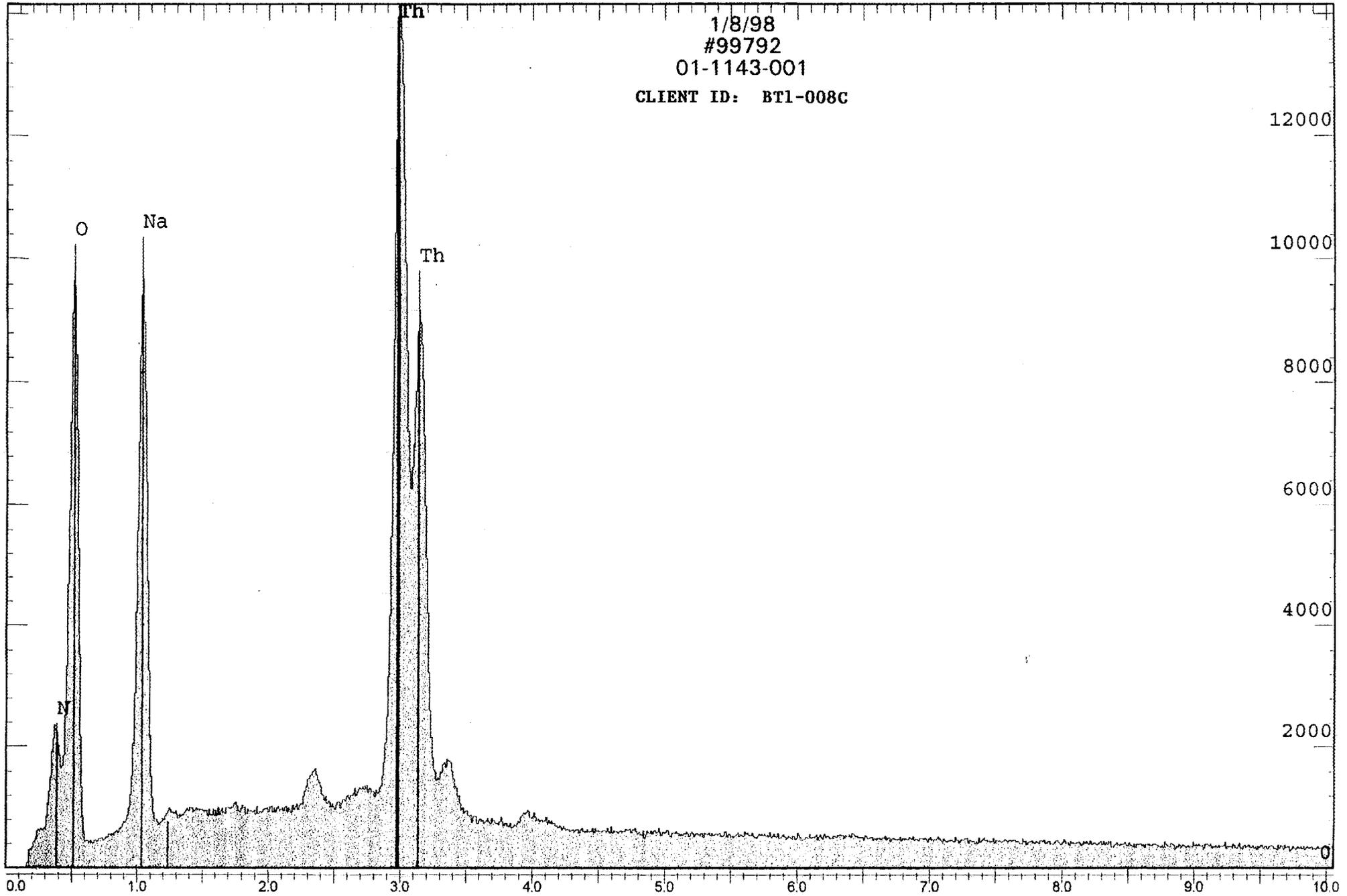
Total Counts=778588. Linear Auto-VS=9367



Spectrum FS571

Range: 20 keV

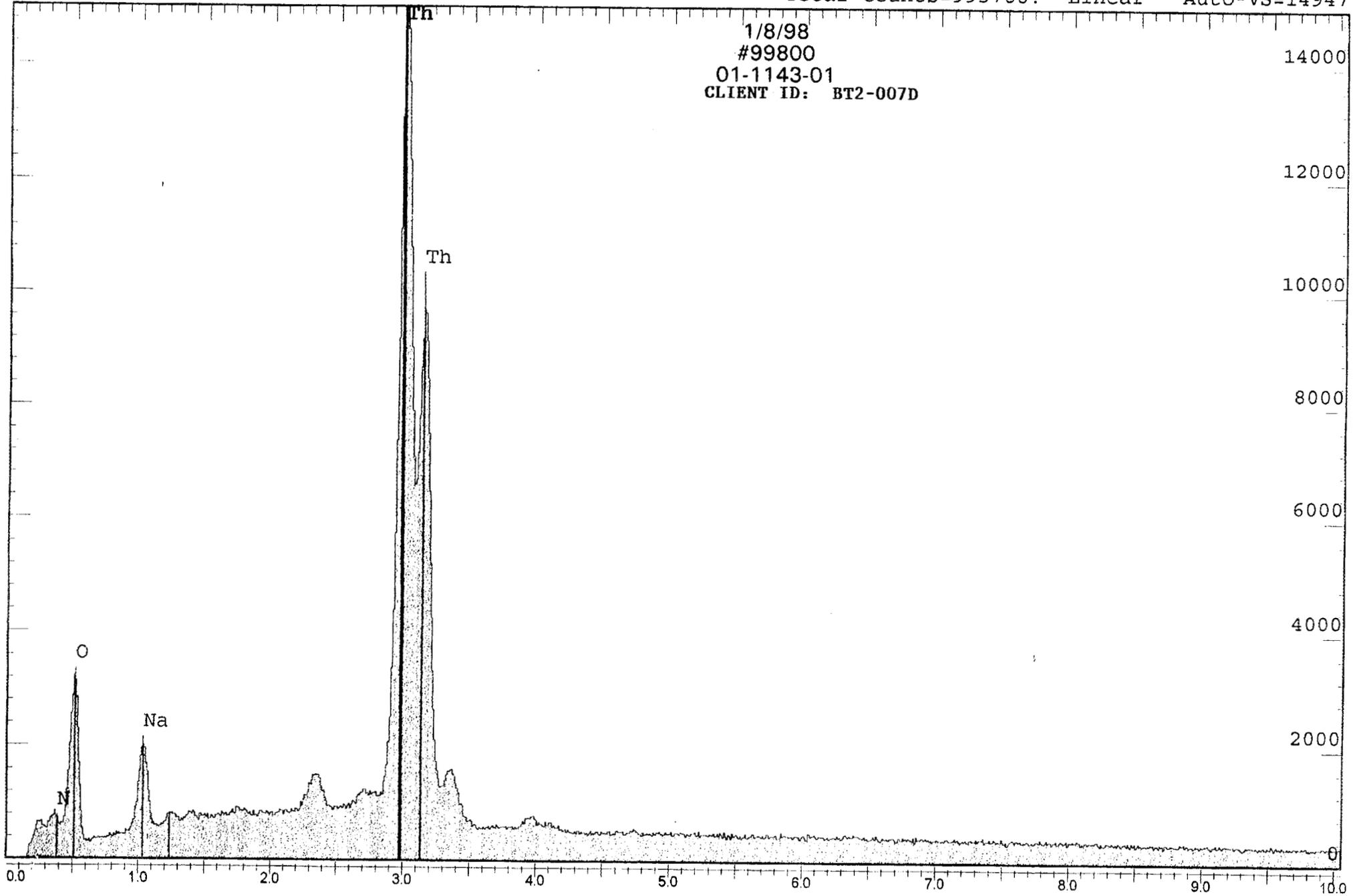
Total Counts=1207531. Linear Auto-VS=14136



Spectrum: JFS572

Range: 20 keV

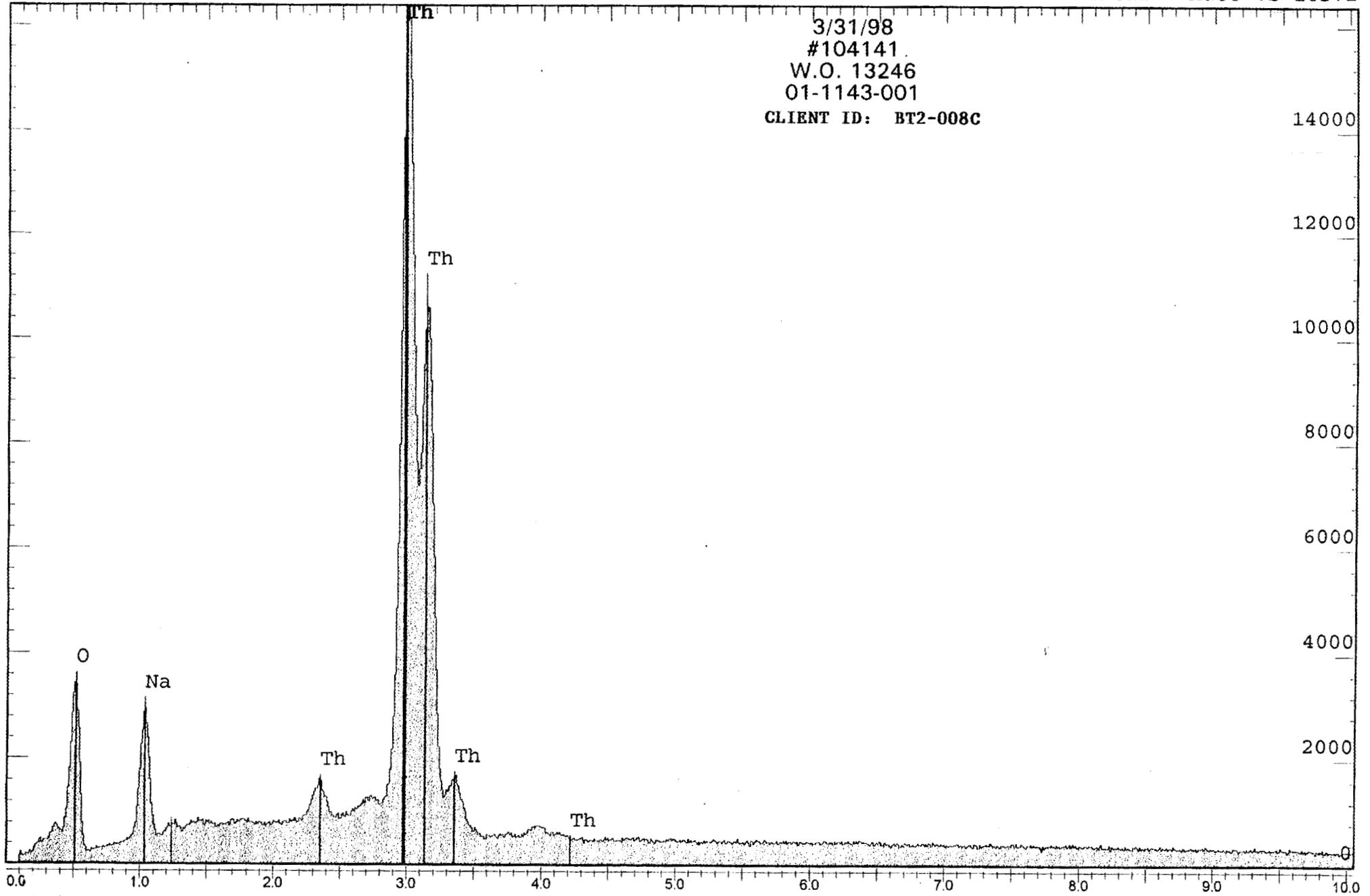
Total Counts=993788. Linear Auto-VS=14947



Spectrum. FS611

Range: 20 keV

Total Counts=1014174. Linear Auto-VS=16372





June 9, 1998

Mr. Tom Yarbough  
Permafix Environmental  
1940 N.W. 67 Place  
Gainesville, Florida 32653

Dear Mr. Yarbough:

Enclosed with this letter are data reports for samples analyzed by QST for the Project: Teladyne Brown. As you requested these are copies of the reports faxed to you on May 21, 1998 by Suzanne Woodward.

Please contact Hugh Prentice at 333-1606 with any questions concerning these reports.

Sincerely;

A handwritten signature in black ink that reads "Virginia C. O'Brien". The signature is written in a cursive style.

Virginia C. O'Brien



PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP !TBDW PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

SAMPLE ID'S PARAMETERS UNITS	STORET METHOD	BT4-009A !TBDW 13	BT5-001A !TBDW 14	BT5-004A !TBDW 15	BT5-006A !TBDW 16	BT5-009A !TBDW 17	CLP1-001A !TBDW 18	CLB1-001C !TBDW 19	CLB1-002A !TBDW 20	CLB1-002C !TBDW 21	CLB2-001A !TBDW 22	CLB2-001C !TBDW 23	CLB2-002A !TBDW 24
DATE TIME		12/12/97 10:52	12/12/97	12/12/97	12/12/97	12/12/97	01/13/98 09:49	01/13/98 09:49	01/13/98 17:52	01/13/98 17:53	01/14/98 08:05	01/19/98 08:05	01/19/98 15:00
SODIUM, TOTAL UG/L	82035 6010-G	35300	NRQ	78000000	23900000	14200	NRQ	24800	NRQ	30000	NRQ	25500000	NRQ
NITROGEN, NO2+NO3 MG/L AS N	630 353.2-G	15.1	88100	42500	15000	15.0	NRQ	13.7	NRQ	9.09	NRQ	18600	NRQ
ANTIMONY, TOTAL UG/L	1097 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
ARSENIC, TOTAL UG/L	1002 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
BARIUM, TOTAL UG/L	1007 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
BERYLLIUM, TOTAL UG/L	1012 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
CADMIUM, TOTAL UG/L	1027 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
CHROMIUM, TOTAL UG/L	1034 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
LEAD, TOTAL UG/L	1051 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
MERCURY UG/L	71900 7470-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
NICKEL, TOTAL UG/L	1067 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
SELENIUM, TOTAL UG/L	1147 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
SILVER, TOTAL UG/L	1077 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	
THALLIUM, TOTAL UG/L	1059 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ		NRQ		NRQ		NRQ	

QST Environmental DATE 05/15/98 STATUS : PAGE 3  
 PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP !TBDW PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

SAMPLE ID'S PARAMETERS UNITS	STORET METHOD	CLB2-002C !TBDW 25	CLB3-001A !TBDW 26	CLB3-001C !TBDW 27	CLB3-002A !TBDW 28	CLB3-002C !TBDW 29
DATE		01/19/98	01/15/98	01/15/98	01/15/98	01/15/98
TIME		15:01	07:24	07:24	15:58	15:59
SODIUM, TOTAL	82035	25700000	NRQ	38000000	NRQ	40800000
UG/L	6010-G					
NITROGEN, NO2+NO3	630	43600	NRQ	31300	NRQ	27500
MG/L AS N	353.2-G					
ANTIMONY, TOTAL	1097	NRQ		NRQ		NRQ
UG/L	6020-G					
ARSENIC, TOTAL	1002	NRQ		NRQ		NRQ
UG/L	6020-G					
BARIUM, TOTAL	1007	NRQ		NRQ		NRQ
UG/L	6020-G					
BERYLLIUM, TOTAL	1012	NRQ		NRQ		NRQ
UG/L	6020-G					
CADMIUM, TOTAL	1027	NRQ		NRQ		NRQ
UG/L	6020-G					
CHROMIUM, TOTAL	1034	NRQ		NRQ		NRQ
UG/L	6020-G					
LEAD, TOTAL	1051	NRQ		NRQ		NRQ
UG/L	6020-G					
MERCURY	71900	NRQ		NRQ		NRQ
UG/L	7470-G					
NICKEL, TOTAL	1067	NRQ		NRQ		NRQ
UG/L	6020-G					
SELENIUM, TOTAL	1147	NRQ		NRQ		NRQ
UG/L	6020-G					
SILVER, TOTAL	1077	NRQ		NRQ		NRQ
UG/L	6020-G					
THALLIUM, TOTAL	1059	NRQ		NRQ		NRQ
UG/L	6020-G					



PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP !TBTDS PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

✓ 5

SAMPLE ID'S PARAMETERS UNITS	STORET METHOD	BT4-007C !TBTDS 13	BT5-003B !TBTDS 14	BT5-005B !TBTDS 15	BT5-007B !TBTDS 16	BT5-007C !TBTDS 17	BT1-009B !TBTDS 18	BT2-008A !TBTDS 19	BT4-008A !TBTDS 20	BT5-008A !TBTDS 21
DATE TIME		12/12/97 12:13	12/12/97	12/12/97	12/12/97	12/12/97	02/26/98 15:02	02/26/98 15:05	02/26/98 15:09	02/26/98 15:13
ANTIMONY MG/KG-DRY	1098 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.050	NRQ	NRQ	NRQ
ARSENIC MG/KG-DRY	1003 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.099	NRQ	NRQ	NRQ
BARIUM MG/KG-DRY	1008 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.497	NRQ	NRQ	NRQ
BERYLLIUM MG/KG-DRY	1013 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	0.041	NRQ	NRQ	NRQ
CADMIUM MG/KG-DRY	1028 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.020	NRQ	NRQ	NRQ
CHROMIUM MG/KG-DRY	1029 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	4.58	NRQ	NRQ	NRQ
LEAD MG/KG-DRY	1052 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.199	NRQ	NRQ	NRQ
MERCURY MG/KG-DRY	71921 7471-G	NRQ								
NICKEL MG/KG-DRY	1068 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	0.563	NRQ	NRQ	NRQ
SELENIUM MG/KG-DRY	1148 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.199	NRQ	NRQ	NRQ
SILVER MG/KG-DRY	1078 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	0.013	NRQ	NRQ	NRQ
THALLIUM MG/KG-DRY	34480 6020-G	NRQ	NRQ	NRQ	NRQ	NRQ	<0.010	NRQ	NRQ	NRQ
NITROG, NO2+NO3, SED MG/KG-DRY	633 353.2M-G	NRQ	8780	6190	3000	NRQ	34900	18500	5970	18000
MOISTURE %WET WT	70320 ASTM-G	NRQ	0.05	0.05	0.05	NRQ	0.05	0.05	0.05	0.05
SODIUM MG/KG-DRY	934 6010-G	NRQ	20400	13000	27300	NRQ	NRQ	NRQ	NRQ	NRQ
TCLP EXTRACTION-METALS	97160 1311M-G	01/21/98	NRQ	NRQ	NRQ	01/21/98	NRQ	NRQ	03/13/98	NRQ

SAMPLE ID'S		BT1-001A	BT1-004B	BT1-006B	BT1-008B	BT1-008D	BT2-003B	BT2-005B	BT2-007B
PARAMETERS	STORET	!TBTDS							
UNITS	METHOD	1	2	3	4	5	6	7	8
DATE		11/18/97	11/19/97	11/20/97	11/20/97	11/20/97	12/03/97	12/03/97	12/03/97
TIME		12:58	17:50	11:00	20:45	20:48	11:00	15:30	21:23
ANTIMONY	1098	<0.036	NRQ						
MG/KG-DRY	6020-G								
ARSENIC	1003	<0.073	NRQ						
MG/KG-DRY	6020-G								
BARIUM	1008	<0.364	NRQ						
MG/KG-DRY	6020-G								
BERYLLIUM	1013	0.078	NRQ						
MG/KG-DRY	6020-G								
CADMIUM	1028	<0.015	NRQ						
MG/KG-DRY	6020-G								
CHROMIUM	1029	<0.364	NRQ						
MG/KG-DRY	6020-G								
LEAD	1052	<0.146	NRQ						
MG/KG-DRY	6020-G								
MERCURY	71921	0.047	NRQ						
MG/KG-DRY	6020-G								
NICKEL	1068	<0.364	NRQ						
MG/KG-DRY	6020-G								
SELENIUM	1148	0.385	NRQ						
MG/KG-DRY	6020-G								
SILVER	1078	0.027	NRQ						
MG/KG-DRY	6020-G								
THALLIUM	34480	<0.007	NRQ						
MG/KG-DRY	6020-G								
NITROG, NO2+NO3, SED	633	95600	47100	9590	33800	NRQ	8570	6090	10100
MG/KG-DRY	353.2M-G								
MOISTURE	70320	0.05	0.05	0.05	0.05	NRQ	0.05	0.05	0.05
%WET WT	ASTM-G								
SODIUM	934	NRQ	47600	37200	79500	NRQ	26500	20200	31200
MG/KG-DRY	6010-G								
CHLORIDE, SED	99120	NRQ	NRQ	NRQ	NA	NRQ	NRQ	NRQ	525
UG/G-DRY	TITR								
TCLP EXTRACTION-METALS	97160	NRQ	NRQ	NRQ	NRQ	01/21/98	NRQ	NRQ	NRQ
	1311M-G								

-----  
 A method was not performed for % moisture. The moisture content for these samples was assumed to be negligible.

QST Environmental DATE 05/21/98 STATUS : FINAL PAGE 2  
 PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP !TBIDS PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

SAMPLE ID'S		BT2-007C	BT4-003B	BT4-005B	BT4-007B	BT4-007C	BT5-003B	BT5-005B	BT5-007B
PARAMETERS	STORET	!TBIDS							
UNITS	METHOD	9	10	11	12	13	14	15	16
DATE		12/03/97	12/11/97	12/11/97	12/12/97	12/12/97	12/12/97	12/12/97	12/12/97
TIME		21:24	17:29	19:03	12:12	12:13			
NITROG,NO2+NO3,SED	633	NRQ	6040	2040	3690	NRQ	8780	6190	3000
MG/KG-DRY	353.2M-G								
MOISTURE	70320	NRQ	0.05	0.05	0.05	NRQ	0.05	0.05	0.05
%WET WT	ASTM-G								
SODIUM	934	NRQ	9040	7510	12400	NRQ	20400	13000	27300
MG/KG-DRY	6010-G								
TCLP EXTRACTION-METALS	97160	01/21/98	NRQ	NRQ	NRQ	01/21/98	NRQ	NRQ	NRQ
	1311M-G								

-----  
 A method was not performed for % moisture. The moisture content for these samples was assumed to be negligible.

SAMPLE ID'S PARAMETERS UNITS	STORET METHOD	BT5-007C	BT1-009B	BT2-008A	BT4-008A	BT5-008A
		!TBTDS 17	!TBTDS 18	!TBTDS 19	!TBTDS 20	!TBTDS 21
DATE TIME		12/12/97	02/26/98 15:02	02/26/98 15:05	02/26/98 15:09	02/26/98 15:13
ANTIMONY MG/KG-DRY	1098 6020-G	NRQ	<0.050	NRQ	NRQ	NRQ
ARSENIC MG/KG-DRY	1003 6020-G	NRQ	<0.099	NRQ	NRQ	NRQ
BARIUM MG/KG-DRY	1008 6020-G	NRQ	<0.497	NRQ	NRQ	NRQ
BERYLLIUM MG/KG-DRY	1013 6020-G	NRQ	0.041	NRQ	NRQ	NRQ
CADMIUM MG/KG-DRY	1028 6020-G	NRQ	<0.020	NRQ	NRQ	NRQ
CHROMIUM MG/KG-DRY	1029 6020-G	NRQ	4.58	NRQ	NRQ	NRQ
LEAD MG/KG-DRY	1052 6020-G	NRQ	<0.199	NRQ	NRQ	NRQ
MERCURY MG/KG-DRY	71921 6020-G	NRQ	0.016	NRQ	NRQ	NRQ
NICKEL MG/KG-DRY	1068 6020-G	NRQ	0.563	NRQ	NRQ	NRQ
SELENIUM MG/KG-DRY	1148 6020-G	NRQ	<0.199	NRQ	NRQ	NRQ
SILVER MG/KG-DRY	1078 6020-G	NRQ	0.013	NRQ	NRQ	NRQ
THALLIUM MG/KG-DRY	34480 6020-G	NRQ	<0.010	NRQ	NRQ	NRQ
NITROG, NO2+NO3, SED MG/KG-DRY	633 353.2M-G	NRQ	34900	18500	5970	18000
MOISTURE %WET WT	70320 ASTM-G	NRQ	0.05	0.05	0.05	0.05
TCLP EXTRACTION-METALS	97160 1311M-G	01/21/98	NRQ	NRQ	03/13/98	NRQ

-----  
 A method was not performed for % moisture. The moisture content for these samples was assumed to be negligible.

QST Environmental DATE 05/21/98 STATUS : FINAL PAGE 1

PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP !TBTDSL PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

SAMPLE ID'S		BT1-008D	BT2-007C	BT4-007C	BT5-007C	BT4-008A
PARAMETERS	STORET	!TBTDSL	!TBTDSL	!TBTDSL	!TBTDSL	!TBTDSL
UNITS	METHOD	5	9	13	17	20
DATE		01/21/98	01/21/98	01/21/98	01/21/98	03/13/98
TIME						
ANTIMONY, TOTAL	1097	1.5	<0.5	<0.5	22.8	<0.5
UG/L	6020-G					
ARSENIC, TOTAL	1002	4.1	<1.0	<1.0	3.2	<1.0
UG/L	6020-G					
BARIUM, TOTAL	1007	1160	520	635	2770	146
UG/L	6020-G					
BERYLLIUM, TOTAL	1012	2.2	<0.2	<0.2	14.3	<0.2
UG/L	6020-G					
CADMIUM, TOTAL	1027	0.2	0.2	0.2	0.9	<0.1
UG/L	6020-G					
CHROMIUM, TOTAL	1034	79.6	5.3	6.1	84.7	4.1
UG/L	6020-G					
LEAD, TOTAL	1051	23.1	10.5	5.3	23.7	0.6
UG/L	6020-G					
MERCURY, TOTAL	71900	0.386	<0.200	<0.200	0.626	<0.200
UG/L	6020-G					
NICKEL, TOTAL	1067	32.7	2.0	3.7	26.4	1.1
UG/L	6020-G					
SELENIUM, TOTAL	1147	12.7	<2.0	<2.0	26.1	<2.0
UG/L	6020-G					
SILVER, TOTAL	1077	0.2	0.1	<0.1	0.4	<0.1
UG/L	6020-G					
THALLIUM, TOTAL	1059	<0.1	<0.1	<0.1	<0.1	<0.1
UG/L	6020-G					

PROJECT NUMBER 1297373 0201 PROJECT NAME TELADYNE BROWN: THORIUM DEMO  
 FIELD GROUP 1TBTDLSL PROJECT MANAGER  
 ALL ALL LAB COORDINATOR RICHARD ROBINSON

SAMPLE ID'S		BT1-008D	BT2-007C	BT5-005B	BT4-007C	BT5-007C	BT4-008A
PARAMETERS	STORET	1TBTDLSL	1TBTDLSL		1TBTDLSL	1TBTDLSL	1TBTDLSL
UNITS	METHOD	5	9		13	17	20
DATE		01/21/98	01/21/98	12/12/97	01/21/98	01/21/98	03/13/98
TIME							
ANTIMONY, TOTAL	1097	1.5	<0.5	NRQ	<0.5	22.8	<0.5
UG/L	6020-G						
ARSENIC, TOTAL	1002	4.1	<1.0	NRQ	<1.0	3.2	<1.0
UG/L	6020-G						
HARIUM, TOTAL	1007	1160	520	NRQ	635	2770	146
UG/L	6020-G						
BERYLLIUM, TOTAL	1012	2.2	<0.2	NRQ	<0.2	14.3	<0.2
UG/L	6020-G						
CADMIUM, TOTAL	1027	0.2	0.2	NRQ	0.2	0.9	<0.1
UG/L	6020-G						
CHROMIUM, TOTAL	1034	79.6	5.3	NRQ	6.1	84.7	4.1
UG/L	6020-G						
LEAD, TOTAL	1051	23.1	10.5	NRQ	5.3	23.7	0.6
UG/L	6020-G						
MERCURY, TOTAL	71900	0.386	<0.200	NRQ	<0.200	0.626	<0.200
UG/L	6020-G						
NICKEL, TOTAL	1067	32.7	2.0	NRQ	3.7	26.4	1.1
UG/L	6020-G						
SELENIUM, TOTAL	1147	12.7	<2.0	NRQ	<2.0	26.1	<2.0
UG/L	6020-G						
SILVER, TOTAL	1077	0.2	0.1	NRQ	<0.1	0.4	<0.1
UG/L	6020-G						
THALLIUM, TOTAL	1059	<0.1	<0.1	NRQ	<0.1	<0.1	<0.1
UG/L	6020-G						

PERMA-FIX ENVIRONMENTAL SERVICES, INC.

LABORATORY

2010 N.W. 67TH PLACE  
GAINESVILLE, FL. 32653

(352) 373-6066  
fax (352) 338-7922

FAX

TO: Ben Crocker

FAX#: (423) 425 - 1248

FROM: Tom Yarbrough

DATE: 02/05/98

SUBJECT: Calcining Test Results

PAGES: 2

(Including cover)

NOTES: I found another calc error. Most <sup>NO<sub>3</sub></sup> QST results now agree with ours. I will try to resolve any discrepancies and fax you a comparison. The attached results are all from Perma-Fix lab.

SENT BY: Tom

Pilot Test Calcining Results

Test No.	Ploughshare Product % Th-232	Ploughshare Product % NO3	Crucible/Lid Mass (g)	Crucible + Sample (g)	After 120 C Dry (g)	After 1000 F Calcine (g)	Initial Net Sample (g)	Dry Sample (g)	Initial Moisture (%)	Calcined Net Sample (g)	Weight Change (%)	Calcined Th-232 (%)	Calcined NO3 (%)
BT-1	51.1%	2.0%	30.6314	75.7407	71.9279	67.6176	45.1093	41.2965	8.5%	36.9862	-10.4%	57.0%	20.8%
			31.3484	77.0619	72.7976	68.7851	45.7135	41.4492	9.3%	37.4367	-9.7%		
			31.0404	72.1116	68.2124	64.6149	41.0712	37.1720	9.5%	33.5745	-9.7%		
			31.0324	71.2550	67.5348	63.8689	40.2226	36.5024	9.2%	32.8365	-10.0%		
			31.2056	74.1682	70.4454	66.4284	42.9626	39.2398	8.7%	35.2228	-10.2%		
			30.7208	72.8928	68.6042	65.2687	42.1720	37.8834	10.2%	34.5479	-8.8%		
						257.2512	233.5433	9.2%	210.6046	-9.8%			
BT-2	54.6%	5.0%	89.8185	172.4856	153.6154	150.4503	82.6671	63.7969	22.8%	60.6318	-5.0%	74.2%	7.8%
			31.1695	48.6283	44.4555	43.9927	17.4588	13.2860	23.9%	12.8232	-3.5%		
			30.7068	50.7382	45.9988	45.4431	20.0314	15.2920	23.7%	14.7363	-3.6%		
			31.4106	51.6178	46.5432	46.0000	20.2072	15.1326	25.1%	14.5894	-3.6%		
			31.3178	58.3522	51.8021	51.0834	27.0344	20.4843	24.2%	19.7656	-3.5%		
						167.3989	127.9918	23.5%	122.5463	-4.3%			
BT-4	70.8%	2.3%	82.9744	187.0430	171.8509	167.5901	104.0686	88.8765	14.6%	84.6157	-4.8%	76.4%	2.6%
			31.9937	60.8977	56.7591	55.6263	28.9040	24.7654	14.3%	23.6326	-4.6%		
			31.5560	64.1433	59.4867	58.1307	32.5873	27.9307	14.3%	26.5747	-4.9%		
			31.4304	64.3513	59.3729	58.1938	32.9209	27.9425	15.1%	26.7634	-4.2%		
			31.7812	61.0394	56.6026	55.6216	29.2582	24.8214	15.2%	23.8404	-4.0%		
						227.7390	194.3365	14.7%	185.4268	-4.6%			
BT-5	41.3%	0.74%	84.8429	189.5279	166.4119	161.2075	104.6850	81.5690	22.1%	76.3646	-6.4%	71.3%	9.7%
			31.4989	63.4598	56.1905	54.2071	31.9609	24.6916	22.7%	22.7082	-8.0%		
			31.1790	63.4077	56.2348	54.5276	32.2287	25.0558	22.3%	23.3486	-6.8%		
			32.0339	66.6448	58.7034	56.8650	34.6109	26.6695	22.9%	24.8311	-6.9%		
			31.8211	63.1239	55.7921	54.2859	31.3028	23.9710	23.4%	22.4648	-6.3%		
						234.7883	181.9569	22.5%	169.7173	-6.7%			

**Appendix B**

**Laboratory Analytical Reports**

**Split Samples Analyzed by Lockheed Martin Energy Systems, Inc.**

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Thorium		230000			mg/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Antimony	<	200			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Barium	<	1000			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Beryllium	<	200			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Cadmium	<	300			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Chromium	<	500			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Lead	<	500			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Nickel	<	5000			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Selenium	<	1000			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Silver	<	200			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Thallium	<	200			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Vanadium	<	200			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	ICPMS2008	Zinc	<	2000			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	IONCHROM	Nitrate		310000			mg/L
KWMK116	THORIUM1	A980480119	BT1-002C	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Actinium-228		2.14E7	150000		pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Cadmium-109		2.06E7	800000		pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Thorium-234		3.59E6	370000		pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980480119	BT1-002C	TOTALACT-WP	Total Activity		2.46E8	500000		pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Thorium		260000			mg/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Antimony	<	200			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Barium	<	1000			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Beryllium	<	200			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Cadmium	<	300			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Chromium	<	500			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Lead	<	500			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Nickel	<	5000			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Selenium	<	1000			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Silver	<	200			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Thallium	<	200			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Vanadium	<	200			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	ICPMS2008	Zinc	<	2000			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	IONCHROM	Nitrate		410000			mg/L
KWMK116	THORIUM1	A980480120	BT2-001C	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Actinium-228		2.47E7	150000		pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cadmium-109		7.25E6	810000		pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cerium-144		1.59E5	110000		pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Thorium-234		3.78E6	390000		pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PRÉFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480120	BT2-001C	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980480120	BT2-001C	TOTALACT-WP	Total Activity		2.83E8	540000		pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Thorium		260000			mg/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Antimony	<	200			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Barium	<	1000			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Beryllium	<	200			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Cadmium	<	300			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Chromium	<	500			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Lead	<	500			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Nickel	<	5000			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Selenium	<	1000			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Silver	<	200			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Thallium	<	200			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Vanadium	<	200			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	ICPMS2008	Zinc	<	2000			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	IONCHROM	Nitrate		350000			mg/L
KWMK116	THORIUM1	A980480121	BT4-001C	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Actinium-228		2.44E7	160000		pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Cadmium-109		2.35E7	760000		pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Potassium-40		NA			pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Thorium-234		6.38E6	420000		pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980480121	BT4-001C	TOTALACT-WP	Total Activity		2.84E8	540000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Thorium		260000			mg/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Antimony		290			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Barium	<	1000			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Beryllium	<	200			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Cadmium	<	300			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Chromium	<	500			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Lead	<	500			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Nickel	<	5000			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Selenium	<	1000			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Silver	<	200			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Thallium	<	200			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Vanadium	<	200			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	ICPMS2008	Zinc		13000			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	IONCHROM	Nitrate		410000			mg/L
KWMK116	THORIUM1	A980480122	BT5-001C	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Actinium-228		2.51E7	160000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Cadmium-109		6.60E6	790000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Cobalt-57		NA			pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Protactinium-234m		4.31E6	2800000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Thorium-234		4.12E6	380000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	GAMSPEC-WP	Uranium-235		3.85E4	19000		pCi/L
KWMK116	THORIUM1	A980480122	BT5-001C	TOTALACT-WP	Total Activity		2.68E8	520000		pCi/L
KWMK116	THORIUM1	A980480123	BT2-005d	ICP6010	Sodium		21200			mg/kg
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Thorium		780000			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Antimony	<	2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Arsenic	<	10			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Barium	<	10			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Beryllium	<	2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Cadmium	<	3			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Chromium	<	5			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Lead	<	5			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Nickel	<	50			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Selenium	<	10			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Silver	<	2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Thallium	<	2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Vanadium	<	2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	ICPMS2008	Zinc	<	20			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	IONCHROM	Nitrate		36000			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	HG7471	Mercury	<	0.2			ug/g
KWMK116	THORIUM1	A980480123	BT2-005d	KARL-FISCHER	Moisture		465000			ug/g

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Actinium-228		3.24E4		660	pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Cadmium-109		2.05E4		2800	pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Cesium-134		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Cesium-137		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Cobalt-57		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Cobalt-60		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Potassium-40		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Protactinium-234m		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Thorium-234		5.01E3		1300	pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GAMSPEC-WP	Uranium-235		NA			pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GROSSAB-WP	Alpha activity		3.20E5		13000	pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	GROSSAB-WP	Beta activity		1.33E5		6000	pCi/g
KWMK116	THORIUM1	A980480123	BT2-005d	TOTALACT-WP	Total Activity		3.73E5		3800	pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICP6010	Sodium		7600			mg/kg
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Thorium		870000			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Antimony	<	2			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Arsenic	<	10			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Barium	<	10			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Beryllium	<	10			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Cadmium	<	3			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Chromium	<	5			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Lead	<	5			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Nickel	<	50			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Selenium	<	10			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Silver	<	2			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Thallium	<	2			ug/g

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Vanadium	<	2			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	ICPMS2008	Zinc	<	20			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	IONCHROM	Nitrate		12000			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	HG7471	Mercury	<	0.2			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	KARL-FISCHER	Moisture		253000			ug/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Actinium-228		3.96E4	640		pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Cesium-134		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Cesium-137		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Cobalt-57		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Cobalt-60		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Potassium-40		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Protactinium-234m		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Thorium-234		9.42E3	1100		pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GAMSPEC-WP	Uranium-235		NA			pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GROSSAB-WP	Alpha activity		4.33E5	14000		pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	GROSSAB-WP	Beta activity		1.57E5	6200		pCi/g
KWMK116	THORIUM1	A980480124	BT4-005d	TOTALACT-WP	Total Activity		4.79E5	4100		pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICP6010	Sodium		12300			mg/kg
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Thorium		640000			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Antimony	<	2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Arsenic	<	10			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Barium	<	10			ug/g

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Beryllium	<	2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Cadmium	<	3			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Chromium	<	5			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Lead	<	5			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Nickel	<	50			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Selenium	<	10			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Silver	<	2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Thallium	<	2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Vanadium	<	2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	ICPMS2008	Zinc	<	20			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	IONCHROM	Nitrate		38000			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	HG7471	Mercury	<	0.2			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	KARL-FISCHER	Moisture		209000			ug/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Actinium-228		2.13E4		520	pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Cadmium-109		1.83E4		2000	pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Cesium-134		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Cesium-137		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Cobalt-57		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Cobalt-60		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Potassium-40		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Protactinium-234m		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Thorium-234		3.18E3		900	pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GAMSPEC-WP	Uranium-235		NA			pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GROSSAB-WP	Alpha activity		2.59E5		11000	pCi/g
KWMK116	THORIUM1	A980480125	BT5-005d	GROSSAB-WP	Beta activity		8.72E4		4600	pCi/g

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL CNFDNC	UNIT
KWMK116	THORIUM1	A980480125	BT5-005d	TOTALACT-WP	Total Activity		3.35E5	3400	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	ICP6010	Sodium		32000		mg/kg
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMS2008	Thorium		490000		ug/g
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Antimony	<	200		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Arsenic	<	1000		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Barium		710		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Beryllium	<	20		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Cadmium	<	30		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Chromium	<	50		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Lead	<	50		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Nickel	<	39		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Silver	<	20		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Thallium	<	20		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Vanadium	<	20		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	ICPMSTCLP	Zinc		390		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	IONCHROM	Nitrate		58000		ug/g
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPEXN-NV	Extraction fluid number		2		none
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPEXN-NV	Percent Solids		100		%
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPEXN-NV	pH		5.87		none
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPEXN-NV	Sample Weight		100.01		g
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPHG	Mercury	<	20		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPSE	Selenium	<	400		ug/L
KWMK116	THORIUM1	A980490201	BT2-007e	TCLPSE	Selenium	<	400		ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Actinium-228		5.73E4		710	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Cadmium-109		3.77E3		4000	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Cesium-134		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Cesium-137		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Cobalt-57		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Cobalt-60		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Potassium-40		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Protactinium-234m		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Thorium-234		7.33E3		1500	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GAMSPEC-WP	Uranium-235		NA			pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GROSSAB-WP	Alpha activity		1.36E5		7300	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	GROSSAB-WP	Beta activity		6.63E4		3700	pCi/g
KWMK116	THORIUM1	A980490201	BT2-007e	TOTALACT-WP	Total Activity		5.76E5		4000	pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	ICP6010	Sodium		13900			mg/kg
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMS2008	Thorium		27000			ug/g
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Antimony	<	200			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Nickel	<	300			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Vanadium	<	20			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL CNFDNC	UNIT
KWMK116	THORIUM1	A980490202	BT4-007e	ICPMSTCLP	Zinc	<	200		ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	IONCHROM	Nitrate		22000		ug/g
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPEXN-NV	Extraction fluid number		1		none
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPEXN-NV	Percent Solids		100		%
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPEXN-NV	pH		3.11		none
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPEXN-NV	Sample Weight		100.07		g
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPHG	Mercury	<	20		ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPSE	Selenium	<	400		ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	TCLPSE	Selenium	<	400		ug/L
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Actinium-228		7.05E4	770	pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Cadmium-109		4.57E4	3800	pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Cesium-134		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Cesium-137		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Cobalt-57		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Cobalt-60		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Potassium-40		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Protactinium-234m		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Thorium-234		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GAMSPEC-WP	Uranium-235		NA		pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GROSSAB-WP	Alpha activity		5.95E5	15000	pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	GROSSAB-WP	Beta activity		2.38E5	6400	pCi/g
KWMK116	THORIUM1	A980490202	BT4-007e	TOTALACT-WP	Total Activity		6.84E5	4200	pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	ICP6010	Sodium		29200		mg/kg

THORIUM (PERMA-FIX) — SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMS2008	Thorium		570000			ug/g
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Antimony	<	200			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Arsenic	<	1000			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Barium		840			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Cadmium	<	50			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Nickel	<	300			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	ICPMSTCLP	Zinc		210			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	IONCHROM	Nitrate		70000			ug/g
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPEXN-NV	Extraction fluid number		1			none
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPEXN-NV	Percent Solids		100			%
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPEXN-NV	pH		2.02			none
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPEXN-NV	Sample Weight		75.42			g
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPHG	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPSE	Selenium	<	400			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	TCLPSE	Selenium	<	400			ug/L
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Actinium-228		4.39E4	580		pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Cadmium-109		2.61E4	2700		pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Cesium-134		NA			pCi/g

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Cesium-137		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Cobalt-57		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Cobalt-60		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Potassium-40		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Protactinium-234m		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Thorium-234		5.32E3		1200	pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GAMSPEC-WP	Uranium-235		NA			pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GROSSAB-WP	Alpha activity		3.80E5		11000	pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	GROSSAB-WP	Beta activity		1.55E5		5000	pCi/g
KWMK116	THORIUM1	A980490203	BT5-007e	TOTALACT-WP	Total Activity		5.11E5		3500	pCi/g
KWMK116	THORIUM1	A980490211	BT2-009c	ICP6010	Sodium		20			mg/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	ICPMS2008	Thorium		530			mg/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490211	BT2-009c	IONCHROM	Nitrate		1300			mg/L
KWMK116	THORIUM1	A980490211	BT2-009c	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Actinium-228		9.21E4		1700	pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Cadmium-109		6.42E4		6700	pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Thorium-234		1.58E4		3200	pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490211	BT2-009c	TOTALACT-WP	Total Activity		9.77E5		9700	pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICP6010	Sodium		30700			mg/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Chromium		210			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Thallium	<	20			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	ICPMS2008	Thorium	<	0.10			mg/L
KWMK116	THORIUM1	A980490212	BT2-006a	IONCHROM	Nitrate		94000			mg/L
KWMK116	THORIUM1	A980490212	BT2-006a	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Actinium-228		6.49E3	620		pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Thorium-234		1.81E3	1200		pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	GAMSPEC-WP	Uranium-235		1.76E2	330		pCi/L
KWMK116	THORIUM1	A980490212	BT2-006a	TOTALACT-WP	Total Activity		7.55E4	3100		pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICP6010	Sodium		40			mg/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Lead	<	50			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	ICPMS2008	Thorium		350			mg/L
KWMK116	THORIUM1	A980490213	BT4-009c	IONCHROM	Nitrate		240			mg/L
KWMK116	THORIUM1	A980490213	BT4-009c	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Actinium-228		8.08E4		1300	pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Cadmium-109		1.50E4		5200	pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Thorium-234		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490213	BT4-009c	TOTALACT-WP	Total Activity		9.79E5		9700	pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICP6010	Sodium		3570			mg/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Arsenic	<	100			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	ICPMS2008	Thorium		0.24			mg/L
KWMK116	THORIUM1	A980490214	BT2-006c	IONCHROM	Nitrate		11000			mg/L
KWMK116	THORIUM1	A980490214	BT2-006c	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Actinium-228		9.07E4	1600		pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Cadmium-109		3.72E4	5300		pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Thorium-234		8.54E3	2600		pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490214	BT2-006c	TOTALACT-WP	Total Activity		7.94E5	8800		pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490215	BT5-009c	ICP6010	Sodium		40			mg/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Silver		23			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	ICPMS2008	Thorium		250			mg/L
KWMK116	THORIUM1	A980490215	BT5-009c	IONCHROM	Nitrate		1500			mg/L
KWMK116	THORIUM1	A980490215	BT5-009c	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Actinium-228		9.87E4	1800		pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Cadmium-109		8.04E4	10000		pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Protactinium-234m		NA			pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Thorium-234		1.43E4		4500	pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490215	BT5-009c	TOTALACT-WP	Total Activity		9.97E5		9800	pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICP6010	Sodium		24900			mg/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Chromium		51			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	ICPMS2008	Thorium		7.0			mg/L
KWMK116	THORIUM1	A980490216	BT5-006c	IONCHROM	Nitrate		80000			mg/L
KWMK116	THORIUM1	A980490216	BT5-006c	HG7470	Mercury		180			ug/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Actinium-228		5.62E3		520	pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Cesium-137		3.50E2		160	pCi/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Thorium-234		5.18E3		910	pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	GAMSPEC-WP	Uranium-235		2.34E2		190	pCi/L
KWMK116	THORIUM1	A980490216	BT5-006c	TOTALACT-WP	Total Activity		7.07E4		3000	pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICP6010	Sodium		40			mg/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490233	CLB1-002d	ICPMS2008	Thorium	<	0.1			mg/L
KWMK116	THORIUM1	A980490233	CLB1-002d	IONCHROM	Nitrate		530			mg/L
KWMK116	THORIUM1	A980490233	CLB1-002d	HG7470	Mercury	<	20			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Radium-226		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Thorium-234		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	TOTALACT-WP	Total Activity		2.60E3		1700	pCi/L
KWMK116	THORIUM1	A980490233	CLB1-002d	TOTALRA-ENV	Total Radium Alpha		220		40	pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICP6010	Sodium		28500			mg/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Thorium	<	0.1			mg/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Chromium	<	50			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Vanadium	<	20			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490234	CLB2-002d	ICPMS2008	Zinc	<	100			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	IONCHROM	Nitrate		90000			mg/L
KWMK116	THORIUM1	A980490234	CLB2-002d	HG7470	Mercury	<	20			ug/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Actinium-228		2.01E3		560	pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Cesium-137		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Radium-226		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Thorium-234		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	GAMSPEC-WP	Uranium-235		NA			pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	TOTALACT-WP	Total Activity		6.87E3		1800	pCi/L
KWMK116	THORIUM1	A980490234	CLB2-002d	TOTALRA-ENV	Total Radium Alpha		400		54	pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICP6010	Sodium		44400			mg/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Thorium	<	0.1			mg/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Antimony	<	20			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Arsenic	<	100			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Barium	<	100			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Beryllium	<	20			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Cadmium	<	30			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Chromium	<	50			ug/L

THORIUM (PERMA-FIX) ----- SEE OFFICIAL LAB REPORT.

PROJ	SUB	SMPL ID	CUST SMPL ID	TEST	ANALYTE	PREFIX	RESULT	QUAL	CNFDNC	UNIT
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Lead	<	50			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Nickel	<	500			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Selenium	<	100			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Silver	<	20			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Thallium	<	20			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Thorium		NA			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Vanadium	<	20			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	ICPMS2008	Zinc	<	200			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	IONCHROM	Nitrate		130000			mg/L
KWMK116	THORIUM1	A980490235	CLB3-002d	HG7470	Mercury		76			ug/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Cesium-134		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Cesium-137		3.00E3	270		pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Cobalt-57		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Cobalt-60		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Iodine-129		1.39E3	93		pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Potassium-40		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Protactinium-234m		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Radium-226		NA			pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Thorium-234		3.91E3	920		pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	GAMSPEC-WP	Uranium-235		1.91E2	160		pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	TOTALACT-WP	Total Activity		9.84E3	1900		pCi/L
KWMK116	THORIUM1	A980490235	CLB3-002d	TOTALRA-ENV	Total Radium Alpha		900	110		pCi/L

Customer Smp1 Id: BT1-002C

Project: K-WM-K116 THORIUM1 STREAM2

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID	Date/Time Sampled: 12/11/97 09:10:00
Sample Description: THORIUM GRAB	Date/Time Received: 02/17/98 13:45:00
Location: PERMA-FIX	Date/Time Needed: 03/25/98 23:59:59
Chain of Custody No: TELEDYNE	Date/Time Completed: 03/25/98 16:03:55
Protocol: NONE	Date/Time Approved: 03/25/98 16:03:55
Charge Number: PN892605	Sample Status: APPROVED
Sampler(s):	Sample Approver:

Customer Comments: See Radcon before opening samples  
Lab Comments:

<<<<< Inorganic >>>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/08/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA Qual</u>	<u>Confidence</u>	<u>Unit</u>
7439976	Mercury	L			100		<20			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/11/98 11:31:00  
Lab Group: IYPMS1

<u>lyte Id</u>	<u>Analyte Name</u>	<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA Qual</u>	<u>Confidence</u>	<u>Unit</u>
J291	Thorium				5000000		230000			mg/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/12/98 14:04:00  
Lab Group: IYPMS1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA Qual</u>	<u>Confidence</u>	<u>Unit</u>
7440360	Antimony				1000		<200			ug/L
7440382	Arsenic				1000		<1000			ug/L
7440393	Barium				1000		<1000			ug/L
7440417	Beryllium				1000		<200			ug/L
7440439	Cadmium				1000		<300			ug/L
7440473	Chromium				1000		<500			ug/L
7439921	Lead				1000		<500			ug/L
7440020	Nickel				1000		<5000			ug/L
7782492	Selenium				1000		<1000			ug/L
7440224	Silver				1000		<200			ug/L
7440280	Thallium				1000		<200			ug/L
7440622	Vanadium				1000		<200			ug/L
7440666	Zinc				1000		<2000			ug/L

Comments: THIS SAMPLE WAS MATRIX QC SAMPLE.  
Digested spike recovery for zinc was outside 75-125% method limit.

<<<< None >>>>

Test: IONCHROM Test Name: Ion Chromatography-Water/Leach (Building 999)  
 Rpt Basis: As-Received Prep Method/Date:  
 Test Req Cnt: 01 Test Status: APPROVED  
 Analysis Meth: ASO-Y/P65-2810 HT Deadline: 01/08/98 23:59:59  
 Approver: R J MCELHANEY/Chemist Date/Time Analyzed: 02/23/98 07:00:00  
 QC Batch/File: Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		310000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP Test Name: Gamma Spectrometry by 160067  
 Rpt Basis: As-Received Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
 Test Req Cnt: 01 Test Status: APPROVED  
 Analysis Meth: ASO-ACD-160067 HT Deadline: 08/24/98 23:59:59  
 Approver: E E CLARK/Lab Supervisor Date/Time Analyzed: 03/18/98 12:00:00  
 QC Batch/File: QC98055037/WP-5317 Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						2.14E7		1.5e5	pCi/L
14109321	Cadmium-109						2.06E7		8.0e5	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m				h		NA			pCi/L
15065108	Thorium-234				h		3.59E6		3.7e5	pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
 Th-232 calculated result was 1.05e8 +/- 1.6e7 pCi/L  
 Pb-212 calculated result was 2.22e7 +/- 9.8e4 pCi/L  
 Tl-208 calculated result was 6.97e6 +/- 6.7e4 pCi/L  
 Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
 3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed. 3/25/98 AML

Test: TOTALACT-WP Test Name: Total Activity using LSC by 160063  
 Rpt Basis: As-Received Prep Method/Date:  
 Test Req Cnt: 01 Test Status: APPROVED  
 Analysis Meth: ASO-ACD-160063 HT Deadline: 06/09/98 23:59:59  
 Approver: E E CLARK/Lab Supervisor Date/Time Analyzed: 03/03/98 16:29:00  
 QC Batch/File: QC98055038/WP-5317 Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
N931	Total Activity						2.46E8		5.0E5	pCi/L

Footnotes:  
 h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smpl Id: BT2-001C

Project: K-WM-K116 THORIUM1 STREAM2

Customer: F R VAN RYN JR, BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID Date/Time Sampled: 12/02/97 10:25:00  
 Sample Description: THORIUM GRAB Date/Time Received: 02/17/98 13:45:00  
 Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
 Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:06:05  
 Protocol: NONE Date/Time Approved: 03/25/98 16:06:05  
 Charge Number: PN892605 Sample Status: APPROVED  
 Sampler(s): Sample Approver:

Customer Comments: See Radcon before opening samples  
 Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: SW846-7470  
 Approver: W E READY  
 QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline: 12/30/97 23:59:59  
 Date/Time Analyzed: 02/24/98 07:00:00  
 Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7439976	Mercury	L			100			<20			ug/L

Test: ICPMS2008  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: EPA-200.8 R4.4  
 Approver: D G AILEY/Lab Supervisor  
 QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline: 05/31/98 23:59:59  
 Date/Time Analyzed: 03/11/98 11:48:00  
 Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7291	Thorium				5000000			260000			mg/L

Test: ICPMS2008  
 Rpt Basis: As-Received  
 Test Req Cnt: 02  
 Analysis Meth: EPA-200.8 R4.4  
 Approver: D G AILEY/Lab Supervisor  
 QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline: 05/31/98 23:59:59  
 Date/Time Analyzed: 03/12/98 14:29:00  
 Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7440360	Antimony				1000			<200			ug/L
7440382	Arsenic				1000			<1000			ug/L
7440393	Barium				1000			<1000			ug/L
7440417	Beryllium				1000			<200			ug/L
7440439	Cadmium				1000			<300			ug/L
7440473	Chromium				1000			<500			ug/L
7439921	Lead				1000			<500			ug/L
7440020	Nickel				1000			<5000			ug/L
7782492	Selenium				1000			<1000			ug/L
7440224	Silver				1000			<200			ug/L
7440280	Thallium				1000			<200			ug/L
7440622	Vanadium				1000			<200			ug/L
7440666	Zinc				1000			<2000			ug/L

<<<<< None >>>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/30/97 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		410000			mg/L

<<<<< Radiochemical >>>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/24/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						2.47E7		1.5e5	pCi/L
14109321	Cadmium-109						7.25E6		8.1e5	pCi/L
14762788	Cerium-144						1.59E5		1.1e5	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
15065108	Thorium-234				h		3.78E6		3.9e5	pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.

Th-232 calculated result was 1.19e8 +/- 1.5e7 pCi/L  
Pb-212 calculated result was 2.40e7 +/- 9.5e4 pCi/L  
Tl-208 calculated result was 8.00e6 +/- 7.4e4 pCi/L  
Ra-224 calculated result was 2.57e7 +/- 6.5e5 pCi/L  
Tl-201 calculated result was 2.96e5 +/- 1.8e5 pCi/L  
Ce-141 calculated result was 8.38e5 +/- 4.2e5 pCi/L  
Ce-139 calculated result was 4.56e4 +/- 4.5e4 pCi/L  
Ra-228, Th-228 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed.

Ce-144 (133.54 keV) and Ce-139 (165.85 keV) share peaks with Tl-201. No peak contribution or correction was performed by the software.  
3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 05/31/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
N931	Total Activity						2.83E8		5.4E5	pCi/L

Notes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BT4-001C

Project: K-WM-K116 THORIUM1 STREAM2

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID  
Sample Description: THORIUM GRAB  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 12/10/97 10:34:00  
Date/Time Received: 02/17/98 13:45:00  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:07:00  
Date/Time Approved: 03/25/98 16:07:00  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening samples  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/07/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
7439976	Mercury	L			100		<20			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/08/98 23:59:59  
Date/Time Analyzed: 03/11/98 11:53:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
291	Thorium				5000000		260000			mg/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/08/98 23:59:59  
Date/Time Analyzed: 03/12/98 14:47:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
7440360	Antimony				1000		<200			ug/L
7440382	Arsenic				1000		<1000			ug/L
7440393	Barium				1000		<1000			ug/L
7440417	Beryllium				1000		<200			ug/L
7440439	Cadmium				1000		<300			ug/L
7440473	Chromium				1000		<500			ug/L
7439921	Lead				1000		<500			ug/L
7440020	Nickel				1000		<5000			ug/L
7782492	Selenium				1000		<1000			ug/L
7440224	Silver				1000		<200			ug/L
7440280	Thallium				1000		<200			ug/L
7440622	Vanadium				1000		<200			ug/L
7440666	Zinc				1000		<2000			ug/L

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 99)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/07/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		350000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/24/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Dilution	Detection	EPA		
		HT	Lim	Fn	MDA	Factor	Limit	Result	Qual	Confidence
14331830	Actinium-228							2.44E7	1.6e5	pCi/L
14109321	Cadmium-109							2.35E7	7.6e5	pCi/L
13967709	Cesium-134							NA		pCi/L
10045973	Cesium-137							NA		pCi/L
13981505	Cobalt-57							NA		pCi/L
10198400	Cobalt-60							NA		pCi/L
13966002	Potassium-40							NA		pCi/L
N2006	Protactinium-234m							NA		pCi/L
15065108	Thorium-234				h			6.38E6	4.2e5	pCi/L
15117961	Uranium-235							NA		pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.

Pb-212 calculated result was 2.50e7 +/- 1.0e5 pCi/L  
Tl-208 calculated result was 7.91e6 +/- 7.3e4 pCi/L

Ra-228, Th-228, Th-232, and Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed.

The sensitivity for this sample had to be changed to 10 in order for the software to process the peaks found. 3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/08/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Dilution	Detection	EPA		
		HT	Lim	Fn	MDA	Factor	Limit	Result	Qual	Confidence
N931	Total Activity							2.84E8	5.4E5	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smpl Id: BT5-001C

Project: K-WM-K116 THORIUM1 STREAM2

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID	Date/Time Sampled: 12/16/97 08:45:00
Sample Description: THORIUM GRAB	Date/Time Received: 02/17/98 13:45:00
Location: PERMA-FIX	Date/Time Needed: 03/25/98 23:59:59
Chain of Custody No: TELEDYNE	Date/Time Completed: 03/25/98 16:07:00
Protocol: NONE	Date/Time Approved: 03/25/98 16:07:00
Charge Number: PN892605	Sample Status: APPROVED
Sampler(s):	Sample Approver:

Customer Comments: See Radcon before opening samples  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/13/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

<u>Analyte Id</u>	<u>Analyte Name</u>	Cust			Dilution	Detection	Result	EPA		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Qual</u>	<u>Confidence</u>		
7439976	Mercury	L			100		<20			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/14/98 23:59:59  
Date/Time Analyzed: 03/11/98 11:59:00  
Lab Group: IYPMS1

<u>yte Id</u>	<u>Analyte Name</u>	Cust			Dilution	Detection	Result	EPA		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Qual</u>	<u>Confidence</u>		
J291	Thorium				5000000		260000			mg/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/14/98 23:59:59  
Date/Time Analyzed: 03/12/98 14:53:00  
Lab Group: IYPMS1

<u>Analyte Id</u>	<u>Analyte Name</u>	Cust			Dilution	Detection	Result	EPA		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Qual</u>	<u>Confidence</u>		
7440360	Antimony				1000		290			ug/L
7440382	Arsenic				1000		<1000			ug/L
7440393	Barium				1000		<1000			ug/L
7440417	Beryllium				1000		<200			ug/L
7440439	Cadmium				1000		<300			ug/L
7440473	Chromium				1000		<500			ug/L
7439921	Lead				1000		<500			ug/L
7440020	Nickel				1000		<5000			ug/L
7782492	Selenium				1000		<1000			ug/L
7440224	Silver				1000		<200			ug/L
7440280	Thallium				1000		<200			ug/L
7440522	Vanadium				1000		<200			ug/L
7440566	Zinc				1000		13000			ug/L

<<<<< None >>>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 999)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/13/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		410000			mg/L

<<<<< Radiochemical >>>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						2.51E7		1.6e5	pCi/L
14109321	Cadmium-109						6.60E6		7.9e5	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m				h		4.31E6		2.8e6	pCi/L
15065108	Thorium-234				h		4.12E6		3.8e5	pCi/L
15117961	Uranium-235						3.85E4		1.9e4	pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.

Th-232 calculated result was 1.07e8 +/- 1.4e7 pCi/L  
Pb-212 calculated result was 5.82e6 +/- 5.3e4 pCi/L  
Tl-208 calculated result was 8.12e6 +/- 7.2e4 pCi/L  
Tl-201 calculated result was 2.87e5 +/- 2.1e5 pCi/L  
Ce-141 calculated result was 6.17e5 +/- 3.5e5 pCi/L  
Ce-139 calculated result was 5.74e4 +/- 4.2e4 pCi/L  
Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed.

Ce-139 (165.85 keV) shares a peak with Tl-201.  
No peak contribution or correction was performed by the software.

3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/14/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
N931	Total Activity						2.68E8		5.2E5	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BT2-005d Project: K-WM-K116 THORIUM1 STREAM8

Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID Date/Time Sampled: 12/03/97 15:33:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:00  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:31:23  
Protocol: NONE Date/Time Approved: 03/25/98 16:31:23  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments:  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7471  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7471  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Solid Waste/Soil/Sludge by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 03/17/98 09:30:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
									Qual	Confidence	Unit
7439976	Mercury	L				1		<0.2			ug/g

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084005/Q98078D

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3050A 03/17/98 16:30:00  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/19/98 17:49:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
									Qual	Confidence	Unit
0235	Sodium					4079		21200			mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet sample basis.

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/23/98 14:29:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
									Qual	Confidence	Unit
7440291	Thorium					500000		780000			ug/g

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/23/98 19:41:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
									Qual	Confidence	Unit
7440360	Antimony					100		<2			ug/g
7440382	Arsenic					100		<10			ug/g
7440393	Barium					100		<10			ug/g
7440417	Beryllium					100		<2			ug/g
7440439	Cadmium					100		<3			ug/g
7440473	Chromium					100		<5			ug/g
0921	Lead					100		<5			ug/g

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
7440020	Nickel				100		<50			ug/g	
7782492	Selenium				100		<10			ug/g	
7440224	Silver				100		<2			ug/g	
7440280	Thallium				100		<2			ug/g	
7440622	Vanadium				100		<2			ug/g	
7440666	Zinc				100		<20			ug/g	

Test: PREP3050  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3050A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 16:30:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/26/98 13:30:00  
Lab Group: MYCHM1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
14797558	Nitrate	L			1		36000			ug/g	

Test: KARL-FISCHER  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASTM-D1533-88  
Approver: C A CHAMBERS/Lab Supervisor  
QC Batch/File: QC98071019

Test Name: Karl Fischer Reagent Moisture Analysis  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/06/98 07:00:00  
Lab Group: MYWST1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
N544	Moisture				1		465000			ug/g	

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 08:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
14331830	Actinium-228						3.24E4		6.6e2	pCi/g	
14109321	Cadmium-109						2.05E4		2.8e3	pCi/g	
13967709	Cesium-134						NA			pCi/g	
10045973	Cesium-137						NA			pCi/g	
13981505	Cobalt-57						NA			pCi/g	
10198400	Cobalt-60						NA			pCi/g	
13966002	Potassium-40						NA			pCi/g	
N2006	Protactinium-234m						NA			pCi/g	
15065108	Thorium-234			h			5.01E3		1.3e3	pCi/g	
15117961	Uranium-235						NA			pCi/g	

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
Th-232 calculated result was 9.11e4 +/- 5.2e4 pCi/g  
Tl-208 calculated result was 1.24e4 +/- 3.3e2 pCi/g  
Pb-212 calculated result was 2.73e4 +/- 4.1e2 pCi/g  
Ra-228, Ra-224, Th-228: these isotopes were analyzed for but not detected.  
3/18/98 kal

Test: GROSSAB-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
ysis Meth: ASO-ACD-160082  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
Test Status: APPROVED  
HT Deadline: 09/07/98 23:59:59  
Date/Time Analyzed: 03/16/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
12587461	Alpha activity						3.20E5		1.3E4	pCi/g
12587472	Beta activity						1.33E5		6.0E3	pCi/g

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 14:26:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						3.73E5		3.8e3	pCi/g

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smpl Id: BT4-005d Project: K-WM-K116 THORIUM1 STREAM8

Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID Date/Time Sampled: 12/11/97 19:06:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:00  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:32:57  
Protocol: NONE Date/Time Approved: 03/25/98 16:32:57  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments:  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7471  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7471  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Solid Waste/Soil/Sludge by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/08/98 23:59:59  
Date/Time Analyzed: 03/17/98 09:30:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Lim	Fn	Cust	Dilution	Factor	Detection	Limit	Result	EPA			
											Qual	Confidence	Unit	
7439976	Mercury	L				1				<0.2				ug/g

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084005/Q98078D

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3050A 03/17/98 16:30:00  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/19/98 17:49:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	HT	Lim	Fn	Cust	Dilution	Factor	Detection	Limit	Result	EPA			
											Qual	Confidence	Unit	
7440235	Sodium					4944				7600				mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet sample basis.

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/23/98 14:52:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Lim	Fn	Cust	Dilution	Factor	Detection	Limit	Result	EPA			
											Qual	Confidence	Unit	
7440291	Thorium					500000				870000				ug/g

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/23/98 20:06:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Lim	Fn	Cust	Dilution	Factor	Detection	Limit	Result	EPA			
											Qual	Confidence	Unit	
7440360	Antimony					100				<2				ug/g
7440382	Arsenic					100				<10				ug/g
7440393	Barium					100				<10				ug/g
7440417	Beryllium					100				<10				ug/g
7440439	Cadmium					100				<3				ug/g
7440473	Chromium					100				<5				ug/g
7439921	Lead					100				<5				ug/g

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
0020	Nickel				100			<50			ug/g
02492	Selenium				100			<10			ug/g
7440224	Silver				100			<2			ug/g
7440280	Thallium				100			<2			ug/g
7440622	Vanadium				100			<2			ug/g
7440666	Zinc				100			<20			ug/g

Test: PREP3050  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: SW846-3050A  
 Approver: R M WILKES/Chemist  
 QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline:  
 Date/Time Analyzed: 03/17/98 16:30:00  
 Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-Y/P65-2810  
 Approver: R J MCELHANEY/Chemist  
 QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline: 01/08/98 23:59:59  
 Date/Time Analyzed: 02/26/98 13:30:00  
 Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
14797558	Nitrate	L			1			12000			ug/g

Test: KARL-FISCHER  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASTM-D1533-88  
 Approver: C A CHAMBERS/Lab Supervisor  
 QC Batch/File: QC98071019

Test Name: Karl Fischer Reagent Moisture Analysis  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline:  
 Date/Time Analyzed: 03/06/98 07:00:00  
 Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
N544	Moisture				1			253000			ug/g

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-ACD-160067  
 Approver: E E CLARK/Lab Supervisor  
 QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
 Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
 Test Status: APPROVED  
 HT Deadline: 09/03/98 23:59:59  
 Date/Time Analyzed: 03/09/98 08:00:00  
 Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit	
14331830	Actinium-228							3.96E4		6.4e2	pCi/g
13967709	Cesium-134							NA			pCi/g
10045973	Cesium-137							NA			pCi/g
13981505	Cobalt-57							NA			pCi/g
10198400	Cobalt-60							NA			pCi/g
13966002	Potassium-40							NA			pCi/g
N2006	Protactinium-234m							NA			pCi/g
15065108	Thorium-234				h			9.42E3		1.1e3	pCi/g
15117961	Uranium-235							NA			pCi/g

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
 Th-232 calculated result was 1.20e5 +/- 5.9e4 pCi/g  
 Pb-212 calculated result was 4.12e4 +/- 3.7e2 pCi/g  
 Tl-208 calculated result was 1.59e4 +/- 3.5e2 pCi/g  
 Ra-224, Ra-228, Th-228 were analyzed for but were not detected.  
 3/18/98 kal

Test: GROSSAB-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160082  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
Test Status: APPROVED  
HT Deadline: 09/07/98 23:59:59  
Date/Time Analyzed: 03/16/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
12587461	Alpha activity			t			4.33E5	1.4E4		pCi/g
12587472	Beta activity						1.57E5	6.2E3		pCi/g

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 14:26:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity			d			4.79E5	4.1e3		pCi/g

Footnotes:

- d - Spike control limits do not apply, sample activity exceeds the activity of the spike
- h - Daughter of uranium isotopes, reported for comparison purposes only
- t - Acceptable spike recovery limits for non-aqueous matrices are 50%-150%

Customer Smp1 Id: BT5-005d

Project: K-WM-K116 THORIUM1 STREAM8

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 12/18/97 09:54:00  
Date/Time Received: 02/17/98 13:45:00  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:35:03  
Date/Time Approved: 03/25/98 16:35:03  
Sample Status: APPROVED  
Sample Approver:

Customer Comments:  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7471  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7471  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Solid Waste/Soil/Sludge by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 03/17/98 09:30:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7439976	Mercury	L				1		<0.2			ug/g

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084005/Q98078D

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3050A 03/17/98 16:30:00  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/19/98 17:49:00  
Lab Group: IYICP2

lyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
J235	Sodium					4373		12300			mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet sample basis.

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/23/98 15:09:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7440291	Thorium					500000		640000			ug/g

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/23/98 20:24:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7440360	Antimony					100		<2			ug/g
7440382	Arsenic					100		<10			ug/g
7440393	Barium					100		<10			ug/g
7440417	Beryllium					100		<2			ug/g
7440439	Cadmium					100		<3			ug/g
7440473	Chromium					100		<5			ug/g
7439921	Lead					100		<5			ug/g

Official Report

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
7440020	Nickel				100			<50			ug/g
7782492	Selenium				100			<10			ug/g
7440224	Silver				100			<2			ug/g
7440280	Thallium				100			<2			ug/g
7440622	Vanadium				100			<2			ug/g
7440666	Zinc				100			<20			ug/g

Test: PREP3050  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: SW846-3050A  
 Approver: R M WILKES/Chemist  
 QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline:  
 Date/Time Analyzed: 03/17/98 16:30:00  
 Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-Y/P65-2810  
 Approver: R J MCELHANEY/Chemist  
 QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline: 01/15/98 23:59:59  
 Date/Time Analyzed: 02/26/98 13:00:00  
 Lab Group: MYCHM1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
14797558	Nitrate	L			1			38000			ug/g

Test: KARL-FISCHER  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASTM-D1533-88  
 Approver: C A CHAMBERS/Lab Supervisor  
 QC Batch/File: QC98071019

Test Name: Karl Fischer Reagent Moisture Analysis  
 Prep Method/Date:  
 Test Status: APPROVED  
 HT Deadline:  
 Date/Time Analyzed: 03/06/98 07:00:00  
 Lab Group: MYWST1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
N544	Moisture				1			209000			ug/g

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-ACD-160067  
 Approver: E E CLARK/Lab Supervisor  
 QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
 Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
 Test Status: APPROVED  
 HT Deadline: 09/03/98 23:59:59  
 Date/Time Analyzed: 03/09/98 08:00:00  
 Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
14331830	Actinium-228						2.13E4		5.2e2	pCi/g
14109321	Cadmium-109						1.83E4		2.0e3	pCi/g
13967709	Cesium-134						NA			pCi/g
10045973	Cesium-137						NA			pCi/g
13981505	Cobalt-57						NA			pCi/g
10198400	Cobalt-60						NA			pCi/g
13966002	Potassium-40						NA			pCi/g
N2006	Protactinium-234m						NA			pCi/g
15065108	Thorium-234				h		3.18E3		9.0e2	pCi/g
15117961	Uranium-235						NA			pCi/g

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
 Tl-208 calculated result was 1.24e4 +/- 3.0e2 pCi/g  
 Pb-212 calculated result was 2.81e4 +/- 3.4e2 pCi/g  
 Ra-228, Ra-224, Th-232, Th-228 were analyzed for but not detected.  
 3/18/98 kal

Test: GROSSAB-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
/sis Meth: ASO-ACD-160082  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
Test Status: APPROVED  
HT Deadline: 09/07/98 23:59:59  
Date/Time Analyzed: 03/16/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
12587461	Alpha activity						2.59E5		1.1E4	pCi/g
12587472	Beta activity						8.72E4		4.6E3	pCi/g

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 14:26:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						3.35E5		3.4e3	pCi/g

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BT2-007e Project: K-WM-K116 THORIUM1 STREAM11B

Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID	Date/Time Sampled: 12/03/97 21:26:00
Sample Description: THORIUM DEMO	Date/Time Received: 02/17/98 13:45:00
Location: PERMA-FIX	Date/Time Needed: 03/25/98 23:59:59
Chain of Custody No: TELEDYNE	Date/Time Completed: 03/26/98 08:26:27
Protocol: NONE	Date/Time Approved: 03/26/98 08:26:27
Charge Number: PN892605	Sample Status: APPROVED
Sampler(s):	Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: ICP6010	Test Name: Elements by EPA 6010A ICP-AES
Rpt Basis: As-Received	Prep Method/Date: SW846-3050A 03/17/98 16:30:00
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: SW846-6010A	HT Deadline: 06/01/98 23:59:59
Approver: R M WILKES/Chemist	Date/Time Analyzed: 03/20/98 13:43:00
QC Batch/File: QC98084006/Q98079E	Lab Group: IYICP2

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>	
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
7440235	Sodium				7047			32000		mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet weight sample basis.  
Secondary 20 fold dilution prior to analysis

Test: ICPMS2008	Test Name: Elements by EPA 200.8 ICPMS
Rpt Basis: As-Received	Prep Method/Date:
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: EPA-200.8 R4.4	HT Deadline: 06/01/98 23:59:59
Approver: D G AILEY/Lab Supervisor	Date/Time Analyzed: 03/23/98 16:57:00
QC Batch/File:	Lab Group: IYPMS1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>	
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
7440291	Thorium				100000			490000		ug/g

Test: ICPMSTCLP	Test Name: Elements in TCLP Extracts by ICPMS
Rpt Basis: As-Received	Prep Method/Date:
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: SW846-6020	HT Deadline: 08/23/98 23:59:59
Approver: D G AILEY/Lab Supervisor	Date/Time Analyzed: 02/27/98 12:35:00
QC Batch/File: QC98084009/C980324A	Lab Group: IYPMS1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>	
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
7440360	Antimony	P			1000			<200		ug/L
7440382	Arsenic	P			1000			<1000		ug/L
7440393	Barium	P			100			710		ug/L
7440417	Beryllium	P			100			<20		ug/L
7440439	Cadmium	P			100			<30		ug/L
7440473	Chromium	P			100			<50		ug/L
7439921	Lead	P			100			<50		ug/L
7440020	Nickel	P			100			<39		ug/L
7440224	Silver	P			100			<20		ug/L
7440280	Thallium	P			100			<20		ug/L
7440622	Vanadium	P			100			<20		ug/L
7440666	Zinc	P			100			390		ug/L

Test: PREP3050  
Rpt Basis: As-Received  
t Req Cnt: 01  
Analysis Meth: SW846-3050A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 16:30:00  
Lab Group: IYICP2

Test: TCLPHG  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury In TCLP Extract by Cold Vapor AA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 03/24/98 23:59:59  
Date/Time Analyzed: 02/26/98 07:00:00  
Lab Group: MYWST1

Analyte Id Analyte Name  
7439976 Mercury

HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
P			1		<20			ug/L

Test: TCLPSE  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7740  
Approver: W E READY  
QC Batch/File:

Test Name: Selenium In TCLP Extract by GFAA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/20/98 07:00:00  
Lab Group: MYWST1

Analyte Id Analyte Name  
7782492 Selenium

HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
		de	200		<400			ug/L

Footnotes:

- d - Dilution is due to sample matrix
- e - Results should be considered estimated

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/26/98 13:30:00  
Lab Group: MYCHM1

Analyte Id Analyte Name  
14797558 Nitrate

HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA Qual	Confidence	Unit
L			1		58000			ug/g

Test: TCLPEXN-NV  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-1311  
Approver: C A HUBBUCH  
QC Batch/File: QC98054014

Test Name: TCLP Extn for NonVolatiles  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/17/97 23:59:59  
Date/Time Analyzed: 02/23/98 08:40:00  
Lab Group: MYWST1

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 08:00:00  
Lab Group: RKRAD1

Analyte Id Analyte Name  
14331830 Actinium-228  
14109321 Cadmium-109  
13967709 Cesium-134  
15973 Cesium-137

HT	Lim	Fn	MDA	Detection Limit	Result	EPA Qual	Confidence	Unit
					5.73E4		7.1e2	pCi/g
		f			3.77E3		4.0e3	pCi/g
					NA			pCi/g
					NA			pCi/g

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
13981505	Cobalt-57						NA			pCi/g
10198400	Cobalt-60						NA			pCi/g
13966002	Potassium-40						NA			pCi/g
N2006	Protactinium-234m						NA			pCi/g
15065108	Thorium-234			h			7.33E3	1.5e3		pCi/g
15117961	Uranium-235						NA			pCi/g

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
 Th-232 calculated result was 1.90e5 +/- 3.5e4 pCi/g  
 Pb-212 calculated result was 5.85e4 +/- 4.3e2 pCi/g  
 Tl-208 calculated result was 1.89e4 +/- 3.5e2 pCi/g  
 Ra-228, Ra-224, Th-228 isotopes were analyzed for, but were not detected.  
 3/18/98 kal

Test: GROSSAB-WP  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-ACD-160082  
 Approver: E E CLARK/Lab Supervisor  
 QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
 Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
 Test Status: APPROVED  
 HT Deadline: 09/07/98 23:59:59  
 Date/Time Analyzed: 03/16/98 12:00:00  
 Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
12587461	Alpha activity						1.36E5	7.3E3		pCi/g
12587472	Beta activity						6.63E4	3.7E3		pCi/g

Test: TOTALACT-WP  
 Rpt Basis: As-Received  
 Test Req Cnt: 01  
 Analysis Meth: ASO-ACD-160063  
 Approver: E E CLARK/Lab Supervisor  
 QC Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
 Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
 Test Status: APPROVED  
 HT Deadline: 09/03/98 23:59:59  
 Date/Time Analyzed: 03/09/98 14:26:00  
 Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						5.76E5	4.0e3		pCi/g

Footnotes:  
 f - Tentatively identified isotope (TII)  
 h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BT4-007e Project: K-WM-K116 THORIUM1 STREAM11B

Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID	Date/Time Sampled: 12/12/97 12:14:00
Sample Description: THORIUM DEMO	Date/Time Received: 02/17/98 13:45:00
Location: PERMA-FIX	Date/Time Needed: 03/25/98 23:59:59
Chain of Custody No: TELEDYNE	Date/Time Completed: 03/26/98 08:26:27
Protocol: NONE	Date/Time Approved: 03/26/98 08:26:27
Charge Number: PN892605	Sample Status: APPROVED
Sampler(s):	Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: ICP6010	Test Name: Elements by EPA 6010A ICP-AES
Rpt Basis: As-Received	Prep Method/Date: SW846-3050A 03/17/98 16:30:00
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: SW846-6010A	HT Deadline: 06/10/98 23:59:59
Approver: R M WILKES/Chemist	Date/Time Analyzed: 03/20/98 13:43:00
QC Batch/File: QC98084006/Q98079E	Lab Group: IYICP2

Analyte Id	Analyte Name	Cust			Dilution Factor	Detection Limit	Result	EPA		Unit
		HT	Lim	Fn				Qual	Confidence	
7440235	Sodium				8834		13900			mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet weight sample basis.  
Secondary 29.99999 fold dilution prior to analysis

Test: ICPMS2008	Test Name: Elements by EPA 200.8 ICPMS
Rpt Basis: As-Received	Prep Method/Date:
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: EPA-200.8 R4.4	HT Deadline: 06/10/98 23:59:59
Approver: D G AILEY/Lab Supervisor	Date/Time Analyzed: 03/23/98 15:21:00
QC Batch/File:	Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution Factor	Detection Limit	Result	EPA		Unit
		HT	Lim	Fn				Qual	Confidence	
7440291	Thorium				10000		27000			ug/g

Test: ICPMSTCLP	Test Name: Elements in TCLP Extracts by ICPMS
Rpt Basis: As-Received	Prep Method/Date:
Test Req Cnt: 01	Test Status: APPROVED
Analysis Meth: SW846-6020	HT Deadline: 08/23/98 23:59:59
Approver: D G AILEY/Lab Supervisor	Date/Time Analyzed: 02/27/98 13:05:00
QC Batch/File: QC98084009/C980324A	Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution Factor	Detection Limit	Result	EPA		Unit
		HT	Lim	Fn				Qual	Confidence	
7440360	Antimony	P			1000		<200			ug/L
7440382	Arsenic	P			1000		<1000			ug/L
7440393	Barium	P			100		<100			ug/L
7440417	Beryllium	P			100		<20			ug/L
7440439	Cadmium	P			100		<30			ug/L
7440473	Chromium	P			100		<50			ug/L
7439921	Lead	P			100		<50			ug/L
7440020	Nickel	P			100		<300			ug/L
7440224	Silver	P			100		<20			ug/L
7440280	Thallium	P			100		<20			ug/L
7440622	Vanadium	P			100		<20			ug/L
7440666	Zinc	P			100		<200			ug/L

Test: PREP3050  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3050A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 16:30:00  
Lab Group: IYICP2

Test: TCLPHG  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury In TCLP Extract by Cold Vapor AA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 03/24/98 23:59:59  
Date/Time Analyzed: 02/26/98 07:00:00  
Lab Group: MYWST1

Analyte Id Analyte Name  
7439976 Mercury

Cust			Dilution	Detection	EPA			
HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
P			1		<20			ug/L

Test: TCLPSE  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7740  
Approver: W E READY  
QC Batch/File:

Test Name: Selenium In TCLP Extract by GFAA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/10/98 23:59:59  
Date/Time Analyzed: 03/20/98 07:00:00  
Lab Group: MYWST1

Analyte Id Analyte Name  
7782492 Selenium

Cust			Dilution	Detection	EPA			
HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
			de 200		<400			ug/L

ootnotes:

- d - Dilution is due to sample matrix
- e - Results should be considered estimated

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/09/98 23:59:59  
Date/Time Analyzed: 02/26/98 14:00:00  
Lab Group: MYCHM1

Analyte Id Analyte Name  
14797558 Nitrate

Cust			Dilution	Detection	EPA			
HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
L			1		22000			ug/g

Test: TCLPEXN-NV  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-1311  
Approver: C A HUBBUCH  
QC Batch/File: QC98054014

Test Name: TCLP Extn for NonVolatiles  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/26/97 23:59:59  
Date/Time Analyzed: 02/23/98 08:40:00  
Lab Group: MYWST1

<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 08:00:00  
Lab Group: RKRAD1

Analyte Id Analyte Name  
14331830 Actinium-228  
14109321 Cadmium-109  
13967709 Cesium-134  
10045973 Cesium-137

Cust			Dilution	Detection	EPA			
HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
					7.05E4		7.7e2	pCi/g
					4.57E4		3.8e3	pCi/g
					NA			pCi/g
					NA			pCi/g

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
981505	Cobalt-57						NA			pCi/g
98400	Cobalt-60						NA			pCi/g
13966002	Potassium-40						NA			pCi/g
N2006	Protactinium-234m						NA			pCi/g
15065108	Thorium-234						NA			pCi/g
15117961	Uranium-235						NA			pCi/g

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
Th-232 calculated result was 2.54e5 +/- 5.2e4 pCi/g  
Pb-212 calculated result was 1.57e4 +/- 2.2e2 pCi/g  
Tl-208 calculated result was 2.34e4 +/- 3.7e2 pCi/g  
Ra-228, Ra-224, Th-228 isotopes were analyzed for, but were not detected.  
Ce-141 calculated result was 1.17e3 +/- 1.1e3 pCi/g  
3/18/98 kal

Test: GROSSAB-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160082  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
Test Status: APPROVED  
HT Deadline: 09/07/98 23:59:59  
Date/Time Analyzed: 03/16/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
12587461	Alpha activity						5.95E5		1.5E4	pCi/g
12587472	Beta activity						2.38E5		6.4E3	pCi/g

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 14:26:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						6.84E5		4.2e3	pCi/g

Customer Smp1 Id: BT5-007e

Project: K-WM-K116 THORIUM1 STREAM11B

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: SOLID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 12/18/97 15:19:00  
Date/Time Received: 02/17/98 13:45:00  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/26/98 08:27:07  
Date/Time Approved: 03/26/98 08:27:07  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084006/Q98079E

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3050A 03/17/98 16:30:00  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/20/98 13:43:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		Unit
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence		
7440235	Sodium				9591						mg/kg

Comments: Results obtained from 1gm subsample and may not be representative of sample in the container from which the subsample was taken. Results are reported on a wet weight sample basis.  
Secondary 30 fold dilution prior to analysis

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/23/98 17:02:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		Unit
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence		
7440291	Thorium				100000						ug/g

Test: ICPMSTCLP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6020  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File: QC98084009/C980324A

Test Name: Elements in TCLP Extracts by ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 08/23/98 23:59:59  
Date/Time Analyzed: 02/27/98 13:17:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		Unit
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence		
7440360	Antimony	P			1000			<200			ug/L
7440382	Arsenic	P			1000			<1000			ug/L
7440393	Barium	P			100			840			ug/L
7440417	Beryllium	P			100			<20			ug/L
7440439	Cadmium	P			100			<50			ug/L
7440473	Chromium	P			100			<50			ug/L
7439921	Lead	P			100			<50			ug/L
7440020	Nickel	P			100			<300			ug/L
7440224	Silver	P			100			<20			ug/L
7440280	Thallium	P			100			<20			ug/L
7440622	Vanadium	P			100			<20			ug/L
7440666	Zinc	P			100			210			ug/L

Test: PREP3050  
Rpt Basis: As-Received  
t Req Cnt: 01  
Analysis Meth: SW846-3050A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98072028

Test Name: Prep by 3050 (Soil/Sludge/Solid)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 16:30:00  
Lab Group: IYICP2

Test: TCLPHG  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury In TCLP Extract by Cold Vapor AA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 03/24/98 23:59:59  
Date/Time Analyzed: 02/26/98 07:00:00  
Lab Group: MYWST1

Analyte Id   Analyte Name  
7439976   Mercury

<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA</u>		
						<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
P			1		<20			ug/L

Test: TCLPSE  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7740  
Approver: W E READY  
QC Batch/File:

Test Name: Selenium In TCLP Extract by GFAA  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/20/98 07:00:00  
Lab Group: MYWST1

Analyte Id   Analyte Name  
7782492   Selenium

<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA</u>		
						<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
			de 200		<400			ug/L

Footnotes:

- d - Dilution is due to sample matrix
- e - Results should be considered estimated

<<<<<   None   >>>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 02/27/98 12:00:00  
Lab Group: MYCHM1

Analyte Id   Analyte Name  
14797558   Nitrate

<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Dilution Factor</u>	<u>Detection Limit</u>	<u>Result</u>	<u>EPA</u>		
						<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
L			1		70000			ug/g

Test: TCLPEXN-NV  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-1311  
Approver: C A HUBBUCH  
QC Batch/File: QC98054014

Test Name: TCLP Extn for NonVolatiles  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/01/98 23:59:59  
Date/Time Analyzed: 02/23/98 08:40:00  
Lab Group: MYWST1

Comments: TCLP - Insufficient sample to extract 100 g. 75.42g sample extracted in 2000 ml extraction fluid in error. Result corrections must be made by the user of this data. Sample should have been extracted in 1508 ml extraction fluid. 2-24-98 CA Hubbuch 34856

<<<<< Radiochemical >>>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055034/WP-5318

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 03/07/98 13:50:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 08:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						4.39E4		5.8e2	pCi/g
14109321	Cadmium-109						2.61E4		2.7e3	pCi/g
13967709	Cesium-134						NA			pCi/g
10045973	Cesium-137						NA			pCi/g
13981505	Cobalt-57						NA			pCi/g
10198400	Cobalt-60						NA			pCi/g
13966002	Potassium-40						NA			pCi/g
N2006	Protactinium-234m						NA			pCi/g
15065108	Thorium-234			h			5.32E3		1.2e3	pCi/g
15117961	Uranium-235						NA			pCi/g

Comments: Ra-228, Ra-224, Th-232, Th-228, Pb-212, and Tl-208 were analyzed at the customer's request.  
Th-232 calculated result was 9.63e4 +/- 4.3e4 pCi/g  
Pb-212 calculated result was 5.27e4 +/- 3.6e2 pCi/g  
Tl-208 calculated result was 1.81e4 +/- 3.2e2 pCi/g  
Ra-228, Ra-224, Th-228 isotopes were analyzed for, but were not detected.  
3/18/98 kal

Test: GROSSAB-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160082  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055036/WP-5318

Test Name: Gross Alpha/Beta Act. by 160060  
Prep Method/Date: ASO-ACD-160068 03/11/98 10:30:00  
Test Status: APPROVED  
HT Deadline: 09/07/98 23:59:59  
Date/Time Analyzed: 03/16/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
12587461	Alpha activity						3.80E5		1.1E4	pCi/g
12587472	Beta activity						1.55E5		5.0E3	pCi/g

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055035/WP-5318

Test Name: Total Activity using LSC by 160063  
Prep Method/Date: ASO-ACD-160084 03/07/98 12:30:00  
Test Status: APPROVED  
HT Deadline: 09/03/98 23:59:59  
Date/Time Analyzed: 03/09/98 14:26:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
N931	Total Activity						5.11E5		3.5e3	pCi/g

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BT2-009c

Project: K-WM-K116 THORIUM1 STREAMS13

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 12/03/97 21:17:00  
Date/Time Received: 02/17/98 13:45:42  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:32:53  
Date/Time Approved: 03/25/98 16:32:53  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7439976	Mercury	L			100		<20			ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

lyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
J235	Sodium				20		20			mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/12/98 15:41:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440360	Antimony				100		<20			ug/L
7440382	Arsenic				100		<100			ug/L
7440393	Barium				100		<100			ug/L
7440417	Beryllium				100		<20			ug/L
7440439	Cadmium				100		<30			ug/L
7440473	Chromium				100		<50			ug/L
7439921	Lead				100		<50			ug/L
7440020	Nickel				100		<500			ug/L
7782492	Selenium				100		<100			ug/L
7440224	Silver				100		<20			ug/L
7440280	Thallium				100		<20			ug/L
7440291	Thorium				100		NA			ug/L
7440622	Vanadium				100		<20			ug/L
7440666	Zinc				100		<200			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/20/98 14:07:00  
Lab Group: IYPM51

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440291	Thorium				10000		530			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<<< None >>>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		1300			mg/L

<<<<< Radiochemical >>>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Dilution	Detection	EPA		
		HT	Lim	Fn	MDA	Factor	Limit	Result	Qual	Confidence
14331830	Actinium-228						9.21E4		1.7e3	pCi/L
14109321	Cadmium-109						6.42E4		6.7e3	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
15065108	Thorium-234				h		1.58E4		3.2e3	pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.

Th-232 calculated result was 2.48e5 +/- 1.6e5 pCi/L  
Pb-212 calculated result was 9.95e4 +/- 1.0e3 pCi/L  
Tl-208 calculated result was 3.44e4 +/- 8.8e2 pCi/L  
Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed. 3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
t Req Cnt: 01  
/sis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fa</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity			d		9.77E5		9.7E3	pCi/L

Footnotes:

- d - Spike control limits do not apply, sample activity exceeds the activity of the spike
- h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smpl Id: BT2-006a Project: K-WM-K116 THORIUM1 STREAMS13  
Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID Date/Time Sampled: 12/03/97 15:22:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:42  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:31:23  
Protocol: NONE Date/Time Approved: 03/25/98 16:31:23  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Cust			Detection Limit	Result	EPA		Unit
			Lim	Fn	Factor			Qual	Confidence	
7439976	Mercury	L			100	<20				ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084006/Q98079E

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/20/98 13:43:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	HT	Cust			Detection Limit	Result	EPA		Unit
			Lim	Fn	Factor			Qual	Confidence	
7440235	Sodium				40	30700				mg/L

Comments: PREPARED BY SW846 3010A.  
Secondary 2 fold dilution prior to analysis

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:00:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Cust			Detection Limit	Result	EPA		Unit
			Lim	Fn	Factor			Qual	Confidence	
7440360	Antimony				100	<20				ug/L
7440382	Arsenic				100	<100				ug/L
7440393	Barium				100	<100				ug/L
7440417	Beryllium				100	<20				ug/L
7440439	Cadmium				100	<30				ug/L
7440473	Chromium				100	210				ug/L
7439921	Lead				100	<50				ug/L
7440020	Nickel				100	<500				ug/L
7782492	Selenium				100	<100				ug/L
7440224	Silver				100	<20				ug/L
7440280	Thallium				100	<20				ug/L
7440291	Thorium				100	NA				ug/L
7440622	Vanadium				100	<20				ug/L
7440666	Zinc				100	<200				ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:19:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7440291	Thorium				100			<0.10			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 12/31/97 23:59:59  
Date/Time Analyzed: 02/23/98 09:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
14797558	Nitrate	L			1			94000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit	
14331830	Actinium-228							6.49E3		6.2e2	pCi/L
13967709	Cesium-134							NA			pCi/L
10045973	Cesium-137							NA			pCi/L
13981505	Cobalt-57							NA			pCi/L
10198400	Cobalt-60							NA			pCi/L
13966002	Potassium-40							NA			pCi/L
N2006	Protactinium-234m							NA			pCi/L
15065108	Thorium-234							1.81E3		1.2e3	pCi/L
15117961	Uranium-235							1.76E2		3.3e2	pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Pb-212 calculated result was 2.52e3 +/- 2.2e2 pCi/L  
Tl-208 calculated result was 7.97e2 +/- 2.3e2 pCi/L  
Th-232, Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

LIMS 05.02.024  
03/26/98 10:35

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Page: 3 of 3  
Lab Smp1 Id: A980490212

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/01/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						7.55E4		3.1e3	pCi/L

Footnotes:

- h - Daughter of uranium isotopes, reported for comparison purposes only
- v - Result is less than MDA, confidence level is less than 95%

\*\*\*\*\* END OF REPORT \*\*\*\*\*  
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Customer Smpl Id: BT4-009c Project: K-WM-K116 THORIUM1 STREAMS13

Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID Date/Time Sampled: 12/12/97 10:52:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:42  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:34:36  
Protocol: NONE Date/Time Approved: 03/25/98 16:34:36  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/09/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit		Qual	Confidence	
7439976	Mercury	L			100		<20			ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/10/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

vte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit		Qual	Confidence	
0235	Sodium				20		40			mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/10/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:06:00  
Lab Group: IYFMS1

Analyte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit		Qual	Confidence	
7440360	Antimony				100		<20			ug/L
7440382	Arsenic				100		<100			ug/L
7440393	Barium				100		<100			ug/L
7440417	Beryllium				100		<20			ug/L
7440439	Cadmium				100		<30			ug/L
7440473	Chromium				100		<50			ug/L
7439921	Lead				100		<50			ug/L
7440020	Nickel				100		<500			ug/L
7782492	Selenium				100		<100			ug/L
7440224	Silver				100		<20			ug/L
7440280	Thallium				100		<20			ug/L
7440291	Thorium				100		NA			ug/L
7440622	Vanadium				100		<20			ug/L
7440666	Zinc				100		<200			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G ALLEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/10/98 23:59:59  
Date/Time Analyzed: 03/20/98 14:24:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440291	Thorium				10000		350			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/09/98 23:59:59  
Date/Time Analyzed: 02/23/98 09:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		240			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228					8.08E4		1.3e3		pCi/L
14109321	Cadmium-109					1.50E4		5.2e3		pCi/L
13967709	Cesium-134					NA				pCi/L
10045973	Cesium-137					NA				pCi/L
13981505	Cobalt-57					NA				pCi/L
10198400	Cobalt-60					NA				pCi/L
13966002	Potassium-40					NA				pCi/L
N2006	Protactinium-234m					NA				pCi/L
15065108	Thorium-234					NA				pCi/L
15117961	Uranium-235					NA				pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Th-232 calculated result was 1.71e5 +/- 6.5e4 pCi/L  
Pb-212 calculated result was 5.02e4 +/- 8.2e2 pCi/L  
Tl-208 calculated result was 1.56e4 +/- 5.8e2 pCi/L  
Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed. 3/25/98 AML

LIMS 05.02.024  
03/26/98 10:35

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Page: 3 of 3  
Lab Smp1 Id: A980490213

Test: TOTALACT-WP  
Rpt Basis: AS-Received  
t Req Cnt: 01  
ysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/10/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>	<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Detection</u>	<u>Limit</u>	<u>Result</u>	<u>EPA</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity								9.79E5			9.7e3	pCi/L

\*\*\*\*\* END OF REPORT \*\*\*\*\*  
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Customer Smp1 Id: BT2-006c Project: K-WM-K116 THORIUM1 STREAMS13  
Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID Date/Time Sampled: 12/11/97 18:28:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:42  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:32:57  
Protocol: NONE Date/Time Approved: 03/25/98 16:32:57  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<<< Inorganic >>>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/08/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7439976	Mercury	L			100		<20			ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440235	Sodium				20		3570			mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:12:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Detection		EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440360	Antimony				100		<20			ug/L
7440382	Arsenic				100		<100			ug/L
7440393	Barium				100		<100			ug/L
7440417	Beryllium				100		<20			ug/L
7440439	Cadmium				100		<30			ug/L
7440473	Chromium				100		<50			ug/L
7439921	Lead				100		<50			ug/L
7440020	Nickel				100		<500			ug/L
7782492	Selenium				100		<100			ug/L
7440224	Silver				100		<20			ug/L
7440280	Thallium				100		<20			ug/L
7440291	Thorium				100		NA			ug/L
7440622	Vanadium				100		<20			ug/L
7440666	Zinc				100		<200			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Req Cnt: 02  
ysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:25:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
7440291	Thorium				100		0.24			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/08/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit
14797558	Nitrate	L			1		11000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
ysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Dilution	Detection	EPA			
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						9.07E4		1.6e3	pCi/L
14109321	Cadmium-109						3.72E4		5.3e3	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
15065108	Thorium-234			h			8.54E3		2.6e3	pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Th-232 calculated result was 2.32e5 +/- 1.1e5 pCi/L  
Pb-212 calculated result was 6.61e4 +/- 8.2e2 pCi/L  
Tl-208 calculated result was 2.42e4 +/- 7.7e2 pCi/L  
Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed by the software. 3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/09/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fr</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						7.94E5		8.8e3	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

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Official Report

Customer Smpl Id: BT5-009c      Project: K-WM-K116      THORIUM1      STREAMS13  
Customer: F R VAN RYN JR      BLDG 1037, MS 7349      (423)574-1907

Matrix: LIQUID      Date/Time Sampled: 12/18/97 15:25:00  
Sample Description: THORIUM DEMO      Date/Time Received: 02/17/98 13:45:42  
Location: PERMA-FIX      Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE      Date/Time Completed: 03/25/98 16:35:03  
Protocol: NONE      Date/Time Approved: 03/25/98 16:35:03  
Charge Number: PM892605      Sample Status: APPROVED  
Sampler(s):      Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<<<      Inorganic      >>>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
								Qual	Confidence	Unit
7439976	Mercury	L			100		<20			ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A      03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
								Qual	Confidence	Unit
J235	Sodium				20		40			mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G ALLEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:18:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA		
								Qual	Confidence	Unit
7440360	Antimony				100		<20			ug/L
7440382	Arsenic				100		<100			ug/L
7440393	Barium				100		<100			ug/L
7440417	Beryllium				100		<20			ug/L
7440439	Cadmium				100		<30			ug/L
7440473	Chromium				100		<50			ug/L
7439921	Lead				100		<50			ug/L
7440020	Nickel				100		<500			ug/L
7782492	Selenium				100		<100			ug/L
7440224	Silver				100		23			ug/L
7440280	Thallium				100		<20			ug/L
7440291	Thorium				100		NA			ug/L
7440622	Vanadium				100		<20			ug/L
7440666	Zinc				100		<200			ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/20/98 14:36:00  
Lab Group: IYPMS1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>	<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
7440291	Thorium				10000		250			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>	<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
14797558	Nitrate	L			1		1500			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
14331830	Actinium-228						9.87E4		1.8e3	pCi/L
14109321	Cadmium-109						8.04E4		1.0e4	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
15065108	Thorium-234				h		1.43E4		4.5e3	pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Th-232 calculated result was 2.37e5 +/- 1.3e5 pCi/L  
Pb-212 calculated result was 1.02e5 +/- 9.7e2 pCi/L  
Tl-208 calculated result was 3.24e4 +/- 8.4e2 pCi/L  
Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

Cd-109 (88.03 keV) shares peaks with Ac-228 and Pb-212. A peak interference correction was performed by the software. 3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
/sis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>En</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						9.97E5		9.8e3	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smp1 Id: BTS-006c Project: K-WM-K116 THORIUM1 STREAMS13  
Customer: F R VAN RYN JR BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID Date/Time Sampled: 12/18/97 09:32:00  
Sample Description: THORIUM DEMO Date/Time Received: 02/17/98 13:45:42  
Location: PERMA-FIX Date/Time Needed: 03/25/98 23:59:59  
Chain of Custody No: TELEDYNE Date/Time Completed: 03/25/98 16:35:03  
Protocol: NONE Date/Time Approved: 03/25/98 16:35:03  
Charge Number: PN892605 Sample Status: APPROVED  
Sampler(s): Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7439976	Mercury	L			100		180				ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7440235	Sodium				20		24900				mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:24:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
7440360	Antimony				100		<20				ug/L
7440382	Arsenic				100		<100				ug/L
7440393	Barium				100		<100				ug/L
7440417	Beryllium				100		<20				ug/L
7440439	Cadmium				100		<30				ug/L
7440473	Chromium				100		51				ug/L
7439921	Lead				100		<50				ug/L
7440020	Nickel				100		<500				ug/L
7782492	Selenium				100		<100				ug/L
7440224	Silver				100		<20				ug/L
7440280	Thallium				100		<20				ug/L
7440291	Thorium				100		NA				ug/L
7440622	Vanadium				100		<20				ug/L
7440666	Zinc				100		<200				ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:31:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit		Qual	Confidence	
7440291	Thorium				100		7.0			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IXICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 01/15/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit		Qual	Confidence	
14797558	Nitrate	L			1		80000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust			Dilution	Detection	Result	EPA		Unit
		HT	Lim	Fn	MDA	Limit		Qual	Confidence	
14331830	Actinium-228					5.62E3		5.2e2		pCi/L
13967709	Cesium-134					NA				pCi/L
10045973	Cesium-137					3.50E2		1.6e2		pCi/L
13981505	Cobalt-57					NA				pCi/L
10198400	Cobalt-60					NA				pCi/L
13966002	Potassium-40					NA				pCi/L
N2006	Protactinium-234m					NA				pCi/L
15065108	Thorium-234				h	5.18E3		9.1e2		pCi/L
15117961	Uranium-235					2.34E2		1.9e2		pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Ra-224 calculated result was 4.68e3 +/- 3.0e3 pCi/L  
Pb-212 calculated result was 2.53e2 +/- 2.0e2 pCi/L  
Tl-208 calculated result was 3.03e2 +/- 1.9e2 pCi/L  
Ra-228, Th-228, Th-232 were analyzed for but not detected.  
3/24/98 kal

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 06/16/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						7.07E4		3.0e3	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only

Customer Smpl Id: CLB1-002d

Project: K-WM-K116 THORIUM1 STREAMS14

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 01/13/98 17:53:00  
Date/Time Received: 02/17/98 13:45:08  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:36:57  
Date/Time Approved: 03/25/98 16:36:57  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/10/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust			Dilution		Detection		Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit	Qual	Confidence				
7439976	Mercury	L			100			<20				ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 07/12/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

yte Id	Analyte Name	Cust			Dilution		Detection		Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit	Qual	Confidence				
.0235	Sodium				20			40				mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/12/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:30:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust			Dilution		Detection		Result	EPA		Unit
		HT	Lim	Fn	Factor	Limit	Qual	Confidence				
7440360	Antimony				100			<20				ug/L
7440382	Arsenic				100			<100				ug/L
7440393	Barium				100			<100				ug/L
7440417	Beryllium				100			<20				ug/L
7440439	Cadmium				100			<30				ug/L
7440473	Chromium				100			<50				ug/L
7439921	Lead				100			<50				ug/L
7440020	Nickel				100			<500				ug/L
7782492	Selenium				100			<100				ug/L
7440224	Silver				100			<20				ug/L
7440280	Thallium				100			<20				ug/L
7440291	Thorium				100			NA				ug/L
7440666	Zinc				100			<200				ug/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/12/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:36:00  
Lab Group: IYPM51

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>		
7440291	Thorium				100			<0.1			mg/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/10/98 23:59:59  
Date/Time Analyzed: 02/23/98 09:00:00  
Lab Group: MYCHM1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>		
14797558	Nitrate	L			1			530			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Detection</u>		<u>EPA</u>		<u>Unit</u>
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	
13967709	Cesium-134							NA	pCi/L
10045973	Cesium-137							NA	pCi/L
13981505	Cobalt-57							NA	pCi/L
10198400	Cobalt-60							NA	pCi/L
13966002	Potassium-40							NA	pCi/L
N2006	Protactinium-234m							NA	pCi/L
13982633	Radium-226							NA	pCi/L
15065108	Thorium-234							NA	pCi/L
15117961	Uranium-235							NA	pCi/L

Comments: Th-232, Ra-228, Ac-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer. These isotopes were analyzed for but not detected. 3/24/98 kal

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/12/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Detection</u>		<u>EPA</u>		<u>Unit</u>	
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>		<u>Confidence</u>
N931	Total Activity							2.60E3	1.7e3	pCi/L

LIMS 05.02.024  
03/26/98 10:35

UNCLASSIFIED  
ASO Operating ESLIMS  
P. O. Box 2009 Oak Ridge, TN 37831  
Official Report

Page: 3 of 3  
Lab Smpl Id: A980490233

Test: TOTALRA-ENV  
Rpt Basis: As-Received  
t Req Cnt: 01  
ysis Meth: EPA-903.0-904.0  
Approver: S W BURCHAM/Data Reviewer  
QC Batch/File: QC98076026

Test Name: Total Radium Alpha/Beta Activity (Env Samples)  
Prep Method/Date: ASO-TP-7211 03/17/98 07:00:00  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 11:00:00  
Lab Group: RURAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N1730	Total Radium Alpha				19		220		40	pCi/L

\*\*\*\*\* END OF REPORT \*\*\*\*\*  
UNCLASSIFIED

Customer Smpl Id: CLB2-002d

Project: K-WM-K116 THORIUM1 STREAMS14

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 01/14/98 17:53:00  
Date/Time Received: 02/17/98 13:45:08  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:37:12  
Date/Time Approved: 03/25/98 16:37:12  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<<< Inorganic >>>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/11/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7439976	Mercury	L				100		<20			ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 07/13/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7440235	Sodium					20		28500			mg/L

Comments: PREPARED BY SW846-3010A

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/13/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:42:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7440291	Thorium					100		<0.1			mg/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/13/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:36:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	HT	Cust			Dilution Factor	Detection Limit	Result	EPA		
			Lim	Fn	Factor				Qual	Confidence	Unit
7440360	Antimony					100		<20			ug/L
7440382	Arsenic					100		<100			ug/L
7440393	Barium					100		<100			ug/L
7440417	Beryllium					100		<20			ug/L
7440439	Cadmium					100		<30			ug/L
7440473	Chromium					100		<50			ug/L
7439921	Lead					100		<50			ug/L
7440020	Nickel					100		<500			ug/L

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
2492	Selenium				100			<100			ug/L
.0224	Silver				100			<20			ug/L
7440280	Thallium				100			<20			ug/L
7440291	Thorium				100			NA			ug/L
7440622	Vanadium				100			<20			ug/L
7440666	Zinc				100			<100			ug/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/11/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

Analyte Id	Analyte Name	Cust			Dilution		Detection		EPA		
		HT	Lim	Fn	Factor	Limit	Result	Qual	Confidence	Unit	
14797558	Nitrate	L			1			90000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
atch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
14331830	Actinium-228						2.01E3		5.6e2	pCi/L
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						NA			pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
13982633	Radium-226						NA			pCi/L
15065108	Thorium-234						NA			pCi/L
15117961	Uranium-235						NA			pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer.  
Ra-228, Th-228, Ra-224, Th-232, Pb-212 and Tl-208 were analyzed for but not detected.  
3/24/98 kal

Test: TOTALACT-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/13/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

Analyte Id	Analyte Name	Cust				Detection		EPA		
		HT	Lim	Fn	MDA	Limit	Result	Qual	Confidence	Unit
N931	Total Activity						6.87E3		1.8e3	pCi/L

LIMS 05.02.024  
03/26/98 10:36

UNCLASSIFIED  
ASO Operating ESLIMS  
P. O. Box 2009 Oak Ridge, TN 37831  
Official Report

Page: 3 of 3  
Lab Smp1 Id: A980490234

Test: TOTALRA-ENV  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-903.0-904.0  
Approver: S W BURCHAM/Data Reviewer  
QC Batch/File: QC98076026

Test Name: Total Radium Alpha/Beta Activity (Env Samples)  
Prep Method/Date: ASO-TP-7211 03/17/98 07:00:00  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 11:00:00  
Lab Group: RURAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>	<u>EPA</u>			
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N1730	Total Radium Alpha				5.0		400	54		pCi/L

\*\*\*\*\* END OF REPORT \*\*\*\*\*  
UNCLASSIFIED

Customer Smp1 Id: CLB3-002d

Project: K-WM-K116 THORIUM1 STREAMS14

Customer: F R VAN RYN JR

BLDG 1037, MS 7349 (423)574-1907

Matrix: LIQUID  
Sample Description: THORIUM DEMO  
Location: PERMA-FIX  
Chain of Custody No: TELEDYNE  
Protocol: NONE  
Charge Number: PN892605  
Sampler(s):

Date/Time Sampled: 01/15/98 15:59:00  
Date/Time Received: 02/17/98 13:45:08  
Date/Time Needed: 03/25/98 23:59:59  
Date/Time Completed: 03/25/98 16:37:12  
Date/Time Approved: 03/25/98 16:37:12  
Sample Status: APPROVED  
Sample Approver:

Customer Comments: See Radcon before opening sample  
Lab Comments:

<<<< Inorganic >>>>

Test: HG7470  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-7470  
Approver: W E READY  
QC Batch/File:

Test Name: Mercury in Liquid Waste/Extracts/Waters by CVAAS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/12/98 23:59:59  
Date/Time Analyzed: 02/24/98 07:00:00  
Lab Group: MYWST1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA			
									Qual	Confidence	Unit	
7439976	Mercury	L				100		76				ug/L

Test: ICP6010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-6010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98084007/Q98077C

Test Name: Elements by EPA 6010A ICP-AES  
Prep Method/Date: SW846-3010A 03/18/98 12:00:00  
Test Status: APPROVED  
HT Deadline: 07/14/98 23:59:59  
Date/Time Analyzed: 03/18/98 17:28:00  
Lab Group: IYICP2

lyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA			
									Qual	Confidence	Unit	
40235	Sodium					200		44400				mg/L

Comments: PREPARED BY SW846-3010A

Secondary 10 fold dilution prior to analysis

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/14/98 23:59:59  
Date/Time Analyzed: 03/20/98 15:48:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA			
									Qual	Confidence	Unit	
7440291	Thorium					100		<0.1				mg/L

Test: ICPMS2008  
Rpt Basis: As-Received  
Test Req Cnt: 02  
Analysis Meth: EPA-200.8 R4.4  
Approver: D G AILEY/Lab Supervisor  
QC Batch/File:

Test Name: Elements by EPA 200.8 ICPMS  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/14/98 23:59:59  
Date/Time Analyzed: 03/12/98 16:42:00  
Lab Group: IYPMS1

Analyte Id	Analyte Name	Cust	HT	Lim	Fn	Dilution Factor	Detection Limit	Result	EPA			
									Qual	Confidence	Unit	
7440360	Antimony					100		<20				ug/L
7440382	Arsenic					100		<100				ug/L
7440393	Barium					100		<100				ug/L
7440417	Beryllium					100		<20				ug/L
7440439	Cadmium					100		<30				ug/L
7440473	Chromium					100		<50				ug/L
9921	Lead					100		<50				ug/L

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
7440020	Nickel				100			<500			ug/L
7782492	Selenium				100			<100			ug/L
7440224	Silver				100			<20			ug/L
7440280	Thallium				100			<20			ug/L
7440291	Thorium				100			NA			ug/L
7440622	Vanadium				100			<20			ug/L
7440666	Zinc				100			<200			ug/L

Test: PREP3010  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: SW846-3010A  
Approver: R M WILKES/Chemist  
QC Batch/File: QC98064022

Test Name: Prep by 3010 (Total Elements)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/18/98 12:00:00  
Lab Group: IYICP2

<<<< None >>>>

Test: IONCHROM  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-Y/P65-2810  
Approver: R J MCELHANEY/Chemist  
QC Batch/File:

Test Name: Ion Chromatography-Water/Leach (Building 9995)  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 02/12/98 23:59:59  
Date/Time Analyzed: 02/23/98 07:00:00  
Lab Group: MYCHM1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>			<u>Dilution</u>		<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>Factor</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>	
14797558	Nitrate	L			1			130000			mg/L

<<<< Radiochemical >>>>

Test: GAMSPEC-WP  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: ASO-ACD-160067  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055037/WP-5317

Test Name: Gamma Spectrometry by 160067  
Prep Method/Date: ASO-ACD-160092 02/25/98 15:00:00  
Test Status: APPROVED  
HT Deadline: 08/24/98 23:59:59  
Date/Time Analyzed: 03/20/98 12:00:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
13967709	Cesium-134						NA			pCi/L
10045973	Cesium-137						3.00E3	2.7e2		pCi/L
13981505	Cobalt-57						NA			pCi/L
10198400	Cobalt-60						NA			pCi/L
15046841	Iodine-129						1.39E3	9.3e1		pCi/L
13966002	Potassium-40						NA			pCi/L
N2006	Protactinium-234m						NA			pCi/L
13982633	Radium-226						NA			pCi/L
15065108	Thorium-234				h		3.91E3	9.2e2		pCi/L
15117961	Uranium-235						1.91E2	1.6e2		pCi/L

Comments: Th-232, Ra-228, Th-228, Ra-224, Pb-212 and Tl-208 were requested by the customer. Th-232, Pb-212, Tl-208, Ra-228, Th-228, Ra-224 were analyzed for but not detected.  
3/24/98 kal

I-129 was reported by the gamma software. The peaks found were at 29.61 and 33.60 keV.

The 84.21 keV U-235 peak shares peaks with several of the requested isotopes. Other peaks for those isotopes were not identified. The 185.72 keV peak for U-235 was also identified. The software attributed both peaks to U-235 and reported an average of the two peaks.  
3/25/98 AML

Test: TOTALACT-WP  
Rpt Basis: As-Received  
t Req Cnt: 01  
Analysis Meth: ASO-ACD-160063  
Approver: E E CLARK/Lab Supervisor  
QC Batch/File: QC98055038/WP-5317

Test Name: Total Activity using LSC by 160063  
Prep Method/Date:  
Test Status: APPROVED  
HT Deadline: 07/14/98 23:59:59  
Date/Time Analyzed: 03/03/98 16:29:00  
Lab Group: RKRAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N931	Total Activity						9.84E3		1.9e3	pCi/L

Test: TOTALRA-ENV  
Rpt Basis: As-Received  
Test Req Cnt: 01  
Analysis Meth: EPA-903.0-904.0  
Approver: S W BURCHAM/Data Reviewer  
QC Batch/File: QC98076026

Test Name: Total Radium Alpha/Beta Activity (Env Samples)  
Prep Method/Date: ASO-TP-7211  
Test Status: APPROVED  
HT Deadline:  
Date/Time Analyzed: 03/17/98 11:00:00  
Lab Group: RURAD1

<u>Analyte Id</u>	<u>Analyte Name</u>	<u>Cust</u>				<u>Detection</u>		<u>EPA</u>		
		<u>HT</u>	<u>Lim</u>	<u>Fn</u>	<u>MDA</u>	<u>Limit</u>	<u>Result</u>	<u>Qual</u>	<u>Confidence</u>	<u>Unit</u>
N1730	Total Radium Alpha				31		900		110	pCi/L

Footnotes:

h - Daughter of uranium isotopes, reported for comparison purposes only



**Appendix C**  
**Thorium Materials Market Survey**



# **THORIUM MATERIALS**

## **MARKET SURVEY**

**PREPARED FOR**

**PERMA-FIX ENVIRONMENTAL  
SERVICES, INC.**

**BY**

**TELEDYNE BROWN ENGINEERING, INC.**

**MARCH, 1998**



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**Attachments**

- 1-1 Contacts**
- 1-2 Reference Documents**



## **1.0 Executive Summary**

The U.S. Army Defense Logistics Agency (DLA) currently has approximately 7,000,000 pounds of thorium nitrate tetra-hydrate (TNT), stockpiled in 21,000 containers, varying in size from 30-gallon drums to 85-gallon overpacks. Approximately 90 percent of the material is located in Curtis Bay, Maryland, with the remainder located in Hammond, Indiana. Approximately 3,500 of the drums contain mantel grade thorium, while the remainder contains nuclear reactor grade.

To volumetrically reduce the size of the stockpile, the DLA has contracted private companies to demonstrate TNT conversion processes. Each selected conversion process were applied to approximately 2,000 pounds of TNT in which it was converted to a more stable and less voluminous form for long-term retrievable storage. To support the demonstration projects, the DLA also contracted a thorium materials market survey be performed to identify the potential market outlets for the final end-use product and conversion process by-product materials.

The thorium materials market survey has determined that thorium is in an oversupply situation world-wide with a prediction of an overall decline in non-nuclear use. Thorium demand remains depressed as industrial consumers express concerns with the potential liabilities, the costs of complying with environmental monitoring and regulations, and cost increase at approved waste disposal sites. The domestic industrial market has recognized the decline in the need for thorium by the fact that monazite, the primary source of the world's thorium, has not been domestically mined since the end of 1994. Essentially all of the thorium compounds, metal, and alloys currently used by the domestic industry are derived from imports, company stocks, or material sold from United States Government stocks.

Sodium nitrate is a TNT conversion process by-product and has a market that is in a stable supply situation. The thorium materials market survey revealed a potential application for use of all of the sodium nitrate generated by the TNT conversion process. The U.S. Army has displayed an interest in the sodium nitrate for use by their pyrotechnics and ordnance sector for use in mortars production.

## **1.1 Purpose of Survey**

To identify and quantify the potential markets for thorium and conversion process by-product materials on a domestic and world wide market basis. The market survey also identified potential consumers, past volume which has been consumed, and a prediction of market growth, decline or stability for thorium and conversion process by-product materials.

## **1.2 Methodology Summary**

The market survey's methodology was first to research literature and documentation available for thorium and conversion process by-product materials use in the United States and throughout the world. The survey obtained documentation from the United States Nuclear Regulatory Commission (NRC), Fernald Environmental Management Project (FEMP), U.S. Geological Survey (USGS), Department of Energy (DOE) and, from searches from throughout the internet. The initial literature research provided background information on the current status of material use and consumption and provided direction for further research and corporation contacts. The survey then identified organizations that were licensed to use thorium by the Nuclear Regulatory Commission and we contacted all of the identified organizations. We contacted by telephone the identified companies and received their input for this survey analysis. The market survey also obtained the description of a previous survey for the sale of stockpiled thorium by the DOE which provides support to the findings of this market survey.

### **Department of Energy Thorium Attempted Sale Process**

In April of 1991 a notice was published in the Commerce Business Daily (CBD) by the DOE offering thorium for sale to the private sector. There was no response to the first publishing. In May of 1991 the CBD notice was re-issued and was sent to 46 firms who were licensed to handle >150 kgs of thorium. Only 4 firms responded, and, of these, only two expressed interest in purchasing thorium. The only interest these firms had was in thorium metal and some of the oxides and nitrates in the inventory at the Feed Materials Production Center (FMPC). The Fernald Environmental Management Project (FEMP) has been a repository for thorium material within the DOE complex since the mid 1960s. The thorium was residual inventory from early government-sponsored breeder reactor research and was obtained in anticipation of a nuclear fuel demand that has never materialized. Thorium at the FEMP was stored in five buildings, rated from "Fair" to "Good" condition, and in various containers, rated from "Poor" to "Excellent" condition. The thorium material was stored in approximately 14,730 containers and varied in assay and purity. This attempt by the DOE to liquidate their stockpiled inventory was unsuccessful. This was due to the fact that the potential purchaser required the funding for sampling, purity analysis, physical and visual inspection of containers of each lot of thorium be paid for by the government. This inspection required excessive funding from the government and thus promoted the DOE to declare the thorium material as waste and as excess to the needs of the federal government. The failure of this sale of thorium in 1993 by the federal government supports the findings of this survey that an oversupplied situation of thorium currently exists throughout the world.

## **2.0 Thorium and Sodium Nitrate Market Discussion**

Thorium production, which is primarily a byproduct of the processing of heavy-mineral sands for titanium, zirconium and tin is only a small portion of the thorium that is consumed world-wide. A majority of the thorium that is produced is discarded as waste. Thus, there is a large imbalance world-wide between thorium production and consumption. The non-nuclear domestic uses for thorium has decreased substantially over the past seven years. Domestic demand is forecast to remain at current depressed levels unless low-cost technology is developed to dispose of the radioactive residues. Manufactures have successfully developed acceptable substitutes for thorium-containing incandescent lamp mantles, paint and coating evaporation materials, magnesium alloys, ceramics, and investment molds. Yttrium compounds have replaced thorium compounds in incandescent lamp mantles and a magnesium alloy containing lanthanides, zirconium, and yttrium can be substituted for magnesium-thorium alloys in aerospace applications. The traditionally small markets in thorium compounds, welding electrodes, and lighting are expected to remain the leading consumers of thorium compounds through the end of the decade. Thorium's potential for growth in non-nuclear applications is limited by its natural radioactivity.

Another potential use for thorium is in an experimental (theoretical) energy amplifier system, theorized by physicist Dr. Carlo Rubbia. This energy amplifier system, if successful (an accelerator will generate subatomic particles that will bombard thorium fuel), may be the future for thorium.

Sodium nitrate, otherwise known as nitratine or soda niter, is one of the few nitrate minerals that is available on the mineral markets. Nitrates are not commonly found due to their general ease in dissolving in water. In fact, some solid nitrate crystals even become liquid by removing water from the moisture in the air, a process called deliquescence. Sodium nitrate is deliquescent and is very soluble in water and thus care should be taken to preserve valuable specimens in air tight containers with desiccant. Most nitrates are found in arid, desert regions such as around the Persian Gulf or found as efflorescences on dry cave or mine walls. Nitrates are similar to carbonates. The nitrogen is surrounded by three oxygens and forms a tight flat triangular  $\text{NO}_3$  ion group just like the carbonate triangular  $\text{CO}_3$  ion group. Thus nitrates are placed in the Carbonate Class of minerals.

## **2.1 Thorium Applications**

Thorium is a naturally-occurring, radioactive metal. Small amounts of thorium are present in all rocks, soil, above-ground and underground water, plants, and animals. These small amounts of thorium contribute to the weak background radiation for such substances. Soil commonly contains an average of about six parts of thorium per million parts of soil. Thorium oxides (oxide, dioxide and hydroxide) are radioactive, heavy, white crystalline powder and are currently available in the United States in stocks of different particle sizes with purities of up to 99.99%.

Thorium has had many different applications throughout its history. Due to its high melting point of 1,750 °C, its ability to emit a brilliant white light when heated to incandescence, and its high-strength characteristics, thorium has been uniquely qualified to be used in a variety of industrial applications.

Use of thorium oxides as a radiopaque medium for x-ray imaging in certain medical diagnostic procedures began around 1930, but was practically discarded after 1945 because harmful late effects from its use were noted. Thorium can be used as a fuel for generating nuclear energy, used to make high temperature ceramics, gas lantern mantles, flame spraying, x-ray contrast medium, and as a catalyst. It is used as a metal in the aerospace industry and in nuclear reactions.

### **2.1.1 Nuclear Applications**

Thorium, like uranium, is a nuclear fuel, but the use of thorium fuel, unlike the use of uranium, has nearly been forgotten. While uranium technology in Light Water Reactors (LWR) has been demonstrated to be dependable for over 30 years and is well understood today, the use of thorium technology has lagged behind uranium's ever since the demise of the Fort St. Vrain commercial High Temperature Gas-Cooled Reactor (HTGR) and the U.S. government cancellation of the Clinch River Breeder Reactor research program.

Although natural thorium cannot be used to produce a nuclear chain reaction by itself, it can, under irradiation, be converted into the fissile fuel uranium ( $^{233}\text{U}$ ). Therefore, thorium ( $^{232}\text{Th}$ ) has potential use in nuclear reactors. Use of thorium in addition to uranium would expand the nuclear fuel supply base. Advanced converter reactors using thorium would not generate plutonium. Plutonium produced during nuclear power generation and its recycling raises nuclear proliferation concerns.

For the above reasons, there were many studies in the 1960s and 1970s to determine the feasibility of using thorium in nuclear power reactors. Studies were focused toward potential applications on High Temperature Gas-Cooled Reactor (HTGR), Light Water Breeder Reactor (LWBR), and Gas-Cooled Fast Breeder Reactor (GCFR). Also, the U.S. government considered a modified Canadian Deuterium Uranium (CANDU) reactor capable of consuming thorium. In the United States, the best known designs using thorium in the reactor core were the LWBR, designed by the Bettis Atomic Power Laboratory at Shippingport, Pennsylvania, and the HTGR, developed by the General Atomic Corporation in San Diego, California.

The only U.S. commercial thorium/uranium fueled HTGR was the Fort St. Vrain reactor near Loveland, Colorado. The reactor, with a capacity of 330 MWe, owned by the Public Service Company of Colorado (PSC), began full operation in early 1979. The operation of the Fort St. Vrain reactor, the full-scale commercial HTGR, however, became unsuccessful due to a combination of economic factors and lingering mechanical problems that resulted in over two years of delays in starting, followed by intermittent operations with a persistently low capacity factor.

With the development of large uranium reserves in North America in the 1970s and 1980s, followed by ample supplies of low-cost uranium, utilities were reluctant to invest in a new thorium-fueled reactor (HTGR), especially one that had not been operated under industrial conditions. Subsequently, all new HTGR orders previously placed were canceled. Eventually, the Fort St. Vrain power plant itself was permanently shutdown in 1989, after a mere 10 years of operation.

In 1983, the U.S. government canceled the Clinch River Breeder Reactor (375 MWe) program that would have required reprocessing plutonium. Since then, there have been few government research efforts on the thorium fuel cycle technology and no commercial development of thorium-fueled reactors.

Present technology allows plutonium from spent fuel to mix with natural uranium, enrichment tails, or depleted uranium to form a mixed oxide fuel through reprocessing, an oxide fuel that is then recycled back to an LWR. The recent trend of interest in LWR Mixed Oxide Fuel (MOX) is increasing in Europe and Japan mainly because of its uranium enrichment savings as well as its being a partial solution to the actinide containing waste disposal. Unlike the Americans, the Europeans and the Japanese also have been actively pursuing reprocessing and recycling of fuel products in connection with FBR and LMFBR, such as Super Phoenix (France) and SNR-300 (Germany) programs. Japan and India continue to be active in research on the development of thorium-fueled breeder reactors.

Thorium can be used in almost any sort of reactor in forms of metal slugs, molten salt, oxide compounds, or carbide compounds. Another type reactor suitable for thorium fuel cycle, other than the HTGR and LWBR, would be the rather exotic Molten-Salt Breeder Reactor (MSBR). The MSBR is an advanced breeder concept which is suited for utilizing thorium for nuclear power generation. Unlike conventional reactors, the MSBR has no external coolant in the reactor core and the fuel salt itself is circulated through a heat exchanger, which transfers the heat produced from fission to a secondary salt for steam generation. This on-line processing scheme makes the MSBR achieve the highest breeding ratio among all thermal breeder reactor.

Recently in the world nuclear community, a new philosophy based on the following three principles has been proposed: (1) thorium utilization, (2) molten-salt fuel concept, and (3) separation of fissile-breeder and power generating function. Such a philosophy is known as "Thorium Molten-Salt Nuclear Energy Synergetic" (THRIMS-NES) and is observed in the typical 155 MWe Small Molten-Salt Power Station (FUJI-II) in Japan. According to the proposal, the THRIMS-NES can effectively provide the essential improvement in issues of resources, safety, power-size flexibility, anti-nuclear proliferation, and economy while also securing the simple operation, maintenance, and rational breeding fuel cycle. If its commercialization would become successful, the improved thorium fuel cycle would provide energy to the Third World nations (e.g., Brazil and India) that would be cleaner, concentrated, and reduce proliferation risk.

There is currently no market in the United States for thorium for use as a breeder reactor fuel. Germany and Japan reprocess and recycle nuclear fuel products and Japan, India, and Brazil continue to research the development of thorium-fueled breeder reactors. However, as long as low-cost uranium is available, there will be no market for the use of thorium as a commercial nuclear fuel.

### **2.1.2 Non-Nuclear Applications**

Non-energy uses accounted for essentially all consumption. Problems associated with thorium's natural radioactivity represent a significant cost to mine, process, manufacture, and use. Thus, alternative, non-radioactive materials are preferred and the use of thorium is decreasing both in the U.S. and the world.

Thorium oxide (thoria) has the highest melting point of all metal oxides, 3,300 °C. This property contributed to its use in several refractory applications. High temperature uses are in ceramics parts, investment molds, and crucibles.

Thorium nitrate is used in the manufacture of mantles for incandescent "camping" lanterns, including natural gas lamps and oil lamps. Thorium mantles provide an intense white light that is adjusted towards the yellow region by a small addition of cerium. Thoriated mantles are not produced domestically due to the development of a suitable thorium-free substitute. Thorium fluoride is used in the manufacture of carbon arc lamps for movie projectors and searchlights to provide a high-intensity light.

Thorium nitrate also is used to produce thoriated tungsten welding electrodes and tungsten filaments. Thoriated tungsten welding electrodes are used to join stainless steels, nickel alloys, and other alloys requiring a continuous and stable arc to achieve precision welds.

The nitrate form is also used to produce thoriated tungsten elements which are used in the negative poles of magnetron tubes. Thorium is used because of its ability to emit electrons at relatively low temperatures when heated in a vacuum. Magnetron tubes are used to emit electrons at microwave frequencies to heat food in microwave ovens and in radar systems to track aircraft and weather conditions.

Thorium is used in other types of electron emitting-tubes, elements in special use light bulbs such as airport running lights, non-silica high-refractivity glass, radiation detectors, computer memory components, catalysts, photo conductive films, target materials for x-ray tubes, and fuel cell elements. Thorium is also used in the manufacture of metal alloys for the aerospace industry, pharmaceuticals, and as a radiopaque medium for x-ray imaging.

In metallurgical applications, thorium is alloyed primarily with magnesium. Thorium metal has a high melting temperature of 1,750 °C and a boiling point of about 4,790 °C. Magnesium-thorium alloys are lightweight and have high strength and excellent creep resistance at elevated temperatures. Thorium-free magnesium alloys with similar properties have been developed and are expected to replace most of the thorium-magnesium alloys presently used. Small quantities of thorium is used in dispersion-hardened alloys for high-strength, high-temperature applications.

## **2.2 Future Applications for Thorium**

The market survey performed research into potentially new product developments and applications outside the nuclear fuel sector which may have a use for thorium. The survey did identify approximately nine potential new products and / or applications which are currently under development by the Southwest Research Institute. However, the Southwest Research Institute would not release descriptions of these new products or applications to the market survey team due to proprietary information restraints. It was made known to the team that although the performance of these new products had not been tested for use with thorium, but it was technically reasonable to be expect that thorium should work in all nine of these applications.

## **2.3 Sodium Nitrate Applications**

Sodium nitrate has many different industrial applications in explosives or pyrotechnics, fertilizers, the manufacturing of ceramics, glass and charcoal briquettes, and in metal treatments. Sodium nitrate is a common component of ceramics and glass batches which require fine oxidizing conditions to aid in the removal of batch impurities. The low melting point of  $\text{NaNO}_3$  acts as a flux to accelerate melting by decreasing the energy necessary to melt the batch ingredients. Sodium nitrate serves as an oxidizer to assist in the combustion of briquettes. The lighter the composition of filler materials in the briquettes—sawdust, lignite coal, wood bark, etc.—the greater the requirement for oxidation. In metal treating, sodium nitrate acts as a steel tempering medium, as a heat treatment of aluminum alloy, and in the annealing of copper. In the secondary recycling of lead, sodium nitrate removes impurities while acting as a scavenger. The application of sodium nitrate in pyrotechnics and fertilizers are further discussed below.

### **• Pyrotechnics Applications**

Sodium nitrate serves as a secondary oxidizer in many slurry water gel, emulsion, and dynamite formulations. It enhances the stability of finished explosive products because of its comparatively low hygroscopicity. It offers a high-energy yield, high density, and low combustibility.

- **Fertilizer Additive Applications**

Commercial grades of sodium nitrate are used for fertilizer. Nitratine is an important source of nitrates for fertilizer and other chemical uses including fireworks. Nowadays, fixed nitrogen from the air has all but replaced nitratine as the main source of nitrogen. An interesting side note is that discarded specimens of nitratine were said to have been thrown into a garden and this is how the importance of nitrates in good plant growth was first discovered.

The largest known and currently the only commercially exploited source of natural nitrates in the world is the caliche ore deposits in northern Chile. The geological origin of the caliche ore deposits in northern Chile is unclear but it is thought that the formation is the result of either deposits of sediments from an ancient inland sea or minerals resulting from the gradual erosion of the Western side of the Andes Mountains. The concentrations of minerals in the caliche ore vary, but averaged 7.66% sodium nitrate and 376.0 ppm iodine in 1994 at the sites the Company was exploiting at that time. The caliche ore is used in the production of sodium nitrate, iodine, sodium sulfate, and potassium nitrate.

**3.0 Historical Consumption**

The U.S. Department of the Interior Bureau of Mines reports total domestic consumption in 1991 at less than 100 metric tons and in 1996 of 4.9 metric tons. This reflects the downward trend of consumption of thorium. The U.S. market for thorium metal and compounds was about \$300,000 in 1996. The markets for thorium in the rest of the world are about the same as in the United States. The problems of storing the large amounts of waste generated as a byproduct of processing for rare earths has eliminated the use of thorium-bearing monazite in many countries. The following table shows the approximate distribution of thorium by end use:

End Use	Percentage
Welding electrodes	62%
Lighting	20%
Ceramics and refractory applications	14%
Aerospace alloys	3%
Nuclear applications	1%

**3.1 Thorium Consumption**

- Domestic Consumption**

The use of thorium in the United States had decreased significantly since 1990. Handling and storage problems associated with thorium, combined with the increasing regulatory environment and public perception of hazards, have affected its use. Increased costs to monitor and dispose of thorium have also caused domestic processors to switch to thorium-free materials. Real and potential costs related to compliance with State and Federal regulations, proper disposal, and monitoring of thorium's radioactivity have limited thorium's commercial value. It is forecast that thorium's use will continue to decline unless a low-cost disposal process is developed.

Domestic consumption of refined thorium products decreased in 1996, according to the U.S. Geological Survey (USGS). Thorium production is primarily from rare-earth thorium-phosphate mineral, monazite, a by-product of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Thorium compounds were produced from monazite during processing for the rare earths. Only a small portion of the thorium produced was consumed, most was discarded as waste. The following table shows the current imported sources for thorium monazite and thorium compounds.

Import Thorium Materials & Source	Percentage
Monazite: Australia	89%
Malaysia	11%
Thorium Compounds: France	99%
Canada, Switzerland, and United Kingdom	1%

The following table shows the domestic consumption and import/export statistics.

Domestic Statistics (Metric Tons)	1992	1993	1994	1995	1996
Imports	14	18	3	60	41
Exports	5	( <sup>1</sup> )	33	( <sup>1</sup> )	( <sup>1</sup> )
Reported Consumption	40	13	17.3	18.1	4.9

(<sup>1</sup>) Less than ½ unit

• **Worldwide Consumption**

The major monazite-producing countries were Brazil, China, India, Malaysia, and Sri Lanka. All imports into the U.S. with radiation contents of 500 parts per million thorium and/or uranium need special permits. One of the greatest world wide potential use for thorium exists in energy applications, as a nuclear fuel or subatomic fuel, in an industry that accepts radioactivity. In the long term, high disposal costs, increasing regulations, and public concerns related to thorium's natural radioactivity are expected to continue to depress its future use. The following table indicates which non-domestic countries have imported thorium products from out of country sources:

Country (in Kgs)	1992	1993	1994	1995	1996	Jan-May 1997
World	93	189	7	75	58	9
Canada	0	0	0	0	8	0
Costa Rica	6	0	0	0	0	0
United Kingdom	0	11	2	0	0	3
Netherlands	0	0	0	0	0	4
France	0	0	0	0	0	2
Germany	0	19	0	64	50	0
Hungary	0	0	0	3	0	0
Switzerland	0	20	0	0	0	0
Spain	0	0	1	0	0	0
Iran	44	0	0	0	0	0
Singapore	0	9	0	0	0	0
China	43	0	0	0	0	0
Japan	0	130	0	8	0	0
Australia	0	0	1	0	0	0
Algeria	0	0	3	0	0	0

### 3.2 Sodium Nitrate Consumption

Sodium nitrate is white or gray or sometimes has tints of red-brown or yellow. It is associated in location with gypsum, halite and other arid region minerals and has characteristics of deliquescent and being slightly sectile. Sodium nitrate is very soluble in water and gives a yellow flame test result. Sodium nitrate has notable occurrences in Chile, Bolivia, Peru, Humboldt Co., Nevada, San Bernardino Co., California and New Mexico, USA. It is consumed by the many different industries throughout the world, most notably it is used in pyrotechnics in black powder, as a fertilizer, the manufacturing of ceramics, glass and charcoal-briquettes, metal treatments, in curing of meats, and as a color fixative of meats. The domestic import for consumption from foreign countries of sodium nitrate in 1996 is illustrated in the following table:

Country	Quantity (Metric Tons)
World Total	97, 945
Belgium	75
Chile	95, 602
West Germany	2, 139
India	1
Poland	128

#### **4.0 Specific Buyers**

During the performance of this task, the market survey team identified potential buyers of the final thorium product and the conversion process by-product materials. These potential buyers formally showed interest with the materials in that they requested samples of the final products produced from the conversion process. Until they can determine the purity of the final products and the conversion process has been performed, they will not pursue a formal purchase. The two firms whom have shown interest are: 1.) a private domestic firm that currently uses thorium nitrate from a non-domestic source for the production of welding electrodes and, 2.) a federal contractor for the U.S. Army that uses sodium nitrate as pyrotechnics for use in the production of mortar devices. The following is a written description of the interested parties, their needs and the necessary requirements that will have to be met to ensure a sale is secured.

- **Allegheny Teledyne Advanced Materials**

Allegheny Teledyne Advanced Materials is owned by Allegheny Teledyne, Inc. and is a sister company of Teledyne Brown Engineering. The company specializes in powder metallurgy for the refractory metals tungsten and molybdenum, and has its executive offices located in Huntsville, Alabama. The company is widely recognized manufacturer of tungsten carbide intermediate and / or finished products. Their tungsten products are used in high-temperature furnaces, electrical contacts, vacuum bulbs and thoriated inert gas welding electrodes. The company has previously purchased thorium nitrate from the DLA, but found the material to be very difficult to work with. They informed the survey that the thorium nitrate was extremely hardened in its current packaged form and that it took them a very long time to convert the material to a useable form. Their current supplier of thorium is a corporation in Canada and the last quoted price from this non-domestic source was \$12.50 per pound. Allegheny Teledyne Advanced Materials would be willing to negotiate a purchase of material from the DLA if the material was in a useable form and at a competitive price. To secure a sale of the thorium to this client, the final product would have to be in a high purity form and in a fine granular form which is best used by their process.

- **Crane AAA**

Crane AAA is a federal contractor to the U.S. Army with location in Crane, Indiana. They provide research and development services within the Energetics and Warhead Division (EWD) located at the Picatinny Arsenal in New Jersey. The company provides research, development, and testing of pyrotechnic compositions and devices from the initial concepts to pilot lot production. The company, through an interface of the Chief of Operations, U.S. Army's Pyrotechnics and Ordnance Sector, has communicated to the market survey team a means for using the TNT conversion process by-product material, sodium nitrate, in its mortar production. The company has requested a 125 lb. sample of dry sodium nitrate for analysis and field demonstration in their mortar program. The material must meet military specification for sodium nitrate "MIL-S-322C." This request is made under the inner federal government transfer of material from the DLA to the U.S. Army's Pyrotechnics and Ordnance Sector. The market survey is following up this request to obtain qualification of the TNT conversion process's by-product material, sodium nitrate, under this program.

**5.0 Defense Logistics Agency Sales Projections**

- **Thorium Sales Projections**

**TO BE COMPLETED LATER**

<b>Year Ending</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>
<b>Annual Amount</b>					

- **Sodium Nitrate Sales Projections**

**TO BE COMPLETED LATER**

<b>Year Ending</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>
<b>Annual Amount</b>					



# **ATTACHMENTS**



## **Attachment 1-1**

### **Contacts**

## Contacts

The following United States companies were contacted by telephone to obtain their current status as associated with use of thorium for product manufacturing. These companies were also asked information pertaining to any use of thorium by their affiliated companies on the world wide markets. The results and information obtained from this survey is reflective of the survey performed by the Department of Energy in 1991 and described earlier in the survey.

Company	Location	Response
All-Chemie, Limited	Mount Pleasant, SC	Uses < 5 kilo / year.
Alfa Chemical Corporation	Central Islip, NY	No longer uses thorium
Allegheny Teledyne Advanced Materials	Huntsville, AL	Uses very little
Alloy International, Incorporated	Central Islip, NY	Buys/uses < 100 kilo/year
Arch City Steel, Incorporated	Ballwin, MO	No longer uses thorium
Atomergic Chemetals Corporation	Farmingdale, NY	Buys / uses < 100 kilo / year
CEICO Chemical, Incorporated	New York, NY	Sells < 100 kilo / year
CERAC, Incorporated	Milwaukee, WI	Buys / sells / brokers < 100 kilo / year
Electronic Space Products International	Ashland, OR	No longer uses thorium
Goodfellow Corporation	Berwyn, PA	Uses very little
Great Western Inorganics	Golden, CO	No longer uses thorium
Infinity Industries, Incorporated	Ronkonkoma, NY	No longer uses thorium
Mallinckrodt, Incorporated	St. Louis, MO	No response
Nuclear Fuel Services, Incorporated	Erwin, TN	Uses very little
Reactor Experiments, Incorporated	Sunnyvale, CA	Uses very little
Surepure Chemetals, Incorporated	Florham Park, NJ	Broker and now sells
United Mineral & Chemical Corporation	Lyndhurst, NJ	No longer uses thorium

**Attachment 1-2  
Reference Documents**

## Reference Documents

1. Department of Energy, Energy Information Administration, *The Role of Thorium in Nuclear Energy*, by Mr. Taesin Chung.
2. U.S. Geological Survey, *Thorium*, by James B. Hendrick, Thorium Commodity Specialist.
3. India Nuclear Society, *Proceedings of the Indo-Japan Seminar on Thorium Utilization*, (Bombay, India, 1991).
4. U.S. Bureau of Mines, *Thorium-Annual Review*, (Washington, DC, July 1995).
5. National Lead Company of Ohio, *The Thorium Production Technology*, prepared under contract with U.S. Atomic Energy Commission (1958).
6. U.S. Geological Survey, *Nuclear Fuels Chapter in United States Mineral Resources*, (1996).
7. U.S. Bureau of Mines, *Thorium, Chapter in Mineral Facts and Problems*, Bulletin 675, (1985).
8. Department of Energy Correspondence 1.) WEMCO: OC: 230-91, D. Yaeger to J. Schneider, "Comments: Invitation for Bid - Depleted UF<sub>4</sub>, December 5, 1991, 2.) WEMCO: PM&A (PS): 92-123, C. D. Conover to E. D. Savage, "Potential Sale of Thorium," February 18, 1992, 3.) WEMCO: EC&QA (RA): 92-105, E. D. Savage to C. D. Conover, "Potential Sale of Thorium," March 6, 1992, 4.) DOE: OC:DP-273, C. G. Halsted to T. J. Rowland, "Thorium Sale," March 5, 1993.

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To Herb Woods	From Bill Herman	
Co.	Co.	
Dept. 205/883-2975	Phone # 210/979-6872	
Fax # 205/885-0561	Fax #	

METRIC

MIL-S-322C  
INTERIM AMENDMENT 1 (OS)  
30 April 1990

Lucky

## MILITARY SPECIFICATION

## SODIUM NITRATE

This interim amendment is approved for use within the Naval Sea Systems Command(OS), with MIL-S-322C, dated 5 February 1968.

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Add the following new paragraphs with new table III:

\*4.4.5.4 Alternate method - ferrous sulfate titration.

4.4.5.4.1 Apparatus. The following apparatus or equivalent shall be used:

- Fisher Titrimeter II System with controller, pH meter, buret-dispenser with 25-ml amber syringe, stirrer, recorder, and platinum and glass electrodes,
- Nitrogen purge on titrant reservoir, 2-ounce-per-square-inch,
- Circulating-cooling bath and a small external bath with coolant maintained between 2° to 5°C.

4.4.5.4.2 Chemicals. The following chemicals shall be used:

- Sulfuric acid ( $H_2SO_4$ ), 95-96 %,
- Potassium nitrate ( $KNO_3$ ),\* NIST, 99.6%,
- Ferrous sulfate ( $FeSO_4$ ), 0.4 % nitrogen per ml. Dissolve 350 gm of  $FeSO_4 \cdot 7H_2O$  in 800 ml distilled water. Slowly add one liter cold 1:1  $H_2SO_4$  and dilute to 2 liters with water. Preserve titrant with nitrogen purge. Allow solution to stand for 3 days.

\*NIST= National Institute of Standards and Technology

AMSC N/A

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FSC 6810

DISTRIBUTION STATEMENT A

Approved for public release; distribution is unlimited.

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**MIL-S-322C**  
**INTERIM AMENDMENT 1(OS)**

**4.4.5.4.3 Standardization of the ferrous sulfate.**

Note: If the system has been down 8 hours, purge the dispensing system. Condition the electrodes in  $H_2SO_4$  for 4 hours. Zero the pH meter by setting the range to 1000 millivolts (mV) according to the manufacturer's instructions.

Grind the  $KNO_3$  standard to the consistency of table salt. Pre-weigh  $0.50 \pm 0.05$  gm  $KNO_3$  in a weighing bottle. Dry in oven at  $135^\circ C$  for 4 hours. If the  $KNO_3$  has been out of the oven for more than 4 hours, redry at  $105^\circ C$  for 2 hours. Store in a desiccator.

Set controller functions (see table III) for a dead-stop potentiometric titration. In a hot-dry beaker, add a stir bar and 150 ml  $H_2SO_4$ . Place beaker in bath on stirrer. Ensure coolant is circulating through the external bath. Weigh  $KNO_3$  to the nearest 0.1 mg and slowly pour into vortex of the acid. Lower the electrodes and delivery tip into acid. Turn meter to 1000 mV. When sample has dissolved, begin titration. Adjust titrant addition rate to obtain an endpoint within 8 to 10 minutes. After endpoint is reached and held for one minute, turn meter to stand-by. Rinse electrodes in  $H_2SO_4$ . Calculate the nitrogen equivalence factor (F):

$$\text{Factor} = \frac{13.855 \times W}{V}$$

Where:

F = factor, % N/ml  
W = weight of  $KNO_3$ , gm  
V = volume of titrant, ml

Perform standardization in duplicate. Checks should agree within 0.0005.

TABLE III. Recommended instrument settings.

METER	temp - $25^\circ C$ function - stand-by or 1000 mV
ENDPOINT	350 mV
PROP BAND	85
MIN DEL	0

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MIL-S-322C  
INTERIM AMENDMENT 1 (OS)

4.4.5.4.4 Procedure. Grind a portion of sample to the consistency of table salt. Weigh  $0.50 \pm 0.05$  gm of sample in a weighing bottle. Dry at  $150^{\circ}\text{C}$  for 2 hours. Repeat 4.4.5.4.3 with the  $\text{NaNO}_3$ . Calculate the nitrogen content of the  $\text{NaNO}_3$ :

$$\text{Percent sodium nitrate} = \frac{6.07 V \times F}{W}$$

Where:

V = volume of titrant, ml

F = equivalence factor, %N/ml

W = weight of  $\text{NaNO}_3$ , gm.

Perform test in triplicate. Checks should agree within 0.03 percent. Record average value to the nearest 0.01 percent.<sup>a</sup>

Preparing Activity:  
Navy-OS  
(Project 6810-N062)

(3)

MIL-S-322C  
 5 February 1968  
 Superseding  
 MIL-S-322B  
 20 September 1962

MILITARY SPECIFICATION

SODIUM NITRATE

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope - This specification covers sodium nitrate for use in the manufacture of pyrotechnics, and other ordnance applications (see 6.1).

\* 1.2 Classification - Sodium nitrate shall be of the following grades and classes as specified (see 6.2):

Grade A (see Table I)	Class 1 (see Table II)
Grade B (see Table I)	Class 2 (see Table II)
Grade C (see Table I)	Class 3 (see Table II)

2. APPLICABLE DOCUMENTS

\* 2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Federal

RR-S-366	Sieve, Test
PPP-D-705	Drum: Metal Shipping, Steel (Over 12 and Under 55 Gallon).

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes.
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FSC 6810

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MIL-S-322C

MIL-STD-109

Quality Assurance Terms and  
Definitions.

MIL-STD-129

Marking for Shipment and Storage

MIL-STD-1293

Procedures for Determining Particle  
Size, Particle Size Distribution and  
Packed Density of Powdered Materials.

(When requesting any of the applicable documents, refer to both title and number. Copies of the applicable documents required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer).

2.2 Other publications - The following documents form a part of this specification. Unless otherwise specified, the issue in effect on date of invitation for bids shall apply.

American Society For Testing And Materials Standards

D1193

Reagent Water

(Copies of ASTM Standards may be obtained from the American Society for Testing and Materials 1915 Race Street, Philadelphia, Pa. 19108.)

American Chemical Society Publications  
Reagent Chemicals, A.C.S. Specifications

(Copies of A.C.S publications may be obtained from the American Chemical Society, 1175 Sixteenth Street, N.W. Washington, D. C.)

Technical Society and technical association specifications and standards are generally available for reference from libraries. They are also widely distributed among technical groups and using Federal agencies.

Interstate Commerce Commission

49 CFR 71-30

Interstate Commerce Commission Rules  
and Regulations for the Transportation  
of Explosives and Other  
Dangerous Articles.

The Interstate Commerce Commission Regulations are now a part of the Code of Federal Regulations and are available from the Superintendent of Documents, Government Printing Office, Washington, D. C. (Orders for the above publications should cite "the latest issue and supplements thereto").

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MIL-S-322C

## 3. REQUIREMENTS

3.1 Material - The sodium nitrate shall be a product of high quality, suitable for the purpose intended, and so formulated as to meet the requirements specified herein for the applicable grade and class of this specification. (see 4.4.1).

\* 3.2 Chemical requirements - The sodium nitrate shall conform to the applicable chemical requirements specified in Table I when tested as specified in the corresponding test paragraphs in Section 4.

TABLE I - Chemical requirements

Property	Grade A		Grade B <sup>1/</sup>		Grade C	
	Percentage		Percentage		Percentage	
	Max.	Min.	Max.	Min.	Max.	Min.
Moisture	0.75	...	0.5	...	0.75	...
Insoluble Matter	0.5	...	0.1	...	0.5	...
Alkalinity(as Na <sub>2</sub> O)	0.05	...	None	...	0.06	...
Nitrates(as NaNO <sub>3</sub> )	...	97.0	...	99.5	...	97.0
Chlorates(as KClO <sub>3</sub> )	0.05	...	None	...	0.06	...
Calcium (as CaO)	0.3	...	0.1	...	0.3	...
Magnesium(as MgO)	0.15	...	0.06	...	0.15	...
Sulfates(as Na <sub>2</sub> SO <sub>4</sub> )	0.5	...	0.2	...	0.45	...
Chlorides(as NaCl)	...	...	0.15	...	0.15	...

<sup>1/</sup> The percentages indicated, except the percent of moisture, are to be obtained in the sodium nitrate after the sample has been dried to constant weight at 302 ± 5°F (150 ± 3°C).

\* 3.3 Granulation - The sodium nitrate shall conform to the granulation requirements of Table II, when determined in accordance with 4.4.11, unless otherwise specified in the contract or order.

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TABLE II-Gradulation requirements

Sieve number 1/	Class 1	Class 2	Class 3
	Percent through	Percent through	Percent retained
	Minimum	Minimum	Minimum
20	...	...	60.0
60	99.0	...	...
100	...	98.0	...
200	...	...	...
325	...	...	...

1/ Use U. S. Standard sieves conforming to Specification 48-51.356.

3.4 Average particle diameter - (applicable to Class 2 only) In addition to conforming to the gradulation requirements specified in Table II, the average particle diameter of Class 2 sodium nitrate shall be 30 to 45 microns, when determined in accordance with 4.4.12.

3.5 Workmanship - The sodium nitrate shall be processed in a manner that will produce the high quality product necessary to meet the requirements of this specification (see 4.4.1).

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification when such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of inspection - The examination and testing of the sodium nitrate shall be entirely by quality performance inspection.

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\* 4.3 Quality conformance inspection - The quality conformance inspection shall consist of an examination for acceptability of quality control methods used by the manufacturer, an examination of filled containers for conformance to packaging, packing, and marking requirements, and examinations and tests of samples (4.3.3) for all the requirements of this specification. The inspection terms used herein are defined in MIL-STD-109.

\* 4.3.1 Quality conformance samples - Quality conformance samples shall consist of a sample for tests (4.3.3) and samples for examination of filled containers (4.3.4). Samples shall be labeled completely with information identifying the purpose of the sample, name of product, specification number, lot and batch number, date of sampling, and contract number.

\* 4.3.2 Lot and batch - For the purpose of sampling and inspection, a lot shall consist of sodium nitrate from one batch offered for delivery at one time, but not to exceed 24 consecutive hours under essentially the same manufacturing conditions and with no change in materials, providing the operation is continuous. A batch is that quantity of material which has been subjected to some unit chemical or physical mixing process intended to make the final product substantially uniform. In the event the process is a batch operation, each batch shall constitute a lot.

\* 4.3.3 Sample for tests - Ten (10) primary samples of equal weight, 25 grams each, shall be randomly selected from each lot of material and thoroughly mixed to form a composite sample representative of the lot. The container shall be labeled to identify the sample with the lot represented. If there are less than 10 containers in a lot, a sample shall be taken from each container. The composite sample shall be subjected to the conformance inspection specified herein. A lot shall be unacceptable if a sample fails to meet any of the test requirements specified.

4.3.4 Sample for examination of filled containers - A random sample of filled containers shall be selected from each lot of sodium nitrate in accordance with MIL-STD-105 at inspection level I and acceptable quality level (AQL) = 2.5 percent defective.

4.4 Inspection methods - Unless otherwise specified, the physical and chemical values specified in Section 3 shall apply to the average of the determinations made on the unit of product.

4.4.1 Conformance of the sodium nitrate to the requirements for material (3.1) and workmanship (3.5) shall be determined by appropriate examination and testing in accordance with Section 3.

4.4.1.1 Reagent water conforming to D1193 and reagent chemicals conforming to American Chemical Society (A.C.S.) specifications (see 2.2) shall be used throughout the tests. Weighings shall be made to the nearest 0.0001 gram (gm). Unless otherwise specified herein, solutions shall be made up on a weight basis.

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4.4.2 Moisture - Transfer a weighed 10 gr portion of the sodium nitrate to a previously tared shallow weighing bottle, heat in an air bath for 2 hours at  $302 \pm 5^\circ\text{F}$ . ( $150 \pm 3^\circ\text{C}$ .), cover, cool in a desiccator and weigh. Calculate the loss in weight as the percentage of moisture in the sample.

$$\text{Percent moisture} = \frac{100 (A-B)}{W}$$

Where:

A = Weight of bottle plus sample before drying in grams.

B = Weight of bottle plus sample after drying in grams.

W = Weight of sample in grams.

4.4.3 Insoluble matter - Transfer a weighed 25 gm portion of sodium nitrate to a beaker. Heat to boiling with 200 ml of water and decant the solution through a filtering crucible of fine porosity (a nominal maximum pore diameter of 4.5 to 5.0 microns) which has been dried at  $212 \pm 5^\circ\text{F}$ . ( $100 \pm 3^\circ\text{C}$ .) and weighed. Rinse the beaker with boiling distilled water and transfer any adhering insoluble matter to the filter. Decant the wash waters from the beaker through the filter. Catch the filtrate and wash waters in a 500-ml volumetric flask and retain for the determination of alkalinity (see 4.4.1.) The filtering crucible shall be dried in an oven at  $221 \pm 9^\circ\text{F}$ . ( $105 \pm 5^\circ\text{C}$ .) for 3 hours, cooled in a desiccator, and weighed. The increase in weight shall be calculated to percent insoluble matter as follows:

$$\text{Percent insoluble matter} = \frac{100 (A-B)}{W}$$

Where:

A = Weight of crucible plus residue in grams.

B = Weight of crucible in grams.

W = Weight of sample in grams.

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4.4.4 Alkalinity - Using freshly boiled distilled water, make up the filtrate obtained as specified in 4.4.3 to 500-ml and mix thoroughly. Pipet 100 ml of this solution into a flask, add 3 to 5 drops of phenolphthalein indicator and if the solution is alkaline, titrate with 0.1N acid. A blank determination shall be made on the distilled water and a correction applied if necessary. Calculate to percentage Na<sub>2</sub>O in the sample as follows:

$$\text{Percent Na}_2\text{O} = \frac{3.1 \text{ VN}}{W}$$

Where:

V = ml acid used in the titration.

N = Normality of acid used.

W = Weight in grams of sample represented by the aliquot.

4.4.5 Nitrates

4.4.5.1 Standardization of the nitrometer

4.4.5.1.1 Absolute method - Assemble the nitrometer (DuPont or equivalent) after thoroughly cleaning and drying all parts. The various parts, with the exception of the reservoir bulbs, are completely filled with mercury. Place 25 ml of 94.5 ± 0.5 percent sulfuric acid in the generating bulb. Draw air into the bulb to nearly the level of the lower shoulder by lowering the mercury reservoir and opening both stopcocks. Close both stopcocks and shake vigorously for 3 minutes. Connect the generating bulb into the compensating tube by adjustment of the two mercury reservoirs, keeping open the stopcock of the measuring tube. Continue the introduction of the air until the mercury in the reading tube is nearly at the 12.50 mark. Seal the compensating tube by means of a small blowpipe flame. Desiccate similarly in the generating bulb another portion of air and transfer this to the reading tube until the mercury in the reading tube, compensating tube, and their mercury reservoirs are at the same level, the mercury in the reading tube being approximately at the 12.50 mark. It is not necessary that these gas volumes be exact or equal. Fill a small U-tube manometer with sulfuric acid and attach to the reading tube. Allow the apparatus to come to constant temperature and then adjust the mercury levels in the reading tube, compensating tube, and their mercury reservoirs so that the air in the reading tube is under atmospheric pressure, as shown by the acid levels in the arms of the manometer tube. Take the reading on the graduated scale of the calibrated reading tube, and at the same time note the temperature and barometric pressure. From these readings calculate the volume of air at 20°C. and 760 mm. pressure in the reading tube by means of the following formula:

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$$V = R \frac{P \times 293(1 - 0.00018t)}{760(273 + T)(1 - 0.00018 \times 20)} = \frac{0.98552 PR(1 - 0.00018t)}{273 - t}$$

Where:

V = ml air at 20°C. and 760 mm., barometer at 20°C.

R = ml air at the observed temperature (T°C.) and at the observed pressure (Pmm).

t = Temperature (°C.) of the barometer.

The factor 0.00018 represents the correction to be applied for the coefficient of expansion of mercury in the barometer. When V has been calculated, adjust the heights of the reading tube, compensating tube, and their reservoirs so that, with the mercury in the reading and compensating tubes on a level, the mercury in the reading tube marks the calculated volume of the air. Paste a strip of paper on the tube so as to mark the height of the mercury in the compensating tube. Take this as the standard volume of air with which every volume of gas to be measured is compared.

Note. The use of dry air tends to form a scum around the reading level of the compensating tube, thus requiring frequent restandardization of the nitrometer. This scum is caused by reaction of oxygen in the air with mercury or by impurities. Dry nitrogen eliminates this condition and should be used, if available. A half drop of sulfuric acid will also prevent this scum.

4.4.5.1.2 Potassium nitrate method - Recrystallize three times from 95 percent alcohol a sample of chemically pure grade of potassium nitrate, and grind this to pass through a U. S. Standard No. 100 sieve. After drying at 275 to 302°F. (135 to 150°C.) for 2 or 3 hours, weigh a portion of exactly 1 gm into a small weighing bottle and transfer this portion to the cup of the generating bulb. Wash the potassium nitrate into the generating bulb by means of 8 to 10 portions of 94.5 ± 0.5 percent nitrogen-free sulfuric acid cooled to approximately 41°F. (5°C.) using a total volume of 25 ml of the acid. With the lower stopcock of the generating bulb open and the mercury reservoir low enough to maintain a slightly reduced pressure in the generating bulb, shake the sample until most of the gas has been generated. Adjust the mercury reservoir until the mercury drops nearly to the lower shoulder of the generating bulb. Close the lower stopcock and shake the bulb vigorously for 3 minutes. Replace the bulb on the rack, open the lower stopcock, and allow the tube to stand for 5 minutes, the levels in the generating bulb and reservoir being approximately the same. 1/ Close the lower stopcock, and shake the generating bulb for 1 additional minute. Transfer the gas to the reading

2/ Having previously introduced desiccated air into the compensating tube as described under the absolute method.

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tube, and adjust the levels of the mercury in the reading and compensating tubes to approximately the same height. Allow the gas to stand for about 20 minutes to permit equalization of the temperature. With a sulfuric acid U-tube leveling device, make careful adjustment, so that the mercury in both tubes are at the same level and that in the reading tube it is at the 13.85 mark (the percentage of nitrogen in potassium nitrate). Make a mark in the compensating tube to show the volume occupied by the air equivalent to the volume of nitric oxide gas liberated from exactly 1 gm of potassium nitrate. This mark is usually made on a strip of gummed paper attached to the compensating tube.

Note 1: In order to avoid any doubt regarding the purity of the potassium nitrate, it is desirable to check the standardization obtained by the use of potassium nitrate by means of the absolute method. If the agreement is within one-or two-hundredths of 1 percent, the potassium nitrate can be considered as of satisfactory quality and used in subsequent periodic standardizations. It has been found by actual experimentation that the solubility of nitric oxide in sulfuric acid of the strength prescribed is so small that no correction need be applied to bring the value in agreement with the mark set by the absolute method.

Note 2: If the nitrometer is standardized by both the absolute and potassium nitrate methods, the results may not be in agreement by 0.01 to 0.04 percent nitrogen due to expansion of the brass barometer scale. Such difference may be removed by applying the brass scale correction corresponding to the temperature.

4.4.5.2 Procedure -- Crush a portion of about 3 gm of the sodium nitrate so that it will pass through a U. S. Standard No. 100 sieve and dry for 2 hours at  $302 \pm 5^\circ\text{F}$ . ( $150 \pm 3^\circ\text{C}$ .). Accurately weigh approximately 0.85 gm of the dried sample and transfer it to the cup of a standardized five-part nitrometer (DuPont or equivalent). Measure into a small graduate 25 ml of nitrogen-free  $94.5 \pm 0.5$  percent sulfuric acid cooled to approximately  $41^\circ\text{F}$ . ( $5^\circ\text{C}$ .). Wash out the weighing bottle into the nitrometer cup with 5 ml of the sulfuric acid. Lower the mercury reservoir sufficiently to maintain a reduced pressure in the generating bulb. Open wide the upper stopcock and open the lower stopcock sufficiently to draw the acid mixture into the generating bulb. Make successive 4 ml rinsings with the rest of the sulfuric acid until it has all been drawn in. Close the upper stopcock, leaving the lower one open, and adjust the mercury reservoir just low enough to maintain a slightly reduced pressure in the generating bulb. Shake the bulb gently until most of the gas has been generated. Lower the mercury reservoir until the level of the mercury in the generating bulb is at the height of the lower shoulder, then close the lower stopcock and shake vigorously for 3 minutes. Replace the bulb on the rack, open the lower stopcock, and adjust the mercury reservoir until the mercury in the generating bulb is at approximately the same height as the mercury in the reservoir. This will bring the pressure inside the generating bulb to approximately one atmosphere, and the solubility of the nitric oxide gas in the sulfuric acid will be normal. Close the lower stopcock and shake the bulb vigorously for an additional 1 minute.

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W = Weight of dry sample in grams.

Where:

$$\text{Percent purity} = \frac{100W}{(V_1 - V_2)F}$$

Calculate the percentage purity of sodium nitrate as follows:

CAUTION: Too much alloy may cause excessive foaming and consequent contamination of the distillate.

Procedure: Using a 250 ml Erlenmeyer flask add 50 ml of standard acid (1N hydrochloric) with a few drops of methyl red indicator. Connect the flask to the outlet end of a condenser so that the condenser tip is immersed in the liquid. To a Kjeldahl flask, add consecutively 200 to 250 mg of the sample, Devarda's alloy, 100 ml water, and 5 ml of 20% sodium hydroxide. Quickly wash down the walls of the flask with 25 ml water and connect it to the condenser through a spray trap. Be sure all connections are gas tight before proceeding further. Heat the flask to boiling and continue the distillation until 100 ml of distillate has been collected. Lower the receiving flask until the tip of the condenser is out of the distillate and stop the distillation. Disconnect the spray and wash the inside of the condenser into the receiver with water. Titrate the contents of the receiver with 1N sodium hydroxide.

Alternate method: The DEVARDA method consists of placing the sample in a Kjeldahl flask, adding water, caustic soda and Devarda's reducing alloy to the flask and heating the mixture to reduce the nitrate to ammonia. The ammonia is distilled over and the excess hydrochloric acid is titrated with 1N sodium hydroxide. The purity of the nitrate is calculated from results obtained.

R = Reading of the measuring tube.  
W = Weight of dry sample in grams.

Where:

$$\text{Percent sodium nitrate} = \frac{W}{5.078}$$

Transfer the gas to the measuring tube, adjust the levels of the mercury in the compensating and measuring tubes to approximately the same height. Let the gas stand for 20 minutes in order to permit equilibration at the temperature of the gas in the two tubes, and adjust the mercury levels equally with a eudiometric leveling device, the mercury level in the compensating tube being at the standard volume mark. Calculate the percentage of sodium nitrate as follows:

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Na = Normality of the standard acid.

Vb = Titer of aliquot of standard base in ml.

Nb = Normality of the standard base.

n = Number of nitrogen atoms in the formula.

w = Weight of sample in grams corrected for moisture.

F = Formula weight of the nitrate being determined.

4.4.6 Chlorates - Transfer a weighed 25 gm portion of sodium nitrate to a beaker and dissolve in hot distilled water. Add 5 ml of HNO<sub>3</sub> and an excess of silver nitrate solution and stir. Filter the solution to remove any chlorides which may have been precipitated. Add to the solution 10 ml of 30 percent formaldehyde solution and heat on the water bath for 1/2 hour. Chlorate is thus reduced to chloride and precipitated by the excess silver nitrate. Filter off the precipitate on a tared filtering crucible which has previously been dried at 212 ± 5°F. (100 ± 3°C.) and which has a nominal maximum pore diameter of 4.5 to 5.0 microns. Dry the crucible and precipitate for 3 hours at 212 ± 5°F. (100 ± 3°C.). Cool in a desiccator and weigh. Calculate to percentage of potassium chlorate as follows:

$$\text{Percent potassium chlorate} = \frac{85.8A}{W}$$

Where:

A = Weight of the precipitate in grams.

W = Weight of sample in grams.

\* 4.4.7 Calcium - By means of a pipet, transfer to a beaker 100 ml of the solution prepared as specified in 4.4.4. Make distinctly acid with 5 ml of concentrated HNO<sub>3</sub>. Then make distinctly alkaline with NH<sub>4</sub>OH and heat to boiling. Precipitate the calcium by adding 10 ml of a saturated solution of ammonium oxalate. Continue the boiling for a few minutes, filter the precipitate on #42 Whatman paper or equivalent, wash with cold distilled water containing a little NH<sub>4</sub>OH, and determine the percentage of calcium oxide either gravimetrically or volumetrically. (Save the filtrate for the magnesium determination in 4.4.8).

\* 4.4.7.1 Gravimetric determination. Place the precipitate and filter paper in a weighed crucible and cover. Heat gently until the water is expelled and the paper charred. Transfer the crucible and contents to a muffle furnace and heat to 1200°C for 5 to 10 minutes. Remove the cover for an instant from time to time to assist the escape of carbon dioxide during the heating. Cool the covered crucible and its contents in a desiccator containing concentrated sulfuric acid. Weigh the cooled calcium oxide and repeat ignition until the weight is constant. Calculate the percent of calcium oxide as follows:

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$$\text{Percent calcium oxide} = \frac{100(A-B)}{W}$$

Where: A = Weight of crucible plus residue in grams.  
 B = Weight of crucible in grams.  
 W = Weight in grams of sample represented by the aliquot.

4.4.7.2 Volubetric determination - Wash the filter paper and precipitate thoroughly and then transfer paper and precipitate to a beaker containing 400 ml hot water to which has been added 10 ml of 18N sulfuric acid. Disintegrate the paper by stirring vigorously with a glass rod and then titrate rapidly while hot with approximately 0.05N  $\text{KMnO}_4$  solution until a pink end point persists for one-half minute.

Calculate the percent of calcium oxide as follows:

$$\text{Percent calcium oxide} = \frac{2.8 VN}{W}$$

Where:

V = ml of  $\text{KMnO}_4$  solution used.  
 N = Normality of  $\text{KMnO}_4$  solution.  
 W = Weight in grams of sample represented by the aliquot.

This method is preferred for small amounts of calcium since it is more accurate.

4.4.8 Magnesium - Catch the filtrate and wash water from the calcium determination (see 4.4.7) in a beaker. Add 10 ml of a 10 percent solution of disodium phosphate and then a volume of concentrated ammonium hydroxide (27 to 30 percent) of 1/10 volume of the beaker. Mix thoroughly and allow to stand overnight. Filter the precipitate on #42 Whatman paper or equivalent, wash with 5 percent  $\text{NH}_4\text{OH}$  and ignite in a tared platinum crucible. If the ignition does not result in a white precipitate, cool the crucible and contents, add a few drops of nitric acid or ammonium nitrate solution, heat gradually and then ignite fully. Spattering should be avoided especially during the early part of the heating. Cool in a desiccator and weigh. Calculate the increase in weight to percent magnesium oxide as follows:

$$\text{Percent magnesium oxide} = \frac{36.2(A-B)}{W}$$

Where:

A = Weight of precipitate plus crucible in grams.  
 B = Weight of crucible in grams.  
 W = Weight in grams of sample represented by the aliquot.

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4.4.9 Sulfates - By means of a pipet, transfer to a beaker 200 ml of the solution prepared as specified in 4.4.4. Add sufficient HCl to make the solution slightly acid, and heat to boiling. Slowly add 10 ml of a 10 percent solution of BaCl<sub>2</sub> and continue boiling for several minutes. Settle the precipitate on a steam bath and then filter in a tared filtering crucible of fine porosity, having a nominal maximum pore diameter of 4.5 to 5.0 microns. Wash with hot distilled water. Ignite, cool in a desiccator and weigh. Calculate the increase in weight to percentage of sodium sulfate as follows:

$$\text{Percent sodium sulfate} = \frac{60.9(A-B)}{W}$$

Where:

A = Weight of precipitate plus crucible in grams.

B = Weight of crucible in grams.

W = Weight in grams of sample represented by the aliquot.

4.4.10 Chlorides - An accurately weighed 25 gm portion of sodium nitrate shall be transferred to a 600 ml beaker. The sample shall be dissolved in 300 ml of hot approximately 185°F. (85°C.) distilled water and 5 ml of concentrated nitric acid added. Twenty-five milliliters of approximately 0.1N silver nitrate solution shall be added to the solution with the aid of a pipet. The solution shall be heated to boiling on a hot plate with occasional stirring and boiling moderately for approximately 2 minutes with constant stirring. The beaker and contents shall be removed from the hot plate. The precipitate shall be allowed to settle (if the precipitate does not settle readily it is permissible to filter the solution as specified and test the filtrate) and one drop of the supernatant liquid shall be added to one drop of a one percent solution of sodium chloride on a black porcelain spot plate. If no precipitate occurs on the spot plate, a second 25 ml portion of silver nitrate solution shall be added to the sample, boiled as indicated above, and the spot test repeated. The addition of silver nitrate solution shall be continued and the spot test repeated as specified above until a precipitate of silver chloride is obtained. The supernatant solution shall be filtered through a tared pyrex sintered glass crucible having a nominal maximum pore diameter of 4.5 to 5.0 microns, and with the aid of suction, the filtrate shall be collected in a 1000 ml filtering flask or 500 ml beaker. The silver chloride precipitate shall be transferred quantitatively to the filtering crucible with the aid of five 20 ml portions of 1:100 nitric acid solution and one 20 ml portion of distilled water. The crucible and contents shall be dried in an oven at 230 ± 9°F. (110 ± 5°C.) for 3 hours. The crucible shall be cooled in a desiccator and weighed. The percent chlorides, as sodium chloride, in the sample shall be calculated as follows:

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Percent sodium chloride = 30.80%

Where:

- A = Weight of crucible plus precipitate in grams
- B = Weight of crucible in grams.
- W = Weight of sample in grams.

4.4.11 Consulation - Attach a bottom pan to the required U. S. Standard sieves. Place two metal washers (flat SAF standard galvanized, OD 1 1/16 in., ID 17/32 in., thickness 0.004 in.) and a 100 gm portion of the sample on the sieves, cover and shake for 5 minutes by means of a mechanical shaker geared to produce 300 ± 15 gyrations and 150 ± 10 taps of the striker per minute. Weigh the amounts retained or passing through the sieves and calculate the percentage as required.

4.4.12 Average particle diameter (Applicable to Class 2 only)- Determine the average particle diameter by the procedure specified in MIL-STD 1233, Method 100.

\* 4.4.13 Examination of filled containers - Each sample of filled containers selected in accordance with 4.3.4 shall be examined for defects of construction of the container and closure, evidence of leakage, and unsatisfactory markings. Any container in the sample having one or more defects or under required fill shall be rejected, and if the number of defective containers in any sample exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, the lot represented by the sample shall be rejected.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging - Not applicable

5.2 Packing - Packing shall be Level A or B as specified (see 5.2).

5.2.1 Level A - In addition to the following, packing shall be in accordance with the Code of Federal Regulations "49 CFR 71-90".

5.2.1.1 Exterior containers - Sodium nitrate shall be packed in metal drums in accordance with PPP-D-705, Type III. Gross weight of container shall not exceed 120 lbs. Containers shall be provided with 0.004 inch polyethylene liners, sealed by heat sealing.

5.2.2 Level B - Sodium nitrate packed in accordance with the Code of Federal Regulations "49 CFR 71-90" shall be packed to afford protection against damage during shipment from the supply source to the first receiving activity for immediate use. Containers shall conform to the carrier rules and regulations applicable to the mode of transportation.





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5.3 Marking - Unless otherwise specified in the contract or order, marking shall be in accordance with Standard MIL-STD-129 and Code of Federal Regulation "49 CFR 71-90."

6. NOTES

6.1 Intended use - The sodium nitrate covered by this specification is intended for use in the manufacture of pyrotechnic compositions and incendiary mixtures.

6.2 Ordering data - Procurement documents should specify the following:

- (a) Title, number and date of this specification.
- (b) Grade and class of material (see 1.2).
- (c) Quantity required in pounds.
- (d) Type and capacity of containers in which the sodium nitrate is to be furnished, if other than as specified in Section 5.
- (e) Applicable levels of packing, and marking with requirements in detail, if other than as specified in Section 5.
- (f) Instructions regarding availability of inspection records.

\* 6.3 Changes from previous issue - The outside margins of this specification have been marked "X" to indicate where changes (deletions, additions, etc.) from the previous issue have been made. This has been done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in those notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content as written irrespective of the marginal notations and relationship to the last previous issue.

\* Custodian

Army - MU  
Navy - OS  
Air Force - 68

Preparing activity:

Navy - OS  
Project No. 6810-0763

\* Review Activities:

Army - MU, WC  
Navy - OS, AS  
DSA - GS

\* User activity:

Army - MI

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\* Review/user information is current as of the date of this document.  
For future coordination of changes to this document, draft circulation  
should be based on the information in the current Federal Supply  
Classification Listing of DOD Standardization Documents.

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REVIEW COMMENT RECORD (RCR)			Page 1 of 28
Document Title: Demonstration Results Report Thorium De-nitration Pilot Project		Document No. N/A	Document Revision: 0
Reviewed By: LMER		Date: July 31, 1998	Response by: Ben R. Crocker (M&EC)      Date: 9/2/98
No.	Reference	Reviewer's Comments	RESOLUTION
1.	General Page 1, ¶ 1	The report should answer this question: Can the process be designed for flexibility and optimizing unit ops at full scale ... to establish a defensible operations time line and justify a jump step from this demo scale to production operations? Scaling from 200 lbs/day to 200 to 300 lbs/hour ...	Yes, the process can be designed for full scale operation at 200 to 300 lbs/hour from the data obtained during this demonstration project. This represents a scale up factor of only 8 to 12 times the demonstration scale.
2.	General Page 2 ¶ 2	... The tests illustrated inherent problems in pursuing that (thorium hydroxide) pathway. The precipitation of Th (OH) <sub>4</sub> through the addition of NaOH can be a difficult step to control and the pH end point hard to achieve.	<p>The pH control difficulties resulted from two factors which can easily be handled in the design of the full-scale de-nitration system:</p> <p>(1) the lack of direct reading pH metering and caustic injection control. During the pilot scale, all pH measurements were performed manually on samples withdrawn from the reactor. For the full-scale reactors, we plan to install pH sensors in the reactor which will provide feedback data to an automatic pH controller with programmable logic to follow a prescribed titration curve for the de-nitration step.</p> <p>(2) the caustic feed pumps were over-sized requiring the feed rates to be turned down to less than 10 % of capacity. This type of problem is in the nature of pilot projects and does not reflect an insurmountable control problem.</p>

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Document Title: Demonstration Results Report Thorium De-nitration Pilot Project		Document No. N/A	Document Revision: 0
Reviewed By: LMER		Date: July 31, 1998	Response by: Ben R. Crocker (M&EC)      Date: 9/2/98
No.	Reference	Reviewer's Comments	RESOLUTION
3.	Gen. ¶ 2	The final products in the 5 batches consisted of poorly crystalline thorium product and NaNO <sub>3</sub> with significant moisture.	<p>We do not believe that the DLA is in search of perfect crystals. We do believe they are concerned with moisture content and minimizing residual nitrate. Our rinsed and dried product from Batch Test No. 4 had only 1.6 % residual nitrate, a concentration which we believe is low enough for safe storage or disposal. Your concern over final moisture content is valid. Our erratic product moisture content was due to two factors:</p> <p>(1) lack of an instrumental means of measuring humidity in the vapor space of the dryer. We stopped the drying process when the product appeared to be dry by visual and tactile observation methods. In the full-scale dryer a humidity control loop will be incorporated into the design.</p> <p>(2) lack of a carrier gas stream to efficiently transport water vapor out of the dryer. We have been in contact with Littleford, the dryer manufacturer. They have recommended that we operate the dryer at a partial vacuum and that we introduce dry air or nitrogen into the dryer to improve transport of water vapor out of the dryer to the vapor condenser. With the vacuum alone they predict moisture content of less than 2.0% by weight. With the purge stream, the residual moisture can be reduced to 0.5% or less.</p>

**REVIEW COMMENT RECORD (RCR)**

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**Document Title:** Demonstration Results Report  
Thorium De-nitration Pilot Project**Document No.**  
N/A**Document Revision:**  
0**Reviewed By:** LMER**Date:** July 31, 1998**Response by:** Ben R. Crocker (M&EC)**Date:** 9/2/98

No.	Reference	Reviewer's Comments	RESOLUTION
4.	General Page 2, ¶ 2	Only one run was really successful, with the rest resulting in sticky products or other problems. The team gave it a real try, but the issue of whether the flowsheet is fundamentally flawed exists.	<p>We disagree with this conclusion. Our purpose was never to perform five identical repetitions of the same process configuration. Our plan was to evaluate the performance of the basic de-nitration process as represented in Batch Tests 1 and 2. When that was successfully accomplished we planned to test serial rinses with demineralized water in Batch Tests 3 and 4. Finally, Batch Test 5 was to evaluate the process with serial rinsing and the added complexity of recycling sodium nitrate byproduct back to the dissolving step. We consider only Batch Test 3 to be a failure. All other batch tests contributed knowledge which in aggregate provides the level of process knowledge necessary to scale up the process and perform it in Phase II.</p> <p>The only problem we see with the flowsheet is with the amount of thorium solid that ends up in the heels and must be recovered. Batch Test 4 showed only 30 % of the solids lost to the heels. With the pH control improvements described earlier in these comments, we expect that rate to improve in Phase II. Our plan to use a membrane-type tubular ultra-filtration unit to recover small thorium particulate down to 0.01 micron should be an inexpensive but effective way of recovering small thorium solids from the heels.</p>

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5.	General Page 2, ¶ 3	A significant amount of Th was carried over into the supernate and filtrate that had to be recaptured to complete the total product. It was pointed out that rinsing of the filter cake improved it: However, it also served to increase the Th content of the filtrate.	This is a factual statement of the results we obtained in the Phase I Pilot Tests. In our response to comment Nos. 2 and 4, above, we described how we plan to minimize carry over of fine thorium solids by improving the pH control of the precipitation process and to efficiently recover those solids using tubular ultra-filtration technology. One other enhancement to the precipitation process that will improve the size and recoverability of thorium hydroxide precipitates is a change in the type of reactor to be used. Rather than using a plowshare reactor during the precipitation step, we plan to use a conical screw agitated precipitation reactor. These reactors use a tapered helical screw agitator on an orbital arm to provide low-shear mixing. A typical vendor brochure is provided as Attachment 1.

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6.	General Page 2, ¶ 3	The use of the ploughshare unit as the furnace at temperatures of ~ 280°F fails to achieve the necessary temperature to remove NaNO <sub>3</sub> and crystallize to make ThO <sub>2</sub> . The product that results from the ploughshare operation are a poorly crystalline ThO <sub>2</sub> that is associated with the sodium nitrate (two phase Material). This fact was clearly shown by a comparison of two samples, one from the ploughshare (~280°F) unit the other from bench scale heating to 1000°F which yielded 54.2% and 73.3% thorium, respectively.	Our response to Comment No. 3 describes how the moisture content of the thorium hydroxide can be reliably reduced to less than 0.5 % by use of vacuum and dry air or nitrogen purge. We believe this achieves the product stability needed for long term storage if it is combined with multiple containment final packaging such as that demonstrated in our pilot tests. The 1.6 % residual nitrate has no consequence since; (1) the product is not a DOT oxidizer, (2) the nitrate would not impact future efforts to use the product, and (3) would not cause deterioration of the sealed high density polyethylene containers and liners used for primary containment packaging. The percentages cited in the last sentence of the comment paragraph are from the product from Batch Test 2. Serial rinsing in Batch Test 2 was minimal compared to Batch Test 4. In Batch Test 4, the plowshare product was 64.8 % and the calcined sample was 79.4 %. The difference between Batch Tests 2 and 4 was that rinsing reduced nitrate from 4.5 % in Batch Test 2 to 1.6 % in Batch Test 4. Also, Batch Test 4 was drier than Batch Test 2 (14.7% and 23.5 % respectively). Although the dry thorium hydroxide is not in a high integrity crystalline form, it has only slightly less bulk density than the oxide form. We do not believe that the extra cost and ES&H risk posed by a calcining operation is justified by the small improvement in product quality that would be gained. Also, a thorium oxide crystal will be much harder to re-dissolve for anyone who wanted to purchase the product for recycle. With high temperature calcining the Phase II project will be driven in the direction of waste disposal rather than product recycling.

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7.	General Page 2, ¶ 4	... The values of initial pH measured on the five batches are below 1, and these data are not reliable in this extremely low range. Large scale would be more difficult. Obtaining a reliable pH measurement during neutralization of a large batch is difficult because of the inertia of the system while it is homogenizing. The method to obtain a reliable pH reading is to let enough time for equilibrium after each addition; this is not a good way for a process that must treat a large amount per day.	We believe that the use of the conical reactor with tapered helical auger mixing, coupled with on-line pH measurement and control will provided the reliability needed. This reactor design provides rapid mixing without high shear. We anticipate that up to three independent pH sensors will be inserted through the conical shell and will provide real-time pH measurement. The helical auger blades with be notched so that the auger rotation will not damage the pH sensors. Each pH instrument will retract into a housing for automatic flushing and calibration. The signal from each pH sensor will be input to a programmable logic controller (PLC) which will compare the readings, and automatically adjust the feed rate of caustic soda. With these changes, the equilibration time will be minimized, the accuracy of pH measurements will be improved, and control will be greatly enhanced. Remember, the ploughshare unit was a cylinder laying on its side, and it had no in-tank pH measurement or control. The pH readings were done manually on samples collected from the reactor.

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8.	General Page 2, ¶ 4	This analytical characterization of some key locations in the process was satisfactory; however, the mass balance for the entire process is poor. It is not possible to figure out absolute total secondary waste generated during the demonstration. In the best case, high weight percent of NaNO <sub>3</sub> appeared in the final product.	We disagree with this conclusion. The material balances are not perfect, but the theoretical and the analytical typically differ by 2 % or less, which is well within the accuracy needed to scale up a process. The "hop-scotch" analytical approach we used during the pilot scale project was a good balance between the need for data and the need to stay within a project budget. The analytical data provided by this approach provided analytical benchmarks at the necessary points in the process to allow a full understanding of the chemical transformations taking place, and to verify that the process proceeds in agreement with the theoretical reactions. Much of the variability seen in this project is reflected in the variability of thorium content in the feed material. The dissolving step was performed the same way every time, but the actual thorium concentration of the resulting solution varied significantly from the theoretical, indicating that some non-thorium materials (probably residual nitric acid) were present in the raw material as a diluent. Variations in residual nitric acid would also explain the variability in the starting pH of the thorium nitrate solution.

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9.	General Page 2, ¶ 5	Reproducible production of filterable solids by controlled caustic addition was not proven. The process was unforgiving in the pilot operation, not producing the "right Product" if the caustic was not added at the "right rate"...	Batch Test 4 reproduced the precipitation success of Batch Test 2 and actually improved upon it. The filter cake from Batch Test 4 was denser, and was not sticky, probably due to the serial rinsing. We believe that most of the difficulties with gelatinous solids were caused by the amount of caustic added during the fast caustic addition which occurred between pH of 0.3 and 2.0. When starting pH trended into the 0.8 to 0.9 range, instead of 0.3 to 0.4, our fast addition appears to have overshot a critical phase of the precipitation. This is what happened to Batch Tests 1, 3 and 5. In Batch Test 5 we used concentrated nitric acid to back-titrate from pH 6.0 back down to pH 2.0, demonstrating a method of recovery from the production of gelatinous solids. In Phase II, we will operate under pH control and will establish a much more efficient and controlled rate of caustic edition, which eliminates the risk of gelatinous solids formation in the critical pH range from 1.5 to 4.0. Above pH 4.0 the precipitation process is much less sensitive to upsets, allowing faster addition rates.

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10.	General Page 3, ¶ 1	Demonstration of the rinsing operation for pilot operation was not proven to be controllable/repeatable. The thorium gel may prevent satisfactory rinsing in the filter, as projected in the scale up. The rinsing operation must allow for migration of the nitrate salts out of the gel.	The success of the rinsing operations can only be judged in reference to the acceptable levels of residual nitrate in the product. Serial rinsing in Batch Test 4 reduced nitrate from 8.0 % in the reactor sludge blanket to 0.9% in the rinsed filter cake exiting the filter press. Drying the filter cake raised the residual nitrate back to 1.6 % due to water removal. Simulated calcining raised it back to 2.6 % by the removal of residual water and conversion of hydroxide to oxide. We believe that a residual nitrate concentration of 1.6% is acceptable for long term storage, disposal, or commercial recycle. The rinsing efficiencies in Batch Test 5 showed a similar trend except that calcining took the dried solids from 1.3 % to 9.7 % nitrate due to the greater amount of residual water removed during calcining. Remember, that in Batch Test 5, the nitrate content of the process at every stage was enriched due to the recycle of sodium nitrate solution back into the thorium dissolving step, an idea that will not be used in Phase II. Our conclusion is that serial rinsing in the filter press as demonstrated in Batch Test 4 and confirmed in Batch Test 5 is as effective as it needs to be. The DOT powder train tests were performed on product from Batch Tests 1 and 2 which had residual nitrate contents of 14.96 % and 4.5 % respectively. Each of these samples passed the DOT oxidizer test. If these high nitrate streams (representing essentially un-rinsed thorium product) are not oxidizers, then the 1.6 to 2.6 % residual nitrate of the rinsed thorium product appears to be adequately protective of DLA's interests.

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11.	General Page 3, ¶ 2	An average of 14.1% moisture (Table 6-5) in the dry thorium product was still left in the material. Also, Material is really excessively fine. The 1.0 micron filters did not function in removal of thorium fine particle from the press filtrate.	See our response to Comment No. 3 for a description of how the use of vacuum and dry air or nitrogen purge flow will reduce final product moisture content to 0.5 %. See our response to Comment No. 4 for a description of how we plan to use tubular ultra-filtration to recover small thorium particulate down to 0.01 microns.
12.	General Page 3, ¶ 3	Difficulties in managing this process are documented in the narratives where removal of the filter cake presented problems which demanded shoveling of the cake from the filter.	In the pilot-scale batch tests, we used manual methods for handling filter cake in two locations; (1) when using a paddle to wipe sticky filter cake off of the filter fabric, and (2) when using a shovel to transfer filter cake from the hopper into one of the side access ports of the plowshare drier. It is not unusual to have to use a paddle to assist filter cake to fall off of the fabric-covered plates. However, the non-sticky filter cake produced in Batch Test 4 released cleanly and fell out of the press as soon as its cavity was opened, leaving virtually no residual solids on the fabric. Even if paddle assist proves necessary, the doses to personnel from this activity are consistent with ALARA.  Use of a shovel to transfer cake from the hopper to the dryer is an activity unique to the pilot-scale demonstration. In Phase II, this transfer will be done by an appropriately engineered conveyance.

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13.	Specific Page 3	Section 2.1 and elsewhere  The template used for this evaluation was to ship the thorium product back to Curtis Bay. This should be defined as a basis for analysis/performance assumption only, and subject to change.	Agreed.	
14.	Specific Page 3	Section 2.2, line 2  Suggest use of low-temp vs. 'non-thermal'	Agreed.	

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15.	Specific Page 3	<p>Section 3.1 (pgs. 6-9)</p> <p>The method selected for drum unpacking seems to be poorly adapted to this program. A wet method of thorium dissolution is preferable with either pH or nitrate electrodes used to determine the concentration (i.e. weight) of the thorium which is important for the process (Section 3.2 pg. 9). Although some drum material can be removed dry, wetting some of the materials should not cause the RCRA paint filter test to fail if they are handled properly.</p>	<p>We still believe that a dry method is preferable to a wet one. Passing the paint filter test is not the only consideration. Corrosion of secondary waste compaction equipment and containers is also important. In order to remove corrosive TNH residues and solutions from the packaging debris it is likely that too much water would have to be used. If the residues on the packaging debris are left dry, all of the packaging debris and any residues it contains could be compacted, overpacked, and the resulting packages would not be corroded by the small amount of dry material remaining in the compacted matrix.</p> <p>We plan to remain with the dry method described in the draft report except that we will not use demolition hammers to break up the fused monolith. Instead, it will be dumped directly into the dissolver where the appropriate amount of dissolving water will be added and then the monolith will be chopped up with the mechanical choppers installed in the dissolver.</p>
16.	Specific Page 3	<p>Pages 8/9</p> <p>Good recognition of the advantages and disadvantages of the approach used in removing the TNH.</p>	<p>We will edit and revise this passage as appropriate to reflect the deletion of demolition hammering as described in our response to Comment No. 15.</p>

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17.	Specific Page 3	Section 3.2, line 2  Explain why is it important to know the weight to 0.1 lb. 0.25 % accuracy is a lot to ask for at these weights.	This is a valid comment. Weights to the nearest pound are adequate. The platform scale used during the pilot tests provided a digital read out to the second decimal place, for weights of 500 pounds or less. In the pilot tests it was important to know the total weight so that an adequate amount of dilute caustic could be prepared before the start of each batch test. We were also looking for discrepancies between a calculated theoretical thorium concentration and the actual concentration after the dissolving step as an indicator of the number of waters of hydration present. These goals will not apply to full-scale operation, hence less accuracy is appropriate.
18.	Specific Page 3	Section 3.3, Page 9  In-tank pH monitoring is needed for this operation. The plowshare mixer equipment limited the ability to test this approach and fully realize the benefits.	We agree that in-tank pH monitoring and control is needed to improve the reliability of this process in the precipitation step. A different reactor configuration and mixing method also would help. Our responses to Comments 2, 4, 5 (including Attachment 1) and 7 describe in detail the pH control system and the reactor proposed to be used in Phase II.

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19.	Specific Page 4	Section 5.1.1, Page 15  Provide the statistical analysis of this characterization scheme...	We did not use a statistical basis for characterization of the raw material, because all material came from the same source (domestic), the same process as evidenced by drum markings (BSD-AE-57-47), and the same Lot (71). Batch numbers were between 1014 and 1028. We used one grab sample to represent the raw material in the interest of concentrating our analytical efforts and budget on intermediate and final product and byproduct streams. We also, performed more sampling in Batch Tests 1 and 2 than in the latter tests because it was not necessary to answer the same question multiple times. We only analyzed for the differences between batches and operations, not for the similarities.
20.	Specific Page 5	Section 5.1.1, Page 15  This is the first place that describes how pH followed during NaOH addition. Need to present this earlier in unit process description.	Agreed. A paragraph describing the caustic soda titration performed in the precipitation step will be added to Section 3.3.

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21.	Specific Page 5	Section 5.1.1, Page 15  Samples are taken for analysis, but results of same not presented (unless it's later in report). These results should be collated, presented, and evaluated.	We chose to present analytical results in the lower half of the Material Balance Tables (Tables 6-2, 6-3, and 6-4 for Batch Tests 2, 4 and 5, respectively), where these data points serve as benchmarks for comparison with the theoretical calculated values presented in the upper half of each table. The narrative text for each batch test provides summary data for key analytical parameters. However, the analytical parameters cited in the text imply that some analyses were performed but not reported. These are erroneous references, which will be corrected in the final revision of the results report.
22.	Specific Page 5	Page 16  Do not refer to the dried filter cake product as thoria (ThO <sub>2</sub> ). This has not been established.	Although the Southwest Research Institute XRD results report dated April 15, 1998 (See Appendix A of the draft results report) identifies the thorium product as poorly crystalline thorianite (ThO <sub>2</sub> ), we will refer to the product as thorium hydroxide.
23.	Specific Page 5	Section 5.1.2, Page 17  The Th yield is low and nitrate content of the product is high...Also, it may not be possible to adequately flow water through this gel...	Please see our answer to Comment No. 10. The Results Evaluation subsection in the Section 5 Batch Test Reports beginning with 5.1.2 on page 17, and ending with 5.5.2 on page 30 evaluate the results of each batch test separately. Section 7.0 takes these findings and proposes a full-scale design which addresses the problems and deficiencies, and capitalizes on the successes of the pilot test program in aggregate. Section 7.0 will be edited to provide more detail on the type of reactor and the pH control system to be utilized in Phase II.

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24.	Specific Page 5	Section 5.2.1, Page 18  Wrong table #, Table 6.2, not 6.1	We will correct in final edits.	

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25.	Specific Page 5	<p>Page 18 (typo)</p> <p>Suggest tables are needed to show: (1) operations times for each step for each batch; and (2) water balance with thorium content identified</p> <p>Describe in some detail how pH was measured, DI added, and predicted accuracy of caustic and DI input weight measurements.</p>	<p>We will provide tables summarizing the time increments of each operation. Tables 6-2, 6-3 and 6-4 summarize the material balances including the water balance. When measuring pH of grab samples from the reactor, the sample tap was flushed and the flush material added to the drip bucket, which was emptied back into the reactor periodically. An aliquot of the sample was poured into a 50 ml beaker which was placed inside a 250 ml beaker of boiling water on an electric hot plate. A mercury thermometer was inserted into the sample beaker and both beakers were covered with watch glasses to retain the heat. The pH probe was recalibrated at ambient temperature each morning. When the temperature of the sample returned to approximately 5 degrees C above the operating temperature, the watch glasses were removed, and the pH probe was inserted. Zero and temperature correction were reset at measurement temperature and the reading was taken. As soon as the watch glasses were removed, the temperature of the sample would begin to fall. Usually, the temperature had returned to the operating temperature by the time the reading was taken. Operating temperature was generally between 90 and 95 degrees C. Demineralized water was added through a totalizing flow meter accurate to 0.1 gallons, with the difference between the starting and ending readings being the total volume delivered. Caustic was metered into the reactor from a metering pump drawing solution from pre-mixed drums of 25 % and 10 % strength. In all five batch tests 100 % of the 25 % solution was added. Then 10 % caustic was added until a pH of 11.0 was achieved.</p>

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26.	Specific Page 5	Table 6.2  Col. 1a. The pentahydrate is the basis for the theoretical quantity of Th from the listed thorium and nitrate masses relative to the total mass. The hydrate water is never accounted for, which can lead to a discrepancy in the water balance.... Distinguishing between 'filtration step recovery' vs. 'reaction yield' is very important.	We will correct Col. 1a to account for the water of hydration. This is the only column of data in the table that does not account for water of hydration. Therefore, the error does not cascade through the calculation from one column to the next. The discrepancy between theoretical thorium and analyzed thorium concentration at Col. 2 is either the result of analytical inaccuracy or a diluent in the raw material that is unaccounted for by the analyses. The variability in starting pH from one batch to another leads us to suspect that residual nitric acid is bound up in the thorium nitrate mass in Col. 1a. In the draft report, we calculated yield based on the filtration step recovery method. This resulted in lower overall percentage yields. A heels recovery process having its own recovery yield would be needed to close the thorium material balance.
27.	Specific Page 6	Columns 4 & 6a  Explain/interpret the difference in thorium mass here. 17.9 ppm in the supernate is not enough to account for this difference.	Comparing the analyzed concentration of thorium shown for sample BT1-001 with the theoretical concentration in column 1a (38.0 % and 40.7 % respectively), we can conclude that although the XRD analysis indicates thorium nitrate pentahydrate, that there are diluents in the matrix of the raw material, probably nitric acid. If 38.0 % thorium is assumed to be correct, then the nitrate content should be only 40.6 % versus 42.3 % as measured in Sample BT1-001.
28.	Specific Page 6	Columns 6e & 7 equal 6c, but the missing thorium mass shows up again in 11, so apparently thorium was in the heels.	Column 11 was calculated by difference between the starting Column 1a and column 7. Using 38 % thorium content of the raw material, Column 11 would have a thorium content of 52.2 pounds instead of 63.3 pounds.

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29.	Specific Page 6	Page 19  Do not use "thoria" term. Describe location of temperature measurement instrument, suspected interferences/bias if any and accuracy of temperature data.	We will change terminology to thorium hydroxide solids.  The steam temperature was measured by an in-line temperature gauge which had an accuracy of $\pm 3.0$ °F. The reactor temperature was measured by a temperature gauge inserted into a thermowell in the side of the ploughshare reactor below the level of the batch materials.
30.	Specific Page 6	Section 5.4.1, Table 6.3  Same observations as for T6.2 (Comment No. 26)  Two p23s that were slightly different (last line on p24 on one and repeated for other), despite having same date.	Same answer as Comment No. 26.  Extraneous page 23 will be deleted in final.
31.	Specific Page 6	T5.1  Include the nitrate concentrations/contents	Table 6-3 adequately summarizes the nitrate content of the rinseate and the rinsed materials. We will provide graphs to better illustrate the effectiveness of rinsing, but we do not plan to include that information in Table 5-1.
32.	Specific Page 6	Page 24  A plot of product nitrate content in both rinseate and product versus rinse step would be useful to illustrate the effectiveness of # of sequential rinse steps in lowering nitrate content.	We will provide the requested graphs in a separate section dealing with the effectiveness of rinsing.

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33.	Specific Page 6	Section 5.5.1, Table 6.4  Same comments as for T6.2 & 6.3	Same answer as Comment No. 26.
34.	Specific Page 6	Page 27  3x the planned rate! Was this calibration error only for this batch? This error makes all the batches suspect! This part is not clear. A new pump was used for NaOH, but define when it first began use, this batch or another...	This was due to a calibration error, and does not constitute a reason for suspecting other batches. The new metering pump was first used in Batch Test Number 4, which did not suffer from the calibration error of Batch Test Number 5, or from the erratic metering rates of earlier batch tests. The results of Batch Test Number 4 show that the reaction rate can be adequately controlled to produce thorium hydroxide solids which filter well.
35.	Specific Page 7	Table 5.2  Same comment about including concentration info and adding a plot.	We will provide the requested graphs in a separate section dealing with the effectiveness of rinsing.
36.	Specific Page 7	Section 5.7.1  Plots of this data may be helpful.	We believe that tables 5-3, 5-4, and 5-5 adequately present the information.
37.	Specific Page 7	Table 5.3  If the "filtered feed condensate" is the feed for the IX column, why is the Col 1 effluent concentration higher than the filtered feed condensate concentration? Clarification needed.	The term "Filtered Condensate from Reactor" refers to bench scale filtration performed by the Perma-Fix Lab on a single grab sample collected from the reactor before the ion exchange run was started. The time referenced data is for samples collected from the effluent of Column 1 and Column 2 at a specific point in time. We will attempt to clarify in the text and tables.

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38.	Specific Page 7	Section 6.0, Table 6.1  It is interesting to note that a sample of the original ThN did not burn and is not classified as a Division 5.1 substance per Southwest Research results presented Appendix A for 5.1 Materials. Discuss context for stockpile management.	We will add a paragraph in Section 6.0 as requested.
39.	Specific Page 7	Table 6.5  The measured content for the feed was 38% and 42.3 wt % for thorium and nitrate, respectively, not 40.7 and 43.5%. For thorium nitrate pentahydrate, it is 40.7 and 43.5 %, which is assumed to be the basis for the theoretical calculations. If the measured concentration is accurate, other materials are in the feed (e.g., the moisture content is 0.1 wt %) and not as much Th is in the feed as was assumed for the mass balances. The heels are not accounted for in these concentrations, which would increase the Th content significantly for these secondary materials.	We will base Table 6-5 on the measured rather than the theoretical calculations as follows:  Southwest Research Institute characterizes the form of the raw material as thorium nitrate pentahydrate based on sample BT1-001C, but states that other identifiable peaks were present. Based on the thorium and nitrate concentration discrepancies, delineated in this comment, we will assume that the diluent is residual nitric acid trapped in the solid matrix.  We will add a column to the "Primary Thorium Materials" portion of Table 6-5 to account for the heels.

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40.	Specific Page 7	Section 7.0, Page 47  Consider rinsing in the filter, as suggested earlier, assuming water can flow sufficiently through filter cake.	We agree that rinsing should be done only in the filter press, as described in Section 7.2, page 49.
41.	Specific Page 7	Section 7.1, Page 49  Suggest that dissolving from drums would be better than the proposed hands-on break up, if can achieve target concentration.	This issue has been addressed in our response to Comment No. 15.
42.	Specific Page 7	Section 7.2, Page 49  The precipitation reactor should have an in-tank pH probe and mixers sufficient to carefully monitor pH with NaOH addition.	We agree. We will revise this section to reflect the design enhancements described in our response to Comment Numbers 2, 4, 5 and 7.
43.	Specific Page 8	Section 5.1.2, 1 <sup>st</sup> bullet  Explain why the agitator speed is important to go with the data indicating this.	Leaving the agitator at high speed unnecessarily exposed the precipitated solids to a high shear environment thus contributing to the production of fine solids which did not filter well. Batch Tests 2 and 4 demonstrated good filtration ability for batches in which shear was kept low and pH control was kept within optimum parameters. A sentence will be added to the bullet to explain.

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44.	Specific Page 8	Section 5.2.1 and similar sections to follow  It is hard to sort out how long each run took or, of greater interest, how long it would have taken if done without the interruptions inherent in pilot scale operations. X hours for this and Y hours for that are mentioned but a bottom line for each run (or a summary at the end) would be helpful.	We agree. A summary table will be added to capture this information.
45.	Specific Page 8	5.2.2, 1 <sup>st</sup> sentence  A product with the consistency of lard, 70 % recovery, etc is not an unqualified success... Suggest rephrasing in correct context.	We agree. Will rephrase.
46.	Specific Page 8	Page 20, 1 <sup>st</sup> line  Define 'yield' as is used here.	Agreed. See our response to Comment No. 26. We will provide a definition at an appropriate location in the report.
47.	Specific Page 8	Page 20, 2 <sup>nd</sup> paragraph  It is not a DOT oxidizer. The issue has to do with addressing whether it is stable for long-term storage and disposal, e.g., what do alpha particles do to it?	We do not understand the logical basis of this comment. Alpha particles will be present in any thorium product produced by any process. What linkage is there between the presence of alpha bearing materials and the nitrate concentration in the product? Nitrate content only impinges on the chemical resistance of the packaging, and any special precautions required to manage the material if it were a DOT oxidizer.

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48.	Specific Page 8	Page 21, middle  A sentence attributes the difference in starting pH to variations in ThN quality. Explain difficulties associated with accomplishing this during the demo.	The sentence in question merely points out that starting pH was highly variable, and attributable only to the chemical characteristics of the raw material, since the same amount of dilution water from the same source was used in every test. A pH monitor in the reactor will make it easier to normalize the process to compensate for variations in raw material quality
49.	Specific Page 8	Section 5.3.2, end of 1 <sup>st</sup> paragraph  Define the critical pH range	The critical pH range for the start of precipitation appears to be in the range of 1.5 to 2.0, and less so up to a pH of 4.0. Above pH 4.0, the process is much less sensitive to upsets, allowing faster addition rates. This discussion will be added to the report in an appropriate location.
50.	Specific Page 8	Section 5.7.1, end of 1 <sup>st</sup> paragraph  Define removal efficiency - the numerator and denominator. Are the values for IX for that alone or cumulative?	The values for removal efficiency presented in the text and in Tables 5-3, 5-4 and 5-5 are calculated on an accumulative basis using the "Condensate in Dryer" concentration as the denominator and the specific effluent concentration as the numerator.
51.	Specific Page 9	Section 5.7.1  Based on the data presented, most of the residual Th is removed by the filtration and the ion exchange does not appear to be worthwhile. However, this may depend on the answer to the above comment. Expand discussion.	We agree that most of the benefit of treatment is derived from the filtration step, however Liquid Batch Test No. 2 shows significant removal of Th in the ion exchange unit. For Phase II, we propose to use a tubular ultra-filter in place of the bag filtration step and the ion exchange step. For particles down to 0.01 microns, this unit should provide high capture efficiency for thorium hydroxide solids. An ion exchange unit could be used on the ultra-filter effluent if additional polishing is needed, however we do not call for one in the Phase II concept (Section 7.0).

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52.	Specific Page 8	Table 5-3  Define Column 1 and Column 2	We will reconfigure these tables to be more easily understood.
53.	Specific Pages 8 and 9	Table 6-2 and similar (or Table 6-6)  Information on the concentration of Ra and its daughters are needed for the effluent streams.  It is preferable to have All of the batch test results summarized in tabular form and not just the selected favorable results (i.e., Table 6-2, 6-3, 6-4 only give results for batch tests number 2, 4 and 5). The results of the two 'failure' tests (1 & 3) should also be included or qualified clearly as to why they were not presented.	This information based on LMER analyses will be added to Table 6-6.  The approved Pilot Scale Test Plan for this project committed to performing only three material balance investigations. That is the purpose of Tables 6-2, 6-3 and 6-4. Batch Test Number 1 was not a failure, but it was not as successful as Batch Test Number 2. The three batch tests developed into material balances provided the most useful information for evaluating the basic de-nitration process and its reasonable permutations. Analytical data for Batch Test Number 1 is included in the Appendix, but including it in the bulk of the report would only add a layer of confusion to the report. The samples collected for Batch Test Number 3, the only true 'failure' test were not analyzed, per the approved Pilot Scale Test Plan.
54.	Specific Page 9	Section 8.5, 3 <sup>rd</sup> paragraph  Define the radiological content in tabular form with back-up analysis. If not, how is it known that there is a market without characterizing the radiological contents?	This project budget was not sufficient to completely resolve all issues relating to recycle and release of the byproduct materials. Table 6-6 ( <b>5-10 instead</b> ) will be expanded to capture the, activity, thorium, and radium data that was measured.

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<b>No.</b>	<b>Reference</b>	<b>Reviewer's Comments</b>	<b>RESOLUTION</b>	
55.	Specific Page 9	Page 55, top  Define value (payment from the Army) for a dried product in terms of a full-scale production project.	We do not know at this time what the Army would be willing to pay for dried sodium nitrate. These liquid recycle issues, internal to the Army, will have to remain unresolved until Phase II. We provided a path forward to a potential market, which is the limit of our contractual requirement.	
56.	Specific Page 9	Per Section 5  Several samples were submitted for XRD analysis. The diffraction results are shown in the appendix. These results and information should be provided.	We will provide a summary table at an appropriate location in the report.	

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57.	Specific Page 9	<p>Table 6-1 (pg 40)</p> <p>It is stated that ignitability (D001) analysis was performed. Provide the results and discuss in the context...</p> <p>The appendix has a Section for x-ray fluorescence (XRF) analysis and some results are shown. This is not listed in Table 6-1...</p> <p>In the appendix of analytical results almost no detection limits are provided for the analyses....</p> <p>No radium-228/224 was detected for any of the samples. Provide a discussion and basis.</p>	<p>Ignitability was determined by Southwest Research Institute by performing the DOT oxidizer test. We will provide a summary in the text. No other ignitability tests were performed.</p> <p>We will add this information in an appropriate location.</p> <p>We did not ask for the results to be reported with lab QA/QC data. We do not intend to go back to the labs for additional information, LMER may contact them directly if you choose.</p> <p>We did not ask for radium analyses, therefore they were not reported. We will incorporate radium data produced by LMER.</p>

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58.	Specific Page 9	Table 8-6  Discuss basis for absence and/or identify projected costs for: ...	Table 8-6 is a summary table providing rolled up costs from Tables 8-1 through 8-5. All listed items except for depot drum preparation, NEPA and sampling/analysis are covered in the other tables. We will add lines to the existing tables to cover these issues. NEPA is such a nebulous activity as to be unpredictable. Therefore, we will plug in a guess, and you can modify it as you see fit. In the alternative case, NEPA review has already been performed for the East Tennessee Technology Park as part of the Re-industrialization Initiative, so the destination NEPA cost are insignificant. Origin site NEPA will be considered to be a FONSI or a categorical exemption for shipments leaving the site. For on-site treatment, NEPA would be much more complicated as the modified cost tables will reflect.

**ATTACHMENT 2**

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**Pilot Demonstration Results Report  
for  
Conversion of Thorium Nitrate to  
Thorium Oxide**

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*Subcontract No. 96K-03684V*

Document No. R-108-03

September 1998

Prepared for:  
**Lockheed-Martin Energy Systems**  
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## ThN Treatment Demonstration Project (TTDP)

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## 1.0 SUMMARY

The Defense Logistics Agency (DLA) manages the storage of about 3,580 tons of crystalline thorium nitrate (ThN) contained in 21,609 overpack drums of various sizes. Contact with moisture from over thirty years of storage has caked the material into solid monoliths typically contained in three or four plastic and steel drums. The current state of this material poses a potential hazard, which could adversely impact human health and safety and/or the environment.

To reduce or eliminate this potential hazard, DLA through the U.S. Department of Energy (DOE) and their contractor, Lockheed Martin Energy Systems, Inc., (LMES) was seeking a means of converting the ThN to a stable thorium oxide form with a reduced mass and volume. This final form would, with minimum effort, be recoverable for eventual use as a feed in the manufacture of thorium products or be acceptable for placement in a repository.

Recovery Dynamics, LLC (Recodyne) developed an approach to convert the ThN to thorium oxide. The ThN is dissolved in water and then converted to thorium oxalate by precipitation with oxalic acid. The solids are filtered off and calcined at a temperature greater than 600 °C. Although the precipitation of thorium oxalate and its conversion to the oxide has been extensively studied and practiced on a commercial scale in the past, the poor chemical and physical state of the ThN precludes direct application of the technology without additional information from pilot testing. A demonstration was thus required in which a pilot plant would convert one ton of DLA ThN to thorium oxide. The results of the pilot plant would be used to confirm the feasibility of ThN conversion and provide the bases for full-scale plant design and estimation of life cycle costs.

The pilot plant was set up and operated at a commercial facility licensed to possess and handle nuclear materials. Ten drums of ThN from the DLA inventory were processed over a three-week period. Key steps in the conversion process that were demonstrated included: 1) separation with water of ThN from its packaging, 2) precipitation and filtration of thorium oxalate, 3) calcining thorium oxalate to the oxide and 4) evaporation of spent nitrate liquor to a solid secondary waste.

The pilot demonstration results confirmed the feasibility of converting DLA ThN to thorium oxide by oxalate precipitation. The ThN was removed easily from its container by a stream of hot water. The thorium in the resulting liquor was precipitated to the oxalate with an efficiency of greater than 99.9%. The thorium oxalate filtered well once the precipitation time was extended to 12 hours. Conversion to thorium oxide was accomplished in a rotary kiln

to 90 - 95% with increases in kiln temperature and/or residence time. Consolidation tests on the resulting thorium oxide powder showed that it could be pressed into a dense tablet with the addition of a binder such as graphite.

The performance of the pilot plant was used as the bases for the preliminary design of a full-scale plant. Plant capacity was based on a total of 3,580 tons of ThN processed over a period of 5 years. The process would be located at an existing commercial facility possessing a nuclear materials license. The process has been designed for the zero discharge of wastewater. Thus, secondary wastes from the process that would require LLW disposal include sodium nitrate solids resulting from the evaporation of spent nitrate liquor as well as the ThN overpack drums.

The converted thorium oxide product would be shipped back to DLA for long-term storage. Of the licensed facilities that have expressed interest in the full-scale processing, two have indicated their capability to provide long-term storage of the entire thorium oxide inventory. This alternate approach warrants further investigation, since eliminating the transportation and storage of thorium product by DLA may provide substantial benefits with respect to regulatory approval of the project.

The preliminary design of the process is provided in this report and includes an equipment list, process flow and instrumentation diagrams and mass and energy balances. A project time line for the construction and start up of the full-scale process was developed showing an 18-month duration. Time line activities include detailed engineering, secondary waste qualification, hazard analysis, equipment procurement and installation, developing operating procedures and performance testing.

Life cycle costs were estimated for the full-scale system. A fixed capital cost of \$5,318,635 was estimated that includes the purchase of equipment, installation and engineering. Annual manufacturing costs including transportation, labor, utilities and secondary waste disposal was estimated at \$7,026,415. For the 5-year project, total cost including decommissioning was estimated at \$40,768,507. A breakdown of these costs on a percentage basis is as follows.

Fixed Capital -	13%
LLW disposal -	17%
Direct labor -	11%
Product transport -	7%
Other Manuf. Cost -	48%
Decommissioning -	4%

## 2.0 INTRODUCTION

The DLA manages the Defense National Stockpile Center (DNSC) storage of about 3,580 tons of crystalline ThN contained in 21,609 overpack drums of various sizes. ThN is very soluble in water and therefore has a high potential for environmental mobility following an accidental spill. Contact with moisture from over thirty years of storage has caked the bulk of the material into solid monoliths typically contained in small fiber drums overpacked in two larger drums. Chemical analysis of ThN samples taken during a previous pilot test project showed concentrations of arsenic, chromium, lead and silver which, if present throughout the ThN stockpile, would total over 19 tons of combined heavy metals. The current state of this material suggested that a potential hazard existed which could adversely impact human health and safety and/or the environment.

To reduce or eliminate this potential hazard, DLA through the U.S. DOE and their contractor LMES, Inc. is seeking a means of converting the DNSC ThN to a stable form with a reduced mass and volume. This final form would, with minimum effort, be recoverable for eventual use as a feed in the manufacture of thorium products or be acceptable for placement in a repository. With respect to the chemistry, the oxide thoria ( $\text{ThO}_2$ ) is considered the most stable form of thorium reasonably attainable from ThN. To produce thoria, a thorium salt is usually subjected to a thermal process in which the anion is converted to a gas and driven off at high temperature.

Recodyne developed an approach to convert the ThN to thorium oxide via aqueous precipitation of an intermediate thorium compound. Besides reducing or eliminating the need to control nitrogen oxide emissions, the conversion of ThN to an aqueous feed facilitates easy removal from its packaging, since the caked material should dissolve readily in a stream of hot water. Although precipitation of thorium salts and their conversion to  $\text{ThO}_2$  has been successfully operated on a pilot or commercial scale in the past, the poor chemical and physical state of the DLA ThN precludes their direct application without obtaining additional information from pilot testing. A demonstration was thus required in which a pilot plant would convert 1 ton of DLA ThN to  $\text{ThO}_2$  over a two week period. The results of the pilot plant would be used to confirm the feasibility of ThN conversion and provide the bases for full-scale design and estimation of life-cycle costs.

Bench-scale tests with synthetic solutions of thorium nitrate and silver indicated that thorium could be selectively precipitated as the peroxide leaving the heavy metals in solution. A relatively complex process was thus initially proposed for the Demonstration which not only had the capability to convert the ThN to the oxide, but also to isolate and convert the heavy metals to a form that had commercial value as a silver concentrate. It was suspected, however, that the analytical results obtained in previous studies and which the

peroxide precipitation process was based on, were high biased such that the actual concentration of heavy metals in the ThN was much lower than reported. In subsequent discussions with LMES, it was agreed that a much simpler conversion process utilizing the intermediate precipitation of thorium oxalate could be demonstrated if the heavy metals were not present or would otherwise not cause the final thorium oxide product to be considered characteristically hazardous. Recodyne had considered this approach in its development of the original demonstration proposal; however, it had been discounted, since review of the chemistry indicated that the bulk of the silver and lead would precipitate along with the thorium. Since Recodyne had intended to confirm at bench scale the chemistry of the proposed process with the actual ThN to be used in the demonstration test, an opportunity existed to further analyze the ThN composition and determine if switching to oxalate precipitation was feasible.

The oxalate precipitation and thorium oxide calcination steps were tested in the laboratory on a composite sample of the DLA ThN. The sample was diluted down to 110 g/L thorium and oxalic acid ( $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ ) added. The resulting precipitate was filtered, washed and calcined in a muffle furnace at a temperature of 800°C to form thorium oxide. Analysis of the filtrates by Direct Coupled Plasma – Atomic Emission Spectrometry (DCP-AES) indicated that essentially all of the thorium was precipitated by the oxalate addition (1-PPM in filtrate). None of the four heavy metals were detected. Based on these positive results, generation of a final wastewater meeting NRC criteria for free release was also considered a possibility.

The possibility was further examined by determining if the radium left behind after thorium precipitation could be reduced to an acceptable level by the standard technique of co-precipitation on barium sulfate. A single stage precipitation with barium chloride and filtration of the resulting barium sulfate provided a 99.9% removal of radium. A two-stage barium sulfate precipitation was thus included in the pilot plant flow sheet as an option with the expectation that radium activity could be reduced to less than 50 pCi/L. Regulatory approval, however, for the free release of wastewater from a radioactive process has a degree of uncertainty that preclude it as the sole approach to nitrate liquor disposal. The final step in the pilot demonstration was therefore based on a zero discharge to be achieved by evaporation of the nitrate wastewater to dryness.

To finalize the pilot plant flow sheet, potential hazards associated with the  $\text{ThO}_2$  product were also examined. The  $\text{ThO}_2$  product generated from the composite sample was leached with acetic acid as specified by the Toxicity Characteristic Leach Procedure (TCLP). The four heavy metals were not detected by DCP-AES analysis indicating that the final  $\text{ThO}_2$  product would

not be considered as characteristically hazardous. The other concern with the thorium product was its physical nature and the associated requirements for storage in a repository. The future handling and long term storage of the  $\text{ThO}_2$  product as an unconsolidated material, particularly a fine powder, could pose a significant risk of becoming an airborne hazard. Preliminary bench-scale tests indicated that the product could be pressed into tablets with the addition of a binder such as lime. A tablet press was added to the pilot plant operation to demonstrate the feasibility of this approach.

Based on these positive bench-scale results, it was decided that the conversion process to be demonstrated would be based on the intermediate conversion of ThN to thorium oxalate. The following Results Report describes the pilot plant, its operation and the results obtained from the conversion of approximately 2,000 lb. of DLA ThN to  $\text{ThO}_2$ . Included in the Report is an Engineering Study (ES) which provides the design bases and a preliminary process flow diagram and mass/energy balances for the full-scale system. The life cycle cost for constructing, operating and decommissioning a full-scale system for converting the entire DLA inventory was estimated based on this design. Potential health and environmental issues regarding the full-scale operation were also examined.

### 3.0 PILOT DEMONSTRATION RESULTS

Based on the evaluations conducted by Recodyne and LMES, it was decided that 10 drums of ThN with a MD-1 configuration would constitute a representative sample from the DLA inventory. This configuration consisted of 200 LB of ThN contained in a 20 gallon fiberboard drum that is overpacked in a 30 gallon fiberboard drum followed by a 35 gallon plastic or fiberboard drum and finally, by a 35 gallon steel drum. Over 70% of the ThN inventory with respect to its weight and drum type are contained in the MD-1 configuration. Of the 10 drums shipped, nine were of this configuration while the tenth container had four overpack drums: a 30 gallon fiber, 35 gallon fiber, 55 gallon plastic and finally a 55 gallon steel drum.

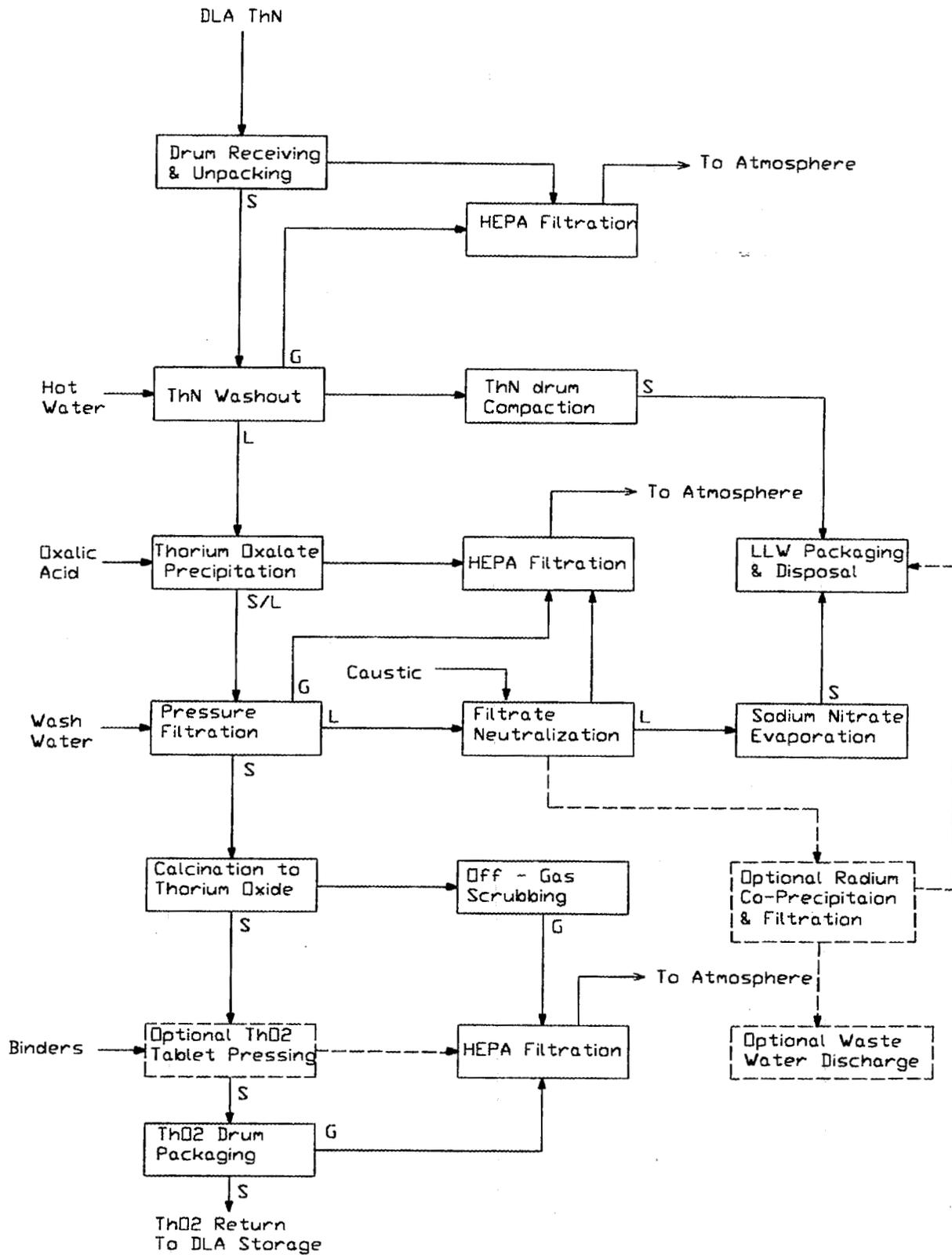
The 10 drums were shipped directly to a licensed facility where, under Recodyne supervision, each was opened and a kilogram grab sample taken off the top of each inner fiberboard drum. Each of the fiber overpack drums were enclosed in a plastic bag that had to be cut open before the sample could be taken. A positive pressure was released upon opening each drum that emitted a noticeable amount of gas into the workplace area. A grab sample of ThN was taken from each drum. A composite was made by dissolving 200 g of ThN from each of the 10 grab samples in water. The aqueous composite had a density of 1.431 g/ml and a measured thorium concentration of 256 g/L, which as  $\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$ , accounted for over 99% of the ThN sample weight.

The key steps to converting ThN to  $\text{ThO}_2$  were: 1) separation with water of ThN from its packaging, 2) precipitation and filtration of thorium oxalate, 3) calcining thorium oxalate to  $\text{ThO}_2$ , and 4) neutralization and evaporation of spent nitrate liquor to a solid secondary waste. Other steps in the process that were part of the demonstration included volume reduction of the ThN packaging by compaction, water scrubbing of kiln off-gas, pressing  $\text{ThO}_2$  into tablets, radium co-precipitation on barium sulfate and HEPA filtration of workspace air. A box flow diagram of the demonstration process is shown in Figure 1.

#### 3.1 Process Chemistry

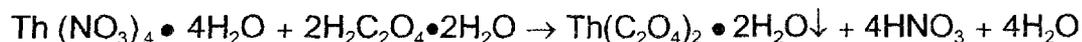
Due to its high solubility (754 g  $\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$  per liter of solution @ 20°C), the ThN cake is easily dissolved when exposed to a stream of hot water. The amount of water added was set to achieve liquor having a 100-g/L thorium content. Oxalic acid ( $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ ) was added to the ThN liquor in an agitated tank at about 1.25 times the stoichiometric amount to precipitate

Figure 1: BOX FLOW DIAGRAM OF THE PILOT DEMONSTRATION PROCESS

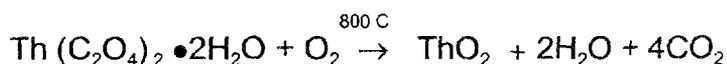


G = Gas  
 L = Liquid  
 S = Solid

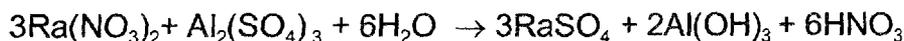
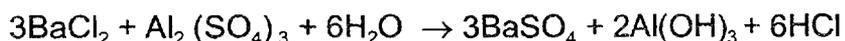
thorium oxalate as shown in the following chemical equation. The reaction also generates nitric acid, which was neutralized with sodium hydroxide. Thus, the major component of the final wastewater stream is dissolved sodium nitrate.



The final thorium oxide ( $\text{ThO}_2$ ) product is obtained by thermal decomposition of the thorium oxalate at a temperature in the range of 600 to 900°C, as shown in the following equation.



The removal of radium in the liquor prior to its discharge as wastewater was also tested. As shown in the following equation, radium removal was accomplished by co-precipitation on barium sulfate.



### 3.2 Operations Summary

The pilot plant was designed as a series of batch operations. The batch size was based on the 200 LB of ThN contained in one of the 10 MD-1 containers. The required 2,000-LB of ThN was thus converted to ten batches of ThN liquor in about 13 days. Details of the processing are provided in an Operation Log given in Appendix A. A process flow diagram for the pilot plant is shown in Figure 2 with the corresponding theoretical mass balance given in Table 1.

#### Drum receiving, unpacking and washout of ThN

The overpack drums were separated from the inner ThN containers by placing the entire package on a drum dump located inside the enclosed washout station. The overpack drums were clamped onto the drum dump so that when the drum was tilted, the inner ThN container would slide out. This container was opened and positioned by the drum dump such that a stream of hot water was directed at the contents from outside the enclosure. The thorium nitrate went into solution with little effort. Key field observations and measurements for process scale-up included:

FIGURE 2: PILOT PLANT PROCESS FLOW DIAGRAM

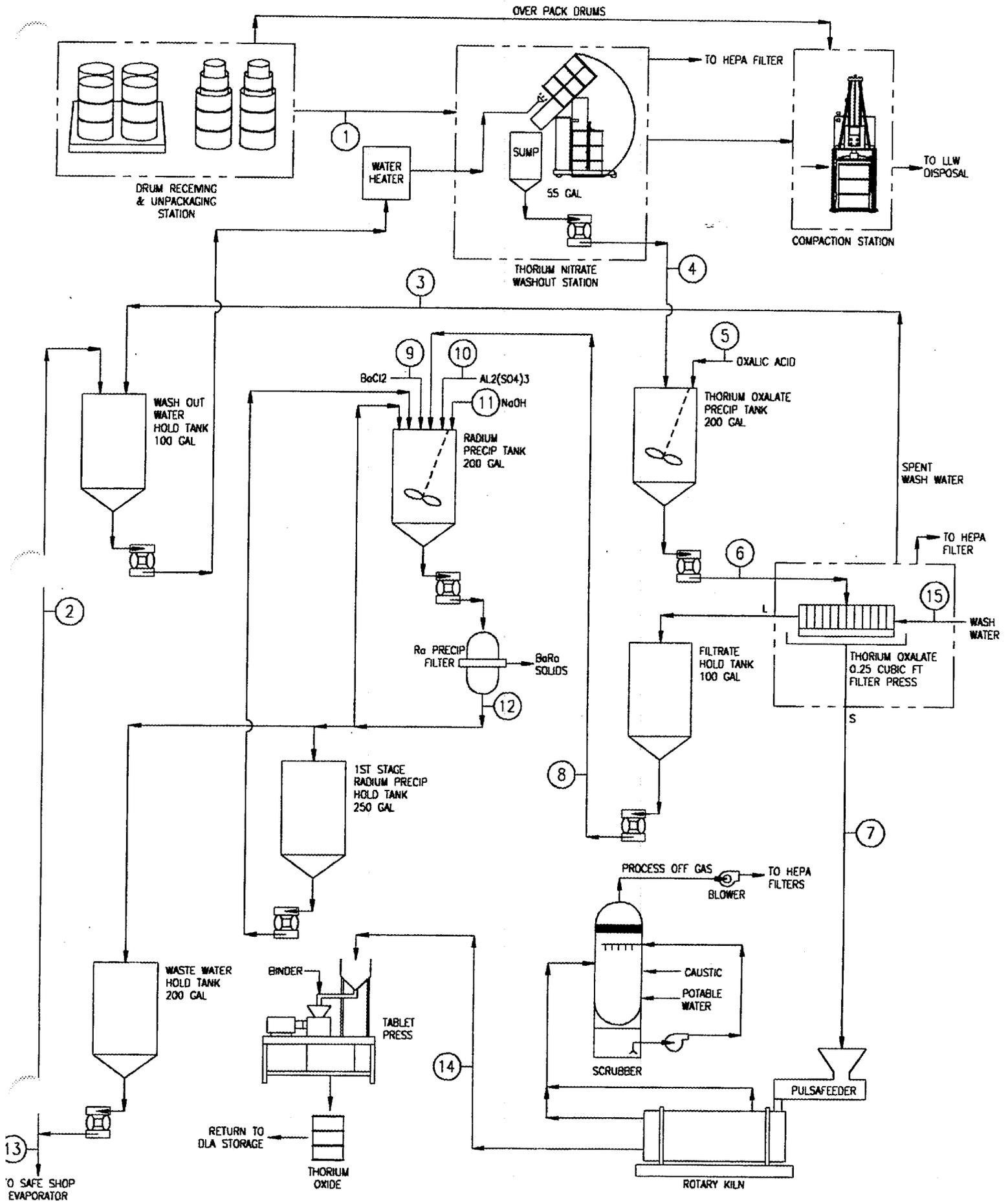


TABLE 1: PILOT PLANT MASS BALANCE

STREAM COMPONENT	UNITS	1	2	3	4	5	6	7	8	9	10		11	12	13	14	15
		ThN FEED DRUM	WASTE WATER WASHOUT	SPENT WASHOUT WATER	THORIUM NITRATE SOLUTION	OXALIC ACID	THORIUM OXALATE SLURRY	Th Oxalate PRESS CAKE	THORIUM OXALATE FILTRATE	BaCl2	Al2(SO4)3	(Ba, Ra) Solids	NaOH (50%)	WASTE WATER	WASTE WATER TO EVAP.	THORIUM PRODUCT	WASH WATER
THORIUM	LB	81			81		81	81								81	
Th(NO3)4*5H2O (ThN)	LB	200															
Th(NO3)4	LB				168												
Th(C2O4)2*2H2O	LB						156	156									
ThO2	LB															93	
WATER	LB		263	476	770		781	104	677			2.24	74	789	526		476
H2C2O4*2H2O	LB					114	25		25								
NaOH	LB												74				
HNO3	LB			1	1		91		91								
NaNO3	LB		62		62		62		62					185	123		
Na2C2O4	LB		13		13		13		13					40	27		
BaCl2	LB									0.40							
Al2(SO4)3*14H2O	LB										0.30						
(Ba, Ra) - SO4	LB											0.67					
TOTAL	LB	200	338	476	1,014	114	1,128	260	868	0.40	0.30	2.92	148	1,014	676	92.6	476
TEMPERATURE	deg C	20	40	35	50	20	40	20	35	20	20	20	20	30	30	800	20
pH	----	----	7	4.4	----	----	2.44	----	2.33	----	----	----	----	7	7	9	7
SPECIFIC GRAVITY	----	----	1.14	1.01	1.25	1.65	----	1.70	1.10	3.86	1.69	----	1.51	1.00	1.14	86*	1
VOLUME	GAL	----	36	57	98	----	109	18	95	----	----	----	12	1	71	5.5	57
FREQUENCY	----	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH
DURATION	MIN	60	30	30	45	15	30	150	30	5	5	15	15	30	----	----	10
REMARKS				spent wash water	conc Th, g/L 100		conversion 100%					PD 30%					*lb/cu ft bulk den.

- 1) Opening the drums and cutting the plastic bags were done prior to placing the drum onto the drum dump and removal of the inner container was achieved with the use of the drum dump.
- 2) For each drum of ThN, the entire wash out operation took less than one hour to complete. For the wash water delivery of 5 gpm at 10-psig pressure, there was little or no breakup of the inner ThN fiber drum.
- 3) The mass balance specified 88 gallons of water would be used to wash out 200 LB of ThN. The drums were visually empty after applying 60 gallons of water.
- 4) The 35 gallon steel overpack drums were found to be in good physical shape and survey measurements found exterior surface contamination to be below free release limits.
- 5) The actual weight of ThN contained in the 10 drums totaled 2,046 LB.

#### Thorium oxalate precipitation and pressure filtration

The ThN liquor generated from the washout operation was pumped into an agitated 200-gallon tank where powdered oxalic acid was added. Liquor volumes were measured by calibrating the liquid level in the tanks to a corresponding control volume. Initially the precipitation was carried out at 90°F for one hour. Under these conditions the resulting thorium oxalate slurry did not filter well in the 0.25-ft<sup>3</sup> plate and frame filter press. After the first batch the thorium oxalate precipitation time was increased to 12 hours. This resulted in a significant increase in thorium oxalate filterability. Subsequent review of the literature supports this effect (a). Other key field observations and measurements included:

- 1) To filter each batch of thorium oxalate slurry required about 10 drops of the filter press. With a press capacity of 0.25 ft<sup>3</sup> this represents 2.5 ft<sup>3</sup> of press cake generated for every 200 LB of ThN feed.
- 2) The press was filled with cake in about 15 minutes.
- 3) With the longer precipitation time, the cake handled well discharging off the plates with minimal effort.

### Thorium oxalate calcination

The press cake from the filter was fed to a rotary kiln equipped with a 5" Monel tube that was adjustable with respect to rotational speed and pitch. The unit had three heating zones and was capable of operating at 1,000°C. The kiln was operated at 800 °C for 8 of the 10 batches drums and one each at 600 °C and 900 °C. A hopper-feeder with an adjustable speed screw was designed to accept the filter press discharge and feed the kiln at a measurable rate.

The thorium product (ThP) generated in the rotary kiln discharged into an eight-gallon drum. A portion of the ThP was set aside for feed to the tablet press. When full the eight-gallon drums were placed back into the original over-pack drums in which the thorium nitrate was received. Key field observations and measurements included:

- 1) Operation of the kiln at 800 to 900 °C was without problems. The ThP was a free flowing, white powder with some lumps. At the higher temperature the powder had a yellow tint. Visual observations while handling the material indicated that it was not prone to dusting.
- 2) The ThP powder generated by the kiln at 600 °C was lumpy and moisture was apparently still present. The lower temperature also caused plugging problems in the rotary kiln because the ventilation trap collected too much moisture.
- 3) Conversion of a batch of thorium oxalate press cake took approximately 10 hours of rotary kiln operation. On a ThN basis this represents a throughput of 20 LB per hour. On a thorium oxalate basis this represents a throughput of 16 LB of press cake per hour.
- 4) The ThP produced from the 2,046 LB of ThN processed weighed 1,088 LB and represents a mass reduction of 53.2%. Field measurements of the final product weights are given on the last page of Appendix A. Conversion of ThN to ThP generated 6 over pack drums containing eleven 8-gallon drums and one 12-gallon drum full of material. The total volume of product was 100 gal, which represents a volume reduction of 50% from the original ThN volume of approximately 200 gallons. Container survey sheets on these drums are found in Appendix B.

### Pressing thorium product tablets

Consolidation of the ThP was demonstrated with a small tablet press. Tablets were made in two sizes, 1/4" diameter by 1/8" thick for the 800 °C powder and 5/8" diameter by 1/8" thick for the 900 °C powder. Three binders: lime, graphite and stearic acid, were each tested at two different dosages. The test matrix is detailed in Appendix B, Thorium Oxide Tablet Testing. A simple qualitative drop test was used to evaluate the integrity of the tablets. The tablets discharged from the press from a height of about 4 feet and dropped into a bucket. If the tablets maintained their shape after impact and did not splinter or otherwise fall apart, the binder dosage was considered adequate. Key field observations and measurements include:

- 1) Pressing the 800 °C powder with a 5% dose of graphite resulted in a high integrity tablet with no apparent tendency to splinter or powder. The pellets also did not form powder when physically handled. Tablets with graphite made with the 900 °C powder were considered adequate but not as good as those made from the 800 °C powder. Poor physical characteristics precluded the making of tablets from the 600 °C powder.
- 2) The use of lime and stearic acid as binders was also successful. The required dosage for lime was high at 20%. A 5% stearic acid addition produced a tablet that did not fracture from the initial impact. However, these tablets did have some breakage into powder when physically handled. It was estimated that a 10% stearic acid addition would produce a tablet with the integrity of the graphite tablets.
- 3) The bulk density of the graphite tablets at either size was measured at 2.0 g/mL or 124.5 LB per cubic foot.

### Filtrate neutralization and sodium nitrate evaporation

The filtrate from the press contained nitric acid generated in the oxalate precipitation step. Sodium hydroxide was added to neutralize the filtrate and convert the acid to sodium nitrate. The nitrate solution was reduced to a solid secondary waste in a batch evaporator.

### Radium co-precipitation and filtration

Radium was removed from the press filtrate in a 200-gallon agitated tank. Aluminum sulfate and barium chloride were added to co-precipitate radium on barium sulfate. After passing this slurry through a pressure filter, the resulting filtrate was returned to the agitated tank for a second radium co-precipitation.

After the second barium sulfate filtration, the nitrate liquor was discharged to a wastewater hold tank. A portion was typically sent back to the front of the process and reused as washout water. Key field observations and measurements included:

- 1) Solids generated in the barium sulfate precipitation and neutralization steps were excessive resulting in the bag filter overloading. Excess solids were most evident when excess oxalic acid was added in the oxalate precipitation step and the amount of nitrate-liquor recycled to the wash out step approached two thirds of the total. With no liquor recycle and 1.25 times excess oxalic acid, solids generation was also minimal. With a solubility of 37 g/L, it was concluded that the excess solids were sodium oxalate. With two thirds wastewater recycle and the excess oxalic acid added in the precipitation step, 40 LB of sodium oxalate would be produced in the neutralization step at a concentration of 44.5 g/L (108 gal liquor). No excess solids were precipitated once the stoichiometric excess of oxalic acid was maintained at 1.25 and the wastewater recycle was limited to one-third the total volume.

#### Off-gas scrubbing and HEPA filtration

The off-gases generated by the kiln were passed through a wet scrubber containing 100 gal of water. The scrubber was operated throughout the demonstration with no discharge, i.e., with 100% recirculation of solution. A sample was taken daily of scrubber solution for analysis of thorium and the heavy metals. Exhaust from the scrubber was discharged to the facility's ventilation system.

Exhaust air from room ventilation, the washout station, filter press and the scrubber was discharged to the HEPA filtration system. These filters were part of the facility's air treatment system and thus were not available to determine if any thorium particulate was present.

#### LLW Packaging and Disposal

The empty ThN containers with the exception of the 35 gallon and 55 gallon steel overpack drums were combined with the sodium nitrate solids and volume reduced directly in a B-25 compactor box. The 1 ton of ThN was contained in nine 35-gallon drums and one 55-gallon drum for a total volume of 49 ft<sup>3</sup>. The conversion to thorium product generated about 20 ft<sup>3</sup> of compacted secondary LLW waste or 41% of the original volume. On this basis conversion of the 3,500-ton stockpile would yield 2,600 yd<sup>3</sup> of LLW waste.

### 3.3 Analytical Data Summary

During the pilot demonstration test a set of process samples were collected from each batch to confirm the mass balance shown in Table 1 and to determine the performance of the various unit operations. The pH of the aqueous streams were measured in the field and the results shown in Table 2. Samples of the following aqueous streams were collected in triplicate and preserved for later metals analysis (up to 6 months) by adding 1-2 ml of concentrated nitric acid.

- 1) ThN liquor
- 2) Thorium oxalate filtrate
- 3) Final wastewater
- 4) Wet scrubber solution

TABLE 2: FIELD MEASUREMENTS OF PROCESS STREAM pH

Batch No.	Thorium Nitrate Liquor	Thorium Oxalate slurry	Thorium Oxalate Filtrate	Final Waste Water	Scrubber Solution
	1	0.99	0.02	0.37	7.45
2	0.98	0.02	0.27	5.52	7.99
3	0.07	0.04	0.01	7.82	7.81
4	0.76	0.01	0.16	6.92	7.66
5	0.35	0.01	0.01	6.58	7.81
6	0.40	0.01	0.06	7.50	7.76
7	0.16	0.01	0.01	7.16	7.80
8	0.19	0.01	0.01	7.10	7.05
9	0.47	0.01	0.07	7.06	7.84
10	0.21	0.01	0.01	6.41	7.29
Average	0.458	0.015	0.098	6.952	7.627

Samples of the thorium oxalate filter cake and of the ThO<sub>2</sub> powder and tablets were also collected from each batch. Besides thorium, the final wastewater samples and the wet scrubber solution were analyzed by DCP for the heavy metals, silver, lead, chromium and arsenic. Detailed laboratory results are given in Appendix C.

The final wastewater and the wet scrubber water were analyzed by DCP for the four heavy metals. The instrument detection limits (IDL) in PPM for lead,

chromium, silver and arsenic are 0.01, 0.002, 0.004, and 0.08, respectively. However, these limits are for optimal conditions with analytical standards. Quantitative limits for these metals in wastewater typically range from 0.1 to 1 PPM. Lead, chromium and silver could be detected at the 1 PPM level in both the wastewater and the scrubber water without difficulty. These metals were not detected in any of the samples. Arsenic, however, was not measurable at these levels. A series of 2-PPM arsenic spikes were added to the samples and the arsenic standards that had been matrix matched for sodium nitrate content. The DCP was capable of differentiating the 2-PPM increase in the standards but not in the samples. This lack of sensitivity was attributed to thorium. Concentrations of up to 155 PPM and 78 PPM were measured in wastewater and scrubber water, respectively. The relatively high thorium concentrations caused an interference that prevented quantitative measurement of arsenic at these low levels.

The thorium results for the four aqueous streams are summarized in Table 3. The excellent precipitation efficiency indicated by the low residual thorium concentrations in the oxalate filtrate are similar to that obtained in the preliminary laboratory testing, i.e., 1 PPM or less. The wastewater samples, however, showed much higher thorium concentrations of up to 113 PPM. This was surprising, since the only difference between the filtrate and the wastewater batches were the intermediate barium sulfate precipitation and the caustic neutralization steps. DCP analysis of spiked filtrate samples did not reveal the presence of any interference. Review of the actual sampling times, however, indicated that there was a 4 to 6-hour lag time between generation of the filtrate and sampling which can explain the discrepancy between the filtrate and wastewater thorium results. Thorium solids that had passed through the filter press in the filtrate could have settled out in the tank causing the sample not to be representative. These same solids could have also passed through the bag filter and into the wastewater hold tank which was sampled shortly after it was filled. It is noteworthy that there was a downward trend in wastewater thorium concentration from batch to batch suggesting that as the new filter cloths in the press became impregnated with fine solids their filtration efficiency increased.

The discrepancy in the two sets of DCP thorium results was further examined by comparison to the radiochemical results. Accu-Labs Research, Inc. using radiochemical techniques analyzed each wastewater sample. Besides measuring the radium-228 level for the purpose of determining the effectiveness of the radium removal step, Accu-Labs measured the activity of a number of radionuclides including thorium-232. These results are shown in Table 4 along with the DCP thorium results for comparison. Detailed radiochemical results are shown in Appendix C.

TABLE 3: THORIUM ANALYTICAL RESULTS FOR PILOT PROCESS STREAMS

Batch No.	Stream No. 1 Th in Batch Kg	Stream No. 4 ThN liquor, g/L	Stream No. 8 Oxalate filtrate, PPM	Stream No. 12 Wastewater, PPM	Wet scrubber solution, PPM
1	37.4	150	<1	113	7
2	38.3	103	<1	60	15
3	37.9	92	8	84	6
4	37.7	142	<1	59	9
5	37.7	96	<1	22	26
6	37.7	100	1	25	78
7	38.1	92	<1	9	27
8	37.9	99	2	36	23
9	37.7	99	4	41	16
10	37.9	93	<1	16	28

TABLE 4: RADIUM AND THORIUM RESULTS FOR FINAL WASTEWATER

Batch No.	Waste water vol., gal.	DCP Th, PPM	DCP Calc. Th wt., g	Accu-Labs Th-232, PPM <sup>a</sup>	Accu-Labs Calc. Th wt., g	Average <sup>b</sup> Th wt., g	Accu-Labs Ra-228, pCi/L
1	178	113	76	82	55	65"10	1.1E6
2	178	60	40	47	31	35"4.5	7.0E5
3	176	84	56	53	35	45"10	1.2E6
4	182	59	41	53	37	39"2.0	8.3E5
5	168	22	14	20	13	13"0.5	1.4E6
6	148	25	14	155	87	50"37	1.1E6
7	150	9	5.1	32	18	12"6.5	9.2E5
8	153	36	21	27	16	19"2.5	1.0E6
9	140	41	22	31	16	19"3.0	5.6E5
10	170	16	10	7	4.8	7.4"2.6	1.9E6

Total Thorium, g                      299.1                                      312.8

<sup>a</sup> Original results given in pCi/L were converted to PPM by the conversion factor: 1.095E5 pCi per g Th-232.

<sup>b</sup> Average thorium mass from DCP and radiochemical determinations, A, with half the difference between the two results, d, expressed as: A"d

The wastewater thorium results are indicative of highly efficient oxalate precipitation. Though the “ range for the average thorium weight derived from the two measurements was 3.7% to 72%, the differences with respect to the thorium content of secondary waste are not significant. Applying the highest “ range of 72% to the highest average thorium weight of 65 g gives an upper value for thorium in the wastewater batch of 112 g. Comparing this thorium loss to the amount input to each batch of about 39,500 g, the minimum oxalate precipitation efficiency was 99.72%. This lower efficiency would result in a thorium content in the sodium nitrate solids of 0.13 wt.%, which is acceptable for LLW disposal. Comparing the minimum thorium loss to wastewater of 5 g gives a precipitation efficiency of 99.99%. On a cumulative basis about 300 g thorium reported to the wastewater which would represent a thorium content in sodium nitrate waste of only 0.03 wt. %.

Also shown in Table 4, the radium co-precipitation performed poorly with residual activities all above 500,000 pCi/L. From the previous bench-scale results reported in the Demonstration Test Plan the ThN liquor will have a Ra-228 activity of about 850,000 pCi/L. This was based on gross beta and Ac-228 measurements of 1,000,000 and 850,000 pCi/L, respectively. Ra-228 is strictly a beta emitter and should be in equilibrium with its daughter Ac-228. This was confirmed by treating the ThN liquor with barium to co-precipitate radium. A residual Ra-228 activity of 750 pCi/L was measured which corresponded to gross beta and Ac-228 activities of 810 and 1,500 pCi/L, respectively. In the pilot plant radium co-precipitation and liquor neutralization were conducted in the same tank which may have caused the poor removal. A long-term study at a uranium mill determined that under basic conditions (pH approaching 9.5), the co-precipitated radium is released back to the liquid phase (b).

While it may be possible to demonstrate adequate radium removal with further testing, the relatively high thorium concentrations shown in Table 4 preclude the release of wastewater without further treatment. In the demonstration test each batch of wastewater was converted to a sodium nitrate salt for disposal as a solid secondary waste. With this approach the need to discharge wastewater is eliminated.

Laboratory analyses of the thorium input (Th oxalate cake) and output (ThP) was also conducted. The moisture content of the filter cake was higher than expected though well within the range of typical filter press performance, i.e., filter cake having a 50 to 65% solids content. As shown in Table 5, Loss on Ignition (LOI) and bulk density was measured on a sample of ThP from each of the batches. The LOI was measured on samples dried at 110°C to determine moisture content. The dried samples were weighed before and after ignition at 1,000°C for 12 hours in a muffle furnace. A high LOI is

indicative of unreacted anhydrous thorium oxalate and apparently is correlated with a low bulk density. Using the difference in mole weight between oxalate and molecular oxygen, the thorium oxalate content in the product was calculated from the LOI results and are shown in the last column of Table 5. LMES analyzed ThP samples from Batch No. 5 and No.10 by XRD and obtained similar results. Batch No. 5 ThP contained a mixture of thorium oxide and oxalate while Batch No. 10 consisted of crystalline thorium oxide only.

TABLE 5: BULK DENSITY AND LOI FOR THORIUM PRODUCT

Batch No.	Th oxalate cake, % moisture	Rotary kiln Temp., °C	Bulk density, g/ml	LOI <sup>a</sup> , %	Calc. Th Oxalate, wt.%
1	44	800	1.196	12.7	36
2	46	800	1.287	9.9	28
3	43	800	1.373	14.3	41
4	47	800	1.326	10.8	31
5	45	800	1.495	7.0	20
6	46	800	1.113	25.7	73
7	44	600	1.015	36.5	103
8	39	900	1.800	3.3	9.3
9	44	800	1.269	14.1	40
10	46	800	1.882	1.9	5.5

<sup>a</sup> LOI determined by heating sample to 1,000°C in a muffle furnace.

As indicated from the calculated thorium oxalate content, conversion efficiency in the rotary kiln was highly variable. There was essentially no conversion to ThO<sub>2</sub> on Batch No. 7 run at the low temperature of 600°C. The calculated thorium oxalate content was over 100% indicating that waters of hydration were still present. Increasing the calcination temperature to 900°C improved conversion to 90% ThO<sub>2</sub>. The best conversion of 94.5% was achieved in the last run (Batch No. 10) when the run time was increased by 50%.

A composite of ThO<sub>2</sub> product made from the 800°C runs was submitted to Barringer, Inc. for TCLP metals analysis. QC standards for analysis followed the appropriate SW-846 or EPA methodology. The TCLP regulatory levels and the detection levels are listed in Table 6. The analytical results given in Appendix C show that none of the heavy metals were detected in the TCLP

extract at the limits shown in Table 6. The thorium product is therefore not characteristically hazardous.

TABLE 6: TCLP REGULATORY LEVELS AND DETECTION LIMITS

Analyte	Regulatory Level	Detection Limit
Arsenic	5.0	0.5
Barium	100.0	0.1
Cadmium	1.0	0.03
Chromium	5.0	0.1
Lead	5.0	0.3
Mercury	0.2	0.002
Selenium	1.0	0.5
Silver	5.0	0.05

A sample of the scrubber liquor was taken after processing each batch. The relative volatility of arsenic, lead and chromium would suggest that the off-gas from the rotary kiln would be the likely pathway for these metals, if they were present in the ThN. Though the heavy metals were not detected, thorium was found in the scrubber water at levels ranging from 7 to 78 PPM indicating small amounts of thorium were emitted from the rotary kiln. Since the 100 gallon volume of scrubber solution was operated in a 100% recirculation mode the maximum

An acceptable mass balance on thorium was obtained for the demonstration test. In Table 7 the thorium input as calculated from the DCP results and ThN tank volumes is compared to the input and output of thorium derived from weight measurements of ThN and ThP in the field. The weight percent thorium in ThN was based on thorium nitrate pentahydrate while the thorium output was based on the ThP weight adjusted down by the percent LOI to determine thorium as thorium oxide. With the exception of Batch No.4, the two measurements of thorium input are in agreement with a “ range of 0.4% to 2.7%. The larger discrepancies between the inputs and the thorium output are due to the hold-up of material in the pilot plant between batch runs. Based on the weight measurements and LOI for ThP, the difference in the cumulative amount of thorium in and out of the process totaled 3 LB or 0.36% of the total thorium input or output.

TABLE 7: THORIUM MASS BALANCE RESULTS FOR DEMONSTRATION TEST

Batch No.	ThN liquor volume, Gal.	ThN liquor <sup>a</sup> by DCP, g/L Th	ThN batch input by DCP and vol., LB Th	ThN batch input by wt., LB Th	ThP output based on wt. And LOI, LB Th
1	67	150 <sup>±</sup> 5.0	83.7	82.2	78.2
2	96	103 <sup>±</sup> 0.1	82.3	84.3	73.6
3	115	92 <sup>±</sup> 2.2	88.1	83.4	93.1
4	98	142 <sup>±</sup> 0.7	116	83.0	76.0
5	107	96 <sup>±</sup> 4.6	85.5	83.0	86.6
6	101	100 <sup>±</sup> 1.0	84.1	83.0	67.2
7	107	92 <sup>±</sup> 2.8	82.0	83.8	60.8
8	105	99 <sup>±</sup> 3.9	86.5	83.4	66.3
9	100	99 <sup>±</sup> 7.9	82.4	83.0	67.9
10	106	93 <sup>±</sup> 3.7	82.1	83.4	160
Thorium total, LB			873	833	830

<sup>a</sup> Average of two analytical determinations, A, with half the difference between the two results, d, expressed as: A<sup>±</sup>d

#### 4.0 ENGINEERING SURVEY

The demonstrated equipment capacities and performance of the pilot plant was used as the bases for specifying the full-scale design. Plant capacity is based on a total of 3,580 tons of thorium nitrate to be processed in five years with an operating efficiency of 82%, i.e., 300 operating days per year. This translates to a 24-hour operation 7 days per week with two major shutdowns, annually. Based on the predominant container configuration, the processing rate of 4,800 LB/day ThN will require that 24 drums be emptied daily.

For the purpose of this engineering survey and study it is assumed that the full-scale process will be located at an existing commercial facility licensed by the NRC. The design is based on the use of existing utilities, buildings, support services and shipping, receiving and storage facilities.

#### 4.1 Technical Justification for Pilot Sizing

The capacities and sizes of the pilot equipment were well within acceptable scale-up ratios. Recodyne successfully started up a process involving uranium leaching, solvent extraction, precipitation and filtration with scale-up ratios ranging from 100 to 200. Typical pilot plant to commercial scale-up ratios for liquid and solid reactants, as reported in the literature, range between 20 and 250 (c). In Table 8, capacity and size ratios are tabulated for the full-scale plant based on the processing schedule given above. The ratios do not exceed 11 indicating that the sizing of the pilot plant was within acceptable levels of risk for scale-up.

#### 4.2 Full Scale Design Bases

The results of the pilot demonstration, as described in the Operations Summary and the Analytical Data Summary sections, were used as the design bases for the full-scale system. Design criteria for each operation were established as follows:

TABLE 8: SCALE-UP RATIOS BASED ON THE PILOT PLANT

Equipment parameter	Daily capacity/size		Scale-up Ratio
	Pilot	Full-scale	
ThN drum unpacking	600 LB	4,800 LB	8
	3 drums	24 drums	8
Washout station	55-gallon drums	55-gallon drums	1
Drum dump	30 drum/day	30 drum/day	1
Oxalate precip tank	200 gal	1,100 gal	5.5
Pressure filter	7.5 ft <sup>3</sup>	60 ft <sup>3</sup>	8
Rotary kiln	384 LB	3,860 LB	10
	5" dia. Tube	12" dia tube	2.4
Filtrate hold tank	100 gal	1,100 gal	11
Neutralization tank	200 gal	1,100 gal	5.5
Pumps	10 gpm	30 gpm	3
Wastewater evaporator	1,440 gal	2,880 gal	2

#### Drum Receiving and Unpacking

The design of full-scale drum receiving and unpacking was based on the 10 drums of ThN used in the demonstration test. Of the 10 drums, nine were in the MD-1 configuration representing over 70% of the ThN inventory. The conversion plant will begin processing ThN in this configuration for the first full year of operation to build up an inventory of 35-gallon steel drums for use as ThP containers. The remaining ThN inventory is contained in a variety of drum configurations including 85-gallon overpack drums. Since they contain larger quantities of ThN, only six to eight of these larger drums will need to be unpacked to satisfy the 4,800 LB/day feed rate. The design criteria for receiving and unpacking are summarized below.

- 1) Sufficient space and equipment to handle a three-month supply of ThN is required. For the MD-1 containers, this represents about 2,160 35-gallon drums occupying 50% of a 5,500 ft<sup>2</sup> area with 5 drums to a pallet stacked three high.
- 2) The gas pressure inside the drums will be released with a punch device and the off-gas contained and vented to the air filtration system before unpacking the drums.
- 3) To minimize material handling and secondary LLW volume, the inner drum in contact with the ThN will be separated from all overpack

drums. If not contaminated, inner overpack drums will be compacted separately and disposed of as non-radioactive solid waste.

- 4) As demonstrated, the washout station is capable of handling the inner overpack drums if they cannot be separated easily from the ThN. In this case all inner drums will be compacted, combined with sodium nitrate solids and packaged as secondary waste for shipment to a LLW disposal facility.
- 5) The outer 35-gallon and 55-gallon overpack steel drums will be inspected, surveyed and released to on-site storage for use as final product containers. Damaged drums or those with fixed contamination will be compacted and packaged for disposal.

### ThN Washout

A 100 g/L Th concentration in the ThN liquor was established as a setpoint for the oxalate precipitation. Since there was uncertainty as to the amount of water actually required to physically remove ThN from its container, the pilot plant was designed to test wastewater reuse as a portion of the washout water. Test results showed, however, that the amount of water required to washout ThN was less than that required to maintain the thorium setpoint concentration in ThN liquor. Wastewater recycle is thus not necessary for the full-scale design. By not reusing wastewater the possibility of sodium contamination in the thorium product is also eliminated.

The size and operating conditions of the full-scale wash out station will be identical to the demonstration test unit. Wash water will be delivered at a 5 gpm rate under 10 psi pressure to remove the ThN without breaking up the fiber drum. The design criteria for ThN washout are summarized below.

- 1) The volume of wash water is specified as the amount required to generate a ThN liquor with a 100 g/L thorium concentration.
- 2) Two washout stations of the size used in the demonstration are required to remove 4,800 LB/day ThN from its containers. The wash water is delivered at a pressure of 10 psi and at a rate of 5 gpm.
- 3) After washing out the ThN, the drum along with any of the inner overpack drums exposed to the washout are compacted and packaged for LLW disposal.

## Oxalate Precipitation and Filtration

The precipitation of thorium oxalate and its subsequent conversion to thorium oxide suitable for fuel manufacture has been studied extensively and documented in the scientific literature. Precipitation temperature, ThN concentration, acidity, and rate of precipitation have been shown to have significant effects on the filtering characteristics of thorium oxalate and the resulting particle morphology of the thorium oxide powder obtained in the calcination step. Though the demonstration process was not specifically designed to produce thorium oxide suitable for fuel fabrication, the filtration characteristics of the oxalate cake are important for obtaining efficient separation of the oxalate solids from the ThN liquor. In the demonstration test the filtration of the thorium oxalate was improved by increasing the precipitation time from 1 hour to 12 hours. This increase resulted in a filter cake that was easily removed from the press and fed to the calciner. The 12-hour duration for oxalate precipitation has been maintained in the full-scale design.

The capability to conduct the precipitation at elevated temperature (50 – 70°C) has also been included in the full-scale design. Though not an objective of the demonstration test, producing thorium oxide with a particle morphology conducive to fuel fabrication could be a future objective of the full-scale project. The literature indicates that besides improving the oxalate filtration characteristics, elevated precipitation temperatures can have a significant effect on the surface area, bulk density and particle size of the calcined thorium oxide powder (a). In turn, these variables can impact the performance properties of fuel pellets made from the thorium oxide.

Sizing of the oxalate precipitation and filtration equipment is largely dependent on the ThN throughput and the amount of wash water required for removing ThN from its containers. As in the demonstration test, this wash water volume has been set to generate a volume of ThN liquor having a thorium concentration of 100 g/L. For a throughput of 4,800 LB/day, 2,400 gal of ThN liquor will thus be generated regardless of the time required for precipitation. The filter must provide a minimum filtration rate of 1.7 gpm allowing the reactor to be emptied in 8 hours so that a new batch of ThN liquor can be made up during the next shift. This filtration rate is equivalent to 6,792 LB/day of thorium oxalate cake at 55% solids or on a volume basis 63 ft<sup>3</sup>. To minimize operator contact with thorium oxalate, the pressure filter used in the full-scale design should have an automatic cake discharge. Details of the design for thorium oxalate precipitation and filtration are summarized below.

- 1) Oxalate precipitation and filtration will be conducted in a batch mode.

- 2) For a throughput of 4,800 LB/day, 2,400 gal of ThN liquor needs to be precipitated with a 10% excess of oxalic acid and a residence time of 12 hours. Reactor agitation should be sufficient to keep oxalate solids suspended.
- 3) The precipitation tanks are constructed of stainless steel and are outfitted with steam jackets to allow the precipitation to be carried out at a maximum temperature of 70°C.
- 4) A pressure filter with automatic cake discharge is specified with a capacity to separate 63 ft<sup>3</sup>/day of thorium oxalate solids from the ThN liquor. Maximum operating pressure for filtration is 100 psi. The filter is equipped with automatic air drying and water wash cycles.

#### Thorium Oxalate Conversion to Oxide

At 800°C adequate conversion of thorium oxalate to the oxide was only obtained in the demonstration test when the residence time in the rotary kiln was increased by 50%. Calcination temperature also had a significant effect on conversion efficiencies with essentially no conversion evident at 600°C while over 90% conversion was obtained at 900°C. The sensitivity of these effects on conversion efficiency suggests that the kiln was being overloaded with water fed in with the oxalate filter cake, since the literature indicates that the oxalate will convert to the oxide at temperatures as low as 400°C. To insure adequate performance in the full-scale process, i.e., over 95% conversion to oxide, the design has been upgraded to a two-stage operation similar to that used on a production scale by National Lead Company at Fernald, OH in the 1950's (d).

In a two-stage operation the wet cake from the pressure filter is processed in a continuous dryer before being fed to the rotary kiln. Besides reducing the heat requirement of the rotary kiln, variations in filter cake characteristics such as moisture content will be dampened out to provide a more consistent feed to the kiln. The dryer will be capable of operating at a temperature of 150°C. Based on the literature this temperature will generate a thorium oxalate powder with a maximum of two waters of hydration (a). The filter cake throughput of 6,792 LB/day at 55% solids requires the dryer to evaporate water at a rate of 130 LB/hr.

The dried thorium oxalate is converted to the oxide in a rotary kiln operating at a temperature of 800°C. On a dry weight basis the full-scale unit will be required to convert 160 LB/hr of thorium oxalate to the oxide. To ensure that the product will meet a 95% or greater thorium oxide specification, the

residence time in the kiln has been increased by 50% to match the conditions used in the demonstration test for batch 10. Operation of the kiln will be based on routine measurements of bulk density and LOI which have been correlated to thorium oxide content by XRD or other instrumental analysis during performance testing of the process. Details of the two-stage design are summarised below.

- 1) The filter cake from the pressure filter is to be dried at a temperature of 150°C.
- 2) To dry the thorium oxalate generated from a 4,800 LB/day ThN throughput, the dryer must be capable of evaporating water at a rate of 130 LB/hr.
- 3) A rotary kiln capable of operating in a temperature range of 700 to 1,000°C is required to convert 160 LB/hr of thorium oxalate to oxide.
- 4) The rotary kiln will be sized to provide a solids residence time of 40 minutes in the tube heating section, which is equivalent to the time used in Batch 10 of the demonstration test.

#### Thorium Product Packaging and Storage

In the current design thorium oxide powder discharged from the rotary kiln will be packaged in 35-gallon steel drums previously used as overpack drums for ThN. Full drums will weigh about 500 LB each. These drums are overpacked in 55-gallon steel drums and then shipped back to DLA for storage. An alternative to this approach would be the long-term storage of the product at the processing facility thereby eliminating transportation and subsequent storage by DLA. At least two licensed facilities that are candidates for full-scale ThN conversion have the capability to provide long-term storage of the thorium oxide product.

- 1) The 35-gallon steel drums currently in use as overpack drums for the ThN will be used as product containers for the thorium oxide.
- 2) Once full the 35-gallon drums will be overpacked in 55-gallon steel drums in preparation for shipment back to DLA. Each drum will weigh about 500 LB.

### Nitrate Wastewater

The full-scale design is based on a facility requiring zero discharge of wastewater from the conversion process. Zero discharge was obtained in the demonstration test by evaporating the wastewater down to a solid in the facility's on-site evaporator. To prevent nitric acid generated in the oxalate precipitation from evaporating along with the water, 50% sodium hydroxide solution was added to pH 7 to convert the acid to sodium nitrate. The sodium nitrate liquor contained thorium in the range of 10 to 100 PPM and radium-228 activities over one uCi/L. For the full-scale system about 2,400 gpd of wastewater will be evaporated to generate 36 ft<sup>3</sup> of sodium nitrate solids with a moisture content not exceeding 10%. Before evaporation wastewater will be routinely measured for thorium content and gross alpha/beta activity. A maximum of 100 PPM thorium in the wastewater has been set as an action level for troubleshooting the oxalate precipitation and filtration operations. As in the demonstration the sodium nitrate solids will be combined with the inner ThN drums from the washout stations and compacted before shipment to a LLW disposal facility.

- 1) The filtrate from the pressure filter is neutralized with sodium hydroxide to pH 7.0 to convert the nitric acid formed in the oxalate precipitation to sodium nitrate.
- 2) Zero discharge is achieved by evaporating the sodium nitrate wastewater. The resulting sodium nitrate solids are combined with the inner ThN drums, compacted and packaged for disposal at a LLW facility.
- 3) About 2,400 gpd of wastewater will require evaporation to generate 36 ft<sup>3</sup> of sodium nitrate solids.

### Off-gas scrubbing and HEPA filtration

Airborne contaminants consisting of thorium particulate, nitrogen oxides and thoron gas, the short-lived daughter of radium-224 will be emitted from the process. The rotary kiln is considered the major source of thorium particulate and nitrogen oxide emissions. The rotary motion of the kiln will cause particles to become suspended in the gas stream. Nitrogen oxides are produced from any residual nitric acid not washed out of the oxalate filter cake. Due to radioactive decay thoron gas is continuously emitted from solids and liquids containing thorium. Process streams with high concentrations such as ThN liquor and thorium oxide product are of particular concern.

Contaminants will be controlled by workspace ventilation, equipment enclosures, a wet scrubber and a HEPA filter system.

- 1) A room ventilation rate of 7 air changes per hour will be maintained to allow operators to work in the process areas without a separate breathing air supply.
- 2) All major pieces of equipment will be enclosed and vented to the HEPA filtration system to further minimize operator exposure.
- 3) All process off-gas and ventilation air will be treated by HEPA filtration to minimize (ALARA) particulate emissions from the plant. The filters will have a 99.97% removal efficiency for 0.3-micron particles.
- 4) Before discharge to HEPA filtration, a wet scrubber will be used to treat off-gas from the rotary kiln. The major treatment objective of the scrubber is to reduce particulate loading so that the change-out of HEPA filters is minimized. The scrubber will also provide limited removal of gaseous contaminants such as  $\text{NO}_x$ .
- 5) Off-gas streams containing high levels of moisture, i.e., those from the oxalate dryer and the wastewater evaporator will be combined with the process room ventilation air to minimize the possibility of water droplet formation and subsequent clogging of the HEPA filters.

#### General Design Considerations

Based on previous experience in the design and operation of radiochemical processing plants, the following general criteria will be incorporated in the design of the full-scale system.

- 1) Though chloride concentrations of 25 PPM are expected in the ThN liquor, austenitic stainless steels of the 304 or 316 type will provide satisfactory corrosion resistance as a material of construction for most equipment and piping. Nickel based alloys will be used for the tube in the rotary kiln and for the sodium nitrate evaporator. Tanks made of polypropylene can be used for nitrate solutions below 40°C.
- 2) The plant will have secondary containment to control spills and to allow the washdown of floor areas and equipment.
- 3) Unit operations will be enclosed and sufficiently automated to minimize operator exposure to high activity process streams.

### 4.3 Additional Research and Development

Significant requirements for additional R&D design the full-scale conversion plant are not anticipated. To support a fire hazard analysis of the process, the potential for ThN to act as an oxidizer may require additional bench-scale testing. Improvements to or alternatives to barium co-precipitation for radium removal could be further investigated. Isolation of radium may provide additional options for secondary waste disposal depending upon the licensing and regulatory constraints of the specific facility where processing is being considered.

A potential future use for the thorium oxide produced in the process is as reactor fuel. To fully evaluate this potential the magnitude and variability of impurities in the ThN inventory and the impact of the conversion process needs to be examined. Since only 10 drums of ThN were tested in the demonstration, a second objective of this assessment would be to evaluate the effects of variations in the ThN composition on the performance of the conversion process itself. A statistically valid sampling of the inventory population would involve the random selection of between 30 and 60 ThN drums. Random selection could be based on an assigned grid location of drums over the entire inventory or on a random selection of drums by lot.

The ThN samples would be analysed for thorium content and impurities of concern particularly with respect to reactor fuel such as neutron-absorbing rare earths and uranium. Depending upon their composition, selected ThN samples would be converted to thorium oxide on a bench-scale to determine the effect of the conversion process on impurity levels and to evaluate the effect, if any, of the ThN composition on the conversion process. This testing could also evaluate the benefit of using high purity water for the ThN washout. Rather than producing deionized water, the current design could be modified to use steam for the evaporation of the sodium nitrate liquor. Sufficient steam condensate of high purity would thus be available for ThN washout and for washing the oxalate filter cake.

## 5.0 ENGINEERING STUDY

This engineering study is based on the demonstration test results summarized by the above design criteria, previous design experience and input from equipment vendors. The only significant difference in equipment configuration from the pilot plant was the change from a one-step to a two-step oxalate conversion operation. From the design bases a preliminary process flow diagram (PFD) with a mass and energy balance was developed for one ThN batch per 8-hour shift as shown in Figure 3. The overall mass and energy balance for the PFD is given in Table 9. A corresponding Piping and Instrumentation Diagram (P&ID) was then developed from the PFD as shown in Figure 4. Instrumentation was based on the major control variables of volume, temperature and pH. The design was then used in the analysis of the life-cycle conversion costs. The total includes estimates of fixed capital investment, annual manufacturing costs and plant decommissioning after conversion is complete. Finally, a timeline was generated on the major tasks required to construct and start up a licensed plant.

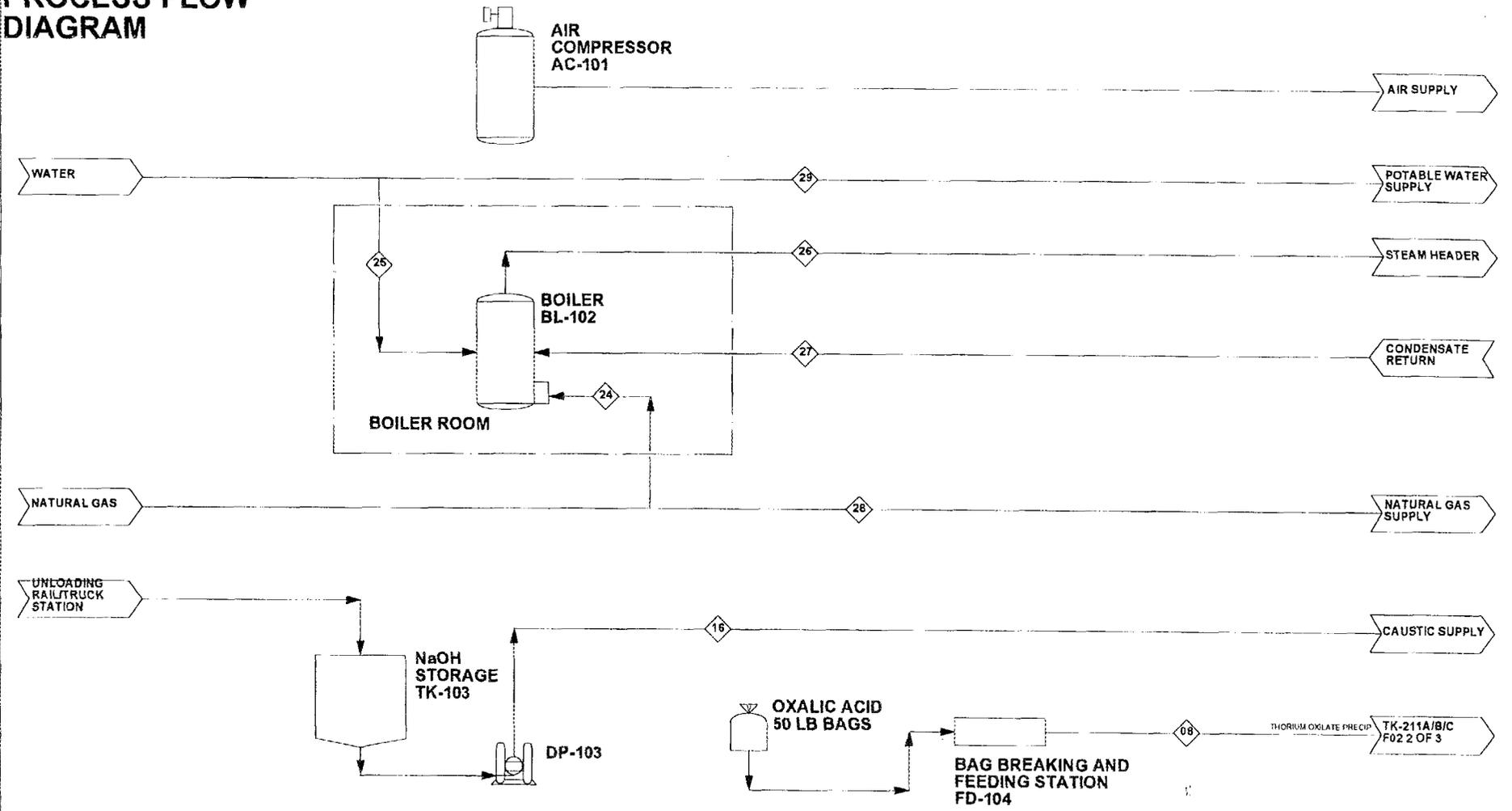
A rough equipment layout was developed to determine room ventilation requirements. It was determined that a 5,000-ft<sup>2</sup> area was sufficient space for the process equipment. With a ceiling height of 18 ft, a ventilation rate of 10,500 acfm is required to provide 7 air changes per hour. Air exhaust from the process room is discharged by a blower to a HEPA filtration system with media having a tested removal efficiency of 99.97% for 0.3-micron size particles.

### 5.1 Detailed Process Description

The initial steps in the process are a series of batch operations designed to provide a continuous feed of thorium oxalate to the calcination operation. The base schedule has been set to process eight MD-1 drums of ThN per batch, three batches per day operating 300 days a year. At this rate the entire stockpile is converted to thorium oxide in five years of processing

Each container of ThN is separated from its various overpack drums in an unpacking station. To meet the required 4,800 LB/day ThN throughput, 1,600 LB or 8 MD-1 containers of ThN need to be unpacked per 8-hour shift. The station has an enclosure equipped with a drum punch and an exhaust vent. The drum punch is designed to penetrate the overpack drum lids and release the gas that has built up inside the drums. After releasing the pressure, the lids are removed and a hoist is used to separate the overpack drums from the ThN container. A conveyor is used to transport the ThN container to the washout station. If the inner overpack drums cannot be separated easily from the ThN container they all will be conveyed to the washout station which is

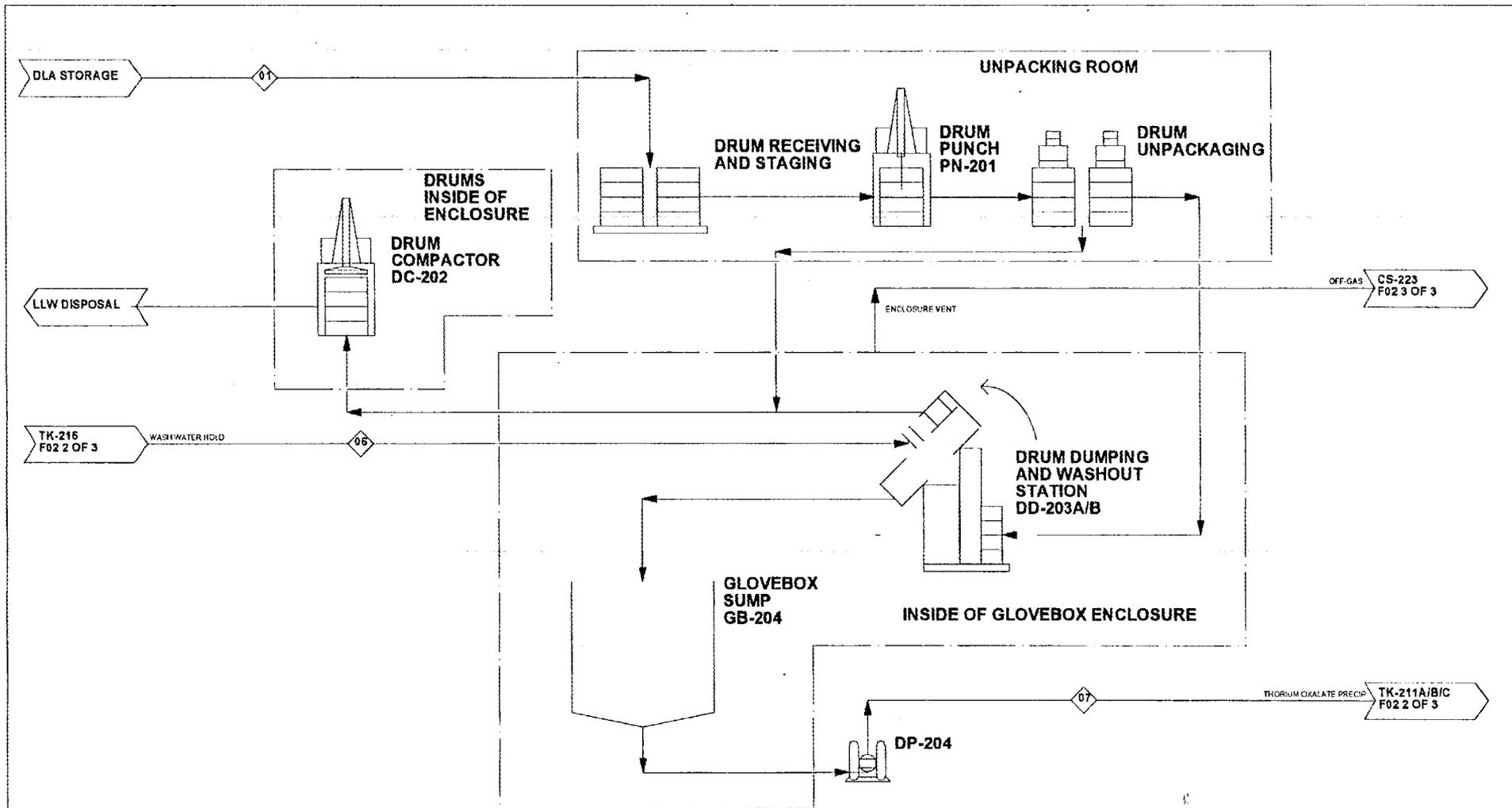
# PROCESS FLOW DIAGRAM



Stream #	08	16	24	25	26	27	28	29
Stream Description	OXALIC ACID	30% NaOH SUPPLY	BOILER GAS	BOILER WATER	STEAM SUPPLY	COND. RETURN	NATURAL GAS	WATER SUPPLY
Thorium (lb)								
H <sub>2</sub> NO <sub>3</sub> ·4H <sub>2</sub> O (lb)								
THNO <sub>3</sub> (lb)								
ThC <sub>2</sub> O <sub>4</sub> ·2H <sub>2</sub> O (lb)								
THO <sub>2</sub> (lb)								
Water (lb)		583		8,012		8,012		8,215
H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> ·2H <sub>2</sub> O (lb)	778							
NaOH (lb)		583						
THO <sub>2</sub> (lb)								
NaOCl (lb)								
Na <sub>2</sub> CO <sub>3</sub> (lb)			477,425		8,012	8,012	472,223	
Total (lb)	778	1,165	477,425	8,012	8,012	8,012	472,223	8,215
Temperature (C)	20	20		20	160			20
pH				7.0			7.0	7.0
Specific Gravity	1.25	1.51	0.815	1.00			1.20	1.00
Volume (gal)		99	197,840	981			391	118,101
Frequency	1/BATCH	1/BATCH	CONT	CONT	CONT	CONT	CONT	1/BATCH
Duration (Min)	20	15						80
Remarks								

## FIGURE 3

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B	05/17/88	FINAL REPORT MODIFICATIONS			
A	07/17/88	PRELIMINARY DRAWING			
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UTILITIES AND CHEMICALS PROCESS FLOW SECTION 100 DIAGRAM					
Scale	1" = 8' 0"	255' 0"	1000' 0"	1000' 0"	1000' 0"
None	DO NOT SCALE	DO NOT SCALE	DO NOT SCALE	DO NOT SCALE	DO NOT SCALE



Stream #	01	05	07
Stream Description	THN FEED	H2O/WATER	THORON SOLUTION
Thorium (lb)	891		891
TRNO3H4H2O (lb)	1,800		
TRNO3H (lb)			1,341
TRC2O4H2O (lb)			
ThO2 (lb)			
Water (lb)		8,234	6,198
H2SO4H2O (lb)			
HNO3 (lb)		8.8	8.8
H2O2 (lb)			
TRC2O4 (lb)			
Total (lb)	1,800	8,234	7,854
Temperature (C)	20	55	55
pH		8.5	0.5
Specific Gravity		1.02	1.20
Volume (Gal)		736	782
Frequency	1/BATCH	1/BATCH	1/BATCH
Duration (Min)	30	20	30
Remarks	8 DRUMS		100g/L Th

**FIGURE 3**

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**THORIUM NITRATE**

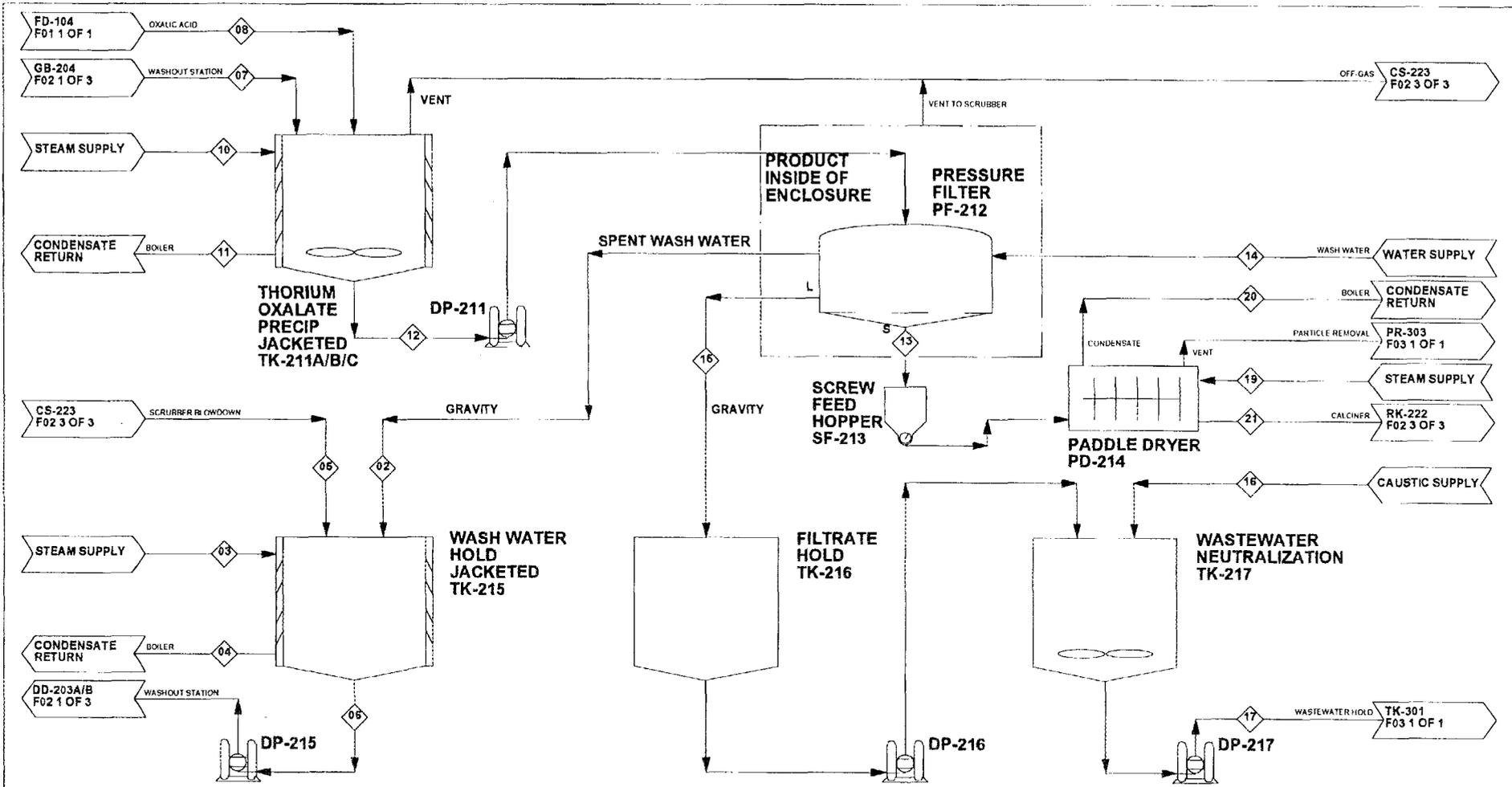
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PROCESS AREA SECTION 200	PROCESS FLOW DIAGRAM
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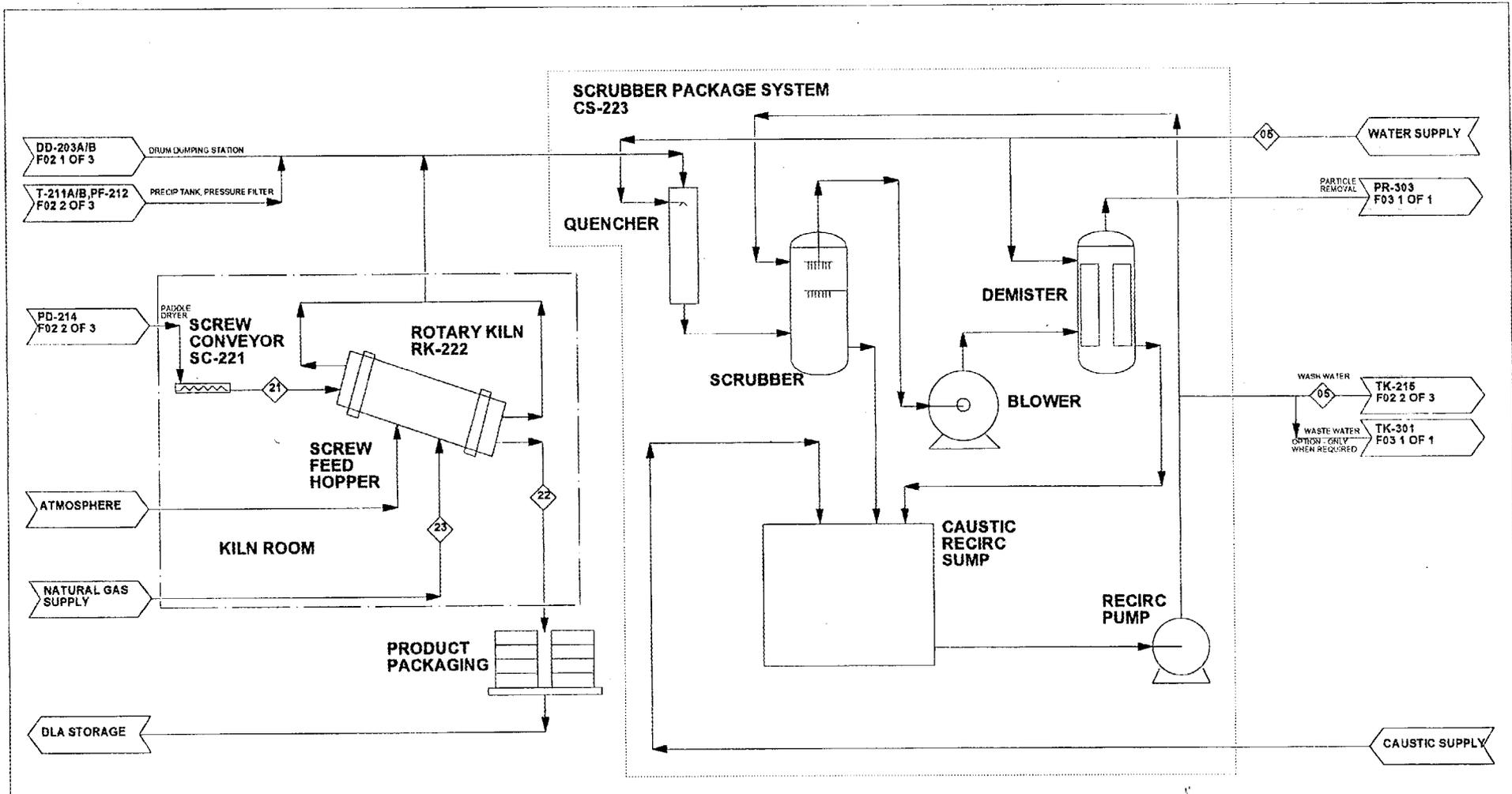
SCALE	PAGE NO.	TOTAL NO. PAGES	DATE	SCALE
NONE	002 OF 021	003 OF 021	FIG	1 OF 3



Stream	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	
Stream Description	SPENT WATER	STEAM SUPPLY	COND. RETURN	SCRUBBER BLOWDOWN	SPENT WATER	THORIUM SOLUTION	OXALIC ACID	STEAM SUPPLY	COND. RETURN	TH OXALATE SLURRY	TH OXALATE CAKE	FRESH WATER	TH OXALATE FILTRATE	NaOH	WASTE WATER	STEAM SUPPLY	COND. RETURN	TH OXALATE CAKE				
Thorium (lb)						851					851	851									851	
TH(NO <sub>3</sub> ) <sub>2</sub> ·4H <sub>2</sub> O (lb)												1,347										1,347
TH(NO <sub>3</sub> ) <sub>3</sub> ·9H <sub>2</sub> O (lb)											1,245	1,245										1,245
THO <sub>2</sub> (lb)																						
Water (lb)	1,885		135	4,550	6,215	6,786			818	8,650	1,018	1,665	5,481	563	6,341				6,341			51
H <sub>2</sub> CO <sub>3</sub> ·4H <sub>2</sub> O (lb)							776				158											
NaOH (lb)														563								
HNO <sub>3</sub> (lb)					8.8	8.8				730			730									
HNO <sub>3</sub> (lb)																						
H <sub>2</sub> SO <sub>4</sub> (lb)																						
Other (lb)		135							818										888			188
Total (lb)	1,764	135	135	4,550	6,254	7,854	776		818	8,832	2,264	1,835	6,369	1,125	7,493	6,341	6,341	6,341	6,341	1,294	1,294	
Temperature (°C)	35	180	100	25	25	25	25	160	100	60	20	20	35	20	30	150	100					
pH	8.5		7.0	7.0	8.5	0.5				7.0	0.5		7.0	0.5		7.0						
Specific Gravity	1.02		1.00	1.00	1.02	1.20		1.05		1.00		1.00	1.06	1.51		1.14						
Volume (Gal)	300		80	348	738	782		110	887	168	203	720	80	788		788						
Frequency	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH		1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH
Duration (Min)	30	120	120	480	30	23		110	120	30	30	30	15	30	480	480	480	480	480	480	480	480
Remarks						100 g/L TH		HEAT BATH				65% PD										50% PD

**FIGURE 3**

D	08-17-88	FINAL REPORT MODIFICATIONS			
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PROCESS AREA SECTION 200			PROCESS FLOW DIAGRAM		
SCALE	7/4 IN	3/8 IN	1/4 IN	1/8 IN	Sheet No
	NONE	DOE1 (22)	DOE1	FO2	2 of 3



Element	06	21	22	23
Stream Description	SCRUBBER H2O & H2O	TH OX CAKE	TH OXIDE PRODUCT	NATURAL GAS
Thorium (lb)		881	881	
Th(NO3)4*4H2O (lb)				
Th(NO3)4 (lb)		1,245	57	
Th(C2O4)2*2H2O (lb)			705	
H2O (lb)	4,860	81		
H2C2O4*2H2O (lb)				
NaOH (lb)				
HN03 (lb)				
NaNO3 (lb)				
H2C2O4 (lb)				
Other (lb)				170,509
Total (lb)	4,860	1,286	761	170,509
Temperature (C)	25		800	AMB
pH	7.0			
Specific Gravity	1.00		888.5	0.415
Volume (Gal)	38		13	48,294
Frequency	18L/HR	CONT	CONT	CONT
Duration (Min)	480			
Remarks		96% PD		

**FIGURE 3**

REV	DATE	DESCRIPTION	BY	CHKD
A	07/17/88	PRELIMINARY DRAWING		

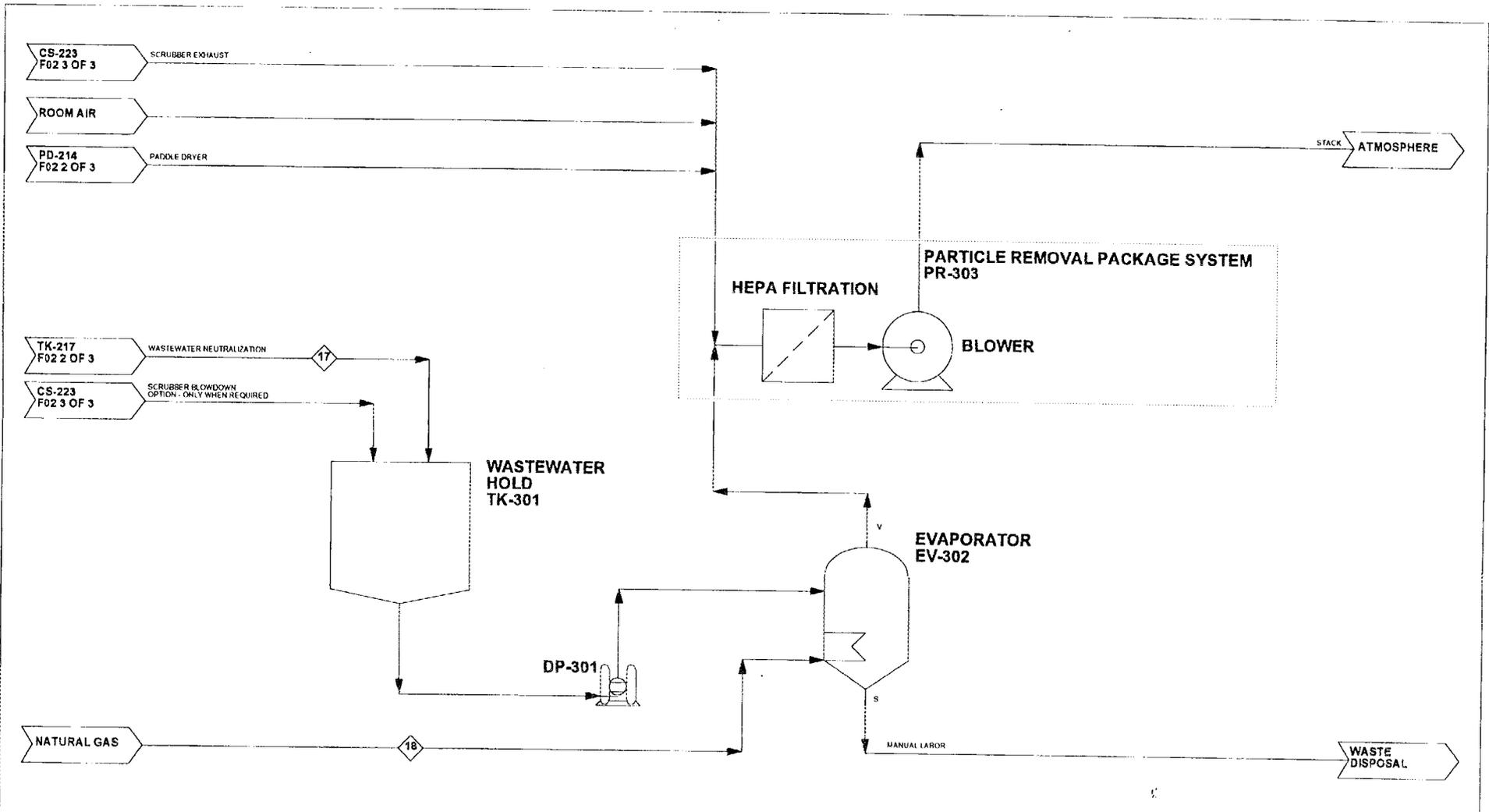
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PROCESS AREA SECTION 200	PROCESS FLOW DIAGRAM
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Scale	File No.	Iss No.	Draw No.	Sheet No.
NONE	DCE023	DCE01	F02	3 OF 3



Stream #	17	18
Stream Description	WASTE WATER	NATURAL GAS
Thorium (lb)	0.5	
Th(NO <sub>3</sub> ) <sub>4</sub> ·H <sub>2</sub> O (lb)		
Th(NO <sub>3</sub> ) <sub>4</sub> (lb)	1	
Th(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ·H <sub>2</sub> O (lb)		
ThO <sub>2</sub> (lb)		
Water (lb)	0.341	
H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> ·H <sub>2</sub> O (lb)		
NaOH (lb)		
HNO <sub>3</sub> (lb)		
NH <sub>4</sub> NO <sub>3</sub> (lb)	388	
NH <sub>4</sub> C <sub>2</sub> O <sub>4</sub> (lb)	188	
Dimer (lb)		241.754
Total (lb)	7.433	241.754
Temperature (C)	30	
pH	7.0	
Specific Gravity	1.14	0.415
Volume (Gal)	788	60.837
Frequency	1/BATCH	1/BATCH
Duration (Min)	30	
Remarks		

**FIGURE 3**

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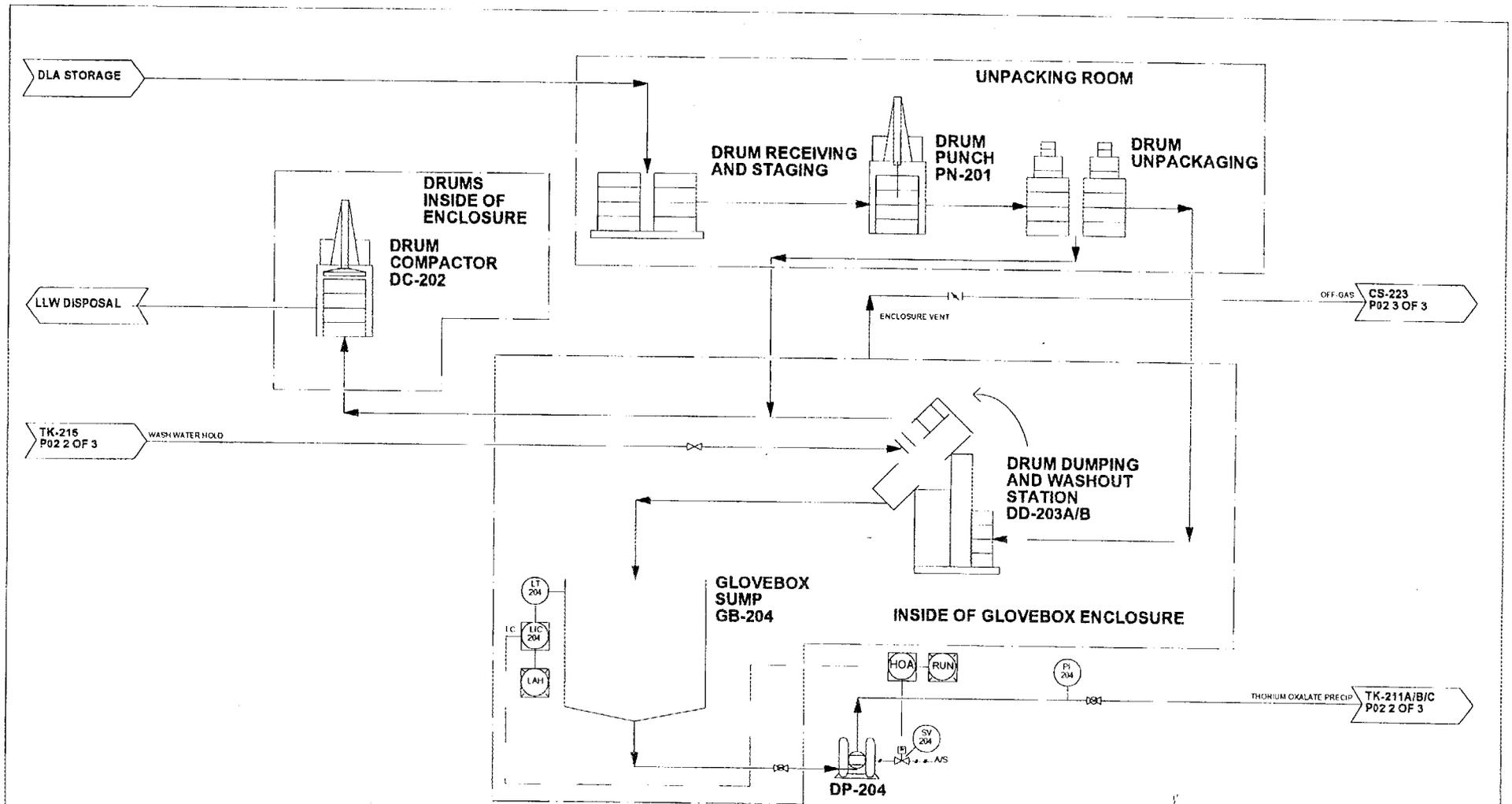
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WASTE TREATMENT SECTION 300	PROCESS FLOW DIAGRAM
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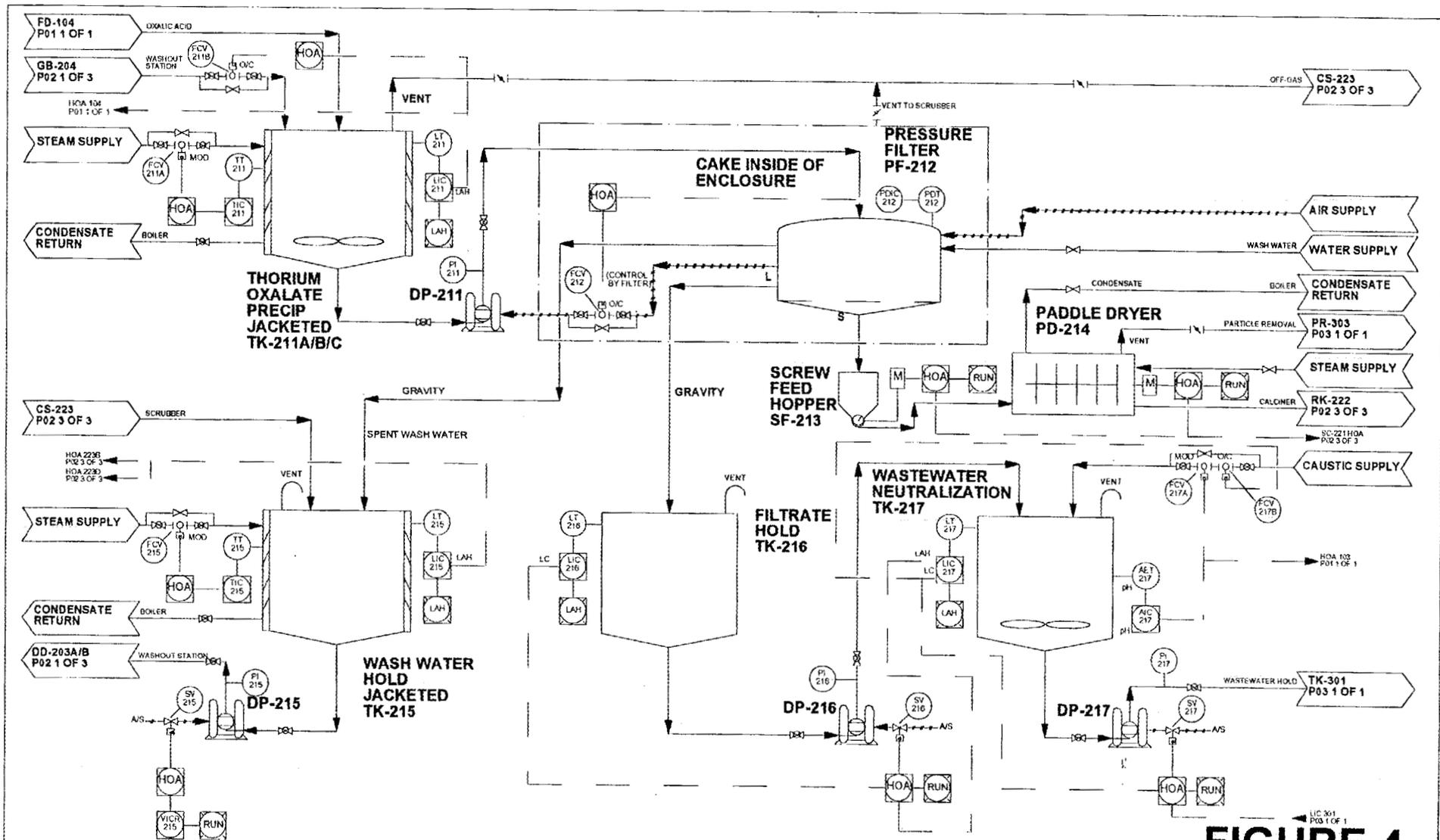
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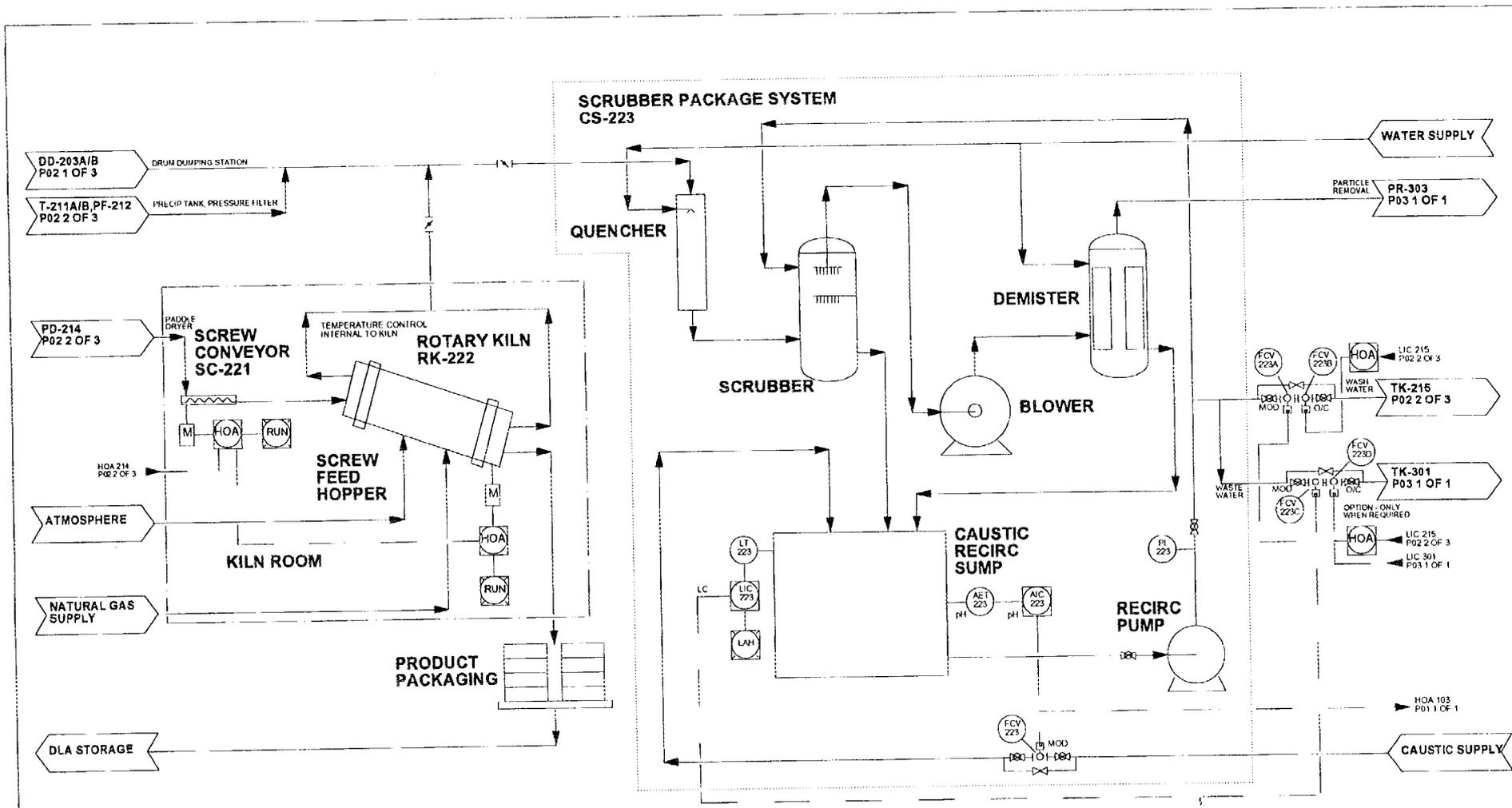
**FIGURE 4**

D	05/17/88	FINAL REPORT MODIFICATIONS			
A	07/17/88	PRELIMINARY DRAWING			
REV.	DATE	DESCRIPTION	BY	CHKD	APPV.
<b>THORIUM NITRATE</b>					
CONVERSION PROJECT					
<small>THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF RECODYNE AND SHALL BE KEPT CONFIDENTIAL AND NOT BE DISCLOSED TO ANY OTHER PARTY WITHOUT THE WRITTEN PERMISSION OF RECODYNE.</small>					
<b>Recodyne</b> <small>RECODYNE PRODUCTS, LLC</small>		<small>200 EAST HUNTER STREET, 8th FLOOR          JOHNSON CITY, TENNESSEE 37604          (615) 975-5555</small>			
PROCESS AREA SECTION 200			PIPING & INSTRUMENTATION DIAGRAM		
SCALE	FILE NO.	DESIGN NO.	ISSUE NO.	DATE	SHEET NO.
NONE	DOEP021	DOE01	P02		1 OF 3



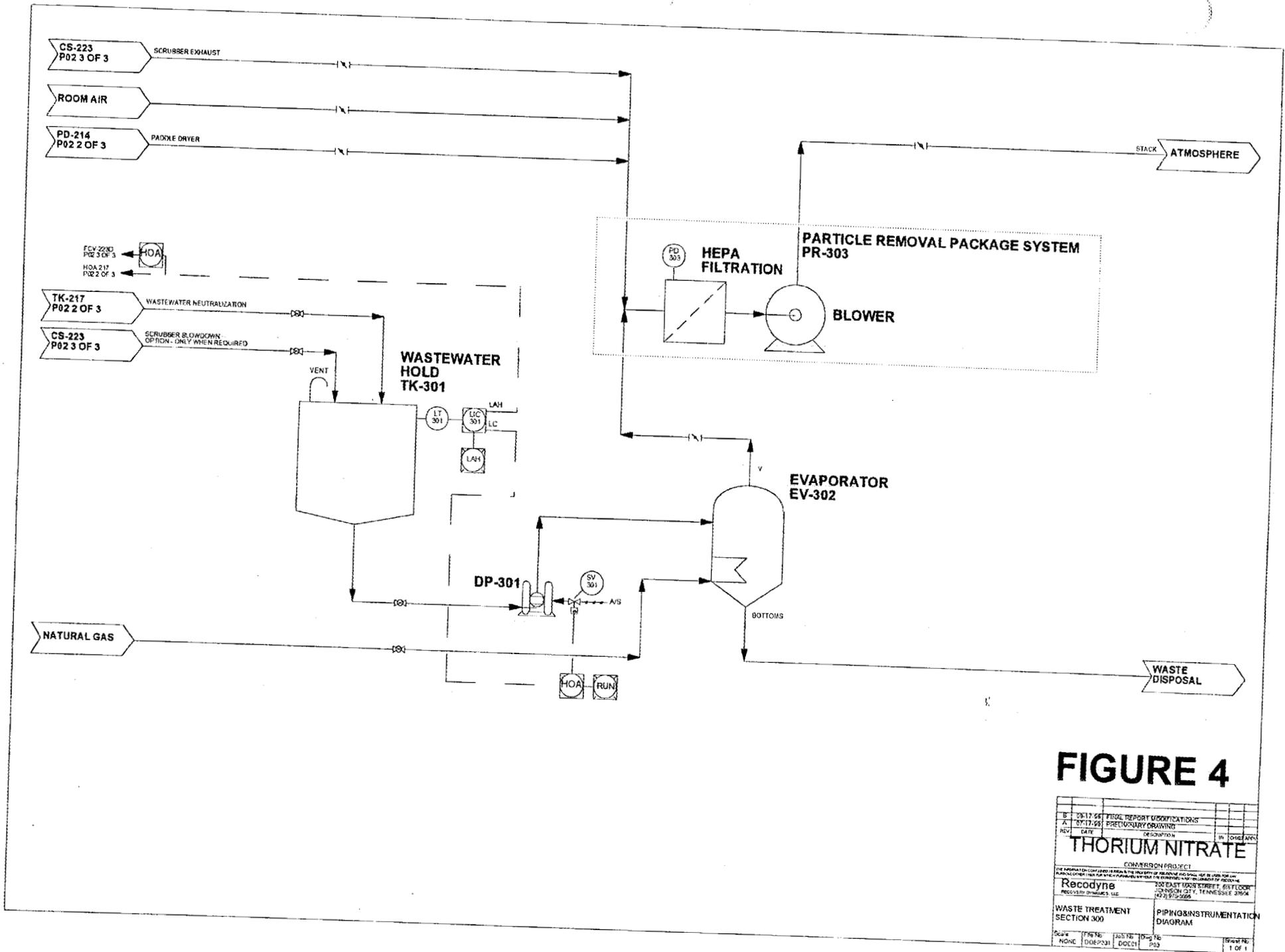
LIC 301  
P03 1 OF 1  
**FIGURE 4**

REV	DATE	DESCRIPTION	BY	CHECKED
1	08/17/28	PIPING REPORT MODIFICATIONS		
2	07/12/28	PROLIFERATION MODIFICATIONS		
<b>THORIUM NITRATE</b>				
CONVERSION PROJECT				
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<b>Recodyne</b> <small>RECODYNE MANUFACTURING, LLC</small>		<small>205 EAST MAIN STREET, 8TH FLOOR          JOHNSON CITY, TENNESSEE 37604          (423) 715-2200</small>		
PROCESS AREA		PIPING & INSTRUMENTATION		
SECTION 200		DIAGRAM		
SCALE	IF #	REV	DATE	BY
NONE	1	DOEP:22	02/01/22	PJZ
				SCALE NO. 2 OF 3



**FIGURE 4**

B	06-17-98	FINAL REPORT MODIFICATIONS		
A	07-17-98	PRELIMINARY DRAWINGS		
REV	DATE	DESCRIPTION	BY	CHECKED
<b>THORIUM NITRATE</b>				
CONVERSION PROJECT				
<small>THE INFORMATION CONTAINED HEREIN IS THE PROPERTY OF RECODYNE AND SHALL NOT BE REPRODUCED OR          COPIED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, WITHOUT THE WRITTEN          PERMISSION OF RECODYNE.</small>				
<b>Recodyne</b> <small>RECODYNE COMPANY, LLC</small>		<small>100 EAST MAIN STREET, SIX FLOOR          JOHNSON CITY, TENNESSEE 37604          (615) 975-6666</small>		
PROCESS AREA		PIPING & INSTRUMENTATION		
SECTION 200		DIAGRAM		
SCALE	1" = 4' N.E.	LOG No.	DOE1	Sheet No.
NONE	30EP923	DOE1	P02	3 OF 3



**FIGURE 4**

REV	DATE	DESCRIPTION	BY	CHKD	APPV
A	07-17-98	PRELIMINARY DRAWING			
B	08-17-98	FINAL REPORT MODIFICATIONS			

**THORIUM NITRATE**

CONVERSION PROJECT

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 CHATTANOOGA, TN 37404  
 (423) 970-5000

WASTE TREATMENT SECTION 300 PIPING & INSTRUMENTATION DIAGRAM

Scale: NONE File No: 006P231 Plot No: 00001 Title No: 000

Sheet No: 1 OF 1

TABLE 9: MASS & ENERGY BALANCE FOR ThN PROCESS

STREAM COMPONENT	UNITS PER BATCH	1	2	3	4	5	6	7	8	9	10	11	12
		ThN FEED DRUM	SPENT WASH WATER	STEAM TO WASTE WATER TANK	CONDENSATE FROM WASTE WATER TANK	SCRUBBER BLOW- DOWN	HEATED WASHOUT WATER	THORIUM NITRATE SOLUTION	OXALIC ACID	THORIUM OXALATE SLURRY	STEAM TO ThOX TANKS 1 & 2	CONDENSATE FROM ThOx TANKS	HEATED Th OXALATE SLURRY
THORIUM	LB	651						651		651			651
Th(NO3)4*5H2O (ThN)	LB	1,600											
Th(NO3)4	LB							1,347		1			1
Th(C2O4)2*2H2O	LB									1245			1245
Th(C2O4)2	LB												
ThO2	LB												
WATER	LB		1,695		135	4,550	6,245	6,498		6,500		916	6,500
H2C2O4*2H2O	LB								778	156			156
NaOH	LB												
HNO3	LB		8.6				8.6	8.6		730			730
NaNO3	LB												
Na2C2O4	LB												
OTHER	LB			135							916		
TOTAL	LB	1,600	1,704	135	135	4,550	6,254	7,854	778	8,632	916	916	8,632
TEMPERATURE	deg C	20	35	160	100	20	50	50	20	40	-----	100	60
pH	-----	-----	6.5	-----	7	7	6.5	0.5	-----	0.5	-----	7	0.5
SPECIFIC GRAVITY	----	----	1.02	-----	1	1	1.02	1.20	1.65	----	-----	1	----
VOLUME	GAL	-----	200	-----	16	546	735	782	----	862	-----	110	862
FREQUENCY	----	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH
DURATION	MIN	60	30	120	120	480	30	30	20	30	120	120	30
		8											
REMARKS		drums						conc Th, g/L		conversion	heating		
								100		99.9%	both tanks		

STREAM COMPONENT	UNITS PER BATCH	13	14	15	16	17	18	19	20	21	22	23	24	25
		Th OXALATE PRESS CAKE	CAKE WASH WATER	THORIUM OXALATE FILTRATE	NaOH (50%)	WASTE WATER TO EVAP	EVAP NATURAL GAS	STEAM TO PADDLE DRYER	CONDENSATE FROM PADDLE DRYER	Th Ox CAKE FROM PADDLE DRYER	THORIUM PRODUCT FROM KILN	KILN NATURAL GAS	BOILER NATURAL GAS	WATER TO BOILER
THORIUM	LB	651		0.5		0.5				651	651			
Th(NO3)4*5H2O (ThN)	LB													
Th(NO3)4	LB			1		1								
Th(C2O4)2*2H2O	LB	1245								1245				
Th(C2O4)2	LB										57			
ThO2	LB										703			
WATER	LB	1,019	1,695	5,481	563	6,341			6,961	51				8012
H2C2O4*2H2O	LB			156										
NaOH	LB				563									
HNO3	LB			730										
NaNO3	LB					986								
Na2C2O4	LB					166								
OTHER	LB						241,714	6,961					170,509	477,425
TOTAL	LB	2,264	1,695	6,368	1,125	7,493	241,714	6,961	6,961	1,296	761	170,509	477,425	8,012
TEMPERATURE	deg C	20	20	35	20	30	-----	160	100	-----	800	-----	-----	20
pH	-----	-----	7	0.5	-----	7	-----	-----	7	-----	-----	-----	-----	7
SPECIFIC GRAVITY		100*	1	1.06	1.51	1.14	0.415	-----	1	-----	86*	0.415	0.415	1
VOLUME	GAL	169	203	720	89	788	69,837	-----	835	-----	5.5	49,264	137,940	961
FREQUENCY	----	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	1/BATCH	CONT.	CONT.	CONT.	CONT.	CONT.	CONT.	CONT.
DURATION	MIN	60	30	30	15	30	----	480	480	----	----	----	----	----
REMARKS		55% PD								PD	*lb/cu ft bulk den.			

equipped to handle drums up to a 55-gallon size. All drums put through the washout station will be volume reduced prior to shipment to a LLW disposal facility.

ThN drums are placed inside one of two enclosed washout stations operated in parallel. The drums are positioned by a drum dump, such that a stream of heated water can be directed at the ThN content from outside the enclosure. Design of the washout station is identical to that used in the demonstration test which was essentially a glove box equipped with a drum dump and a 500-gallon sump. A screen to catch any debris that may fall out of the drum or pieces of the fiber drum itself covers the sump. The enclosure for the ThN washout station is constructed of stainless steel and Plexi-Glas™. The unpacking and washout stations are both ventilated to the HEPA filtration system to minimize personnel exposure to airborne thorium and thoron gas.

The ThN liquor generated in the washout operation is discharged from the sump into one of three agitated 1,100-gallon precipitation reactors. A 1,100-gal reactor was selected as an adequate size (27% freeboard) when splitting the liquor volume into three 800-gal batches or one batch per shift. The excess freeboard provides up to an additional 15% water volume for washing out ThN from the drums. The required precipitation time is obtained by having three reactors operated in parallel with the batch precipitated during the first and second shift operations filtered during the third shift operation. Each 800-gallon batch takes 3 shifts or 24 hours to complete. The following batch sequence of steps for each reactor is staggered by 8 hours so that all steps are being conducted simultaneously over the three reactors.

- |                    |                                 |
|--------------------|---------------------------------|
| 1) First 8 hours:  | a) Fill reactor with ThN liquor |
|                    | b) Begin agitation              |
|                    | c) Bring liquor to temperature  |
|                    | d) Add oxalic acid              |
|                    | e) Begin 12-hour precipitation  |
| 2) Second 8 hours: | f) Complete precipitation       |
| 3) Third 8 hours:  | g) Complete slurry filtration   |

Oxalic acid is added manually with a bag breaking and feeding station. Bags are opened and dumped into a hopper that is connected to a conveyor to feed the mixing tank.

The sizing of the filtration equipment is also minimized by the three-reactor design. The maximum hold-up of thorium oxalate slurry (800 gal over 8

hours) is provided by each reactor in the third shift of its batch sequence. A pressure filter with 7 ft<sup>2</sup> of filtration area and disposable filter media to automatically discharge cake was selected to meet the design criteria. The filter is constructed with two horizontal compartments, an upper chamber for slurry and a lower chamber for filtrate. The two chambers are separated by the filter media. During the filtering cycle the upper chamber is lowered against the lower chamber and a seal is formed on the perimeter of the compartments. Slurries are pumped into the upper chamber and through the filter media and the filtrate is collected in the lower chamber, then drained out. The cake increases in depth until the pressure in the upper chamber reaches the set maximum pressure of 50 psi. The cake is washed with fresh water that is discharged to a 1,100-gallon jacketed hold tank where it is heated to 50°C and reused as washout water for the next batch of ThN. The filter cake is then dried by pressurized air fed into the upper chamber. The upper chamber is then lifted and the filter cake is discharged using a conveyor belt or re-roller drive pulling the media through. New media is automatically replaced and a new filtration cycle is automatically restarted. The equipment is PLC controlled. A chute discharging cake solids to a 12" by 16" opening is used to convey solids to the oxalate conversion operation.

To meet the two-stage heating requirement outlined in the design criteria, the cake from the pressure filter is fed to a continuous dryer operated at a temperature of 150°C. Based on previous experience, a paddle dryer design was chosen for this application. The dryer consist of a trough with counter-rotating screws mounted inside that are steam heated. The filter cake is introduced into one end of the trough and are continually mixed and heated by the rotating screws. A screw conveyor receives the dried oxalate solids at the discharge end of the dryer and conveys them to a rotary kiln.

The design of the rotary kiln for full-scale processing was based on scaling up the demonstration test unit with a 5" diameter tube and a heating section 60" long. Based on the scale-up ratio of 10 for oxalate throughput, i.e., from 16 LB/hr to 160 LB/hr dry wt basis, the full-scale rotary kiln will have a 12" diameter tube and a heating section 8' long. To meet the design criteria, length of the heating section has been increased to 12' to provide 50% more residence time. The product has a ThO<sub>2</sub> specification of 95% or greater which will be maintained by adjusting temperature and, if necessary oxalate feed rate.

The heating section of the tube is followed by a cooling section 8' long. Off-gas from the kiln is discharged at a rate of 6,000 cfm to the wet scrubber by a dedicated blower. The rotary kiln discharges oxide product into a hopper from which 35-gallon drums are filled. The product drums are sealed and moved to a product storage area. Off-spec product containing unreacted oxalate can be

returned to the kiln for additional processing via the filter cake hopper feeding the paddle dryer.

An 1,100-gallon holding tank receives the filtrate discharge from the pressure filter. The filtrate is fed to an 1100-gallon agitated tank where the nitric acid generated in the oxalate precipitation is neutralized with the addition of sodium hydroxide. The resulting wastewater is sent to a 1,100-gallon wastewater hold tank then fed to an evaporator to be volume reduced. The evaporator utilizes natural gas for heating. Crystallized sodium nitrate solids are transferred to the compaction station where they are combined with the overpack ThN drums.

The process operations described above have been used as a basis for developing a preliminary shift schedule for operating personnel. In Table 10 a shift timeline was developed for personnel conducting the required tasks to operate the process. Each shift will require 7 persons to operate and monitor the process. Additionally, a Production Manager will work during the day shift to provide engineering support, reporting functions and overall supervision of the operation. A Laboratory Technologist will also work on the day shift to analyze process and product samples.

**TABLE 10: SHIFT TIME LINE**

LABOR		Hourly Task							
		1	2	3	4	5	6	7	8
Operator 1	1/shift	Fill reactor with ThN liquor Begin agitation and heating	Add oxalic acid Begin precip.	-----Washout ThN drums-----				Compact overpack drums	
Operator 2	1/shift	Obtain ThN from inventory Unpack ThN drums	-----Washout ThN drums-----				Compact overpack drums		
Operator 3	1/shift	----- Filtration, neutralization, evaporation, and scrubber system -----							
Operator 4	1/shift	----- Paddle dryer, rotary kiln, and product packaging and storage -----							
Operator 5	1/shift	----- Paddle dryer, rotary kiln, and product packaging and storage -----							
Operations Supervision	1/shift	----- Process sampling and supervision -----							
HP Tech	1/shift	----- Work area monitoring and drum surveys -----							
Lab Tech	1/day	----- Sample determination -----							
Production Manager	1/day	----- Process engineering, reporting, and supervision -----							

3 shifts = 1 day

## 5.2 Life Cycle Cost Analysis

The cost analysis for the life of the full-scale project is based on estimates of the fixed capital cost to construct and start up the process, annual operating or manufacturing costs and after processing is complete, the cost of decommissioning. For this preliminary cost estimate, direct and indirect capital costs were based on standard factors applied to the cost of purchased equipment. The list of purchased equipment is shown in Table 11 with costs obtained from vendors as budgetary quotes based on the supplied design criteria. Components of the fixed capital cost are listed in Table 12.

Annual operating or manufacturing costs are listed in Table 13. Direct production cost of chemicals and materials, transportation, utilities and secondary waste disposal were estimated directly from the design bases and the mass balance. Fixed charges, plant overheads, general expenses and other expenses such as maintenance were based on standard factors. Labor costs were estimated based on the operating schedule given previously in Table 10. Additional labor costs for the Radiation Safety Officer and an Administrator tasked with inventory control; product/waste shipping and documentation are included under general expenses.

Plant decommissioning costs at the end of the project consist of labor and disposal of plant equipment. The cost was estimated by personnel at the facility where the demonstration test was conducted and was based on the estimated weight of full-scale equipment. This decommissioning cost is incorporated into Table 14 which shows the life cycle cost for the entire project.

## 5.3 Project Time Line for Full Scale Start-Up

A time line of activities required for construction and start up of the full-scale conversion process is shown in Figure 5. These activities include detailed engineering, licensing, construction and performance testing. The 18-month duration is considered to be a reasonable estimate being based on recent experience at two existing facilities involving the full-scale processing of metallurgical residues containing uranium and thorium. Each activity is briefly described below.

### Detailed Engineering

Complete, engineered PFD's, P&ID's and general arrangement drawings of equipment and structures will be completed during this activity. The PFD's are utilized as the basis for filling out equipment specification sheets. The

**Table 11: Process Equipment Cost for ThN Process**

	<b>Equipment Item</b>	<b>Capacity</b>	<b>Manufacturer/Supplier</b>	<b>Model</b>	<b>Cost *</b>
1	ThN washout station enclosure, screen and sump tank #1	500 gal	Inert Systems	120M0011 304 SS	\$ 15,000
2	ThN washout station enclosure, screen and sump tank #2	500 gal	Inert Systems	120M0011 304 SS	\$ 15,000
3	Hydraulic Drum Dump #1	55 gal	Vestil	HDD-36-7S	\$ 2,900
4	Hydraulic Drum Dump #2	55 gal	Vestil	HDD-36-7S	\$ 2,900
5	Unpacking Station & Drum Punch	1 Drum	Vestil		\$ 40,000
6	ThN Sump Pump #1	30 gpm	Wilden	M4	\$ 3,200
7	ThN Sump Pump #2	30 gpm	Wilden	M4	\$ 3,200
8	Wash Out Water Hold Tank	1100 gal	Vanco	SS, jkt.	\$ 14,500
9	Wash Out Water Pump	30 gpm	Goulds	3298	\$ 5,500
10	Thorium Oxalate Precip Tank #1	1100 gal	Vanco	SS, jkt., agit.	\$ 14,500
11	Thorium Oxalate Precip Mixer #1	2 hp	Vanco	Lightning	\$ 7,000
12	Thorium Oxalate Pump #1	30 gpm	Wilden	M4	\$ 3,200
13	Thorium Oxalate Precip Tank #2	1100 gal	Vanco	SS, jkt., agit.	\$ 14,500
14	Thorium Oxalate Precip Mixer #2	2 hp	Vanco	Lightning	\$ 7,000
15	Thorium Oxalate Pump #2	30 gpm	Wilden	M4	\$ 3,200
16	Thorium Oxalate Precip Tank #3	1100 gal	Vanco	SS, jkt., agit.	\$ 14,500
17	Thorium Oxalate Precip Mixer #3	2 hp	Vanco	Lightning	\$ 7,000
18	Thorium Oxalate Pump #3	30 gpm	Wilden	M4	\$ 3,200
19	Oxalic Acid Bag Breaking and Feeding Station	1000 lbs	AFC	25-F	\$ 30,000
20	Pressure Filter	7 sq ft area	Oberlin	OPF 7 MD	\$ 78,000
21	Filtrate Hold Tank	1100 gal	Vanco	SS	\$ 12,000
22	Filtrate Hold Tank Pump	30 gpm	Goulds	3298	\$ 5,500
23	Neutralization Tank	1100 gal	Vanco	SS, agit.	\$ 12,000
24	Neutralization Tank Mixer	2 hp	Vanco	Lightning	\$ 7,000
25	Neutralization Tank Pump	30 gpm	Goulds	3298	\$ 5,500
26	Neutralization Tank pH Electrode	0 -14	Johnson Yokogawa	PH-400	\$ 2,500
27	NaOH Storage Tank #1	2000 gal	Vanco	SS	\$ 12,000
28	NaOH Storage Tank #2	2000 gal	Vanco	SS	\$ 12,000
29	NaOH Storage Tank Pump	10 gpm	Goulds	3298	\$ 3,800
30	Waste Water Hold Tank	1100 gal	Vanco	SS	\$ 12,000
31	Waste Water Hold Tank Pump	30 gpm	Goulds	3298	\$ 5,500
32	Evaporator	120gal/hr	Landa	Water Blaze 120	\$ 160,000
33	Paddle Dryer	107 sq. ft.	Komlime-Sanderson	3W-107	\$ 180,000
34	Rotary Kiln	1000 C	HED Industries	270	\$ 350,000
35	Screw Feed Hopper	25 rpm	WC Forktruck		\$ 15,000
36	Screw Conveyor	25 rpm	WC Forktruck		\$ 15,000
37	Compaction Station	6 yd <sup>3</sup>	JV Manufacturing	vertical	\$ 8,000
38	Scrubber & blower	facility	Duall	M-13-IE	\$ 88,000
39	Scrubber Overflow Tank	50 gal	Chem-Tainer	poly	\$ 600
40	Scrubber Overflow Tank Pump	15 gpm	Wilden	M1	\$ 700
41	HEPA Filter System & HAVC	facility	CSC	2H3W	\$ 95,000
42	Compressor	10 hp	Granger	Speedair	\$ 5,000
43	Boiler	50 hp	Howell	Columbia	\$ 30,000

Sub-total \$ 1,321,400

shipping \$ 198,210

**Total Equipment Cost \$ 1,519,610**

\* NOTE: Some Cost are Estimates

**Table 12: Fixed Capital Cost**

<b>Components</b>	<b>Assumed % of Equipt.</b>	<b>Cost (\$)</b>
<b>DIRECT COST</b>		
Purchased equipment *	100%	\$ 1,519,610
Purchased - equipment installation	39%	\$ 592,648
Instrumentation & Controls (installed)	20%	\$ 303,922
Piping (installed)	31%	\$ 471,079
Electrical (installed)	10%	\$ 151,961
Buildings Improvements	15%	\$ 227,942
Yard Improvements	5%	\$ 75,981
Service Facilities Improvements	10%	\$ 151,961
<b>INDIRECT COST</b>		
Engineering and supervision	32%	\$ 486,275
Construction expense	34%	\$ 516,667
Contractor's fee	18%	\$ 273,530
Contingency	36%	\$ 547,060

**Total Fixed Capital Cost \$ 5,318,635**

• NOTE: Some Cost are Estimates

**Table 13: Annual Manufacturing Cost**

**Direct Production Cost**

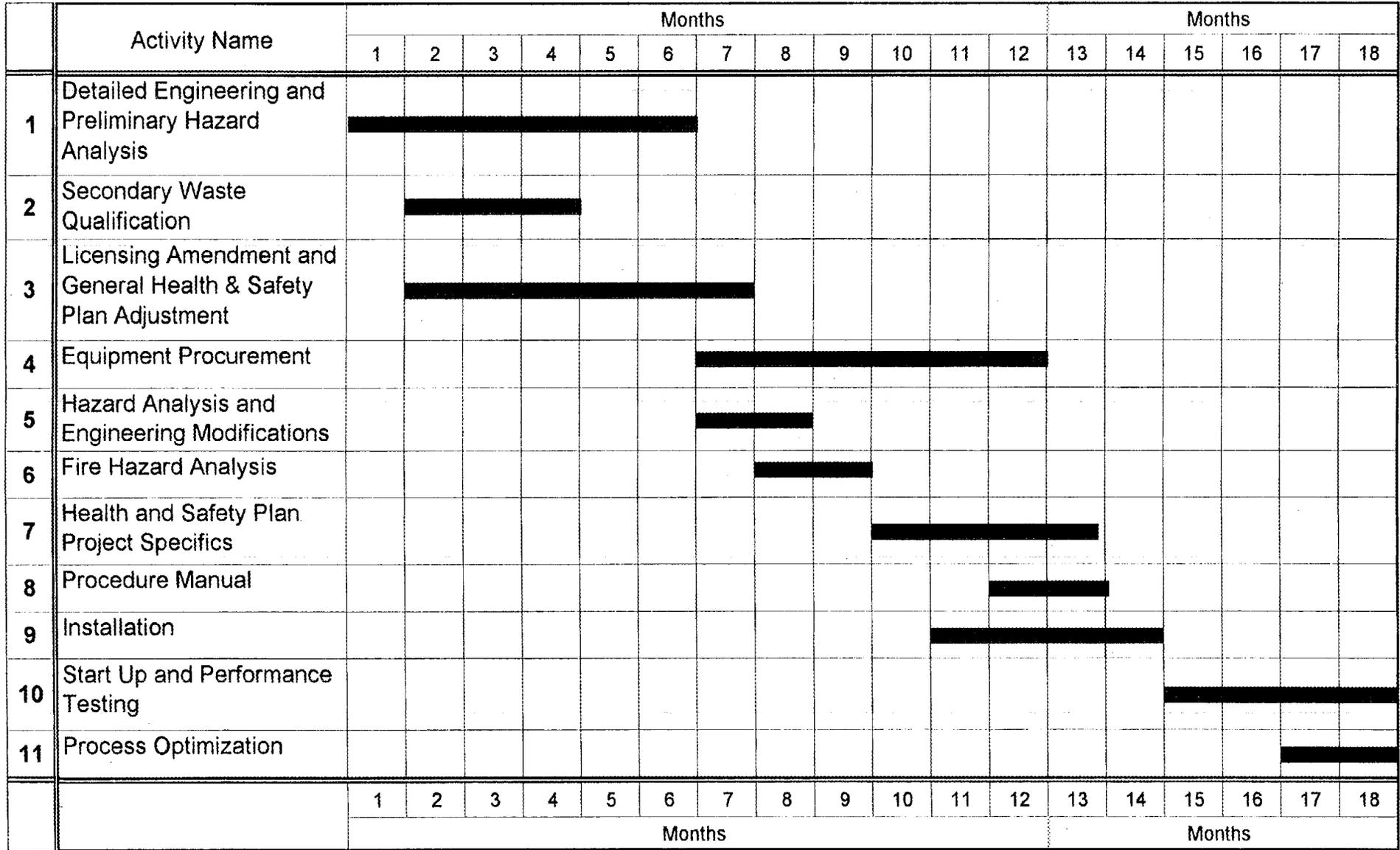
<b>Chemicals &amp; Materials</b>			
	<i>\$/ton</i>	<i>tons/year</i>	<i>cost</i>
Oxalic Acid	1280	500	\$ 640,000
Sodium Hydroxide, 50%	345	626	\$ 215,970
Filter Media	\$1.50/yd	20,000yd	\$ 30,000
			\$ 885,970
<b>Transportation of Feed material</b>			
	<i>\$/load</i>	<i>loads/year</i>	<i>cost</i>
From Curtis Bay	\$ 1,838	103	\$ 189,314
From Hammond	\$ 825	44	\$ 36,300
			\$ 225,614
<b>Labor</b>			
	<i>\$/hr</i>	<i>hr/year</i>	<i>cost</i>
Operating Labor	\$ 12.50	41,600	\$ 520,000
Operating Supervision	\$ 17.50	8,320	\$ 145,600
HP Tech	\$ 13.00	12,480	\$ 162,240
Lab Tech	\$ 15.00	2,080	\$ 31,200
Management	\$ 35.00	2,080	\$ 72,800
			\$ 931,840
<b>Power &amp; Utilities</b>			
	<i>unit \$</i>	<i>Amount</i>	<i>cost</i>
Natural Gas	\$0.02/cu.ft.	35,500,000 cu ft	\$ 710,000
Electricity	\$0.06/KWH	1,500,000 kWh	\$ 90,000
Water	\$0.003/gal	4,200,000 gal	\$ 12,600
			\$ 812,600
<b>Other</b>			
Maintenance and repairs	2%	Fixed Capital	\$ 106,373
Operating supplies	15%	Maint. & Repair	\$ 15,956
Laboratory charges	10%	Operating labor	\$ 52,000
Secondary Waste Disposal	\$80/cu. ft.	14,200 cu. ft.	\$ 1,363,200
Product Packaging	\$65	1700	\$ 110,500
Product Transportation to Curtis Bay	\$ 1,838	320	\$ 588,160
Processing Fee	5%	Manuf. Cost	\$ 350,000
			\$ 2,586,189
<b>Fixed Charges</b>			
Insurance	1%	Fixed Capital	\$ 53,186
Storage	\$1.75/sq.ft	5000 sq. ft	\$ 8,750
Facilities Usage (lease, licensing, etc.)	\$55,000/month	12 months	\$ 660,000
			\$ 721,936
<b>Plant Overhead Cost</b>			
Overhead	35%	Labor & Maint.	363,374
			\$ 363,374
<b>General Expenses</b>			
Administrative expenses	25%	Labor	\$ 232,960
Interest	5%	Fixed Capital	\$ 265,932
			\$ 498,892
<b>TOTAL Manuf. Cost per year</b>			<b>7,026,415</b>

**Table 14: Life Cycle Cost**

<b>Fixed Capital Cost</b>		<b>\$ 5,318,635</b>
<b>Manufacturing Cost</b> (5 years)		<b>\$ 35,132,076</b>
<b>Decommissioning Cost</b>		
Survey, Release & disposal \$2.00/lb	38,400	\$ 76,800
Labor - 4months		
Operating Labor	\$ 12.50	\$ 120,000
Operating Supervision	\$ 17.50	\$ 33,600
HP Tech	\$ 13.00	\$ 33,280
Lab Tech	\$ 15.00	\$ 28,800
Management	\$ 35.00	\$ 22,400
Storage - 4 months	\$1.75/ sq. ft.	\$ 2,917
		<b>\$ 317,797</b>

**TOTAL Project Cost \$ 40,768,507**

# Figure 5: Projected Time Line for Full Scale Start-Up



sheets are submitted to vendors for firm price bids. Instrumentation and control packages are developed from the detailed P&ID's and submitted to vendors for bids. All necessary support services including laboratory analysis will be determined in this activity. Analytical instrumentation required to support process monitoring efforts and product specifications will be determined. It is anticipated that routine thorium analysis of process streams by ICP or DCP will be conducted. The use of outside laboratories particularly during the performance testing activity will also be determined. For example it is anticipated that conversion efficiencies for thorium oxide product can be routinely monitored by simple measurements of bulk density and LOI. The validity of these measurements will be confirmed during the performance testing activity by an outside laboratory using XRD.

A preliminary hazard analysis identifying potential hazards, their consequences and probability of occurrence to plant personnel, the public and the environment is conducted to support the licensing activity. With a focus on potential impacts to the public and the environment, engineering and administrative controls needed to minimise or alleviate potential hazards are identified and incorporated in the process design.

#### Secondary waste qualification

The secondary waste from the process is the combined sodium nitrate solids and the inner ThN drums both having been compacted. The composition of the waste both radiological and chemical, the type and size of packaging to be employed, and the mode of transportation must be submitted to the disposal facility for qualification.

#### Licensing Amendment

An amendment to the existing facility's nuclear material license will be required to construct and operate the process. The amendment application will document in detail the following information.

- a) Process description and chemistry
- b) Preliminary PFD's and P&ID's
- c) Mass and energy balances
- d) Preliminary hazard analysis
- e) Emission estimates and control equipment description
- f) Composition and quantities of products and wastes from the process

## Equipment Procurement

Equipment bids will be evaluated and vendors selected. Vendors will submit equipment drawings for approval before initiating fabrication.

## Final Hazard Analysis

As in the preliminary analysis the materials, chemical reactions and operating conditions for each piece of equipment are organized in a matrix format. A What-If/Checklist methodology will be used for the hazard analysis. The process is divided into logical nodes or worksheets according to unit operations and functional boundaries. Each worksheet has a P&ID for the node as well as information on the materials contained, their toxicity, radioactivity and pertinent physical characteristics such as quantity, concentration and phase condition. For each node potential problems or deviations, consequences and their severity, planned safeguards and the expected probability of each consequence are evaluated. Recommendations for additional safeguards are implemented as engineering modifications.

## Fire Hazard Analysis

A separate fire hazard analysis will also be conducted. By process node all combustible and/or flammable materials will be identified and quantified. All sources of heat and flame in the process are identified and evaluated with respect to their fire hazard potential by comparing their surface temperatures to the autoignition temperatures of the combustible/flammable materials. Fire scenarios are then developed along with the appropriate protection measures.

## Health and Safety Plan

A specific HSP will be developed for the conversion process. The Plan will address dose assessment, work area monitoring, documentation and review, contamination control, exposure control, respiratory protection and environmental monitoring.

## Procedure Manual

A manual of all operating procedures will be developed. A general outline for each procedure is given below.

- 1.0 Introduction
- 2.0 Operating Instructions
  - 2.1 Start Up Procedure
  - 2.2 Operator's Responsibility
  - 2.3 Shutdown Procedure
  - 2.4 Emergency Shutdown

- 3.0 Hazard Identification & Safety
  - 3.1 Personnel Protective Equipment
  - 3.2 Industrial Hazards and Safety
  - 3.3 Chemical Hazards and Safety
  - 3.4 Radiological Hazards and safety

### Installation

Equipment will be set in place based on the general arrangement and structure drawings. Piping and electrical installation will follow. All equipment and piping will be hydrostatically tested before start up.

### Start up and Performance Testing

Process start up is not expected to take more than four weeks. The bulk of the time is required for performance testing. As shown in Table 15, samples of the process streams will be taken routinely on a shift basis and analyzed to determine process performance. Key performance parameters include ThN washout volume, oxalate precipitation efficiency, oxalate filter cake percent moisture, oxide content of thorium product and thorium emissions from the stack. It is anticipated that measurements of Ra-228, ThO<sub>2</sub> and TCLP metals will always be conducted by outside labs with the appropriate QA/QC procedures. Particulate emissions including thorium in the stack discharge will be routinely measured over the life of the plant. Estimates of NOx emissions will be confirmed during performance testing. It is anticipated that the process laboratory will have the capability to analyze for all parameters with the exception of Ra-228, ThO<sub>2</sub> and TCLP metals and NOx. These analytes will be accomplished by outside laboratories identified during the detailed engineering activity.

An internal QA/QC program for in-house analysis will be developed. As part of this program and particularly during performance testing interlaboratory comparisons will be made. Sample splits will be sent to outside labs as a check on the accuracy of in-house analysis.

TABLE 15: PROCESS STREAM ANALYSIS FOR PERFORMANCE TESTING

Analyte	ThN liquor	Filter cake	Dried oxalate	ThO <sub>2</sub> product	Waste water	Stack	LLW
Thorium	XX				XX	XX	XX
Ra-228	XX						XX
Gross alpha/beta	XX					XX	XX
PH	XX	XX			XX		XX
Percent moisture		XX	XX	XX			XX
LOI		XX		XX			
ThO <sub>2</sub> (XRD)				XX			
TCLP metals				XX			XX
Bulk density				XX			
Nitrates		XX					
Nox						XX	
Particulate						XX	

Process Optimization

Once the plant has reached steady state conditions optimization of process operations can begin. Small defined changes to the major process variables affecting throughput and/or product quality are conducted over an 8 to 12 week period. This evolutionary operation (EVOP) approach is conducted in the framework of a factorial experimental design that determines the significance of the independent process variables on throughput and product quality.

## 6.0 ENVIRONMENTAL CONSIDERATIONS

The demonstration results were evaluated in the context of previous experience in the design and operation of radiochemical processing operations to provide a preliminary assessment of environmental issues for full-scale processing. Air emissions from the process consist of thorium particulate, nitrogen oxides and thoron gas, and a short-lived daughter of radium-224. There are no liquid discharges from the process since wastewater is converted to a solid before disposal as a secondary waste.

### 6.1 Air Emissions

The major air emissions from the process that were identified in the design and operation of the pilot plant as thorium, nitrogen oxides and thoron gas. Thorium in the form of particulate and aerosols will be emitted predominantly from the drying and calcination of thorium oxalate and from the drum washout of ThN. Nitric acid not washed out of the oxalate filter cake will also generate nitrogen oxide emissions in the calcination step. Thoron gas (radon-222) will be emitted from unpacking ThN drums, ThN washout, and oxalate precipitation and wastewater evaporation.

Thorium emissions from the full-scale process were estimated using an emission factor derived from actual experience with radiochemical facilities having similar process operations and air pollution controls. The emission factor of 0.0000015 unit weight thorium per unit weight of thorium throughput was applied to the 3.024 MM LB of thorium inventory to yield an estimated total of 4.5 LB or 4.5 mCi of thorium activity emitted over the 5-year lifetime of the plant.

The quantity of nitrogen oxide emissions was estimated from a 90% wash efficiency for the thorium oxalate cake by the pressure filter and a 70% NO<sub>x</sub> removal efficiency by the wet scrubber. For the full-scale operation generating 2,190 LB of nitrates per day, this translates to a daily emission rate of 2 LB NO<sub>x</sub>.

Thoron emissions are not an environmental concern due to their short half-life. However, these emissions must be controlled by room and vessel ventilation to ensure that thoron levels do not build up to unacceptable levels in the workplace.

## 6.2 Primary and Secondary Waste Disposal

The demonstration test confirmed that the thorium oxide product could be consolidated into tablets with the addition of a binder such as graphite. This consolidation would satisfy the requirements for long term storage of the material in a repository. The current full-scale process design, however, has been based on the alternative approach in which the unconsolidated product is contained in 35-gallon steel drums that are overpacked in 55-gallon steel drums.

Secondary waste consist of ThN overpack drums, HEPA filters, personal protection equipment (PPE) and sodium nitrate solids. The sodium nitrate solids will have a radium-228 activity of about 7,000 pCi/g and a thorium activity of about 114 pCi/g. The overpack drums, filters and PPE will be compacted and have an estimated total activity not exceeding 100 pCi/g.

## 6.3 Potential Environmental Impacts

The potential impacts of processing the ThN at an existing licensed facility would be minimal. The plant would require about 5,000-sq. ft. of floor space and can be installed in an existing building. Air emissions from the plant include combustion products from the gas-fired boiler, rotary kiln and evaporator. An additional 6 LB/day of nitrogen oxides are emitted from the wet scrubber. There is no wastewater discharged from the plant. All solid wastes and products generated by the process are shipped off-site for disposal or long-term storage. Secondary containment is incorporated in the design of the plant to control any solid or liquid spills.

## 6.4 Environmental Assessment Information

Information required for environmental assessment is the same as required for a nuclear materials license amendment. Key information includes:

- 1) Description of proposed action
- 2) Description of Materials/Wastes
- 3) Wastewater treatment system
- 4) Control Equipment/Spill prevention
- 5) Air emissions

6) Environmental effects

7) Waste generation and handling

These items have been discussed in the above engineering study and would be further detailed in the license amendment package submitted to the government agencies responsible for regulating the specific facility.

## REFERENCES

- (a) Thorium Dioxide Properties and Nuclear Applications, Ed. J. Belle and R.M. Berman, DOE/NE-0060, Dist. Category UC-25, 78 pp. 364-395
- (b) Huck, P. Removal of Radium from Uranium Mining Effluents - Current Status and New Directions, University of Regina, Saskatchewan, Canada. Pp.321-340
- (c) Bisio, A. and R.L. Kabel, Scaleup of Chemical Processes, John Wiley & Sons, Inc., 1985. P. 6
- (d) Benedict, M., T.H. Pigford and H.W. Levi, Nuclear Chemical Engineering, 2<sup>nd</sup> Edition, McGraw-Hill, Inc., New York. P.310



# APPENDIX A

## Operation Log

Project: Thorium Treatment Demonstration Project

Location: F.W. Hake & Associates

Date: February 16, 1998 – March 11, 1998

Date	Operation	Comments
2/16/98	Unload equipment	Used Hake union workers – slow unloading
2/17/98	Setup eqpt.	Quick disconnects helped speed up things
2/18/98	Setup & hydro test	Fixed a drip on outlet of TK-130. Cleaned bag filter.
2/19/98	Drum #1	55 gal over pack. 0 gal Recycle. 125 lb Ox acid. For #1 Finished cake dumps on #1
2/20/98	Drum #2	Neutralization & 1 <sup>st</sup> Ra precip of #1 0 gal Recycle. 125 lbs Ox acid. For #2 Few cake dumps on #2
2/21/98		Finished Ra precip on #1 Emptied waste water for #1 Finished cake dumps on #2 Neutralization & 1 <sup>st</sup> Ra precip of #2
2/22/98	Drum #3	Finished Ra precip on #2 Emptied waste water for #2 52 gal Recycle. 130 lbs Ox acid. For #3 Finished cake dumps on #3 Neutralization & 1 <sup>st</sup> Ra precip of #3
2/23/98	Drum #4	Finished Ra precip on #3 Bag filter filled 3 bags of solids for #3 52 gal Recycle. 130 lbs Ox acid. For #4
2/24/98	Drum #5	Emptied waste water for #3 Finished cake dump on #4 49 gal Recycle. 130 lbs Ox acid. For #5
2/25/98		Bag filter filled 2 bags of solids for #4 Finished Ra precip on #4 Emptied waste water for #4 Finished cake dumps on #5 Neutralization & 1 <sup>st</sup> Ra precip of #5
2/26/98	Drum #6	Opened door Customers visited 0 gal Recycle. 114 lbs Ox. Acid. For #6 (Dumped #6 & did Oxalate precip. Only)
2/27/98	Drum #7	Finished Ra precip on #5 Emptied waste water for #5 Finished cake dumps on #6 Neutralization & 1 <sup>st</sup> Ra precip of #6 0 gal Recycle. 100lbs Ox. Acid. For #7
2/28/98	Drum #8	Finished Ra precip on #6 Emptied waste water for #6 Finished cake dumps on #7 Neutralization & 1 <sup>st</sup> Ra precip of #7 26 gal Recycle. 114lbs Ox. Acid. For #8

Date	Operation	Comments
3/02/98	Drum #9	Finished cake dumps on #8 Finished all Ra precip on #8 Emptied waste water for #8 0 gal Recycle. 114 lbs. Ox. Acid. For #9
3/03/98	Drum #10	Finished cake dumps on #9 Neutralization & 1 <sup>st</sup> Ra precip of #9 55 gal Recycle. 114 lbs. Ox. Acid. For #10
3/04/98		Finished Ra precip on #9 Emptied waste water for #9 Dumped most of the cake on #10
3/05/98		Finished cake dumps on #10 Finished all Ra precip on #10 Emptied waste water for #10
3/06/98	Decon	Processed lime through filter press and Rotary Kiln
3/07/98	Decon	Took off fittings & valves Trashed small items
3/08/98	Decon	Decon tanks, stands & glove box
3/09/98	Decon	Decon tanks, stands & took apart scrubber
3/10/98	Decon	Hake decon
3/11/98	Decon	Hake – shrink wrapped Rotary Kiln, scrubber & glove box. Removed equipment form safe shop

## Thorium Nitrate Demonstration Test Sampling

Sample # consist of three numbers:

Drum# - P&ID# - Code

Drum#	Actual Drum #	P&ID#	Code
A	71-26	104a	R1
B	71-29	104b	R2
C	71-27	108	R3
D	71-23	121	P
E	71-25	138	L1
F	71-19	123	L2
G	71-22	125	
H	71-24	126	
I	71-21	135	
J	71-20		

Thorium Nitrate liquor  
 Thorium Oxalate Solution  
 Wet filter cake  
 Thorium Oxalate Filtrate  
 Liquid after first Radium Precip.  
 Final Waste Water  
 Thorium Oxide Powder  
 Thorium Oxide Tablets  
 Wet Scrubber Solution

Recodyne #1 - 500mL  
 Recodyne #2 - 500mL  
 Recodyne #3 - 500mL  
 Process Control Testing  
 LMES - 250mL amber glass  
 LMES - 250mL plastic

# Thorium Nitrate Demonstration Project

Day # 1      DRUM (A) # 71-26

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)		
A- 104a- R1	2/19/98	10:55 AM	67	90	0.99	503.0	Density 1245.5 g/L	
A- 104a- R2	2/19/98	10:56 AM	67	90	0.96	516.5		
A- 104a- R3	2/19/98	10:57 AM	67	90	1.02	524.0		
* Added 30 gal of water								Density
A- 104b- R1	2/19/98	3:55 PM	105	80	0.02	407.5	1190.5 g/L	
A- 108- R1	2/19/98	4:35 PM	-	-	-	311.5		
A- 121- R1	2/20/98	9:53 AM	165	78	0.46	448.0		
A- 121- R2	2/20/98	9:54 AM	165	78	0.31	465.5		
A- 121- R3	2/20/98	9:55 AM	165	78	0.33	504.5		
A- 138- P	2/21/98	11:45 AM	178	105	7.43	435.0		
A- 123- R1	2/21/98	3:15 PM	178	98	7.46	457.5		
A- 123- R2	2/21/98	3:13 PM	178	98	7.45	455.0		
A- 123- R3	2/21/98	3:14 PM	178	98	7.45	456.0		
								Bulk Density
A- 125- R1	2/19/98	6:21 PM	-	1472	-	332.5	920.5 g/L * Clumpy	
A- 125- R2	2/19/98	6:20 PM	-	1472	-	262.5		
A- 125- R3	2/19/98	6:22 PM	-	1472	-	316.5		
A- 135- R1	2/20/98	12:21 PM	100	80	7.63	472.0		
A- 135- R2	2/20/98	12:20 PM	100	80	7.51	455.5		
A- 135- R3	2/20/98	12:19 PM	100	80	7.72	452.0		

	(lbs)
Initial weight of ThN drum	294
Weight of empty drum	92
Weight of ThN	202
Weight of ThO2 powder & drum	126
Weight of empty drum	24
Weight of ThO2 Powder	102

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	125 lbs
Barium Chloride	100	2*184 g
Aluminum Sulfate	100/94.6	2*137 g
Sodium Hydroxide	50	11 gal
Fresh Water (gal)	-	85+88 =173

Recycled      0

Cake Wash Water (gal)

*1)	10		6)	6		11)	6
2)	2		7)	6		12)	6
3)	8		8)	6		13)	6
4)	10		9)	10			
5)	6		10)	6		Total	88

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample

- 55 gal overpack drum
- Initially used 55 gal of water to dissolve ThN  
    Added 30 gal of water while adding Ox Acid
- Empty sample jar is 59.0 g
- 500mL sample jars filled ~ 400mL liquid &  
    ~200 mL solid
- Site - Memphis, TN (central time zone)
- 1472 F = 800 C

Specific Gravity of F.W. Hake's Water      996.5 g/L  
pH= 7.05

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 2      DRUM (B) # 71-29

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
B- 104a- R1	2/20/98	1:02 PM	96	105	0.97	457.0	Density <hr/> 1171.0 g/L
B- 104a- R2	2/20/98	1:03 PM	96	105	1.00	496.0	
B- 104a- R3	2/20/98	1:04 PM	96	105	0.98	499.0	
B- 104b- R1	2/20/98	1:37 PM	102	94	0.02	370.5	Density <hr/> 1191.0 g/L
B- 108- R1	2/21/98	11:00 AM	-	-	-	414.0	
B- 121- R1	2/21/98	4:35 PM	176	80	0.35	485.5	
B- 121- R2	2/21/98	4:34 PM	176	80	0.26	423.5	
B- 121- R3	2/21/98	4:33 PM	176	80	0.21	475.5	
B- 138- P	2/22/98	11:06 AM	187	90	5.53	476.5	
B- 123- R1	2/22/98	3:22 PM	178	88	5.52	501.5	
B- 123- R2	2/22/98	3:21 PM	178	88	5.52	452.5	
B- 123- R3	2/22/98	3:20 PM	178	88	5.53	482.5	
B- 125- R1	2/21/98	2:38 PM	-	1472	-	364.0	Bulk Density <hr/> 1105.0 g/L
B- 125- R2	2/21/98	2:36 PM	-	1472	-	280.0	
B- 125- R3	2/21/98	2:37 PM	-	1472	-	313.5	
B- 135- R1	2/21/98	4:52 PM	50	82	7.99	450.0	
B- 135- R2	2/21/98	4:51 PM	50	82	8.01	439.5	
B- 135- R3	2/21/98	4:50 PM	50	82	7.98	426.5	

	(lbs)
Initial weight of ThN drum	262
Weight of empty drum	55
Weight of ThN	207
Weight of ThO2 powder & drum	117
Weight of empty drum	24
Weight of ThO2 Powder	93

### NOTES

- Recodyne - Add 2.5mL HNO3 per 500mL of sample
- \* Cake broke through on #2 - cleaned gaskets  
- added extra rinse water
  - \* Took out 22 gal from Rad. Precip. to run with next batch  
(tank over full)
  - \* Over shot NaOH  
- added a cup of Ox Acid to neutralize filtrate

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	125 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	9 gal
Fresh Water (gal)	-	80+62 = 150

Recycled 0

Cake Wash Water (gal)

1)	10	6)	6	* left 4 gal in cone of ThOx tank to mix with drum C
2)	7	7)	6	
3)	6	8)	6	
4)	6	9)	9	
5)	6			
			Total	62

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

**Day # 3      DRUM (C) # 71-27**

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
C- 104a- R1	2/22/98	9:35 AM	115	102	0.05	501.5	<b>Density</b> 1188.5 g/L
C- 104a- R2	2/22/98	9:37 AM	115	102	0.07	467.0	
C- 104a- R3	2/22/98	9:36 AM	115	102	0.09	473.0	
C- 104b- R1	2/22/98	11:31 AM	120	90	0.04	502.0	<b>Density</b> 1186.0 g/L
C- 108- R1	2/22/98	11:58 AM	-	-	-	337.5	
C- 121- R1	2/22/98	4:18 PM	152	82	0.01	436.0	
C- 121- R2	2/22/98	4:17 PM	152	82	0.01	485.0	
C- 121- R3	2/22/98	4:16 PM	152	82	0.01	498.0	
C- 138- P	2/23/98	3:03 PM	171	92	6.71	492.0	
C- 123- R1	2/24/98	11:28 AM	176	78	7.79	482.5	
C- 123- R2	2/24/98	11:29 AM	176	78	7.84	501.5	
C- 123- R3	2/24/98	11:30 AM	176	78	7.83	474.0	
C- 125- R1	2/22/98	5:00 PM	-	1472	-	380.5	<b>Bulk Density</b> 1105 g/L
C- 125- R2	2/22/98	5:01 PM	-	1472	-	324.0	
C- 125- R3	2/22/98	5:02 PM	-	1472	-	316.0	
C- 135- R1	2/22/98	4:47 PM	100	84	7.80	496.5	
C- 135- R2	2/22/98	4:46 PM	100	84	7.79	499.0	
C- 135- R3	2/22/98	4:45 PM	100	84	7.85	431.5	

\*C-Bag Filter Solids      2/23/98

(lbs)

Initial weight of ThN drum	260
Weight of empty drum	55
Weight of ThN	205
Weight of ThO2 powder & drum	148
Weight of empty drum	24
Weight of ThO2 Powder	124

\* Includes some of drum D powder

### NOTES

- Recodyne - Add 2.5mL HNO3 per 500mL of sample
- \* Recycled 52 gal of waste water
- \* Left TK-121 at pH of 13 overnight
- \* Bag filter filled up with white solids
  - 3 FULL bags
  - looked like powdered sugar
- \* Added 10 gal water to scrubber (2-23-98, 2:00 PM)
- \* Recalibrated lab pH probe off by +0.4
- \* Rad precip. Tank, 165 gal after added NaOH

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	130 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	13 gal
Fresh Water (gal)	-	36+58 =94

Recycled      52

Cake Wash Water (gal)

1)      4	6)      6
2)      6	7)      6
3)      6	8)      6
4)      6	9)      6
5)      6	10)     6
<b>Total      58</b>	

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 4      DRUM (D) # 71-23

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
D- 104a- R1	2/23/98	9:37 AM	98	102	0.73	544.0	Density <hr/> 1266.5 g/L
D- 104a- R2	2/23/98	9:36 AM	98	102	0.78	515.0	
D- 104a- R3	2/23/98	9:35 AM	98	102	0.76	511.5	
D- 104b- R1	2/23/98	10:51 AM	110	90	0.01	466.5	Density <hr/> 1208.5 g/L
D- 108- R1	2/24/98	1:35 PM	-	-	-	352.5	
D- 121- R1	2/24/98	2:06 PM	174	78	0.11	452.0	
D- 121- R2	2/24/98	2:05 PM	174	78	0.15	467.0	
D- 121- R3	2/24/98	2:04 PM	174	78	0.21	440.5	
D- 138- P	2/25/98	10:15 AM	177	92	6.92	507.5	
D- 123- R1	2/25/98	3:25 PM	182	88	6.92	476.5	
D- 123- R2	2/25/98	3:24 PM	182	88	6.92	465.5	
D- 123- R3	2/25/98	3:26 PM	182	88	6.92	434.0	
D- 125- R1	2/25/98	3:15 PM	-	1472	-	267.0	Bulk Density <hr/> 1137.5 g/L
D- 125- R2	2/25/98	3:16 PM	-	1472	-	286.0	
D- 125- R3	2/25/98	3:17 PM	-	1472	-	285.0	
D- 135- R1	2/24/98	4:55 PM	100	82	7.67	423.0	
D- 135- R2	2/24/98	4:54 PM	100	82	7.66	426.0	
D- 135- R3	2/24/98	4:53 PM	100	82	7.66	422.5	

\*D-Bag Filter Solids      2/25/98      10:00 AM  
 \*D-Cake Wash H2O      2/24/98      1:30 PM

(lbs)

Initial weight of ThN drum	260
Weight of empty drum	56
Weight of ThN	204

Weight of ThO2 powder & drum	121
Weight of empty drum	24
Weight of ThO2 Powder	97

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	130 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	12 gal
Fresh Water (gal)	-	35+58 =93

Recycled      52

Cake Wash Water (gal)

1)	6	6)	6	* left 3 gal in cone of ThOx tank to mix with drum E
2)	6	7)	6	
3)	6	8)	4	
4)	6	9)	6	
5)	6	10)	6	
			Total	58

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample

- \* Recycled 52 gal of waste water
- \* Let Th OX precip. Tank mix overnight
- \* Rinse water is milky sometimes
- \* pH of Hake's "tap" water inside shop A is 6.96
- \* Added 10 gal water to scrubber (2-24-98)
- \* Rad precip. Tank, 187 gal after added NaOH
- \* Recalibrated pH meter in TK-121 (2-24-98)

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 5      DRUM (E) # 71-25

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
E- 104a- R1	2/24/98	6:44 PM	107	108	0.33	517.0	Density 1173.5 g/L
E- 104a- R2	2/24/98	6:43 PM	107	108	0.35	448.0	
E- 104a- R3	2/24/98	6:42 PM	107	108	0.35	452.0	
E- 104a- L1	2/24/98	6:40 PM	107	108	0.35	331.5	
E- 104a- L2	2/24/98	6:41 PM	107	108	0.35	206.5	
							Density
E- 104b- R1	2/25/98	9:51 AM	111	88	0.01	490.0	1188.5 g/L
E- 108- R1	2/25/98	10:32 AM	-	-	-	345.0	
E- 108- L1	2/25/98	10:33 AM	-	-	-	234.5	
E- 121- R1	2/25/98	4:27 PM	157	80	0.01	511.5	
E- 121- R2	2/25/98	4:26 PM	157	80	0.01	512.0	
E- 121- R3	2/25/98	4:25 PM	157	80	0.01	461.5	
E- 138- P	2/27/98	9:50 AM	151	88	6.44	441.5	
E- 123- R1	2/27/98	11:55 AM	168	85	6.58	498.0	
E- 123- R2	2/27/98	11:56 AM	168	85	6.60	463.0	
E- 123- R3	2/27/98	11:57 AM	168	85	6.57	508.5	
E- 123- L1	2/27/98	11:58 AM	168	85	6.57	320.5	
E- 123- L2	2/27/98	11:59 AM	168	85	6.57	208.5	
							Bulk Density
E- 125- R1	2/26/98	3:23 PM	-	1472	-	341.0	1070.5 g/L * Tan powder
E- 125- R2	2/26/98	3:24 PM	-	1472	-	290.0	
E- 125- R3	2/26/98	3:25 PM	-	1472	-	308.0	
E- 125- L1	2/26/98	3:26 PM	-	1472	-	174.5	
E- 135- R1	2/25/98	5:14 PM	100	86	7.81	496.0	
E- 135- R2	2/25/98	5:13 PM	100	86	7.81	415.5	
E- 135- R3	2/25/98	5:10 PM	100	86	7.81	435.0	
E- 135- L1	2/25/98	5:11 PM	100	86	7.81	284.5	
E- 135- L2	2/25/98	5:12 PM	100	86	7.81	180.5	

\* E-Bag Filter Solid      2/26/98      3:35 PM  
(lbs)

Initial weight of ThN drum	262
Weight of empty drum	58
Weight of ThN	204
Weight of ThO2 powder & drum	130
Weight of empty drum	24
Weight of ThO2 Powder	106

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample  
 LMES - Solids, 200g in 4oz. amber container  
 Liquid, 250mL in amber glass bottle half full  
 250ml in plastic bottle half full

- \* Recycled 49 gal of waste water  
     + 36 gal fresh water = 85 gal ThN into soln.
- \* Sampled F.W. Hake water 2-25-98
- \* Added 8 gal of water to scrubber (2-25-98, 4:00 PM)
- \* 167 gal in TK-121 after added NaOH

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	130 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	12 gal
Fresh Water (gal)	-	36+58 =94

Recycled      49

Cake Wash Water (gal)

1)      6	6)      4	
2)      6	7)      6	
3)      6	8)      6	
4)      6	9)      6	
5)      6	10)     6	
Total		58

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 6      DRUM (F) # 71-19

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
F- 104a- R1	2/26/98	3:02 PM	101	104	0.39	518.5	Density 1136.0 g/L
F- 104a- R2	2/26/98	3:01 PM	101	104	0.40	460.0	
F- 104a- R3	2/26/98	3:00 PM	101	104	0.42	461.0	
F- 104b- R1	2/27/98	9:01 AM	111	82	0.01	503.0	Density 1177.5 g/L
F- 108- R1	2/27/98	10:22 AM	-	-	-	451.0	
F- 121- R1	2/27/98	3:49 PM	136	84	0.06	272.0	
F- 121- R2	2/27/98	3:48 PM	136	84	0.06	304.0	
F- 121- R3	2/27/98	3:47 PM	136	84	0.06	331.0	
F- 138- P	2/28/98	9:50 AM	148	92	7.53	355.5	
F- 123- R1	2/28/98	11:26 AM	148	92	7.50	320.5	
F- 123- R2	2/28/98	11:25 AM	148	92	7.50	343.5	
F- 123- R3	2/28/98	11:27 AM	148	92	7.50	432.0	
F- 125- R1	2/28/98	8:55 AM	-	1472	-	202.5	Bulk Density 971.0 g/L
F- 125- R2	2/28/98	8:56 AM	-	1472	-	211.0	
F- 125- R3	2/28/98	8:57 AM	-	1472	-	192.0	
F- 135- R1	2/27/98	4:22 PM	100	86	7.76	331.0	*Clumpy
F- 135- R2	2/27/98	4:21 PM	100	86	7.76	324.0	
F- 135- R3	2/27/98	4:20 PM	100	86	7.76	369.0	

	(lbs)	
Initial weight of ThN drum	263	
Weight of empty drum	59	
Weight of ThN	204	
Weight of ThO2 powder & drum	127	
Weight of empty drum	24	
Weight of ThO2 Powder	103	

### NOTES

- Recodyne - Add 2.5mL HNO3 per 500mL of sample
- \* No recycled waste water used (87 gal fresh)
  - \* Oxalate cake is very wet
  - \* Rad precip. Tank, 148 gal after added NaOH
  - \* Very little solids build up in bag filter
  - \* Started filling sample bottles only 1/3 full
  - \* Second drum of ThO2 powder is pretty & white

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	114 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	12 gal
Fresh Water (gal)	-	87+58 =145

Recycled 0

Cake Wash Water (gal)

1)	6	6)	6	* left 4 gal in cone of ThOx tank to mix with drum G
2)	6	7)	6	
3)	6	8)	6	
4)	6	9)	6	
5)	6	10)	4	
			Total	58

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 7      DRUM (G) # 71-22

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
G- 104a- R1	2/27/98	5:52 PM	107	102	0.16	312.0	Density 1235.0 g/L
G- 104a- R2	2/27/98	5:51 PM	107	102	0.16	336.0	
G- 104a- R3	2/27/98	5:50 PM	107	102	0.16	349.0	
G- 104b- R1	2/28/98	9:09 AM	121	82	0.01	319.5	Density 1159.0 g/L
G- 108- R1	2/28/98	11:15 AM	-	-	-	290.0	
G- 121- R1	2/28/98	3:37 PM	140	80	0.01	300.0	
G- 121- R2	2/28/98	3:36 PM	140	80	0.01	377.0	
G- 121- R3	2/28/98	3:35 PM	140	80	0.01	347.0	
G- 138- P	3/1/98	9:25 AM	147	92	7.17	311.5	
G- 123- R1	3/1/98	10:57 AM	150	90	7.16	352.0	
G- 123- R2	3/1/98	10:56 AM	150	90	7.16	306.0	
G- 123- R3	3/1/98	10:58 AM	150	90	7.16	389.0	
G- 125- R1	3/1/98	12:40 PM	-	1112	-	273.0	Bulk Density 1171 g/L
G- 125- R2	3/1/98	12:41 PM	-	1112	-	262.5	
G- 125- R3	3/1/98	12:42 PM	-	1112	-	259.0	
G- 135- R1	2/28/98	3:57 PM	100	80	7.80	312.0	
G- 135- R2	2/28/98	3:56 PM	100	80	7.80	317.0	
G- 135- R3	2/28/98	3:55 PM	100	80	7.80	285.5	

	(lbs)	
Initial weight of ThN drum	260	
Weight of empty drum	54	
Weight of ThN	206	
Weight of ThO2 powder & drum	137	
Weight of empty drum	28	
Weight of ThO2 Powder	109	

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	100 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	12 gal
Fresh Water (gal)	-	89+59 =148

Recycled      0

Cake Wash Water (gal)

1)	5	6)	6	* left 6 gal in cone of ThOx tank to mix with drum H
2)	6	7)	6	
3)	6	8)	6	
4)	6	9)	6	
5)	6	10)	6	
			Total	59

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample

- \* No recycled waste water used (89 gal fresh)
- \* 1112 F = 600 C
- \* Rad precip. Tank, 152 gal after added NaOH
- \* Scrubber overflowed (2-28-98, 1:00 PM)
  - Water was left on and scrubber valve was open
- \* 600 C - ThO2 powder is lumpy, golf ball size
  - Liquid dripped out the end of the kiln's vent tube
- \* Second half of ThO2 powder was dried at 800 C
  - 800 C powder is pretty & white

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 8      DRUM (H) # 71-24

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
H- 104a- R1	2/28/98	5:19 PM	105	110	0.19	343.0	Density 1178.0 g/L
H- 104a- R2	2/28/98	5:18 PM	105	110	0.19	304.0	
H- 104a- R3	2/28/98	5:17 PM	105	110	0.19	334.5	
H- 104b- R1	3/1/98	9:15 AM	115	82	0.01	308.5	Density 1188.0 g/L
H- 108- R1	3/1/98	10:45 AM	-	-	-	325.5	
H- 121- R1	3/2/98	10:37 AM	154	80	0.01	271.0	
H- 121- R2	3/2/98	10:36 AM	154	80	0.01	274.0	
H- 121- R3	3/2/98	10:35 AM	154	80	0.01	252.5	
H- 138- P	3/2/98	3:00 PM	149	110	6.87	285.5	
H- 123- R1	3/2/98	4:26 PM	153	104	7.10	304.0	Bulk Density 1391.0 g/L
H- 123- R2	3/2/98	4:25 PM	153	104	7.10	332.5	
H- 123- R3	3/2/98	4:27 PM	153	104	7.10	422.0	
H- 125- R1	3/3/98	9:37 AM	-	1652	-	327.0	Bulk Density 1391.0 g/L
H- 125- R2	3/3/98	9:36 AM	-	1652	-	279.0	
H- 125- R3	3/3/98	9:35 AM	-	1652	-	278.0	
H- 135- R1	3/2/98	3:11 PM	100	80	7.05	285.0	
H- 135- R2	3/2/98	3:10 PM	100	80	7.05	280.0	
H- 135- R3	3/2/98	3:12 PM	100	80	7.05	336.0	

\*H-Ra Precip Slurry #1      3/2/98      2:45 PM  
 \*H-Ra Precip Slurry #2      3/2/98      4:15 PM  
 (lbs)

Initial weight of ThN drum      260  
 Weight of empty drum      55  
 Weight of ThN      205

Weight of ThO2 powder & drum      92  
 Weight of empty drum      14  
 Weight of ThO2 Powder      78

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	114 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	11 gal
Fresh Water (gal)	-	61+61=122

Recycled      26

Cake Wash Water (gal)

1)	6	6)	6	* left 3 gal in cone of ThOx tank to mix with drum I
2)	6	7)	6	
3)	6	8)	6	
4)	6	9)	6	
5)	6	10)	7	
			Total	61

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample

- \* Recycled 26 gal of waste water  
+ 61 gal fresh water = 87 gal ThN into soln.
- \* Added 10 gal of water to scrubber (3-2-98)
- \* 1652 F = 900 C
- \* ThO2 powder at 900 C had less clumps  
color: mostly white with a little light yellow
- \* Little solids build up in bag filter

Samples Taken By: \_\_\_\_\_

# Thorium Nitrate Demonstration Project

Day # 9      DRUM (I) # 71-21

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
I- 104a- R1	3/2/98	4:12 PM	100	102	0.47	355.5	Density 1190.5 g/L
I- 104a- R2	3/2/98	4:11 PM	100	102	0.47	357.5	
I- 104a- R3	3/2/98	4:10 PM	100	102	0.47	320.5	
I- 104b- R1	3/3/98	9:20 AM	110	80	0.01	309.0	Density N/A
I- 108- R1	3/3/98	10:50 AM	-	-	-	455.0	*Sample Valve stopped up
I- 121- R1	3/3/98	4:05 PM	128	78	0.07	281.0	
I- 121- R2	3/3/98	4:04 PM	128	78	0.07	290.5	
I- 121- R3	3/3/98	4:03 PM	128	78	0.07	300.0	
I- 138- P	3/4/98	9:17 AM	140	90	7.06	313.0	
I- 123- R1	3/4/98	11:57 AM	140	86	7.06	347.0	
I- 123- R2	3/4/98	11:56 AM	140	86	7.06	332.0	
I- 123- R3	3/4/98	11:58 AM	140	86	7.06	386.5	
I- 125- R1	3/4/98	10:00 AM	-	1472	-	255.5	Bulk Density 1149.0 g/L
I- 125- R2	3/4/98	10:01 AM	-	1472	-	225.5	
I- 125- R3	3/4/98	10:02 AM	-	1472	-	232.0	
I- 135- R1	3/3/98	3:32 PM	100	84	7.84	306.0	
I- 135- R2	3/3/98	3:31 PM	100	84	7.84	289.0	
I- 135- R3	3/3/98	3:30 PM	100	84	7.84	276.0	
*I-Ra Precip Slurry #1	3/4/98	9:00 AM	140	88			
*I-Ra Precip Slurry #2	3/4/98	11:18 AM	140				
*G-H-I-Bag Filter Solid	3/4/98	9:45 AM					

Initial weight of ThN drum	260
Weight of empty drum	56
Weight of ThN	204
Weight of ThO2 powder & drum	104
Weight of empty drum	14
Weight of ThO2 Powder	90

### NOTES

Recodyne - Add 2.5mL HNO3 per 500mL of sample

- \* No recycled waste water used (87 gal fresh)
- \* Sample valve on TK-104 (Th Ox precip tank) stopped up
- \* Took pictures on the process
- \* Little solids build up in bag filter

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	114 lbs
Barium Chloride	100	230g +200g
Aluminum Sulfate	100/94.6	180g + 149g
Sodium Hydroxide	50	12 gal
Fresh Water (gal)	-	87+59 =146

Recycled      0

Cake Wash Water (gal)

1)	6	6)	6	* left 3 gal in cone of ThOx tank to mix with drum J
2)	6	7)	6	
3)	6	8)	6	
4)	6	9)	6	
5)	6	10)	5	
			Total	59

Samples Taken By: \_\_\_\_\_

## Thorium Nitrate Demonstration Project

Day # 10      DRUM (J) # 71-20

Sample #	Date	Time	Tank Vol. (gal)	Tank Temp (deg F)	pH	Weight (g)	
J- 104a- R1	3/3/98	5:10 PM	106	106	0.21	297.0	Density N/A
J- 104a- R2	3/3/98	5:11 PM	106	106	0.21	209.5	
J- 104a- R3	3/3/98	5:12 PM	106	106	0.21	332.5	
J- 104a- L1	3/3/98	5:13 PM	106	106	0.21	311.5	
J- 104a- L2	3/3/98	5:14 PM	106	106	0.21	200.5	
Density							
J- 104b- R1	3/4/98	9:12 AM	117	80	0.01	235.5	N/A
J- 108- R1	3/4/98	10:45 AM	-	-	-	433.0	
J- 108- L1	3/4/98	10:46 AM	-	-	-	218.5	
J- 121- R1	3/5/98	9:57 AM	162	80	0.01	291.0	
J- 121- R2	3/5/98	9:56 AM	162	80	0.01	358.0	
J- 121- R3	3/5/98	9:55 AM	162	80	0.01	286.5	
J- 138- P	3/5/98	2:21 PM	170	108	6.32	283.5	
J- 123- R1	3/5/98	5:16 PM	170	100	6.41	290.5	
J- 123- R2	3/5/98	5:15 PM	170	100	6.41	299.5	
J- 123- R3	3/5/98	5:17 PM	170	100	6.41	362.5	
J- 123- L1	3/5/98	5:18 PM	170	100	6.41	307.0	
J- 123- L2	3/5/98	5:19 PM	170	100	6.41	199.5	
Bulk Density							
J- 125- R1	3/5/98	2:03 PM	-	1472	-	337.0	1434.0 g/L
J- 125- R2	3/5/98	2:02 PM	-	1472	-	344.0	
J- 125- R3	3/5/98	2:01 PM	-	1472	-	367.0	
J- 125- L1	3/5/98	2:00 PM	-	1472	-	200.0	
J- 135- R1	3/5/98	3:02 PM	100	82	7.29	317.5	
J- 135- R2	3/5/98	3:01 PM	100	82	7.29	336.0	
J- 135- R3	3/5/98	3:00 PM	100	82	7.29	314.0	
J- 135- L1	3/5/98	3:03 PM	100	82	7.29	303.5	
J- 135- L2	3/5/98	3:04 PM	100	82	7.29	182.5	
*J-Ra Precip Slurry #1	3/5/98	1:45 PM	173				
*J-Ra Precip Slurry #2	3/5/98	3:45 PM	170				

Initial weight of ThN drum	259
Weight of empty drum	54
Weight of ThN	205
Weight of ThO2 powder & drum	240
Weight of empty drum	24
**Weight of lime for cleaning	30
Weight of ThO2 Powder	186

Chemical	% conc.	Amt. Added
Oxalic Acid	99.5	114 lbs
Barium Chloride	100	2*194 g
Aluminum Sulfate	100/94.6	2*149 g
Sodium Hydroxide	50	11 gal
Fresh Water (gal)	-	32+59 =91

Recycled      0

Cake Wash Water (gal)			
1)	6	6)	6
2)	6	7)	6
3)	6	8)	6
4)	6	9)	6

### NOTES

- Recodyne - Add 2.5mL HNO3 per 500mL of sample
- LMES - Solids, 200g & Liquid, 250mL
- \* Recycled 55 gal of waste water  
+ 32 gal fresh water = 87 gal ThN into soln.
- \* Sample valve on TK-104 (Th Ox precip tank) stopped up
- \* Recycled filtrate after cake 5  
cake 6-11 were easier to dump  
did not have to scrape to clean
- \* ThO2 pretty white powder
- \* Had solids loading in bag filter
- \*\*Used 30 lbs of lime to clean out Rotary Kiln,  
this was put into the product drum

Samples Taken By: \_\_\_\_\_

## Weight of Final Product

Drum No.	Capacity (inner Pail)	Gross Wt.* (lbs.)	Tare Wt. Of Pails (lbs.)	Net Wt. (lbs.)
71-21	8 gal.	97	12	85
	8 gal.	111	12	99
	<i>Net Weight of Drum:</i>			184
71-20	8 gal.	112	12	100
	8 gal.	105	12	93
	<i>Net Weight of Drum:</i>			193
71-22	8 gal.	93	12	81
	8 gal.	105	12	93
	<i>Net Weight of Drum:</i>			174
71-26	12 gal.	127	14	113
	8 gal.	95	12	83
	<i>Net Weight of Drum:</i>			196
71-27	8 gal.	90	12	78
	8 gal.	110	12	98
	<i>Net Weight of Drum:</i>			176
71-29	8 gal.	113	12	101
	8 gal.	106	12	94
	<i>Net Weight of Drum:</i>			195

1118

lime for cleaning

30

**Total lbs Thorium Product**

**1088**

- Note: These weights are from Recodyne  
measurements from pilot processing



# APPENDIX B

## ThO2 Tablet Testing

Temp (C)	BASELINE Tablet Size		Binder	%		
	Diameter (inch)	Thickness (inch)				
800	1/4	1/8	CaO	20		
600	5/8	1/4	CaO	10	Very lumpy powder did not make pellets	
	5/8	1/4	Graphite	2		
	5/8	1/4	Stearic Acid	2		
	5/8	1/4	CaO	20		
	5/8	1/4	Graphite	5		
	5/8	1/4	Stearic Acid	5		
900	5/8	1/4	CaO	10	Powder filled up holes good but all pills split when they fell	
	5/8	1/4	Graphite	2		
	5/8	1/4	Stearic Acid	2		
	5/8	1/4	CaO	20		
	5/8	1/4	Graphite	5		GOOD
	5/8	1/4	Stearic Acid	5		Bulk Density 202g/100mL
800	1/4	1/8	CaO	10	Pellet holes too small for powder to fill up the holes	
	1/4	1/8	Graphite	2		
	1/4	1/8	Stearic Acid	2		
	1/4	1/8	CaO	20		
	1/4	1/8	Graphite	5		BEST
	1/4	1/8	Stearic Acid	5		Bulk Density 200g/100mL
* Pellet press damp cake	5/8	1/4	Graphite	2	Did not attempt, cake too wet & sticky	

\*\* As time permits 3/16 thickness will be tested for each

Time did not permit this test

**facsimile**  
TRANSMITTAL

**to:** Kathy Hill  
**fax #:** (423) 975-5569  
**re:** Activities of product drums  
**date:** 4/24/98  
**pages:** 7, including this cover sheet.

Kathy,

Sorry for the delay, things have been crazy over here. Attached are copies of radiological surveys for the drums containing the final product. I have the activities for the drums, they are as follows:

Drum # 27	65.4 mCi
Drum # 22	58.4 mCi
Drum # 29	69.1 mCi
Drum # 21	59.4 mCi
Drum # 20	66.0 mCi
Drum # 26	43.0 mCi

The make and model of the compactor and evaporator are as follows:

**Evaporator**

<b>Make</b>	<b>Model</b>
<b>Landa</b>	<b>M-WB196-4320</b>

**Compactor**

<b>Make</b>	<b>Model</b>
<b>Container Products Corp.</b>	<b>B-100</b>

This is all the info I can provide at this point. I feel free to call if you have any questions.

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-9-98 RWP NUMBER: 98-012 DESCRIPTION: Thorium Drum TECHNICIAN: D. Layman

TIME: 1530 ITEM SURVEYED: DRUM #27 SERIAL NUMBER: 27 SEAL NUMBER: N/A

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X2000</u>	<u>2757</u>	<u>L-177</u>	<u>185075</u>
		<u>2929</u>	<u>142650</u>

SMEAR RESULTS (DPM/100 SQ. CM.)		
NO.	ALPHA	BETA
1	<u>kneda</u>	<u>229.9</u>
2	<u>4.6</u>	<u>113.9</u>
3	<u>kneda</u>	<u>350.4</u>
4	<u>kneda</u>	<u>219.5</u>
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17	<u>N/A</u>	
18		
19		
20		
21		
22		
23		
24		
25		

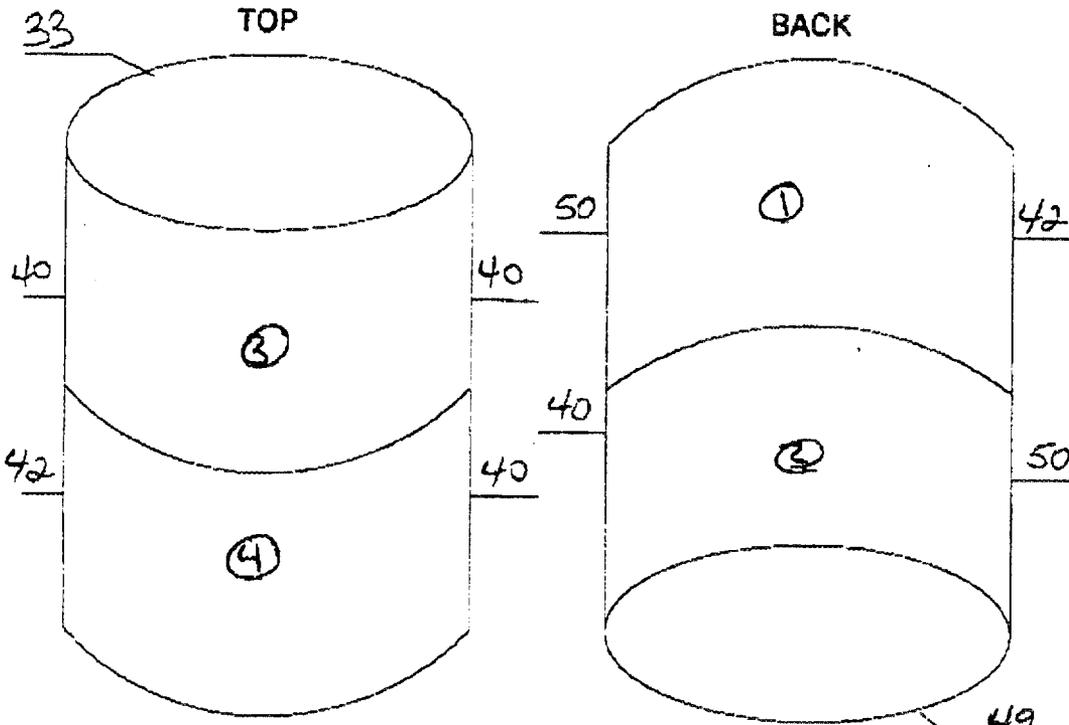
### CONTAINER DATA

WEIGHT: 233 VOLUME: 4.2

PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A

(FOR GE: BY PERMANENT GE REPRESENTATIVE ONLY) VERIFIED BY: N/A

CERT. DUE DATE: N/A INTERNAL CONT. LEVELS: N/A (FWHA)



FRONT total REMARKS: WEIGHT 233 Lbs BOTTOM (tare 35 lbs.)

9 AT ONE METER

All dose rates in mR/hr Las Clin Den

REVIEWED: Fredrick K. B. dk DATE: 4/10/98

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-9-98 RWP NUMBER: 98-012 DESCRIPTION: Thorium Drum TECHNICIAN: D. Layman

TIME: 1515 ITEM SURVEYED: DRUM #22 SERIAL NUMBER: 22 SEAL NUMBER: N/A

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X 2000</u>	<u>2752</u>	<u>L-177</u>	<u>105075</u>
		<u>2929</u>	<u>142650</u>

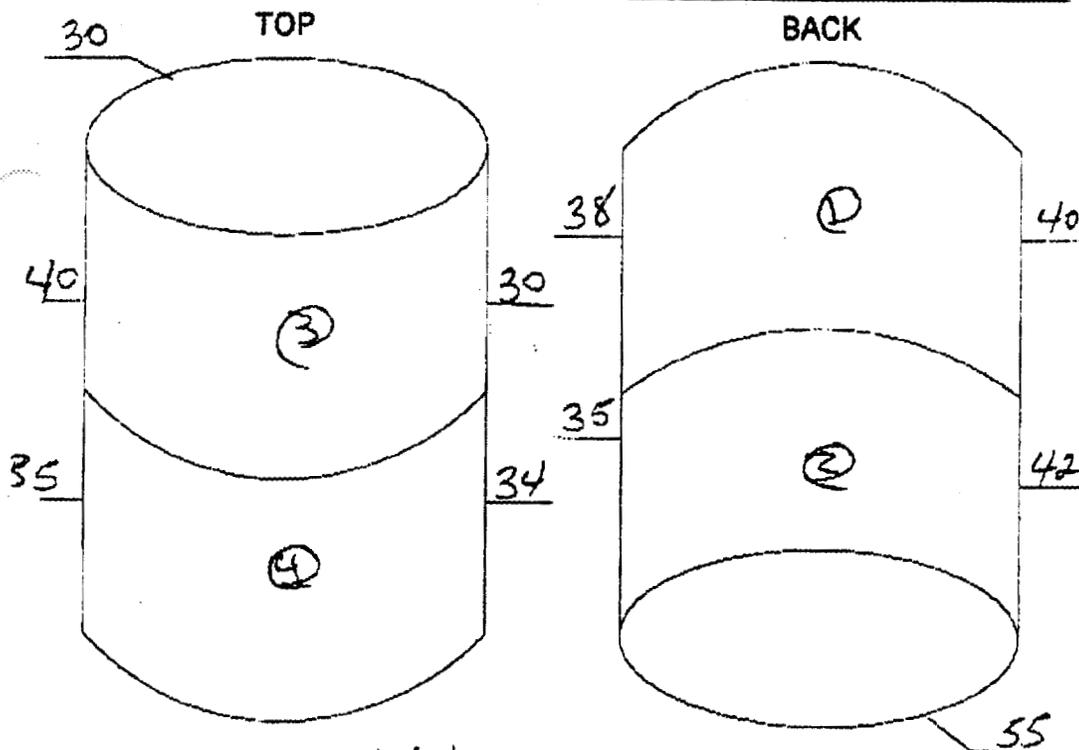
SMEAR RESULTS (DPM/100 SQ. CM)		
NO.	ALPHA	BETA
1	<u>4.6</u>	<u>219.5</u>
2	<u>&lt;LMD</u>	<u>154.6</u>
3	<u>&lt;LMD</u>	<u>57.2</u>
4	<u>&lt;LMD</u>	<u>77.3</u>
5		
6		
7		
8		
9		
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12		
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19		
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21		
22		
23		
24		
25		

### CONTAINER DATA

WEIGHT: 205 VOLUME: 4.2

PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A  
(FOR GE: BY PERMANENT GE REPRESENTATIVE ONLY)  
VERIFIED BY: \_\_\_\_\_

CERT. DUE DATE: 1/10 (FWHA) INTERNAL CONT. LEVELS: N/A



FRONT total REMARKS: WEIGHT 205 LBS (tare 35 lbs.)  
10 AT ONE METER

All dose rates in mR/hr Leas < 1/2 Dpm

REVIEWED: Kevin K. P. K. DATE: 4/10/98

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-9-98 RWP NUMBER: 98-012 DESCRIPTION: Thorium DVF TECHNICIAN: D. Layman

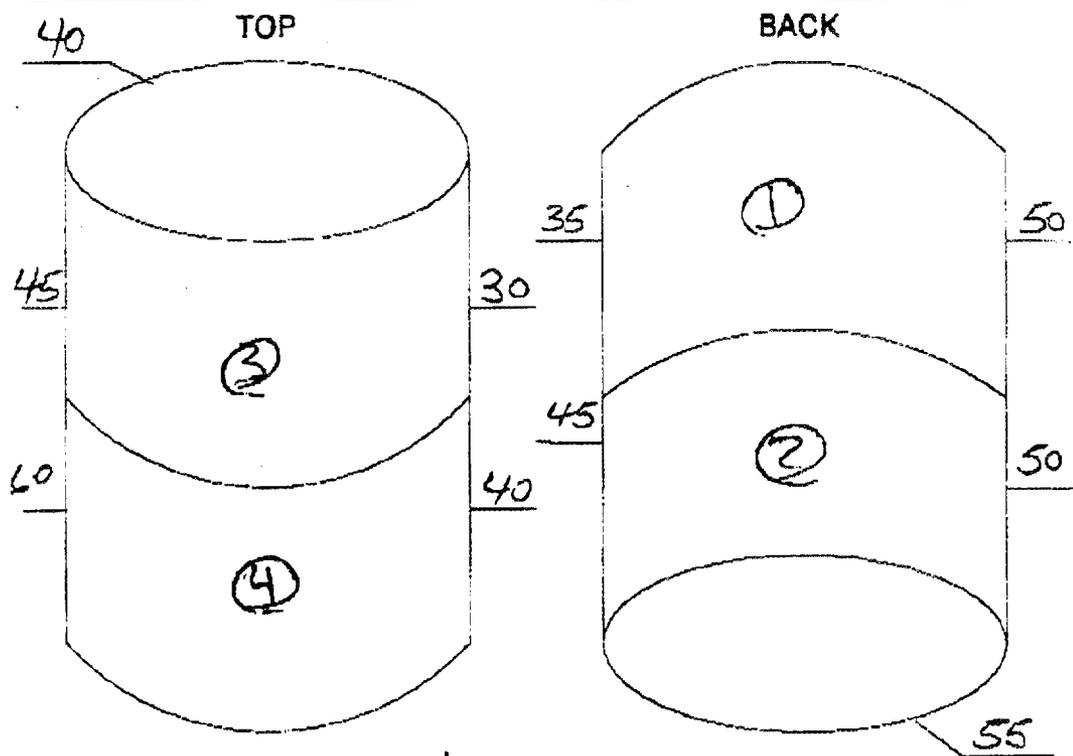
TIME: 1645 ITEM SURVEYED: DEUM#29 SERIAL NUMBER: 29 SEAL NUMBER: N/A

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X2000</u>	<u>2752</u>	<u>L-177</u>	<u>105075</u>
		<u>2929</u>	<u>142650</u>

SMEAR RESULTS (DPM/100 GC. CM.)		
NO.	ALPHA	BETA
1	<u>Count</u>	<u>410.4</u>
2	<u>Count</u>	<u>330.2</u>
3	<u>Count</u>	<u>161.2</u>
4	<u>Count</u>	<u>154.6</u>
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16	<u>N/A</u>	
17		
18		
19		
20		
21		
22		
23		
24		
25		

CONTAINER DATA

WEIGHT: 209 VOLUME: 4.2  
 PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A  
 (FOR GE: BY PERMANENT GE REPRESENTATIVE ONLY)  
 VERIFIED BY: N/A (PWHA)  
 CERT. DUE DATE: N/A INTERNAL CONT. LEVELS: N/A



FRONT <sup>total</sup> REMARKS: WEIGHT 209 LBS (tare 35 lbs)  
9 AT ONE METER

All dose rates in mR/hr Los Alamos

REVIEWED: Kevin K. P. Nook DATE: 4/10/98

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-9-98 RWP NUMBER: 98012 DESCRIPTION: Thorium Drum TECHNICIAN: D. Leymer

TIME: 1500 ITEM SURVEYED: Drum #26 SERIAL NUMBER: 26 SEAL NUMBER: NA

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X2000</u>	<u>2752</u>	<u>L-177</u>	<u>105075</u>
		<u>2929</u>	<u>142650</u>

SMEAR RESULTS (DPM/100 SQ. CM.)		
NO.	ALPHA	BETA
1	<u>Knda</u>	<u>115.1</u>
2	<u>4.6</u>	<u>91.7</u>
3	<u>2.1</u>	<u>113.9</u>
4	<u>Knda</u>	<u>69.6</u>
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17	<u>NA</u>	
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22		
23		
24		
25		

4-9-98 CONTAINER DATA

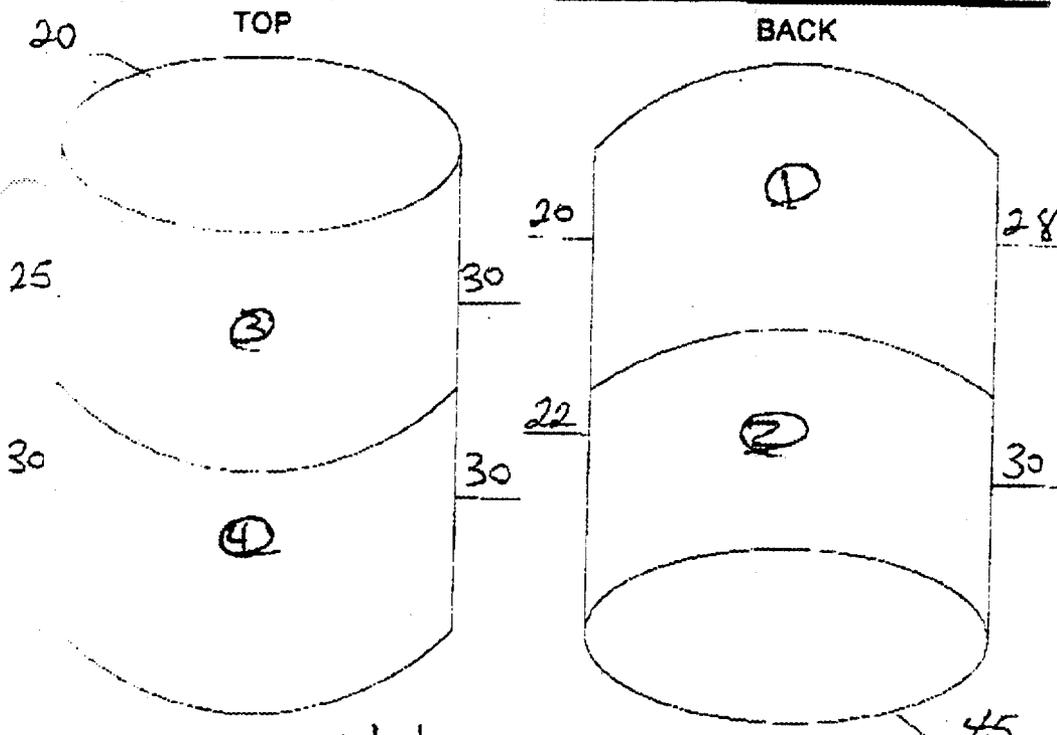
WEIGHT: 277.5 277.5 VOLUME: 4.2

PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A

(FOR GE BY PERMANENT GE REPRESENTATIVE ONLY)

VERIFIED BY: N/A

CERT. DUE DATE: N/A INTERNAL CONT. LEVELS: N/A (FWHA)



REMARKS: WEIGHT 277.5 lbs (tare 53.0 lbs.)  
& AT ONE METER

All dose rates in mR/hr AS < 1 hr Dpm

REVIEWED: Kevin K. Ried DATE: 4/10/98

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-2-98 RWP NUMBER: 98-017 DESCRIPTION: Thorium Drum TECHNICIAN: D. Luxmoor

TIME: 1620 ITEM SURVEYED: DRUM #20 SERIAL NUMBER: 20 SEAL NUMBER: 214

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X2000</u>	<u>2752</u>	<u>L-177</u>	<u>105075</u>
		<u>2229</u>	<u>142650</u>

SMEAR RESULTS (DPM/100 SQ. CM.)		
NO.	ALPHA	BETA
1	<u>4.6</u>	<u>113.9</u>
2	<u>4.6</u>	<u>225.2</u>
3	<u>4.6</u>	<u>320.4</u>
4	<u>4.6</u>	<u>101.2</u>
5		
6		
7		
8		
9		
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19	<u>N/A</u>	
20		
21		
22		
23		
24		
25		

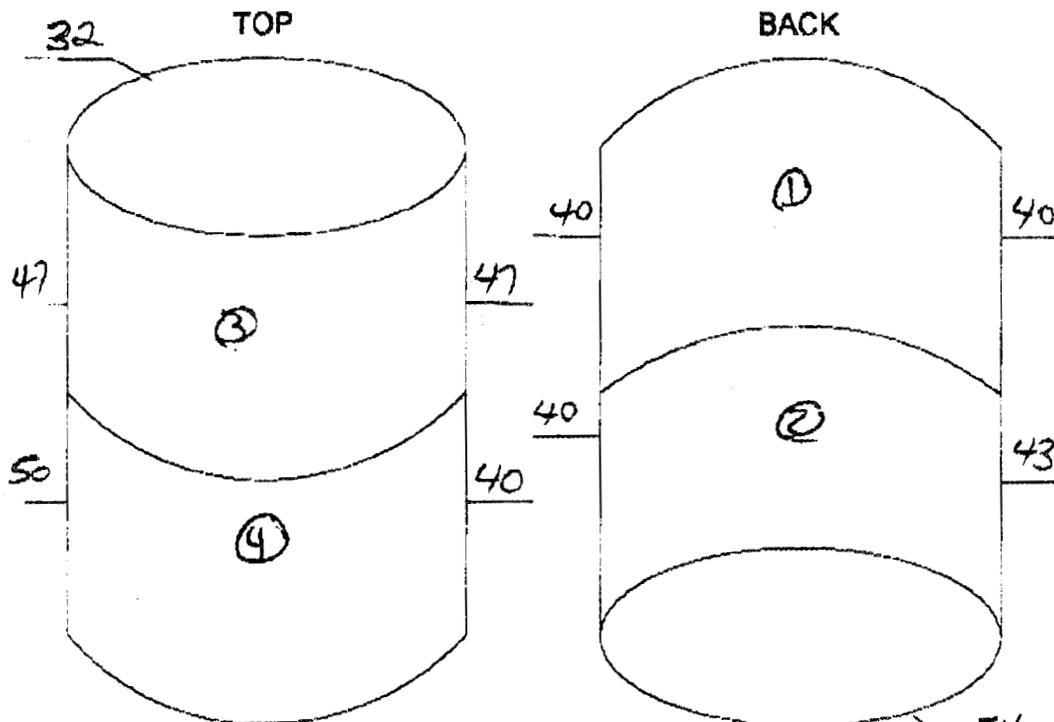
### CONTAINER DATA

WEIGHT: 229 VOLUME: 4.2

PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A  
(FOR GE: BY PERMANENT GE REPRESENTATIVE ONLY)

VERIFIED BY: N/A

CERT. DUE DATE: N/A INTERNAL CONT. LEVELS: N/A (FWHA)



FRONT

BOTTOM

REMARKS: Total  
1 NIGHT 229 LBS (tare 35 lbs.)  
8 AT ONE METER

All dose rates in mR/hr

Gas CLK Dpm

REVIEWED: Kevin K. Plack

DATE: 4/10/98

# FRANK W. HAKE ASSOCIATES

## CONTAINER SURVEY SHEET

DATE: 4-9-98 RWP NUMBER: 98-012 DESCRIPTION: Thorium Drums TECHNICIAN: D. Layman

TIME: 1600 ITEM SURVEYED: DRUM #2 SERIAL NUMBER: 21 SEAL NUMBER: N/A

RADIATION INSTRUMENT	SERIAL NUMBER	CONTAMINATION INSTRUMENT	SERIAL NUMBER
<u>X 2000</u>	<u>2752</u>	<u>L-177</u>	<u>105075</u>
		<u>2929</u>	<u>142650</u>

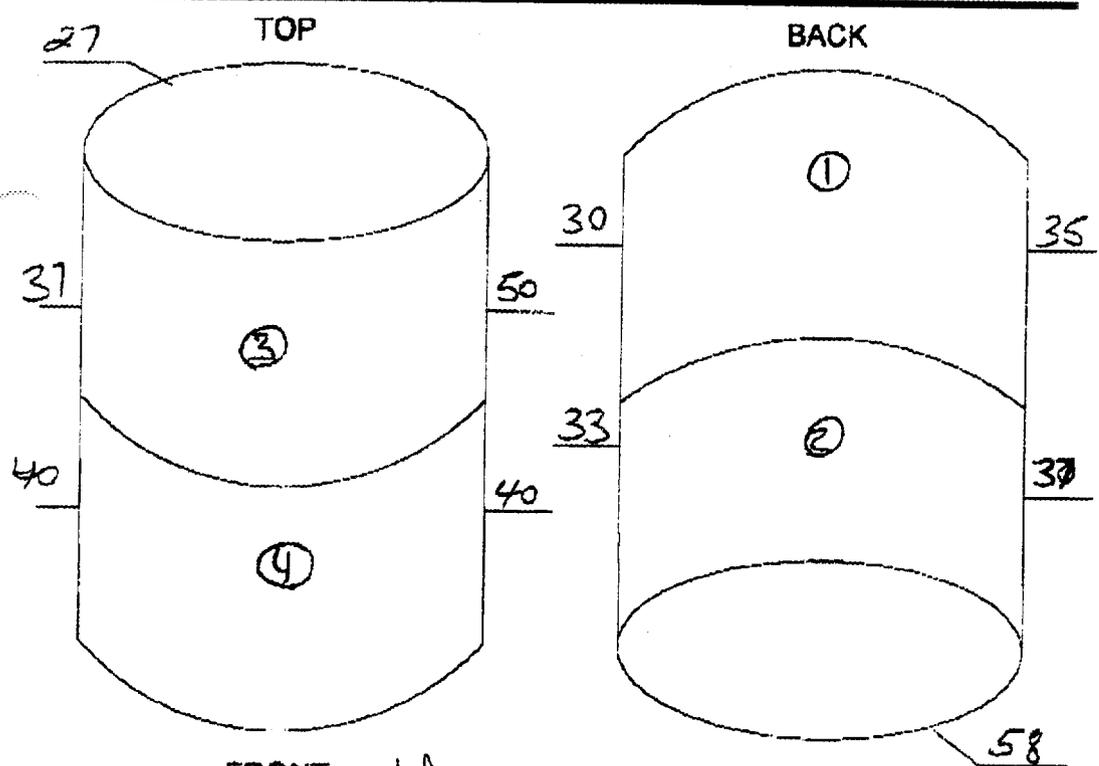
SMEAR RESULTS (DPM/100 SQ. CM.)		
NO.	ALPHA	BETA
1	2.1	229.9
2	4.1	69.6
3	2.1	69.6
4	2.1	310.4
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15	<u>N/A</u>	
16		
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25		

### CONTAINER DATA

WEIGHT: 224 VOLUME: 4.2

PACKED IN ACCORDANCE WITH ATTACHED CHECK SHEET: N/A  
(FOR GE: BY PERMANENT GE REPRESENTATIVE ONLY)  
VERIFIED BY: \_\_\_\_\_

CERT. DUE DATE: N/A INTERNAL CONT. LEVELS: N/A (FWHA)



FRONT total BOTTOM  
REMARKS: WEIGHT 224 lbs. (tare 35 lbs.)  
9 AT ONE METER

All dose rates in mR/hr. Gas like drum

REVIEWED: Kevin K. Block DATE: 4/10/98



# APPENDIX C



### SAMPLING LAB RESULTS

ThN Pilot Demo Sample #	1st result Th g/L	2nd result Th g/L	Average Th g/L	Density g/mL	Moisture %	Lead mg/L	Arsenic mg/L	Chromium mg/L	Silver mg/L
<b>Thorium Nitrate Liquor</b>									
A-104a-R1	155.2	145.2	150.2	1.258	N.R.	N.R.	N.R.	N.R.	N.R.
B-104a-R1	102.9	102.7	102.8	1.187	N.R.	N.R.	N.R.	N.R.	N.R.
C-104a-R1	89.5	94.0	91.8	1.206	N.R.	N.R.	N.R.	N.R.	N.R.
D-104a-R1	142.5	141.2	141.9	1.304	N.R.	N.R.	N.R.	N.R.	N.R.
E-104a-R1	91.1	100.3	95.7	1.185	N.R.	N.R.	N.R.	N.R.	N.R.
F-104a-R1	98.8	100.7	99.8	1.171	N.R.	N.R.	N.R.	N.R.	N.R.
G-104a-R1	89.1	94.8	92.0	1.167	N.R.	N.R.	N.R.	N.R.	N.R.
H-104a-R1	95.2	103.0	99.1	1.191	N.R.	N.R.	N.R.	N.R.	N.R.
I-104a-R1	90.8	106.6	98.7	1.175	N.R.	N.R.	N.R.	N.R.	N.R.
J-104a-R1	89.1	96.5	92.8	1.198	N.R.	N.R.	N.R.	N.R.	N.R.
<b>Wet Filter Cake</b>									
A-108-R1	N.R.	N.R.	N.R.	N.R.	44.2	N.R.	N.R.	N.R.	N.R.
B-108-R1	N.R.	N.R.	N.R.	N.R.	46.2	N.R.	N.R.	N.R.	N.R.
C-108-R1	N.R.	N.R.	N.R.	N.R.	43.1	N.R.	N.R.	N.R.	N.R.
D-108-R1	N.R.	N.R.	N.R.	N.R.	47.0	N.R.	N.R.	N.R.	N.R.
E-108-R1	N.R.	N.R.	N.R.	N.R.	44.6	N.R.	N.R.	N.R.	N.R.
F-108-R1	N.R.	N.R.	N.R.	N.R.	46.2	N.R.	N.R.	N.R.	N.R.
G-108-R1	N.R.	N.R.	N.R.	N.R.	43.9	N.R.	N.R.	N.R.	N.R.
H-108-R1	N.R.	N.R.	N.R.	N.R.	39.2	N.R.	N.R.	N.R.	N.R.
I-108-R1	N.R.	N.R.	N.R.	N.R.	44.4	N.R.	N.R.	N.R.	N.R.
J-108-R1	N.R.	N.R.	N.R.	N.R.	46.1	N.R.	N.R.	N.R.	N.R.
<b>Thorium Oxalate Filtrate</b>									
A-121-R1			<1	1.041	N.R.	N.R.	N.R.	N.R.	N.R.
B-121-R1			<1	1.037	N.R.	N.R.	N.R.	N.R.	N.R.
C-121-R1			8	1.077	N.R.	N.R.	N.R.	N.R.	N.R.
D-121-R1			<1	1.079	N.R.	N.R.	N.R.	N.R.	N.R.
E-121-R1			<1	1.067	N.R.	N.R.	N.R.	N.R.	N.R.
F-121-R1			1	1.045	N.R.	N.R.	N.R.	N.R.	N.R.
G-121-R1			<1	1.046	N.R.	N.R.	N.R.	N.R.	N.R.
H-121-R1			2	1.064	N.R.	N.R.	N.R.	N.R.	N.R.
I-121-R1			4	1.048	N.R.	N.R.	N.R.	N.R.	N.R.
J-121-R1			<1	1.061	N.R.	N.R.	N.R.	N.R.	N.R.

ThN Pilot Demo Sample #	Ra 228 pCi/L	Th 232 pCi/L	Th g/L	Bulk Density	Moisture %	L.O.I. %	Lead mg/L	Arsenic mg/L	Chromiu mg/L	Silver mg/L
<b>Final Waste Water</b>										
A-123-R1	1.10E+06	9000	0.113	-	N.R.	-	<1	*	<1	<1
B-123-R1	7.00E+05	5100	0.060	-	N.R.	-	<1	*	<1	<1
C-123-R1	1.20E+06	5800	0.084	-	N.R.	-	<1	*	<1	<1
D-123-R1	8.30E+05	5800	0.059	-	N.R.	-	<1	*	<1	<1
E-123-R1	1.40E+06	2200	0.022	-	N.R.	-	<1	*	<1	<1
F-123-R1	1.10E+06	17000	0.025	-	N.R.	-	<1	*	<1	<1
G-123-R1	9.20E+05	3500	0.009	-	N.R.	-	<1	*	<1	<1
H-123-R1	1.00E+06	3000	0.036	-	N.R.	-	<1	*	<1	<1
I-123-R1	5.60E+05	3400	0.041	-	N.R.	-	<1	*	<1	<1
J-123-R1	1.90E+06	810	0.016	-	N.R.	-	<1	*	<1	<1
<b>Thorium Oxide Powder</b>										
A-125-R1	-	-	-	1.196	1.40	12.7	N.R.	N.R.	N.R.	N.R.
B-125-R1	-	-	-	1.287	1.26	9.9	N.R.	N.R.	N.R.	N.R.
C-125-R1	-	-	-	1.373	2.50	14.3	N.R.	N.R.	N.R.	N.R.
D-125-R1	-	-	-	1.326	1.06	10.8	N.R.	N.R.	N.R.	N.R.
E-125-R1	-	-	-	1.495	0.63	7.0	N.R.	N.R.	N.R.	N.R.
F-125-R1	-	-	-	1.113	3.66	25.7	N.R.	N.R.	N.R.	N.R.
G-125-R1	-	-	-	1.015	6.34	36.5	N.R.	N.R.	N.R.	N.R.
H-125-R1	-	-	-	1.800	0.41	3.3	N.R.	N.R.	N.R.	N.R.
I-125-R1	-	-	-	1.269	1.33	14.1	N.R.	N.R.	N.R.	N.R.
J-125-R1	-	-	-	1.882	0.45	1.9	N.R.	N.R.	N.R.	N.R.
<b>Wet Scrubber Solution</b>										
A-135-R1	-	-	0.007	-	N.R.	-	<1	*	<1	<1
B-135-R1	-	-	0.015	-	N.R.	-	<1	*	<1	<1
C-135-R1	-	-	0.006	-	N.R.	-	<1	*	<1	<1
D-135-R1	-	-	0.009	-	N.R.	-	<1	*	<1	<1
E-135-R1	-	-	0.026	-	N.R.	-	<1	*	<1	<1
F-135-R1	-	-	0.078	-	N.R.	-	<1	*	<1	<1
G-135-R1	-	-	0.027	-	N.R.	-	<1	*	<1	<1
H-135-R1	-	-	0.023	-	N.R.	-	<1	*	<1	<1
I-135-R1	-	-	0.016	-	N.R.	-	<1	*	<1	<1
J-135-R1	-	-	0.028	-	N.R.	-	<1	*	<1	<1

\* Not measurable due to interference



# Accu-Labs<sup>®</sup> Research, Inc.

3 Table Mountain Drive Golden, Colorado 80403-1650  
(303) 277-9514 FAX (303) 277-9512

Date: 05/01/98  
Page 1 - A

## CASE NARRATIVE

Mr Dan Dilday  
Recovery Dynamics  
200 East Main  
6th Floor  
Johnson City, TN 37604

Lab Job Number: 021492 REC001  
Date Samples Received: 03/11/98

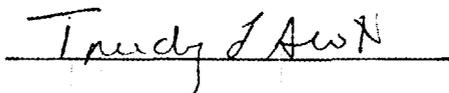
The following samples were received at the laboratory:

98-A4627	Water
98-A4628	Water
98-A4629	Water
98-A4630	Water
98-A4631	Water
98-A4632	Water
98-A4633	Water
98-A4634	Water
98-A4635	Water
98-A4636	Water

The samples were received within EPA recommended holding times and in good condition. The radioactivity screen was performed at sample login, if required, and all results were within acceptable limits. If required, a pH screen confirmed that all samples were preserved to acceptable pH levels. Samples were analyzed within holding times as prescribed by the analytical method. Exceptions to these statements, additional information and any analytical anomalies are noted below.

The temperature of the samples upon arrival was 14 degrees C.

Sections A, B and C of this report contain a total of 14 pages.



Trudy L. Scott  
Laboratory Manager

**RADIOCHEMISTRY DEPARTMENT**  
**METHOD REFERENCES UTILIZED BY ACCU-LABS RESEARCH, INC.**

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**METHOD REFERENCES**  
**CONTINUED**

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28. "Collected Radiochemical Procedures (Radiochemistry Group CNC-11)", LA-1721, 4th Ed., UC-4, Chemistry, April, 1975, Jacob Klienberg and Helen Smith, ed., Los Alamos Scientific Laboratory, Los Alamos, NM 87545.
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**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics  
200 East Main  
6th Floor  
Johnson City, TN 37604

Lab Job Number: 021492 REC001  
Date Samples Received: 03/11/98

ALR Designation: 98-A4627  
Client Designation: A-123-R2  
Sample Location:  
Location II:  
Date/Time Collected 02/21/98 15:13

**General Chemistry (results in mg/L unless noted):**

Barium, Total 22

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 63000 +/- 17000  
Gross Beta, total 200000 +/- 54000  
Radium-228, total 1100000 +/- 130000  
Thorium-228, total 96000 +/- 24000  
Thorium-230, total 3500 +/- 2800  
Thorium-232, total 9000 +/- 3500  
Uranium-233+234, total 40 +/- 130  
Uranium-235, total 19 +/- 93  
Uranium-238, total 43 +/- 76  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 150000 +/- 14000  
Thallium-208 @ 583 KeV (pCi/L) 25000 +/- 2600  
Thallium-208 @ 860 KeV (pCi/L) 25000 +/- 8700  
Lead-212 @ 238 KeV (pCi/L) 81000 +/- 7600  
Actinium-228 @ 338 KeV (pCi/L) 2000000 +/- 740000  
Actinium-228 @ 911 KeV (pCi/L) 1900000 +/- 390000  
Actinium-228 @ 968 KeV (pCi/L) 2000000 +/- 380000

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ALR Designation: 98-A4628  
Client Designation: B-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/22/98 15:20

**General Chemistry (results in mg/L unless noted):**

Barium, Total 21

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 24000 +/- 5500  
Gross Beta, total 110000 +/- 26000  
Radium-228, total 700000 +/- 81000  
Thorium-228, total 42000 +/- 12000  
Thorium-230, total 270 +/- 2200

**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

Lab Job Number: 021492    REC001  
Date Samples Received: 03/11/98

ALR Designation: 98-A4628  
Client Designation: B-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/22/98 15:20

Thorium-232, total 5100 +/- 2500  
Uranium-233+234, total -15 +/- 110  
Uranium-235, total -25 +/- 75  
Uranium-238, total -1.2 +/- 55  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 62000 +/- 8000  
Thallium-208 @ 583 KeV (pCi/L) 11000 +/- 1300  
Thallium-208 @ 860 KeV (pCi/L) 12000 +/- 6800  
Lead-212 @ 238 KeV (pCi/L) 38000 +/- 3800  
Actinium-228 @ 338 KeV (pCi/L) 790000 +/- 29000  
Actinium-228 @ 911 KeV (pCi/L) 800000 +/- 17000  
Actinium-228 @ 968 KeV (pCi/L) 820000 +/- 16000

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ALR Designation: 98-A4629  
Client Designation: C-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/24/98 11:30

**General Chemistry (results in mg/L unless noted):**

Barium, Total 46

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 46000 +/- 19000  
Gross Beta, total 250000 +/- 70000  
Radium-228, total 1200000 +/- 140000  
Thorium-228, total 99000 +/- 26000  
Thorium-230, total 610 +/- 2300  
Thorium-232, total 5800 +/- 2800  
Uranium-233+234, total 63 +/- 120  
Uranium-235, total -15 +/- 75  
Uranium-238, total -3.9 +/- 48  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 22000 +/- 20000  
Thallium-208 @ 583 KeV (pCi/L) 31000 +/- 3700  
Thallium-208 @ 860 KeV (pCi/L) 49000 +/- 14000  
Lead-212 @ 238 KeV (pCi/L) 12000 +/- 12000  
Actinium-228 @ 338 KeV (pCi/L) 2800000 +/- 1000000

**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

Lab Job Number: 021492    REC001  
Date Samples Received: 03/11/98

ALR Designation: 98-A4629  
Client Designation: C-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/24/98 11:30  
  
Actinium-228 @ 911 KeV (pCi/L) 2700000 +/- 560000  
Actinium-228 @ 968 KeV (pCi/L) 2900000 +/- 570000

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ALR Designation: 98-A4630  
Client Designation: D-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/25/98 15:26

**General Chemistry (results in mg/L unless noted):**

Barium, Total 32

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 22000 +/- 5900  
Gross Beta, total 130000 +/- 36000  
Radium-228, total 830000 +/- 94000  
Thorium-228, total 200000 +/- 44000  
Thorium-230, total 10000 +/- 4000  
Thorium-232, total 5800 +/- 2400  
Uranium-233+234, total 17 +/- 130  
Uranium-235, total 21 +/- 93  
Uranium-238, total 1200 +/- 290  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 100000 +/- 11000  
Thallium-208 @ 583 KeV (pCi/L) 14000 +/- 1700  
Thallium-208 @ 860 KeV (pCi/L) 13000 +/- 5600  
Lead-212 @ 238 KeV (pCi/L) 51000 +/- 4800  
Actinium-228 @ 338 KeV (pCi/L) 1300000 +/- 460000  
Actinium-228 @ 911 KeV (pCi/L) 1200000 +/- 250000  
Actinium-228 @ 968 KeV (pCi/L) 1300000 +/- 250000

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**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

Lab Job Number: 021492      REC001  
Date Samples Received: 03/11/98

ALR Designation:                      98-A4631  
Client Designation:                  E-123-R3  
Sample Location:  
Location II:  
Date/Time Collected                02/27/98 11:57

**General Chemistry (results in mg/L unless noted):**

Barium, Total                              33

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total                      39000 +/- 12000  
Gross Beta, total                        250000 +/- 74000  
Radium-228, total                        1400000 +/- 160000  
Thorium-228, total                        140000 +/- 47000  
Thorium-230, total                        2300 +/- 3300  
Thorium-232, total                        2200 +/- 2200  
Uranium-233+234, total                  16 +/- 120  
Uranium-235, total                        59 +/- 92  
Uranium-238, total                        -3.6 +/- 50  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L)      270000 +/- 18000  
Thallium-208 @ 583 KeV (pCi/L)      26000 +/- 3100  
Thallium-208 @ 860 KeV (pCi/L)      28000 +/- 8500  
Lead-212 @ 238 KeV (pCi/L)            100000 +/- 9800  
Actinium-228 @ 338 KeV (pCi/L)      3500000 +/- 1300000  
Actinium-228 @ 911 KeV (pCi/L)      3300000 +/- 680000  
Actinium-228 @ 968 KeV (pCi/L)      3400000 +/- 670000

---

ALR Designation:                      98-A4632  
Client Designation:                  F-123-R3  
Sample Location:  
Location II:  
Date/Time Collected                02/28/98 11:27

**General Chemistry (results in mg/L unless noted):**

Barium, Total                              19

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total                      40000 +/- 11000  
Gross Beta, total                        170000 +/- 47000  
Radium-228, total                        1100000 +/- 120000  
Thorium-228, total                        65000 +/- 20000  
Thorium-230, total                        1100 +/- 2600  
Thorium-232, total                        17000 +/- 6500  
Uranium-233+234, total                  -75 +/- 110

**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

Lab Job Number: 021492    REC001  
Date Samples Received: 03/11/98

ALR Designation: 98-A4632  
Client Designation: F-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 02/28/98 11:27

Uranium-235, total 16 +/- 83  
Uranium-238, total 0.0 +/- 50  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 110000 +/- 14000  
Thallium-208 @ 583 KeV (pCi/L) 23000 +/- 2700  
Thallium-208 @ 860 KeV (pCi/L) 33000 +/- 11000  
Lead-212 @ 238 KeV (pCi/L) 83000 +/- 8600  
Actinium-228 @ 338 KeV (pCi/L) 1400000 +/- 510000  
Actinium-228 @ 911 KeV (pCi/L) 1300000 +/- 280000  
Actinium-228 @ 968 KeV (pCi/L) 1400000 +/- 270000

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ALR Designation: 98-A4633  
Client Designation: G-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 03/01/98 10:58

**General Chemistry (results in mg/L unless noted):**

Barium, Total 38

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 32000 +/- 8500  
Gross Beta, total 170000 +/- 45000  
Radium-228, total 920000 +/- 110000  
Thorium-228, total 71000 +/- 17000  
Thorium-230, total 3300 +/- 2600  
Thorium-232, total 3500 +/- 1800  
Uranium-233+234, total 85 +/- 140  
Uranium-235, total 4.7 +/- 87  
Uranium-238, total -16 +/- 47  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 1300 +/- 26000  
Cesium-137 @ 661 KeV (pCi/L) 210000 +/- 8800  
Thallium-208 @ 583 KeV (pCi/L) 1200 +/- 1200  
Thallium-208 @ 860 KeV (pCi/L) -4800 +/- 12000  
Lead-210 @ 46 KeV (pCi/L) 37000 +/- 7200  
Lead-212 @ 238 KeV (pCi/L) 630 +/- 780  
Actinium-228 @ 338 KeV (pCi/L) -5600 +/- 6300

**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

Lab Job Number: 021492      REC001  
Date Samples Received: 03/11/98

ALR Designation: 98-A4633  
Client Designation: G-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 03/01/98 10:58  
  
Actinium-228 @ 911 KeV (pCi/L) 20000 +/- 42000  
Actinium-228 @ 968 KeV (pCi/L) 8800 +/- 9100

---

ALR Designation: 98-A4634  
Client Designation: H-123-R3  
Sample Location:  
Location II:  
Date/Time Collected 03/02/98 16:27

**General Chemistry (results in mg/L unless noted):**

Barium, Total 36

**Radiochemistry (results in pCi/L unless noted):**

Gross Alpha, total 34000 +/- 10000  
Gross Beta, total 180000 +/- 51000  
Radium-228, total 1000000 +/- 120000  
Thorium-228, total 71000 +/- 19000  
Thorium-230, total 4000 +/- 3100  
Thorium-232, total 3000 +/- 2000  
Uranium-233+234, total -59 +/- 110  
Uranium-235, total -14 +/- 83  
Uranium-238, total -8.5 +/- 49  
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)  
Potassium-40 @ 1460 KeV (pCi/L) 91000 +/- 8500  
Thallium-208 @ 583 KeV (pCi/L) 16000 +/- 2000  
Thallium-208 @ 860 KeV (pCi/L) 19000 +/- 5600  
Lead-212 @ 238 KeV (pCi/L) 54000 +/- 5200  
Actinium-228 @ 338 KeV (pCi/L) 1100000 +/- 420000  
Actinium-228 @ 911 KeV (pCi/L) 1100000 +/- 230000  
Actinium-228 @ 968 KeV (pCi/L) 1100000 +/- 220000

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**REPORT OF ANALYSIS**

Mr Dan Dilday  
Recovery Dynamics

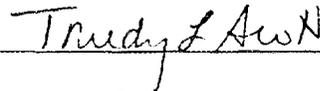
Lab Job Number: 021492    REC001  
Date Samples Received: 03/11/98

ALR Designation:	98-A4636
Client Designation:	J-123-R3
Sample Location:	
Location II:	
Date/Time Collected	03/05/98 17:17
Uranium-235, total	-14 +/- 76
Uranium-238, total	-16 +/- 44
Gamma Spectrometry (peaks identified, N.F. = NOT FOUND)	
Potassium-40 @ 1460 KeV (pCi/L)	190000 +/- 19000
Thallium-208 @ 583 KeV (pCi/L)	29000 +/- 3700
Thallium-208 @ 860 KeV (pCi/L)	22000 +/- 13000
Lead-212 @ 238 KeV (pCi/L)	110000 +/- 11000
Actinium-228 @ 338 KeV (pCi/L)	2400000 +/- 870000
Actinium-228 @ 911 KeV (pCi/L)	2300000 +/- 470000
Actinium-228 @ 968 KeV (pCi/L)	2400000 +/- 480000

NOTES:

Gross Alpha results are based on an Am-241 absorption curve.  
Gross Beta results are based on a Cs-137 absorption curve.  
Variability of the radioactive disintegration process (counting error) at the 95% confidence level is 1.96 sigma and the level of significance may exceed that of the reported analytical result.

Scheduled sample disposal/return date: May 31, 1998.



Trudy L. Scott  
Laboratory Manager

Date: 05/01/98  
Page 1 - C

QA/QC Report for ALR Job Number 021492

PARAMETER	DETECTION LIMIT	DATE OF ANALYSIS	TIME OF ANALYSIS	ANALYST	METHOD
Lab Sample Number: 98-A4627					
Client Sample ID: A-123-R2					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	98 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	190 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	79 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3300 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	180 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	140 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	100 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Lab Sample Number: 98-A4628					
Client Sample ID: B-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	92 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	190 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	120 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1600 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	170 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	130 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	86 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13

Date: 05/01/98  
Page 2 - C

QA/QC Report for ALR Job Number 021492

PARAMETER	DETECTION LIMIT	DATE OF ANALYSIS	TIME OF ANALYSIS	ANALYST	METHOD
Lab Sample Number: 98-A4629					
Client Sample ID: C-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	91 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	180 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	87 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1600 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	160 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	120 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	82 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Lab Sample Number: 98-A4630					
Client Sample ID: D-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	85 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	200 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	110 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3200 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1300 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	180 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	130 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	93 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13

QA/QC Report for ALR Job Number 021492

PARAMETER	DETECTION LIMIT	DATE OF ANALYSIS	TIME OF ANALYSIS	ANALYST	METHOD
Lab Sample Number: 98-A4631					
Client Sample ID: E-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	92 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	190 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	100 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	2300 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	4000 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	2000 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	170 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	120 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	84 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Lab Sample Number: 98-A4632					
Client Sample ID: F-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	94 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	180 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	110 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1800 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3600 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1700 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	170 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	120 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	83 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13

QA/QC Report for ALR Job Number 021492

PARAMETER	DETECTION LIMIT	DATE OF ANALYSIS	TIME OF ANALYSIS	ANALYST	METHOD
Lab Sample Number: 98-A4633					
Client Sample ID: G-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	120 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	180 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	81 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3200 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1300 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	180 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	130 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	91 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Lab Sample Number: 98-A4634					
Client Sample ID: H-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	120 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	180 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	120 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1600 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	170 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	130 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	88 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13

QA/QC Report for ALR Job Number 021492

PARAMETER	DETECTION LIMIT	DATE OF ANALYSIS	TIME OF ANALYSIS	ANALYST	METHOD
Lab Sample Number: 98-A4635					
Client Sample ID: I-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	99 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	190 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	97 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1500 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	170 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	130 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	89 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Lab Sample Number: 98-A4636					
Client Sample ID: J-123-R3					
Total Digestion	NA	3/19/98	10:50	DA	MCAWW Section 4.1.3
Gamma Scan (liquids)	NA	3/24/98	16:36	WP	References 1, 8, 13, 23
Barium, Total	0.01 mg/L	3/30/98	10:37	MG	200.7
Gross Alpha, total	97 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Gross Beta, total	190 pCi/L	4/ 3/98	12:00	MW	References 1, 2, 3, 4, 6, 7, 8
Radium-228, total	100 pCi/L	3/26/98	18:00	CG	References 1, 2, 3, 8
Thorium-228, total	1400 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-230, total	3200 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Thorium-232, total	1300 pCi/L	4/ 2/98	12:00	LN	References 4, 7, 13
Uranium-233+234, total	160 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-235, total	120 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13
Uranium-238, total	82 pCi/L	4/ 2/98	12:00	LN	References 8, 11, 13

The reference summary for the Radiochemistry Methods is attached.

Approved by : TJJ Date : 5-1-98



Kathy Hill  
RECOVERY DYNAMICS, LLC  
200 E. Main Street  
6th Floor  
Johnson City, TN 37604

10-Jul-98  
Page: ii

Attn:  
Project:

PO #:

Received: 25-Jun-98 09:35

Job: 982551E

Status: Final

Lab-ID	Matrix	Client Sample ID	Sampled
982551-1	Solid	Comp-A,B,C,D-125-R1	NA



# BARRINGER LABORATORIES, INC.

15000 W. 6TH AVE., SUITE 300 GOLDEN, CO 80401 (303) 277-1687 FAX (303) 277-1689

10-Jul-98

Page: R-1

Job: 982551E

Status: Final

## RECOVERY DYNAMICS, LLC

Sample Id: Comp-A,B,C,D-125-R1

Lab Id: 982551-1

Date Sampled: NA

Project:

Matrix: Solid

Analyte	Fraction	Method	Concentration	MDL	Date Analyzed
Arsenic	TCLP	6010A	U mg/l	0.5	9-Jul-98
Barium	TCLP	6010A	U mg/l	0.1	9-Jul-98
Cadmium	TCLP	6010A	U mg/l	0.03	9-Jul-98
Chromium	TCLP	6010A	U mg/l	0.1	9-Jul-98
Lead	TCLP	6010A	U mg/l	0.3	9-Jul-98
Mercury	TCLP	7470A	U mg/l	0.002	9-Jul-98
Selenium	TCLP	6010A	U mg/l	0.5	9-Jul-98
Silver	TCLP	6010A	U mg/l	0.05	9-Jul-98

**RECOVERY DYNAMICS, LLC**

**QUALITY CONTROL REPORT**

Sample Id	Arsenic TCLP mg/l	Barium TCLP mg/l	Cadmium TCLP mg/l	Chromium TCLP mg/l	Lead TCLP mg/l
Blank	U	U	U	U	U
LCS (True)	5.00	10.0	1.00	2.00	5.00
LCS (Found)	4.93	10.1	0.97	2.02	4.95
LCS % Rec	98.7	101	96.7	101	99.1
Duplicate	U	3.3	U	0.3	U
Duplicate	U	3.3	U	0.3	U
RPD	NC	1.5	NC	9.5	NC
Spike % Rec	106	102	97.1	99.6	99.4

Sample Id	Mercury TCLP mg/l	Selenium TCLP mg/l	Silver TCLP mg/l
Blank	U	U	U
LCS (True)	0.0050	5.00	1.00
LCS (Found)	0.0048	4.95	0.97
LCS % Rec	96.8	98.9	96.6
Duplicate	U	U	U
Duplicate	U	U	U
RPD	NC	NC	NC
Spike % Rec	79.0	98.6	100



# BARRINGER LABORATORIES, INC.

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10-Jul-98

Page: Q-2

Kathy Hill  
RECOVERY DYNAMICS, LLC  
200 E. Main Street  
6th Floor  
Johnson City, TN 37604

Attn:

Project:

PO #:

Received: 25-Jun-98 09:35

Job: 982551E

Status: Final

Abbreviations:

Units:

mg/l : milligrams per liter

Quality codes:

U : Undetected  
NC : Not Calculated



10-Jul-98  
Page: Q-3

Kathy Hill  
RECOVERY DYNAMICS, LLC  
200 E. Main Street  
6th Floor  
Johnson City, TN 37604

Attn: Project: PO #: Received: 25-Jun-98 09:35

Job: 982551E Status: Final

QUALITY CONTROL DATA SHEET

Received by: kz Via: Fed Ex

Sample Container Type: 1L pl  
Additional Lab Preparation: None

Parameter	Method	Preservative	Init	Analysis Dates
As	6010A	14°C	JH	07/09
Ba	6010A	14°C	JH	07/09
Cd	6010A	14°C	JH	07/09
Cr	6010A	14°C	JH	07/09
Pb	6010A	14°C	JH	07/09
Hg	7470A	14°C	AW	07/09
Se	6010A	14°C	JH	07/09
Ag	6010A	14°C	JH	07/09

Note: TCLP performed.

Barringer Laboratories, Inc. will return or dispose of your samples 30 days from the date your final report is mailed, unless otherwise specified by contract. Barringer Laboratories, Inc. reserves the right to return samples prior to the 30 days if radioactive levels exceed our license.

# APPENDIX D





#1. Thorium Nitrate crystals in the overpack drums.



#2. Dissolving the Thorium Nitrate with hot water inside the glovebox.



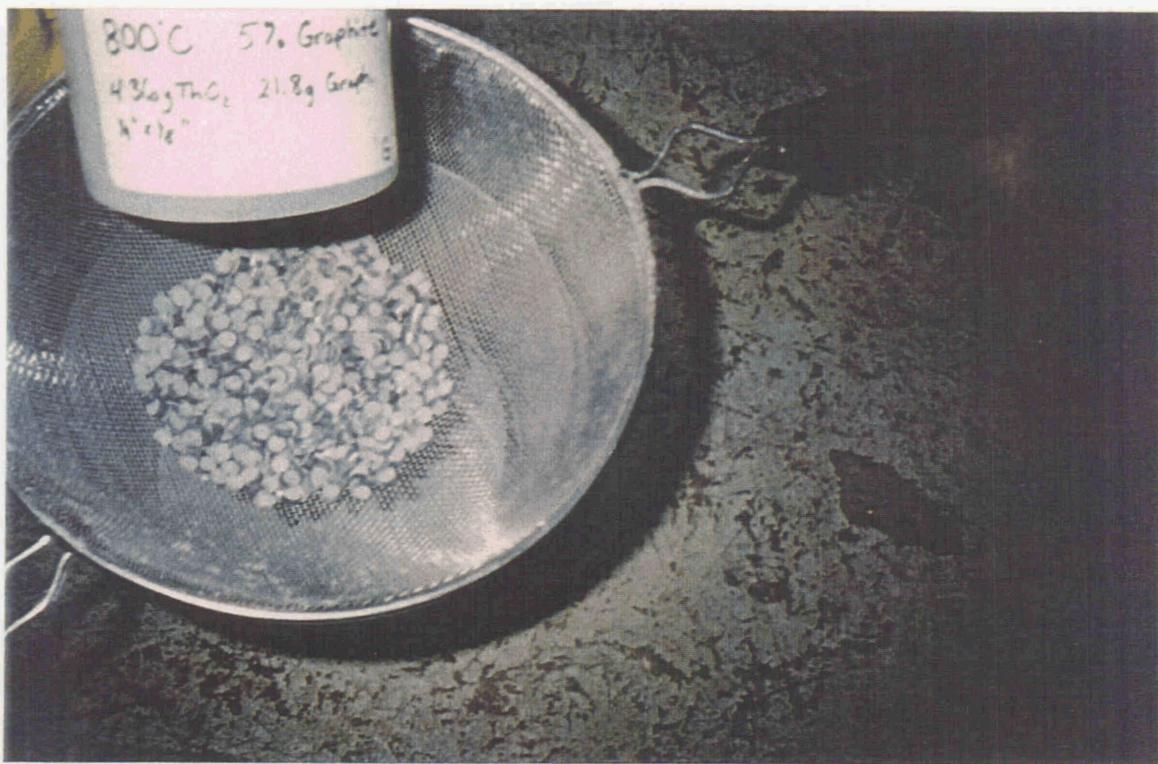
#3. Thorium Oxalate filter cake in the filter press.



#4. Thorium Product drying as it passed through the tube of the rotary kiln.



#5. Thorium Product powder after being dried at 800°C.



#6.  $\frac{1}{4}$ " x  $\frac{1}{8}$ " Tablets: 800°C Thorium Product combined with 5% graphite as a binder.

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COMMENTS / RESPONSE

**Pilot Demonstration Results Report for  
Conversion of Thorium Nitrate to Thorium Oxide**

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September 1998

Prepared for:  
Lockheed-Martin Energy Systems

Prepared by:  
Recovery Dynamics

ROUGH DRAFT REFERENCE	COMMENT ON DRAFT RESULTS REPORT	RESPONSE IN RESULTS REPORT
Section 2.0, page 4	<p><b>1) Paragraph 1.</b> Not clear that ThN is a “strong” oxidizing agent, although it is an oxidizing agent. Is it known that ThN will fail the characteristic test for ignitability or reactivity? Has the test been done or does someone think ThN will fail this test. Either nitrate or radioactive plumes to groundwater are of concern to EPA, so elimination of soluble ThN may be enough justification.</p> <p><b>2) Paragraph 2.</b> Technically, not correct to refer to thoria as the most reduced form of thorium, in a chemical thermodynamic sense.</p>	<p><b>1)</b> See section 4.3</p> <p><b>2)</b> See section 2.0</p>
Section 3.0, page 7	<p><b>1)</b> Unable to read box flow diagram in Figure 1.</p> <p><b>2) Paragraph 2.</b> <math>\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}</math> used for thorium nitrate and in paragraph 4, the number of <math>\text{H}_2\text{O}</math> is only 4. The penta-hydrate is the best model per analytical data.</p> <p><b>3) Paragraph 4.</b> The general unit for solubility is g/L</p> <p><b>4)</b> Expand description of “20 gallon wood drum” (vs. fiberboard drum)</p> <p><b>5)</b> Expand description of nature/composition of drum gas analysis</p>	<p><b>1)</b> Re-printed</p> <p><b>2)</b> Consistently used 5 <math>\text{H}_2\text{O}</math></p> <p><b>3)</b> Convert to g/L</p> <p><b>4)</b> The lids of these drums appeared to be wooden which was misleading. The 20-gallon drums were fiberboard.</p> <p><b>5)</b> The drum gas was not analyzed as originally stated. A discussion of NOx emissions in the same trip report describing the drums was misinterpreted.</p>

<p>Section 3.1, page 7</p>	<p>In the first four batch conversions, a 1.31 to 1.39 times the stoichiometric amount of oxalic acid was used to precipitate thorium oxalate. Between 1.22 to 1.25 times the stoichiometric amounts were used for batches 5, 6, 8 &amp; 10. Only 1.06 was used for batch 7. The suggestion of using 1.25 may be more than needed. Only a slight excess of oxalic acid may be needed (1.10 to 1.15). Per the process used, the acidic filtrate would be neutralized with NaOH to a pH of about 7 and excessive oxalate would be precipitated as sodium oxalate. As pointed out, the solubility of sodium oxalate in water is only about 37 ppm at ambient temperature.</p>	<p>The target for the pilot test was 1.25 times. The pilot did show that as low as 1.06 worked as well. An excess of 1.10 to 1.15 is considered for the full scale processing.</p>
<p>Section 3.2, page 9</p>	<p>1) Some sub-structure is needed here. Discussing each flow sheet step and each product stream, and using the same headings would be a useful approach.</p> <p>2) <b>Page 9. A)</b> Ra equation not balanced  <b>B)</b> The equation for the ppt. Radium with barium chloride and aluminum sulfate is not balanced. At pH7:  <math display="block">3\text{BaCl}_2 + \text{Al}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O} \mid 3\text{BaSO}_4 + 2\text{Al}(\text{OH})_3 + 6\text{H}^+ + 6\text{Cl}^-</math> <math display="block">3\text{Ra}^{+2} + \text{Al}_2(\text{SO}_4)_3 + 6\text{HOH} \mid 3\text{RaSO}_4 + 2\text{Al}(\text{OH})_3 + 6\text{H}^+</math> <p>Aluminum hydroxide is fairly insoluble in the pH range 4 to 8. It would be gelatinous and would co-precipitate with barium and radium sulfate. Furthermore, gelatinous aluminum hydroxide is also an excellent sorbent for many cations and might also play an important role in removing the radium. Aluminum hydroxide is amphoteric, at pHs below 4, it is soluble as <math>\text{Al}^{+3}</math> and at pHs above 8, it forms the soluble complex <math>\text{Al}(\text{OH})_4^-</math>. According to thermo-calculations performed for this review, both barium and radium sulfate would be very insoluble in the pH range of 4 to 10. The problem with radium removal at high pHs (9) probably had more to do with the role of the aluminum.</p> <p>3) <b>Bottom of page 9.</b> The statement 'a third less water' needs to be clarified.</p> </p>	<p>1) Used sub-headings related to flow sheet</p> <p>2) <b>A)</b> Balanced equation.  <b>B)</b> Balanced equation.</p> <p>3) See section 3.2</p>

<p>Section 3.2, page 11</p>	<p><b>1) Table 1.</b> Use of the quadrahydrate immediately throws off the material balance by 2.5% since the amount of Th is based on 200 lb of starting material and will depend on which hydrate. Sect. 3.0 indicated the material is the pentahydrate. This 0.435 lb of 0.5% of the thorium winds up in the filtrate going to the evaporator, but if round-off to nearest lb, then this shows up as 0, which causes significant round-off error. Similarly, mass balance closes pretty well for Th at each step, but 95 lb. of thoria contains 83.49 lb. of thorium, which rounds off as 83 lb. Thorium</p> <p><b>2) Table 1.</b> Mass Balance: Where is the BaRa stream. Stream 2 + 13 should equal 12. It does not. This should be set up to facilitate mass balance determinations.</p>	<p><b>1)</b> Used penta hydrate for mass balance.</p> <p><b>2)</b> Added RaBa stream. Streams add up.</p>
<p>Section 3.2, page 12</p>	<p><b>1)</b> Instead of the very crude bulk density calculation made, perform a density measurement, which is cheap and fast.</p> <p><b>2)</b> Provide more back up about extending processing time (in this case, 1hr to 12 hrs.). Such extension requires much larger equipment to handle the same throughput.</p> <p><b>3) Near Bottom page 12.</b> State whether the product that collected on the gas stream filters was quantified. If so, estimate how much partitioned/carried through.</p> <p><b>4)</b> The thorium oxalate precipitations were conducted at ambient temperature. It is well known in the literature that the temp. of precip. is one of the most important parameters in determining the type precipitate formed. Precip in the range of 50 to 80°C provides a precipitate. That is easier to filter. Also, the average particle size of the thorium oxide powder is larger. Also, it was re-discovered in the batch conversions that the rate of precip is important. By increasing the time of precip. From 1 hr to 12 hrs, a precipitate was obtained that was easier to filter. It would be of interest to know how much time actually is needed. From ORNL experiences and from information found in the literature, other operating parameters such as thorium nitrate concentration, acidity, rate of precipitation, digestion, degree of agitation also have important impacts on the filtering characteristics of the</p>	<p><b>1)</b> Density measurement of ThN material was not specified in the test plan.</p> <p><b>2)</b> See section 3.2</p> <p><b>3)</b> See section 3.2</p> <p><b>4)</b> See section 3.2</p>

<p>Section 3.2</p>	<p>thorium oxalate precipitate and the crystal morphology and particle size of the ThO<sub>2</sub> powder obtained in the calcination step. Optimizing these type parameters can reduce the production scale time line, optimize reduction of airborne particles and volume reduction. The reasons for using the process parameters that were used should be stated.</p> <p><b>5)</b> The ThO<sub>2</sub> should be called 'thorium conversion product' or equivalent since analytical data was not generated/provided to determine the final product compound.</p>	<p><b>5)</b> Referred to as thorium product (ThP)</p>
<p>Section 3.2, page 13</p>	<p><b>1) Item 4.</b> The total thorium oxide volume is 100 gallons. The total container volume must be larger because they are overpacked. Also, what is the density of the ThO<sub>2</sub>?</p> <p><b>2)</b> Reference to the kiln product as ThO<sub>2</sub> should be avoided at this point as quality of product not presented in report yet and the 600°C product quality was suspect/high in oxalate.</p> <p><b>3)</b> The calculated mass reduction to convert Th(NO<sub>3</sub>)<sub>4</sub>* 4H<sub>2</sub>O to ThO<sub>2</sub> from the chemical formulas is 52.2% the reported mass balance found 52.4%. The estimation of the volume reduction based only upon the number and size of the containers in and out – which is very crude approach. A comparison of bulk densities from the original and the resulting product is much preferred considering the value added on this project for tracking volume reduction/storage. etc.</p> <p><b>4)</b> There was no mention of the particle size range of the conversion products – only that the product was free flowing and was not prone to dust. Particle size measurements would add to the quality of the information needed to bracket emergency dispersal issues and control air borne risk during processing.</p>	<p><b>1)</b> See section 3.2</p> <p><b>2)</b> Referred to as thorium product (ThP)</p> <p><b>3)</b> Bulk density measurement of ThN material was not specified in the test plan.</p> <p><b>4)</b> Particle size measurement of Thorium Product was not specified in the test plan</p>

Section 3.2	<p>5) Process control on operating the rotary kiln was finally achieved during the last batch of thorium oxalate (which was converted to the oxide). There are a number of reports in the literature that address this topic and reasons for the methodology used in the demo should be documented. There is a number of heating steps that could be employed to assure complete conversion and particle size control. One recommendation in the report is to dry the precipitate at 150°C to remove the free water and some of the water of hydration (hexa to dihydrate) before feeding it into the rotary kiln. Subsequent heating could be conducted in steps to allow the phase transformation to occur more slowly. Increasing the temperature rapidly through the phase transformation temperatures can result in a ThO<sub>2</sub> product of smaller particle size. Rapid release of water vapor, CO<sub>2</sub> and CO can cause larger particles and agglomerates to break into smaller particles, which constitutes a less desirable product in this process.</p> <p>6) The best tablets were prepared with 5% dose of graphite at 800°C. It should be stated that the density was 2 g/mL.</p> <p>7) <b>Bottom onto page 14.</b> Specify the density of the tablets and the bulk density of a container of pellets. Specify or estimate how much stearic acid is required to make it work.</p>	<p>5) Methodology based on reference (a) pg. 399 – PFD shows one step calcination from thorium oxalate to ThO<sub>2</sub> powder.</p> <p>6) See section 3.2</p> <p>7) See section 3.2</p>
Section 3.2, page 14	<p>1) In the aluminum sulfate – barium chloride precipitation step to remove the radium, the oxalate precipitation filtrate was neutralized with sodium hydroxide. After the solids were removed by filtration, a portion of the filtrate was sent back to the front of the process and reused as washout water. This solution would have a high concentration of sodium nitrate and introduced possible sodium contamination of the subsequent batches of thorium oxalate precipitate. Sodium can be removed by administering an adequate number of washing steps. A better option would have been to use the evaporator condensate as washout water. It would be of interest to know how much sodium was introduced into the conversion products. The ability to keep the product thorium free of impurities is desirable.</p>	<p>1) See section 3.2</p>

<p>Section 3.2</p>	<p>2) The solubility of sodium oxalate at ambient temperature in water (pH 7) is about 37 mg/L; at 95°C it is about 63 g/L. Again, it would have been better to use the evaporator condensate rather than the wastewater liquor, which contained sodium nitrate, for use as thorium nitrate washout water.</p> <p>3) Expand the discussion of the bag filter problems with the removal of radium.</p> <p>4) <b>Item 1.</b> Provide the technical basis to the statement "the solids were considered to be sodium oxalate".</p> <p>5) <b>Item 2</b> 20 cu. ft. from 1 ton? Mixed units.</p> <p>6) Expand discussion: Estimation of the volume of secondary wastes; the drums were compacted and the wastewater was evaporated. The ton of ThN received was estimated having a volume of 200 gal. (P13). The amount of LLW generated from 1 ton was estimated at 20 ft<sup>3</sup>, which is about 150 gal. 1 ton ThN @ 200 gal. (@150 gal. Of secondary waste (75%) or sodium nitrate solids and compacted ThN drum packaging yielded ~2/3 yd<sup>3</sup> of LLW from 1 ton; that is 2400 yd<sup>3</sup> of LLW for the full 5300-ton stockpile.</p>	<p>2) For the full-scale process, the washout water includes the wash water from the pressure filter and not the wastewater.</p> <p>3) See section 3.2</p> <p>4) See section 3.2</p> <p>5) See section 3.2</p> <p>6) See section 3.2</p>
<p>Section 3.3, page 14</p>	<p><b>Analytical data summary:</b> The report does not indicate the methods followed for sample preparation or analysis. The analytical instrument used does not allow detection limit low enough to fulfill the SOW requirements of LDR/UTS limits. The results as provided do not allow for qualification of the wastewater generated according to RCRA, EPA in SW846 does not approve the instrument used.</p>	<p>The sampling and analysis of wastewater was specified in the Test Plan.</p> <p>The evaluation of wastewater according to SW-846 was not in project scope. It was our understanding based on attachment No. 1, supplied by LMES at our meeting on Sept. 3, 1997, the analysis of ThO<sub>2</sub> product was to be adequate to show compliance with TCLP regulatory levels. There are no SOW requirements for analysis at LDR / UTS limits.</p>

Section 3.3,  
page 15

**1) Paragraph 2.** The reference to high backgrounds is not explained sufficiently. It is such that the expected quantitative limit for arsenic was <5 ppm, perhaps 1ppm, but that the "background noise" level raised this quantitative limit to about 5 ppm for some samples. The "normal" (i.e., dilute water) instrument detection limit (IDL) and quantitative limits should be given for these species, either here or in Appendix C. The relatively high thorium concentrations interfered with these analyses and caused the "high background" referred to. This should be explained and stated explicitly, as well as the effect on the quantitative limits.

**2) Table 2. A)** Needs a column showing how much thorium was used in each batch. The average variation of these numbers was about "3%.

1. 38.094 kg	6. 38.156 kg
2. 34.886 kg	7. 37.264 kg
3. 39.963 kg	8. 39.389 kg
4. 36.355 kg	9. 37.362 kg
5. 38.762 kg	10. 37.236 kg

Total 377.457 kg = 832.15 lbs.

$377,457\text{g} / 321.12\text{ g/mol} = 1626.13\text{ mol}$

$1626.13\text{ mol H } 552.12/232.12=897,870\text{g or}$

$1979.5\text{ lbs. Th}(\text{NO}_3)_4 \cdot 4\text{H}_2\text{O}$

Considering the '3% variance, the range would be 1920 to 2039 lbs.

**B)** Label each line with run numbers. Specify which stream numbers in the flow sheet are associated with column headings.

**C)** Each row represents a different drum and batch of ThN. A separate column in the table should be added to clarify this.

**D)** Table 2 needs a column with batch numbers.

**3)** Data in Appendix A does not provide the volume of scrubber solution. In most cases the tank was full. In one case it was not full. This volume information is needed to determine thorium in the scrubber solution.

**1)** See section 3.3

**2) A)** A column was inserted showing stream No. 1, which is the thorium in the batch.

The kg of thorium is calculated based on the penta hydrate.

**B)** A row of stream numbers and a column of batch numbers were added to the table.

**C)** A row of stream numbers and a column of batch numbers were added to the table.

**E)** A row of stream numbers and a column of batch numbers were added to the table.

**3)** A full scrubber tank is 100 gallons. The half-full tank was 50 gallons. This information is included in the data tables in the appendix.

<p>Section 3.3</p>	<p>4) The analytical numbers for thorium in the various streams are found in Appendix C. Are the ones for the wastewaters and scrubber solutions average values?</p> <p>5) A better sampling method for liquid samples would have been to pull a sample and filter half of it through a 0.2 micron filter to remove any suspended, fine thorium particles; add the acid to the filtered and unfiltered samples. Analysis of these samples would reveal the soluble and insoluble thorium. The odds are a large fraction of the thorium in the liquid samples was insoluble and could be removed by filtration such as by cross-flow filtration. Expand lesson learned on this subject in report and apply to full-scale work.</p> <p>6) In discussion section concerning the analytical results in Table 2, it was pointed out that for batch 1 the thorium concentration in the oxalate filtrate was below the detection limit, however, the concentration of thorium in the wastewater was 113 mg/L. How could this be? If there was no thorium in the oxalate filtrate, it is impossible to have thorium in the wastewater. What probably happened had to do with sampling and timing of sampling. To start with, one would not expect to find soluble thorium oxalate in the filtrate. It is likely that some time had elapsed before the thorium oxalate filtrate was sampled which allowed the filtrate to clear (or suspended fine particles had settled to the bottom of the tank). The pumping and mixing involved in the barium chloride and aluminum sulfate precipitate step could have re-suspended these particles. If this were the case, it is still surprising at the high thorium value because the aluminum hydroxide gel should have removed these particles along with the barium, radium sulfates particles. Followed the sampling process described in the previous paragraph above will make future results more informative. Considering how much thorium was being worked with in this facility, another possibility might be sampling contamination.</p>	<p>4) No, only single analyses were performed for the wastewater and scrubber water.</p> <p>5) The sampling and analysis method established in the Test Plan was followed.</p> <p>6) See section 3.3</p>
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Section 3.3	<p><b>7)</b> Results were received from duplicate and triplicate analyses; on that basis the " values should be provided/used. For example, for batch #1 the ThN concentration was given as 150. The two analytical numbers obtained for the sample were 155.2 and 145.2 for an average of 150.2 g/L. A better value for the Table would be 150.2"5. This provides the reader with a better idea of the uncertainty of the number. For batch #2, the two values were 102.9 and 102.7 g/L or 102.8".1 g/L. In the table on page 2 of Appendix C only one number is given. Is this number an average value?</p>	<p><b>7)</b> The " values are given in the appropriate tables. No, only single analyses were preformed for the wastewater and scrubber water.</p>										
Section 3.3, page 16	<p><b>1) Table 3. A)</b> The Safe Drinking Water Act from EPA has a Ra 226/228 limit of &lt;5 pCi/L, to compare with the level found in their wastewater (@ 1,000,000 pCi/L). Beta particles and photon activity = 4 mrem Gross alpha = 15 pCi/L Combined Ra 226/228 = 5 pCi/L Barium = 2 mg/L</p> <p><b>B)</b> The radium results (Table 3, page 16) indicate that radium is present in the wastewater. The high levels of these results (&gt;500,000 pCi/L) are explained (page 16,17) by the pH of the neutralization steps and the solubility of the sulfates. This section references preliminary lab results. If these results are important they should either be shown or more clearly referenced. Was Ra-228 analyzed for in any of the other aqueous streams? Needed to close mass balance.</p> <p><b>C)</b> In Table 3 the totals of thorium in the final wastewater as determined by the two analytical methods were close, 299.1 g as determined by DCP and 312.8 g as determined by Accu-Labs. However, in looking at the calc. Th, it is of interest to consider the " values.</p> <table border="0"> <tr> <td>1. 55"21 g</td> <td>6. 87"33 g</td> </tr> <tr> <td>2. 31"15 g</td> <td>7. 18"90 g</td> </tr> <tr> <td>3. 35"17 g</td> <td>8. 16"11 g</td> </tr> <tr> <td>4. 37"15 g</td> <td>9. 16"90 g</td> </tr> <tr> <td>5. 13"13 g</td> <td>10. 5"60 g</td> </tr> </table> <p>The " range is 38 to 100%. This range should be stated/accuracies addressed. The" values for the Ra-228 average about 12%.</p>	1. 55"21 g	6. 87"33 g	2. 31"15 g	7. 18"90 g	3. 35"17 g	8. 16"11 g	4. 37"15 g	9. 16"90 g	5. 13"13 g	10. 5"60 g	<p><b>1) A)</b> See section 3.3</p> <p><b>B)</b> See section 3.3 The Ra,Ba stream was added to close the mass balance.</p> <p><b>C)</b> The " values are included in the table.</p>
1. 55"21 g	6. 87"33 g											
2. 31"15 g	7. 18"90 g											
3. 35"17 g	8. 16"11 g											
4. 37"15 g	9. 16"90 g											
5. 13"13 g	10. 5"60 g											

Section 3.3	<p>2) In the 2<sup>nd</sup> paragraph discussing interference problems, explain why were some matrixes spike samples not run to evaluate the presence and importance of the interference.</p> <p>3) Correlation between DCP and Accu-Labs Th-232 numbers are not particularly good, DCP gives generally higher results than does Th-232.</p> <p>4) The sodium hydroxide neutralization/barium chloride and aluminum sulfate precipitation step did drastically reduce the soluble oxalate in the wastewater filtrate because of sodium oxalate being precipitated. If the higher oxalate concentration is a problem with DCP analysis of the thorium oxalate filtrate, this should have been thought of and determined beforehand with oversight stated.</p> <p>5) Sampling and analysis: It is noteworthy that even in the worse case, only a small fraction of the initial thorium (0.08%) was found in the wastewater. (0.3 kg out of 389.6 kg). It is useful to understand the fraction of thorium in the wastewater that is soluble or insoluble particulate. Also, determine how much thorium is in the scrubber solutions. A column giving the pH of each wastewater sample would be useful information.</p>	<p>2) See section 3.3</p> <p>3) See section 3.3</p> <p>4) See section 3.3</p> <p>5) See section 3.3</p>
Section 3.3, page 17	<p>1) The discussion was not clear. Is the conclusion that the DCP results are reasonably accurate? Describe in the context of whether or not Ra precipitation is required and effects on Th solubility in the effluents.</p> <p>2) <b>Paragraph 1.</b> This discrepancy/oversight between laboratory set-up design and pilot set-up/testing caused a loss of useful aqueous waste management pilot scale performance/design data. Address how the full-scale design is impacted.</p> <p>3) <b>Table 4.</b> Some suggestions: Better definition of the columns is needed in text. 1<sup>st</sup> 3 col. Pretty clear. Col 4 apparently calculated from col. 2&amp; 3 and is the calculation referred to in text. Col. 5 &amp; 6 not clear. This come from gravimetric weighing of material and then calculating Th content assuming the species (inferred). The DCP is suspect, based on the filtrate results from</p>	<p>1) See section 3.3</p> <p>2) See section 3.3</p> <p>3) See section 3.3</p>

<p>Section 3.3</p>	<p>T3, but these results indicate fair agreement.  Example Batch #1:  How much Th was used?  The average value was 150.2 g/L, 67 gal H 3.785 L/gal H 150.2 g/L = 38,094 g or 38.1 kg or 84 lbs. Th  However, the analytical high number from the Appendix C was 155.2 g/L and the low number was 145.2 g/L.  The high value equates to 39.37 kg or 86.8 lbs. Th and the low value to 36.83 kg or 81.2 lbs. Th.  The range of Th in the form of ThN is between 81.2 and 86.8 lbs. The product wt. of ThO<sub>2</sub> was 102 lbs. (see Appendix A). If the product were ThO<sub>2</sub>, the calculated Th would be 232.04/263 H 102 = 90 lbs. Or 40.8 kg. Table 5, on page 18 shows the product was not pure ThO<sub>2</sub> so the calculated value for the Th product (90 lbs.) is incorrect. Unless the product composition is known, the amount of Th can not be accurately calculated from the weight of the product.</p> <p><b>4) Paragraph 3.</b> Not enough transition between paragraphs and T4 and T5, so that it is unclear what In and Out mean. One sentence/phrase-changing subject from ThN liquor to calcine operation at beginning is all that is needed. Do not refer to the product as ThO<sub>2</sub>. Rather use another term, such as, "calcine product". State in last sentence of para. that these calculated valued are "... and are listed in the last column of Table 5."</p> <p><b>5) Thorium mass balance results.</b>  Mass ThN received: 2046 lbs.      859.7 lbs. Of Th  Calculated Th from liquor:      872.7 lbs.  Field Th received:                  860 lbs.  Field Th produced:                  856 lbs.  From the mass balance, it appears that about 4 lbs. Of thorium might have been combined with some wastewater stream, the calculated process recovery is 99.535%.</p>	<p><b>4)</b> Input and output columns renamed. More discussion involved in transaction between tables.  The product is referred to as thorium product (ThP) instead of ThO<sub>2</sub>.</p> <p><b>5)</b> See section 3.3</p>
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<p>Section 3.3, page 18</p>	<p><b>1) Table 5.</b> How was the moisture content of oxalate cake determined? Was total batch mixed well before taking a sample? Was sample heated at 150°C to a constant weight? Provide details. Need more detail about how LOI was determined. How was the contribution of hydration (water) in the LOI results handled? There is some discrepancy in the correlation of the bulk density and the calculated Th oxalate wt % for the mid-wt % oxalate batch.</p> <p><b>2)</b> The best and complete conversion of thorium oxalate to thorium oxide was the last batch (#10). The lack of complete conversion for the other batches makes it difficult to use these results for a highly defensible process mass balance analysis.</p> <p><b>3) Figure 3.</b> The "Th OUT" symbol should be changed. Not clear on plot and not present in the legend. The system holdup confuses the mass balance on batch by batch basis and cumulative and overall mass balances are the keys. Suggestion: add these cumulative results in T4</p>	<p><b>1)</b> See section 3.3</p> <p><b>2)</b> See section 3.3</p> <p><b>3)</b> Figure 3 no longer necessary. See Table 5.</p>
<p>Section 3.3, page 19</p>	<p><b>1) 1<sup>st</sup> Paragraph. A)</b> What evidence is there that drying will result in consistent conversion efficiencies above 95%? The drying step is broken down into two significant equipment units – address why the rotary calciner cannot be designed for drying and calcination, as was the pilot basis. The two-stage approach is consistent with literature, which indicated a regime of 'heating and holding temperature' would result in best product. Explain on the limitation of 'one short rotary kiln heating'.</p> <p><b>B)</b> It was recognized variations in product output and that calcination of the Th oxalate at 800°C had been incomplete and not produced the wanted product. At this point, additional analyses such as XRD could have been employed for the 800°C material versus 1000°C (loss on ignition) product too as certain directly the identity of the intermediate (800°C) product. In fact, XRD analysis of the 600°C batch would have revealed some ThO<sub>2</sub> present since we would expect conversion to be initiated at temperatures as low as</p>	<p><b>1) A)</b> See section 4.2</p> <p><b>B)</b> See section 4.2</p>

Section 3.3	<p>300°C, which is contrary to the assumption that the batch was still the oxalate. An additional advantage to be obtained by either wet analyses for Th or XRD of the Th oxalate cake is that it serves to identify the specific Th oxalate phase i.e. whether a hexa-hydrate or dehydrate, which is an important factor in conversion. A final note on this subject pertains to XRD data that was not available to Recodyne at this report time. This data reports on the XRD analyses of sample batch 5, which consisted of two phases ThO<sub>2</sub> and Th oxalate, and a second sample from batch 10 that was well crystallized ThO<sub>2</sub>. These data strongly suggests a need to re-evaluate the calcination protocol in order to consistently produce the wanted product.</p> <p>2) Another increase in time of 50%, this is a rather significant piece of equipment/operation. Discuss basis for not needing more tests at various times, and at higher temps.</p> <p>3) <b>Paragraph 2.</b> Is the "synthetic leach liquor" referred to the TCLP extract?...if so, prefer the term "TCLP extract". Suggestion" TCLP extract concentrations be listed in a table in the text along with UTS limits, so the reader can observe that the detection limit referred to is not above the UTS limit.</p> <p>4) The final product to ensure the "purity" of the ThO<sub>2</sub> made was not analyzed which is a significant issue. No XRD or chemical analysis performed. The composite that was tested for TCLP was sent to a lab, which did not have low enough detection limits for lead and selenium.</p> <table border="1"> <thead> <tr> <th></th> <th>TCLP results (mg/L)</th> <th>UTS limits (mg/L)</th> </tr> </thead> <tbody> <tr> <td>Arsenic</td> <td>&lt;0.5</td> <td>5.0</td> </tr> <tr> <td>Barium</td> <td>&lt;0.1</td> <td>7.6</td> </tr> <tr> <td>Cadmium</td> <td>&lt;0.03</td> <td>0.19</td> </tr> <tr> <td>Chromium</td> <td>&lt;0.1</td> <td>0.86</td> </tr> <tr> <td>Lead</td> <td>&lt;0.3</td> <td>0.37</td> </tr> <tr> <td>Mercury</td> <td>&lt;0.002</td> <td>0.2</td> </tr> <tr> <td>Selenium</td> <td>&lt;0.5</td> <td>0.16</td> </tr> <tr> <td>Silver</td> <td>&lt;0.05</td> <td>0.30</td> </tr> </tbody> </table>		TCLP results (mg/L)	UTS limits (mg/L)	Arsenic	<0.5	5.0	Barium	<0.1	7.6	Cadmium	<0.03	0.19	Chromium	<0.1	0.86	Lead	<0.3	0.37	Mercury	<0.002	0.2	Selenium	<0.5	0.16	Silver	<0.05	0.30	<p>2) See section 4.2</p> <p>3) Synthetic leach liquor referred to a TCLP extract.</p> <p>4) See section 3.3</p>
	TCLP results (mg/L)	UTS limits (mg/L)																											
Arsenic	<0.5	5.0																											
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Silver	<0.05	0.30																											

Section 3.3	<p>The analysis of the scrubber solution after each batch was performed, the average results is:</p> <table border="0" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th style="text-align: center;">Average Concentration</th> </tr> </thead> <tbody> <tr> <td>Barium (mg/L)</td> <td style="text-align: center;">31</td> </tr> <tr> <td>Gross Alpha (pCi/L)</td> <td style="text-align: center;">37,000</td> </tr> <tr> <td>Gross Beta (pCi/L)</td> <td style="text-align: center;">188,000</td> </tr> <tr> <td>Ra-228 (pCi/L)</td> <td style="text-align: center;">1,071,000</td> </tr> <tr> <td>Th-232 (pCi/L)</td> <td style="text-align: center;">5,600</td> </tr> <tr> <td>Th-228 (pCi/L)</td> <td style="text-align: center;">104,000</td> </tr> </tbody> </table> <p>These data as presented show levels too high to be discharged; the level of barium present, depending upon the regulation, might render this waste mixed. Discuss.</p>		Average Concentration	Barium (mg/L)	31	Gross Alpha (pCi/L)	37,000	Gross Beta (pCi/L)	188,000	Ra-228 (pCi/L)	1,071,000	Th-232 (pCi/L)	5,600	Th-228 (pCi/L)	104,000	Assumed this was in reference to wastewater not scrubber solution. Full-scale process does not utilize barium precipitation.
	Average Concentration															
Barium (mg/L)	31															
Gross Alpha (pCi/L)	37,000															
Gross Beta (pCi/L)	188,000															
Ra-228 (pCi/L)	1,071,000															
Th-232 (pCi/L)	5,600															
Th-228 (pCi/L)	104,000															
Section 4.0, page 20	<b>2<sup>nd</sup> Paragraph.</b> If this is an assumption, state as such.	See section 4.0														
Section 4.1, page 20	<b>Table 6.</b> Improve discussion and/or provide examples why scale-up of 17X on calciner is with in good design practice. Filter scale-up also appears uncertain to a degree because the proposed filter type is different than that tested. Providing a specific basis would improve credibility.	See section 4.1 & 4.2														
Section 4.2, page 21	<b>Drum receiving &amp; unpacking - # 5.</b> Explain basis for the "fixed contamination steel drums" compacted and packed for disposal with the damaged drums.	See section 4.2														
Section 4.2, page 22	<p><b>1) Oxalate precip &amp; filtration - # 2.</b> State that the three 1100 gal tanks are operated in batch precipitation =&gt; 4800 lbs. ThN/3300 gal =&gt; 174 g ThN/L =&gt; 84 g Th/L. Compared favorably with target concentration of 100 – 150 g Th/L from feed drum.</p> <p><b>2) # 3.</b> Discuss need for/against mixing capability in the tank.</p> <p><b>3) # 4.</b> Improve the description of the automatic filtration unit (at this point in the report).</p> <p><b>4) Nitrate wastewater - # 1.</b> Discuss basis for wastewater neutralization and, if necessary, what is the degree of difficulty in using something that will neutralize or get rid of nitrate without introducing troublesome cations. i.e. ammonium hydroxide vs. NaOH.</p>	<p><b>1)</b> See section 4.2</p> <p><b>2)</b> See section 4.2</p> <p><b>3)</b> See section 4.2</p> <p><b>4)</b> See section 4.2</p>														

<p>Section 5.1, page 24</p>	<p><b>1) 1<sup>st</sup> Paragraph.</b> Refer to the literature for temperature specification. The effects of bulk density on calcination temperature are an econ. Trade-off – per simple calculation/referencing available data, could effect 33% additional volume reduction. The design basis for the processing equipment should be presented as a range to be evaluated that allows processing flexibility and product optimizations. A table showing literature based temperature ranges at duration's (based on effect on product quality would add value in specifying 800°C – 1000°C upper range.</p> <p><b>2) 2<sup>nd</sup> Paragraph.</b> Add or discuss the merits for the Ventilation system including a condenser to remove moisture and mist before the HEPA filter. The off gas stream has a demister. The air stream could have significant humidity.</p>	<p>1) See section 4.2</p> <p>2) See section 4.2</p>
<p>Section 5.1, page 26 - 35</p>	<p><b>Figures 5 &amp; 6.</b> Define how the oxalic acid is being transferred from the bag breaking and feed station to the precip tank. Is oxalic acid being dissolved and fed as solution? Solid? Manually added to tank?</p>	<p>See section 5.1</p>
<p>Section 5.1, page 36</p>	<p><b>Table 5.4.</b> Provide energy balance.</p>	<p>Energy balance provided.</p>
<p>Section 5.0, overall</p>	<p>Note: This is a final catchall section and will be improved during the official draft review.</p> <p><b>1)</b> Address storage and inventory control to accommodate processing a total of ~ 22,000 drums at full scale.</p> <p><b>2)</b> Define hot water delivery pressure limits that accomplish effective dissolution but do not destroy the inner drum/add to contamination.</p> <p><b>3)</b> ThN sample was composited across the 10 feed drums. Discuss resource/effort/methods recommendations to sample additional drums to assess variability from lot to lot on an inventory basis.</p>	<p>1) See section 4.2</p> <p>2) See section 4.2</p> <p>3) See section 4.3</p>

<p>Section 5.0</p>	<p><b>4)</b> The thoria product would ideally be used in a fuel cycle, whereby using de-ionized water allow for minimizing impurities. Identify or at least generally address the mass balance effect on the product, costs and design trade-offs associated with providing DI water (i.e. using standard IX/Culligan units with regeneration off-site).</p> <p><b>5)</b> Discuss applicability of CO<sub>2</sub> being given off during the decomposition of the oxalate to invoke CAA requirements.</p> <p><b>6)</b> There needs to be measures put into place to control the evolution of NO<sub>x</sub> when the drums are opened (air pollution and worker exposure considerations).</p> <p><b>7)</b> Expand on production scale S&amp;A material balance control/QA/QC per lot/costs basis.</p> <p><b>8)</b> Address whether the original radium content of ThN solution was analyzed/benchmarked to allow for completing an accurate mass balance.</p> <p><b>9)</b> Provide information as to what investigations have been made to find existing commercial facilities that are:  <b>A)</b> Interested in participating in full-scale processing and have the general rad material handling licenses;  <b>B)</b> Have RCRA Part B permits or can get them (modified) in a reasonable time frame.  <b>C)</b> Have the infrastructure to support storage, handling, equipment repair, and transportation.</p> <p><b>10)</b> Discuss how the stated surge volumes (holding tank capacity) allow for recycling off-spec products and handling process upset and emergency shutdown conditions.</p> <p><b>11)</b> Address the possibility of the inner drums sticking inside the outer drum and disposition of the 55-gallon drums</p>	<p><b>4)</b> See section 4.3</p> <p><b>5)</b> CO<sub>2</sub> emissions are not applicable to CAA requirements.</p> <p><b>6)</b> See section 4.2</p> <p><b>7)</b> See section 5.3</p> <p><b>8)</b> See section 3.3</p> <p><b>9)</b> Beyond project scope, however, three licensed facilities have expressed interest in full-scale processing.</p> <p><b>10)</b> See section 5.1</p> <p><b>11)</b> See section 5.1</p>
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<p>Section 5.0</p>	<p><b>12)</b> Define the target thorium end product specification and aqueous by-product specification and key parameters to be controlled from batch-to-batch to ensure consistent end product specification compliance.</p> <p><b>13)</b> Define production time line basis in detail per unit op for one train and two trains of equipment. The availability target for the dryer and calciner operations (alloy needed at 1000°C) is reasonable but typically the operation time line is the cost diver over the period of several years of operation. The investment is selected process dual trains of equipment could be justified based on utilizing shift operations most effectively. The unit operations for precipitation and calcining could be off set.</p> <p><b>14)</b> Describe use of in-line process monitors (ion, pH, humidity, and...) to better automate the process and controls.</p> <p><b>15)</b> Describe use of analytical laboratories that can provide consistent, reliable data with complete QA/QC documentation.</p> <p><b>16)</b> Describe need to analytical/materials laboratories to provide phase/chemistry information on the products to validate the chemistry of the system.</p> <p><b>17)</b> Describe scope and schedule of the initial year of performance testing (process validation – i.e. product spec requirements, procedures, throughput, waste stream quantification, permitting, optimization) and production operations.</p> <p><b>18)</b> <b>Section 5.5</b> The assumptions for the basis of Table 11 (annual manufacturing costs) are not clearly defined. This would require that on average almost 11 people per shift (32 people per day) for 300 days per year to operate a full-scale system (76,800 hours/year of labor)? This averages \$25.46/hr (\$24.75/hr full G&amp;A) – not realistic. Provide basis.</p>	<p><b>12)</b> See sections 4.2 &amp; 5.1</p> <p><b>13)</b> See section 5.3</p> <p><b>14)</b> See section 4.2 and P&amp;IDs</p> <p><b>15)</b> See section 5.3</p> <p><b>16)</b> See section 5.3</p> <p><b>17)</b> See section 5.3</p> <p><b>18)</b> See section 5.5</p>
<p>Section 6.0</p>	<p>Will review next draft – important data.</p>	<p>Section 6.0 completed.</p>

# ATTACHMENT 1

# TCLP

## TCLP Regulatory Levels

<u>Analyte</u>	<u>Level</u>	<u>Units</u>
arsenic	5.0	mg/L
barium	100.0	mg/L
cadmium	1.0	mg/L
chromium (total)	5.0	mg/L
lead	5.0	mg/L
mercury	0.2	mg/L
selenium	1.0	mg/L
silver	5.0	mg/L

<u>Analyte</u>	<u>ICPMS</u>		<u>ICPAES</u>	
	<u>Result</u>	<u>Units</u>	<u>Result</u>	<u>Units</u>
arsenic	<1000	µg/L	<40	mg/L
barium	1700	µg/L	2.1	mg/L
cadmium	<50	µg/L	<2.0	mg/L
chromium	<50	µg/L	<4.0	mg/L
lead	<50	µg/L	<20	mg/L
nickel	<100	µg/L	<10	mg/L
selenium	<1000	µg/L		
silver	<50	µg/L	<4.0	mg/L

## Cold Vapor AA Method

<u>Analyte</u>	<u>Result</u>	<u>Units</u>
mercury	<0.02	mg/L

## GFAA Method

<u>Analyte</u>	<u>Result</u>	<u>Units</u>
selenium	<20	µg/L

**Analysis methods used include:**

**CVAA - cold vapor atomic absorption**

**GFAA - graphite furnace atomic absorption**

**ICPAES - inductively coupled plasma-atomic emission spectroscopy**

**ICPMS - inductively coupled plasma-mass spectrometry**

**ICPMS has a lower detection limit for most elements than does ICPAES.**