INNOVATIVE TECHNOLOGY
Summary Report

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Waste Inspection Tomography (WIT)

Industry Programs

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INNOVATIVE TECHNOLOGY
Summary Report

Waste Inspection Tomography (WIT)

OST/TMS ID 259

Industry Programs

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Lawrence Livermore National Laboratory
Rocky Flats Environmental Technology Center
Nevada Test Site

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Problem

The Department of Energy (DOE) has in excess of 600,000 nuclear waste drums currently stored at more than 30 sites within the United States that need to be characterized over the next several years. The contents of these drums must be characterized and designated as high-level waste (HLW), low-level waste (LLW), or transuranic waste (TRU), prior to assigning these drums to a permanent storage location. Many of the drums contain dense materials, such as sludge or cement, making them difficult to characterize by existing non-invasive technologies.

Solution

Bio-Imaging Research, Inc. (BIR) has developed Waste Inspection Tomography (WIT); a non-invasive, waste-drum inspection technology that is contained in a mobile, self-sufficient, semi-trailer and accompanying land/sea container. WIT can be transported to a waste site to perform tomographic characterization of nuclear waste drums using various inspection technologies.

WIT utilizes **Non-Destructive Assay (NDA)** technology to identify and quantify the radioactivity within a drum. WIT's Active and Passive Computed Tomography (A&PCT) NDA provides radioactive element identifications and total alpha currie quantification of isotopes, including LLW and TRU threshold sensitivity.

Non-destructive Examination (NDE) technology is utilized to generate x-ray images of a drum's contents. WIT NDE utilizes Digital Radiography (DR) to provide an entire drum projection, and Computed Tomography (CT) to provide a slice plane and volume x-ray imaging of drum contents. WIT's 2 million-volt (MV) x-ray CT NDE can identify both lightweight matrices, such as clothing, and dense matrices, like sludge, steel pipe overpacks, and lead-lined drums. An NDE image generated by WIT is provided in Figure 1. This drum is a 55-gallon, lead-lined drum containing lab glasses and bottles packed in vermiculite.

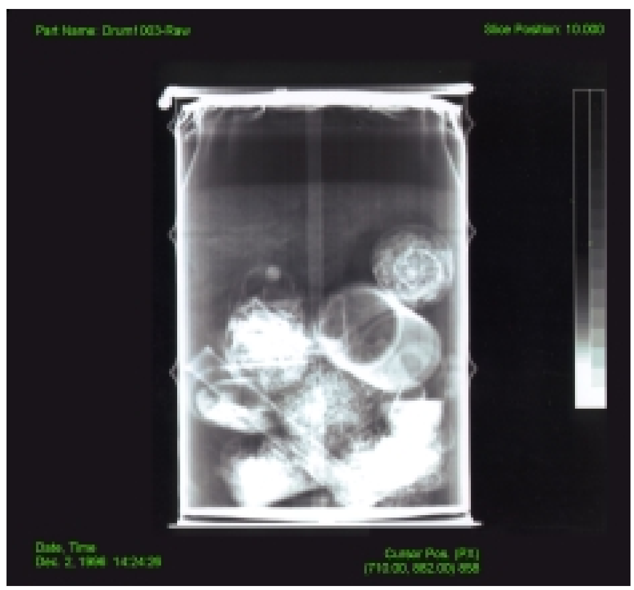

Figure 1. WIT-generated NDE image of lead-lined drum.

Potential Markets

Waste drums appropriate for WIT can be found at numerous DOE sites including:

- Argonne National Laboratory (ANL-East), Argonne, IL;
- Hanford Site near Richland, WA;
- Idaho National Engineering and Environmental Laboratory (INEEL); Idaho Falls, ID;
- Los Alamos National Laboratory (LANL), Los Alamos, NM;
- Oak Ridge National Laboratory (ORNL), Oak Ridge, TN;
- Rocky Flats Environmental Technology Site (RFETS); and
- Savannah River Site (SRS) near Aiken, SC.

Advantages Over Baseline Technology

The baseline technology for NDA is a Segmented Gamma Scanning (SGS) and the baseline technology for NDE is Real-Time Radiography (RTR). Invasive techniques, such as visual inspection, must be utilized if proper characterization can not be accomplished with non-invasive technologies. WIT's NDE and NDA capabilities provides significant advantages over the baseline methods.

- WIT's 2 MV DR/CT system is capable of performing NDE of highly dense drum contents such as sludge, lead-lined drums, and steel pipe overpacks;
- WIT's ability to inspect dense drum contents, which account for over half the inventory of drums at some DOE sites, minimizes the need for invasive inspection;
- WIT is capable of identifying free-liquids, that baseline NDE techniques, such as RTR, can not identify;
- WIT NDA is more accurate than the baseline SGS;
- WIT NDA is an absolute measurement and does not require calibration or prior knowledge of drum contents; and
- The same WIT x-ray and assay techniques are used for all drums.

Demonstration Summary

WIT has completed field tests at a number of interim waste drum storage sites including the Lawrence Livermore National Laboratory (LLNL), RFETS, INEEL, and Nevada Test Site (NTS). WIT has participated in several DOE-sponsored blind tests, including the Performance Demonstration Program (PDP), the Rapid Commercialization Initiative (RCI) Performance Verification Program, and the Capability Evaluation Program (CEP). These tests were designed to evaluate WIT's NDA characterization performance relative to DOE-specified Waste Acceptance Criteria (WAC).

- To date, WIT has passed all DOE-sponsored blind tests;
- WIT can perform NDA on a variety of TRU-waste drum matrices, including low-density matrices like combustibles and high-density sludge;
- WIT's Minimum Detectable Concentration (MDC) is below the National TRU Program requirement of 60 nanocuries/gram (nCi/g) allowing segregation of LLW from TRU waste;
- WIT has received a PDP "approval" letter;
- WIT has received both an R&D-100 and an SBA Tibbitts award.

Commercial Availability and Readiness for Application

WIT has passed all PDP tests and has satisfied all corrective action requests associated with the Carlsbad Area Office (CAO) Quality Assurance (QA) process. WIT's participation in the RCI program was designed to accelerate private-sector technology commercialization and facilitate regulatory acceptance across state and federal jurisdictions. (The RCI product was designed to facilitate multi-state acceptance, following verification of a technology's performance.)

WIT is currently ready to provide drum inspection services to the DOE and its sites. Bio-Imaging Research, Inc. (BIR), the developer of WIT, has been awarded the first phase of a four-phase contract with the Rocky Flats Management and Operation (M&O) contractor, Kaiser-Hill, to provide waste drum inspection services. The four-phase contract includes, documentation, mobilization, qualification, and production phases. Initially, 50 drums are slated for inspection during the production phase, with additional drums being released pending acceptable performance by WIT.

Contacts

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Other

A related project, funded through the TRU & Mixed Waste Focus Area, was the Nondestructive Waste Assay Using Gamma-Ray Active & Passive Computed Tomography, TMS ID 2123. This project supported the LLNL's R&D for the A&PCT system in the NDA portion of WIT.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications." The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Waste Inspection Tomography is 259.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The WIT system consists of two non-invasive drum inspection systems: NDE for x-ray imaging of drum contents, and NDA for identification and quantification of total alpha activity within a drum. The NDE system is housed in a 48-foot tractor-trailer and the NDA system is housed in an accompanying land/sea container. These two systems can be operated in tandem or independently.

WIT NDE

WIT's 2 MV x-ray high energy accelerator has a curved linear array of 896 solid state x-ray detectors for DR, and is capable of providing an x-ray image of an entire drum's contents. WIT utilizes CT to generate thin slice plane, cross-sectional images of a drum. WIT can stack CT slices together and present a cut-away, cinematic, rotating volume rendering (VR). Typical measuring times for WIT x-ray NDE range from 1 minute for a single DR image to 8-30 seconds for a single CT slice, excluding drum handling.

A photograph of WIT's 2 MV x-ray system is provided in Figure 2.

Figure 2. WIT 2MV x-ray NDE.

Summary of WIT NDE Components and Capabilities

- X-ray technique: 2 MV at 3 pulses/period
- DR format 900 lines x 896 detectors
- CT image format (pixels): 512 x 512
- DR /CT image pixel size: about 1mm x 1mm
- DR scan speed: 1 minute per DR image
- CT slice scan speed: 8 seconds/CT slice
- CT/DR slice thickness: 10 mm typical
- Integration period: 64 milliseconds typical DR
- Source Output: 200 rads/min. at 1 meter
- DR image quality: 2%-2T in 2in. thick steel
- 3 DR per drum: 0 & 90 degrees plus tilted
- CT slices per drum: up to 90
- Storage: 20 MB/drum, DAT or optical disk
- 208 V, 3 phase, < 50 amps per phase draw

Support Features of Mobile WIT Tractor-trailer

- Electrically self-sufficient with an 80 kW diesel generator or supplied shore power;
- Self-sufficient communications with cell or shore phones, faxes, and modems;
- Storage capacities of 400 l. liquid nitrogen, 100 gal. diesel fuel, & 20 gal. water.
- Fork lift for loading drums;
- VHS tape, DAT tape, Optical Disc, Hard Copies, photos, and LAN e-mail outputs;
- 12 tons of radiation shielding and a radiation exclusion zone (36 ft. x 120ft.), safety interlocks, and monitoring systems;
- 2 mR/hr radiation limit for the 2 MV Linatron source at the exclusion fence line; and
- Fire suppression, intruder, positive air pressure, and oxygen alarm

WIT NDA

WIT's NDA system, housed in a 20-foot, sea-land container, has the following capabilities:

- Identification of radioactive isotopes
- Mass and activity quantification of isotopes
- Quantification of the total alpha activity
- Measurement of total decay heat
- Measurement of TRU alpha-activity
- Measurement of ^{239}Pu Equivalent Activity

- Pu-239 fissile gram equivalent

The WIT NDA system consists of six collimated High Purity Germanium (HPGe) detectors, six DSPec's (digital data acquisition systems) for detector control, six 7mCi Eu-152 transmission sources, a three axis, computer-controlled drum manipulator, and a motion control/data acquisition computer. An initial active and passive pre-can of a drum is made utilizing a continuous spiral Collimated Gamma Scan (CGS). This prescan determines the vertical location of the activity and the necessary scan times for an accurate and precise assay of the drum using the Active and Passive Computed Tomography (A&PCT) technique. An entire drum is segmented into 2304 individual volume elements (voxels) measuring 2.25 inches on a side. For each voxel, the energy-specific attenuation properties are measured and used to provide attenuation-corrected activity levels for each voxel. The sum of all voxel activities provides the assay value. The individual emission measurements are summed, resulting in a 0-2 MV spectrum that is analyzed to provide gamma spectroscopy information.

WIT NDA drum inspections are absolute and direct measurements that do not require comparative calibration or a-priori knowledge of drum contents. To attain an absolute assay measurement, the A&PCT system is calibrated on an absolute detector efficiency scale by simple measurements with a radioactive point source. Additional calibrations based on Pu-source loadings, or drum matrices are not needed because the A&PCT technique measures the location and activity of the Pu, along with the attenuating properties of the matrix.

Summary of WIT NDA Components and Capabilities

- 6 HPGe Detectors at 60% efficiency
- 6 Eu-152 sources at about 7mCi each
- 16 CT slices per drum (active and passive)
- CT Slice Thickness: 2.25 in. thick
- Detector collimator: 2.25 in. x 2.25 in. (12 x 12 pixels per slice) active and passive
- Active and Passive Computed Tomography
- MCA: 8,192 channels (digital DAS)
- Active and passive prescan and assay
- FWHM: 1.75keV @ 400keV
- AutoTRU Modified MGA Spectroscopy
- 208V, 3 phase, <10 amps per phase draw

System Operation

Operational features of WIT:

- Capable of examining all drum, liners, and shielding including steel pipes and lead;
- Maximum drum size (NDE): 110 gal.volume, 1,600 lb. weight;
- Maximum drum size (NDA): 55 gal., 1,000 lb.
- Does not require acceptable knowledge (AK);
- Has 3 axes of motion for NDE; elevation, rotation and tilt;
- Has 3 axes of motion for NDA; elevation, rotation and translation;
- Two-person operation crew with two days for setup and take down;
- Maximum throughput of 50 drums per day (for three view DR and drum tilt and up to 90 CT slices per drum with typically 2 drums per hour); and
- Assay time increases with decreasing radioactivity
  - Assay time: 25 min/drum for 35-200 g ^{239}Pu
  - Assay time: 45 min/drum for 10-35 g ^{239}Pu
  - Assay time: 2 hr/drum for 1-10 g ^{239}Pu
  - Assay time: 19 hr/drum for <1 g ^{239}Pu

WIT has the following documentation capabilities:

- Safety analysis for environmental safety and health;
- Commercial software releases with QA controls;
- Site operating procedures for safety;
- Operations, maintenance, and training manuals;
- Production documentation;
- WIPP-format QAP;
- WIPP-prescribed NDE and NDA results reporting; and

- Operations and test plans for system validation.

SECTION 3
PERFORMANCE

Demonstration Plan

WIT's performance has been demonstrated and verified through testing conducted under the following programs: Performance Demonstration Program (PDP), RCI, and Capability Evaluation Program (CEP). These programs are described below.

Performance Demonstration Program (PDP)

The PDP is sponsored by DOE CAO and applies to characterization of TRU waste destined for disposal at the Waste Isolation Pilot Plant (WIPP). Participation in the PDP is required for NDA facilities intending to generate data for the National TRU Program. The PDP is designed to help ensure compliance with the National TRU Program Quality Assurance Program Plan (QAPP, US DOE 1995). The QAPP identifies data quality objectives associated with DOE's WIPP TRU waste characterization program.

This DOE-instituted program includes mandatory periodic testing, every 6 to 14 months, to maintain an "approved" status. Each PDP test is referred to as a PDP cycle. The PDP uses blind TRU waste surrogate audit samples to acquire an independent performance measure. Each test involves six replicate measurements of total alpha curies for at least two drums. WIT has participated in the PDP for three cycles; at INEEL in 1997, NTS in 1998, and LLNL in 1999. The PDP test in 1999 was the first PDP test of the 6-detector system. Previous tests were conducted with the single detector system.

Rapid Commercialization Initiative (RCI)

The purpose of the testing under RCI was two-fold. Primarily, RCI testing was to access WIT's capability to meet the NDA accuracy and precision performance criteria which are key performance parameters of the National TRU QAPP required by the Waste Acceptance Criteria (WAC). Secondly, RCI testing demonstrated that WIT could be used for the NDE of TRU drum content. RCI testing was conducted at the Radioactive Waste Management Complex (RWMC) at INEEL in February of 1997. During RCI testing, eight sealed 55-gallon TRU waste drums of varying matrices, levels of radioactivity, and TRU isotopic content were X-ray examined and gamma assayed by WIT. RCI testing was performed with the single HPGe detector WIT NDA system.

Capability Evaluation Program (CEP)

The CEP was conducted in October of 1997 at the RWMC at INEEL and sponsored by DOE Office of Science and Technology (EM-50). CEP testing involved characterization of four drums with eight replicated measurements each with scoring for accuracy and precision determined relative to total alpha activity for a variety of drum matrices. CEP testing was conducted with the single HPGe detector WIT NDA system.

Results

Evaluation criteria and techniques used to assess WIT's NDA performance are primarily based on the National TRU Program QAPP. These evaluation criteria were utilized in the RCI, PDP, and CEP programs. Key evaluation criteria include accuracy and precision based on measurements of total alpha activity, as a direct measurement of grams of ^{239}Pu. Accuracy measurement is based on percent recovery: measured value/known value. Precision is a measure of the reproducibility of results and is based on Relative Standard Deviation (RSD).

Evaluation of NDE performance is qualitative in nature. The quality of the image generated by NDE is the primary measure of performance. There is only one technical performance requirement specified by the DOE for radiography imaging acceptance and that is to see a 2 %-2T hole penetrameter in a steel block. WIT has demonstrated its ability to meet this requirement. WIT has performed numerous NDE characterizations of waste drums representative of DOE's inventory. Selected images will be presented in this section and in Appendix B.

PDP Results

The results of the NDA PDP tests from 1997, 1998 and 1999 are presented in Table 1. The 1999 cycle was the first PDP test of the 6-detector system.

Table 1. WIT PDP NDA performance for six replicate A&PCT measurements per drum

PDP Cycle-Test Date - DOE Test Site	Waste Matrix	Number of detectors (assay time per replicate in hours)	Total Alpha Curies (Actual)	% Recovery[1] (pass/fail)	RSD[2] (%) (pass/fail)
4-9/97-INEEL	combustibles	1 (22.5)	0.51	109.8 (pass)	3.0 (pass)
4-9/97-INEEL	zero (air)	1 (22.5)	7.63	99.1 (pass)	1.5 (pass)
5A-10/98-NTS	combustibles	1 (22.5)	0.31	96.1 (pass)	2.1 (pass)
5A-10/98-NTS	sludge	1 (22.5)	0.55	100.8 (pass)	4.3 (pass)
5A-6/99-LLNL	sludge	6 (7.0[3])	0.54	97.0 (pass)	9.7 (pass)
5B-6/99-LLNL	combustibles	6 (0.75)	0.92	87.9 (pass)	4.0 (pass)
5B-6/99-LLNL	sludge	6 (0.5)	7.91[4]	92.2(pass)	4.0 (pass)
			Avg. of 42 replicates:	**97.6**	**4.1**

(p=pass, f=fail)
[1] measured value over known value
[2] relative standard deviation (RSD)
[3] Assay time was increased due to one bad detector: normal assay time would have been approximately four hours.
[4] The total alpha activity for this sludge drum was less than other DOE sites around the country, for cycle 5B, because of administrative safety limits for this LLNL building.

WIT NDA has never failed a PDP blind test with either the single-detector system or the six-detector system. The six detector system proved to be a significant advancement, decreasing the assay time per replicate from an average time of 22.5 hours to an average time of 0.5 hours.

RCI Results

Under the RCI testing plan, the RCI team referee specified the eight test drums; three surrogates and five actual waste drums, nominally representing a cross-section of the DOE TRU waste form configurations. The three surrogates were loaded with accurately known radioactive sources. The RCI testing did not include replicate testing of each drum. WIT results were reported within 24 hours of measurement. WIT assay results for the RCI testing are provided in Table 2.

Results confirm that WIT passed the RCI test plan assay accuracy parameters for all surrogate and actual waste drums that had known and verifiable TRU alpha activity. The surrogates and actual drums contained TRU alpha activity amounts known to the project referee except for the sludge drum, which did not have verifiable data. WIT NDE results from the three surrogates and five actual waste drums confirmed and verified all drum content codes and matrices.

Table 2. RCI testing results for total alpha activity[1]

Sample ID Number	Waste ID Code	Total Measured Alpha Curies/grams ^{239}Pu	Percent Recovery [2]	Acceptable Range: % Recovery[3]	Pass/Fail
1RF	300: Graphite	02.6/30.0	127.0	57.4-142.6	Pass
2RF	336:Moist Combustibles	Below DL	-	43.5-171.5	Pass
1SG	440: Glass	0.27/3.1	141.4	32.2-197.8	Pass
3RF	442: Raschig rings	1.2/13.6	122.3	33.1-196.9	Pass
2SG	330: Dry Combustibles	0.13/1.4	162.5	32.5-197.5	Pass
4RF	376: Filters/Insulation	6.1/69.4	86.2	51.6-148.4	Pass
3SG	480: Metals	0.11/1.3	179.6	33.5-196.5	Pass
5RF	001: Inorganic Sludge	1.9/21.1	n/a	radiation chemistry unknown	Pass

[1] RCI testing was performed using the single detector WIT system
[2] single measurement x/m (measured value/known value)
[3] taken from PDP scoring technique, range based on upper and lower 95% confidence bounds

CEP Results

The results from the CEP testing are provided in Tables 3 and 4. CEP testing involved characterization of four drums with eight replicate measurements each with scoring for accuracy and precision determined relative to total alpha activity for a variety of drum matrices. Table 3 presents the results with respect to the accuracy criteria (percent recovery). Table 4 presents the results with respect to the precision criteria (relative standard deviation).

Table 3. WIT NDA test results from CEP[1] (Accuracy)

Drum ID No.	Waste ID Code	Net Weight (kg)	Mean Measured ^{239}Pu grams	% Recovery	Allowable % Recovery Range	Pass/ Fail
CEPRF-20	480: Leached Metals	109	4.81	96.8	30.7-199.3	Pass
CEPSG-6	409: MSE Salts	68	47.62	70.7	50.9-149.1	Pass
CEPSG-9	442: Raschig Rings	64	1.41	154.9	33.5-196.5	Pass
CEPRF-1a	003 Organic Sludge	140	2.48	161.4	34.9-195	Pass
CEPRF-1b	003 Organic Sludge	140	2.48	190.9	35.9-194.1	Pass

[1] CEP Testing was performed with the single detector WIT system

Table 4. WIT NDA test results from CEP[1] (Precision)

Drum ID No.	Waste ID Code	Mean Measured ^{239}Pu grams	% Relative Standard Deviation (RSD)	Maximum Allowed %RSD	Pass/Fail
CEPRF-20	480: Leached Metals	4.81	0.8	14	Pass
CEPSG-6	409: MSE Salts	47.62	1.1	7	Pass
CEPSG-9	442: Raschig Rings	1.41	4.2	14	Pass
CEPRF-11a	003 Organic Sludge	2.48	5.0	14	Pass
CEPRF-11b	003 Organic Sludge	2.48	5.9	14	Pass

[1] CEP Testing was performed with the single detector WIT system

NDE Performance

In 1999, WIT NDE DR and CT participated in activities at the NTS consisting of four DOE QA audits and the NDE characterization of 187 TRU drums. Selected NDE images are presented below and in Appendix B.

Figure 3a is a 2 MV DR image with raised edge enhancement of sludge drum from PDP cycle 5a. Figure 3b is a 2MV CT slice of the same drum. The DR image indicates the tubes used to load the Pu sources. Note that in the CT image (right) the phantom sludge material appears very uniform with a small amount of porosity. Sludge porosity can be determined in the enhanced DR image by the depressed characteristics. Figure 3b shows a high-density indication (white areas) of a loaded ^{239}Pu source in the 10 mm-thick CT slice.

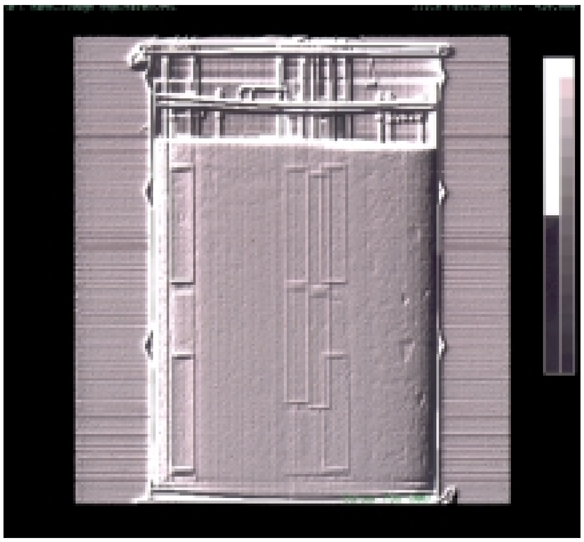

Figure 3a. DR image of sludge drum.

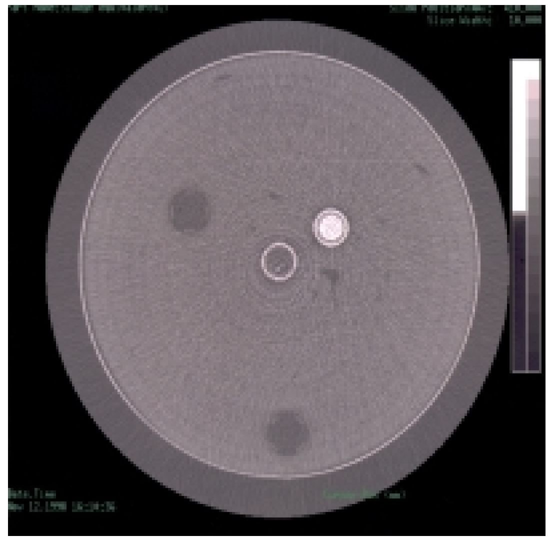

Figure 3b. CT slice of sludge drum

Conclusions

WIT has passed all quantitative NDA test programs in which it has participated, including three PDP cycles. The most recent PDP cycle was completed with the WIT's upgraded six-detector system, while the earlier PDP cycles (and RCI and CEP testing) were performed with the single detector system. As presented in Table 1, WIT demonstrated its accuracy and precision with an average percent recovery of 97.6 percent for 42 replicates, and an average relative standard deviation of 4.1. WIT's upgraded six-detector system has resolved issues related to the slow assay speed of the single detector system. WIT's accuracy, precision, speed, and ability to provide an absolute measure of alpha activity for a wide spectrum of waste types including dense materials are state of the art.

WIT DR and CT NDE images surpass current RTR capability. WIT's 2 MV NDE has the ability to inspect drums containing low and high density materials. WIT has demonstrated the ability to see through lead-lined drums, steel-pipe overpacked drums, and drums that contain sludge, and cement. Baseline RTR methods experience difficulty with dense materials resulting in images that appear black with little contrast or definition. WIT's ability to image dense materials allows for the identification of discontinuities in sludge and cement density, such as shrinkage cracks, voids, and clumping. Free liquids can also be detected with WIT's ability to tilt a drum during NDE.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

NDE Technology

RTR is used to satisfy most NDE needs. A typical RTR unit consists of a conventional, constant current x-ray tube as a radiation source (420-450 kV), an image intensifier with an x-ray detection scintillation screen, and a video camera with six to eight-bits of dynamic range. RTR energies and dynamic range are designed to image lightweight matrices. The main difference between WIT and the RTR systems is the higher energy WIT c-ray source (2 MV) and WIT's x-ray detector with 18-bit dynamic range, which is designed to image both dense and lightweight waste matrices. Also, WIT’s DR CT provides slice-plane and 3-D volume imaging of drum’s content eliminating superpositioning (the overlapping of structures) with practical drum throughput and image resolution.

NDA Technology

The baseline technologies used to assay drums are SGS and gamma spectroscopy. SGS is typically used and is considered the baseline technique with a HPGe detector vertically segmenting a drum for assay. Another gamma NDA system is a tomographic gamma scanner (TGS). There are also neutron-based NDA systems. The main difference between WIT NDA and all of the other NDA systems is that WIT does not require calibration with known matrices and known gram amounts as WIT A&PCT is an absolute direct NDA measurement. All of the other gamma and neutron NDA systems mentioned provide relative measurements and require "acceptable knowledge" (AK) with apriori information about the waste to be assayed in order to calibrate on matrix and gram amount to provide a measurement.

Technology Applicability

WIT is capable of the following NDE and/or NDA inspections:

- drums of items whose volume is equal to or less than a 110 gallon drum;
- items weighing equal to or less than 1,600 pounds each;
- low-level, TRU, and mixed waste;
- all packaging types including metal drums, leaded drum liners, cemented lead shielding, steel pipe overpacks, metal drum overpacks, poly- or fiber-board liners, poly drum liners and poly bags; and
- all matrices including sludge, cement, metal, glass, plastics, and combustibles.

Patents/Commercialization/Sponsor

WIT A&PCT was originally developed by the LLNL. BIR has acquired a commercial license for the copyrighted A&PCT reconstruction code from the University of California. Additional information on LLNL’s development of A&PCT is available in a separate ITSR entitled Non-Destructive Waste Assay using Gamma Ray Active and Passive Computed Tomography (TMS ID 2123). BIR’s development of WIT was funded by the National Energy Technology Laboratory (NETL) formerly the Federal Energy Technology Center (FETC) through contract DE-AC21- 93MC30173.

Two invention disclosures are currently under patent attorney review for WIT NDE and NDA. The decision for “Patents Pending” has not been made as of the publication of this ITSR.

WIT’s participation in the RCI program was designed to accelerate private-sector technology commercialization and facilitate regulatory acceptance across state and federal jurisdictions. Under the RCI program, WIT has received a performance verification statement signed by US-EPA, DOE, DOD, Southern States Energy Board, Western Governors' Association, and environmental regulatory agencies of CA, CO, ID ,SC ,and WA.

SECTION 5
COST

Introduction

The high cost and safety concerns associated with destructive/invasive inspections has been the primary driver behind the development of non-destructive/non-invasive drum characterization technologies. Minimizing the need for invasive/destructive inspections has the greatest potential for reducing overall costs. WIT has the ability to accurately characterize drums that the baseline technology can not. This results in substantial cost savings and reduced human exposure to radioactive materials. For the purpose of this cost analysis, the baseline technology for NDE is considered to be RTR and the baseline technology for NDA is SGS. WIT's cost advantages include the following:

- WIT provides cost savings by minimizing the need for invasive inspections
- WIT provides accurate waste characterization resulting in disposal cost savings

WIT Provides Cost Savings by Minimizing the Need for Invasive Inspections

- Costly visual inspections are required when the baseline NDE technology, RTR, can not effectively image drums with dense packaging or dense contents.

- WIT's high powered 2 MV x-Ray NDE system with CT has demonstrated the ability to produce accurate images of dense matrices.

- Invasive coring and laboratory analysis is required when the baseline NDA technology can not effectively quantify the radioactivity of dense drum contents.

- WIT's A&PCT NDA has demonstrated the ability to quantify the radioactivity of dense matrices, even at very low levels.

WIT Provides Accurate Waste Characterization Resulting in Disposal Cost Savings

- The baseline NDA technology often can not accurately differentiate LLW drums from TRU waste drums, especially for dense matrices.

  - Waste drums with alpha activity below 100 nCi/g are classified as a LLW.
  - TRU waste is characterized as having a total alpha activity greater than 100 nCi/g.
  - The disposal cost for LLW is much less than that for TRU waste

- WIT's low detection limit can accurately differentiate between TRU waste and LLW for dense matrices resulting in reduced disposal costs.

Methodology

The following cost analysis will compare WIT to the baseline NDA and NDE technologies for the characterization of 20,000 waste drums. The cost analysis is based on a hypothetical scenario that is representative of a DOE site with a large inventory of TRU waste drums, e.g. INEEL and RFETS. The cost comparison is not meant to be a comprehensive and detailed cost assessment, but rather a generalized analysis that will attempt to show how WIT can provide substantial cost savings at a typical DOE site. The WIT costs were provided by the technology developer and are based on the assumption that WIT is provided as contracted service with support labor from the site. Actual site costs for the baseline RTR and SGS could not be obtained, therefore estimated cost were applied based on input from the technology developer of WIT. Actual site costs for invasive visual drum inspection and repackaging were provided by a representative from Bechtel Nevada, the Maintenance and Operations (M&O) contractor for the DOE Nevada.

To illustrate the potential cost savings from utilizing WIT, the following hypothetical scenario will be considered:

- 20,000 TRU waste drums to be characterized at a DOE site; and
- 40% of these drums contain dense contents or have dense packaging

It is assumed that the baseline technologies will fail to accurately characterize the drums that contain dense matrices and these drums will require invasive inspection and characterization.

Cost Analysis

The unit costs for WIT, the baseline technologies (RTR and SGS), and invasive inspections are presented below. These costs are then applied to the scenario presented above and summarized in tabular form.

WIT costs

- WIT characterization services (NDA or NDE) $300-700 per drum ($500/drum average)

Assumptions:

- WIT will be provided as contracted service and the host site will provide support labor (included in cost above);
- The cost above does not include mobilization/demobilization; and
- WIT can accurately characterize all waste drums.

Baseline Costs

- NDE by RTR $300/drum(approximately)

- NDA by SGS $300/drum(approximately)

Invasive/Destructive Inspection Costs

- Visual Inspection $5,200/drum
  (glovebox dismantle and repackaging of 85 gallon overpacked drum)

Cost provided by Bechtel Nevada based on semi-annual budget review to DOE Nevada.

Cost Calculations for WIT vs. Baseline Technology

Tables 5 and 6 below summarize the costs for WIT and the baseline technologies respectively, applied to the given scenario. Note that the unit costs used in the calculations below are medians of the unit cost ranges presented above.

Table 5. WIT costs

Description	Quantity of Drums	Unit Cost	Total ($)
WIT NDA	20,000	$500	$10,000,000
WIT NDE	20,000	$500	$10,000,000
		Total	**$20,000,000**

Table 6. Baseline costs

Description	Quantity of Drums	Cost per Drum	Total Cost
Inspection by RTR	20,000	$300	$6,000,000
Inspection by SGS	20,000	$300	$6,000,000
Invasive inspection (40% of drums)	8,000	$5,200	$41,600,000
		Total	**$53,600,000**

Cost Conclusions

In the scenario presented above, the total cost for characterization of 20,000 drums by WIT would be $20 million dollars, assuming WIT could accurately characterize the entire inventory of drums. Overall characterization costs for the same drums by the baseline technologies (RTR and SGS) would be in excess of $53 million, assuming that 40% of the drums would require invasive/destructive inspection. Therefore, utilization of WIT has the potential to provide greater than 50% cost reduction.

Under the scenario above, WIT could "break even" with the baseline if only 8% of the drums (1,600 drums) were dense and could not be characterized by the baseline, thus requiring invasive/destructive examinations. WIT has the potential to provide greater cost saving at sites like INEEL, where dense matrices are reported to make up greater than 50% of the inventory.

Additional cost savings could be provided by minimization of invasive coring and radiography, which is required when the baseline SGS can not successfully assay dense drum contents. Cost saving could be realized by WIT's ability to differentiate LLW drums from TRU drums.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

- WIT complies with the DOE TRU Waste Acceptance Criteria (WAC) for NDE/NDA.
- The use of WIT will be primarily affected by the terms of the operating permit issued to WIPP. The WAC and QAPP contain specific requirements for any technology used to assay and categorize drummed wastes destined for WIPP.
- WIT currently has a National Environmental Policy Act (NEPA) Categorical Exclusion.
- The use of radioisotopic sources onboard WIT required that a Nuclear Regulatory Commission (NRC) license be issued.
- BIR has a State of Illinois license approved by the NRC for sealed isotopic sources, up to 15 mCi each. WIT has only one NRC licensable source, which is Europium 152.
- BIR is required to register the 2 MV x-ray source with the state of Illinois once title and ownership of the WIT system transfers to BIR from DOE.
- BIR has notified each state that WIT is operating and is indeed mobile and temporary. This has typically been done when WIT is operating at a non-DOE or non-Federal site.
- The demonstration of WIT at the INEEL did not require any special permitting requirements at the state or federal level. There were a number of site-specific procedures and policies that had to be adhered to, but these are not expected to be an issue at other sites
- A WIPP-related draft Hazardous Waste Act permit from the state of New Mexico states that dense drum matrices shall require invasive visual examination due to the imaging limitations of the baseline RTR. However, WIT has demonstrated its capability to image dense matrices including sludge at the maximum diameter of the sludge. BIR has petitioned New Mexico to consider WIT's capabilities in a modified permit. New Mexico is expected to approve new language allowing use of WIT.

Safety, Risks, Benefits, and Community Reaction

The WIT system does not pose any risks to the community, any individual in the community, nor the environment. The issues of concern center on the radioactive sources used in the subsystems and on the hazardous nature of the wastes in the drums being scanned. WIT developers have health and safety procedures in place to minimize the possibility of injury to the operators. It is unlikely that the technology will have any measurable economic impact on the community or labor force.

SECTION 7
LESSONS LEARNED

Implementation and Technology Selection Considerations

- WIT has demonstrated its ability to meet the NDE/NDA requirements of the WIPP WAC for a wide variety of TRU waste matrices.
- WIT can be deployed in parallel with existing site capabilities to save new facility construction costs while utilizing and retraining existing site personnel as WIT operators. Presenting WIT as a supplemental service can effectively increase the site's NDE/NDA throughput while providing characterization of difficult matrices not achieved with baseline methods.
- WIT’s cost effectiveness increases with the number of drums to be inspected at a site. Typically, a minimum of 20,000 drums is required for WIT to be economically feasible. This is also true for other mobile drum inspection vendors.

Technology Limitations and Needs for Future Development

- In 1999 the WIT NDA system was upgraded from a single HPGe detector system to a six-detector system. The single detector system was criticized for being too slow. The new six-detector system has increased speed while maintaining accuracy.
- In some cases WIT’s advanced capabilities have not been considered by regulatory agencies. For example, the draft hazardous waste permit for WIPP requires lead-lined or dense matrix drums to be visually examined due to the limitations of the base-line RTR x-ray technology. WIT's 2 MV x-ray computed tomography system can penetrate lead-lined or dense matrix drums, eliminating the need for visual inspection.
- WIT’s A&PCT NDA system is a gamma-ray based technology, therefore it cannot quantify isotopes that do not emit gamma rays. The CAO requirement to report ^{90}Sr, a pure beta emitter cannot be measured by WIT NDA. However, an upper limit of ^{90}Sr can be established based on the quantity of ^{137}Cs detected.

APPENDIX A
REFERENCES

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APPENDIX B
NDE IMAGES

Selected NDE Images

Figure 4. WIT 2 MV tilted 60 sec. DR (above left) and 2 MV 8 sec. 10 mm slice CT (above right) from NTS consisting of a solidified sludge filled inner double wall poly drum set in solidified cement inside the outer steel walled 55-gal. drum. The sludge in the inner drum is not mixed well with non-uniform mass attenuation (white and gray areas) indicated in the CT slice at the right. The sludge also has spatial variations with cracks and porosity indicated, where the cement in the outer drum appears uniform. This TRU drum was rejected because the sealed inner drum was greater than 4 liters.

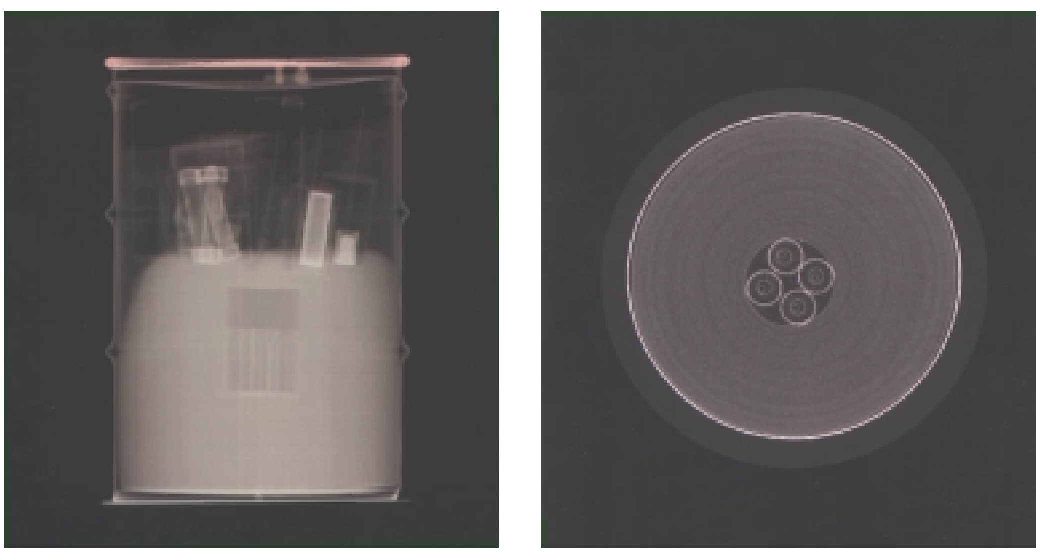

Figure 5. WIT 2 MV 60 sec. DR (above left) and 2 MV 8 sec. 10 mm slice CT (above right) from NTS consisting of discarded laboratory isotopic sources, fixed in a cement solidified drum with a poly liner and inner lid. The CT slice is through the isotope sources in the inner cemented container indicating four separate isotopic sources. WIT NDA spectroscopy identified the isotopic sources as ^{60}Co, ^{137}Cs, ^{249}Cf, ^{243}Cm and ^{241}Am. This drum was rejected because its content code of sludge was incorrect.

Figure 6. Above is a WIT 2 MV DR of a TRU drum from LLNL that has a 5-gal. cemented can containing 20 g ^{239}Pu in addition to other cemented waste forms. Also, an empty bottle is evident in the lower right hand corner. RTR could not see through the 5-gal. can of cement to see the Pu.

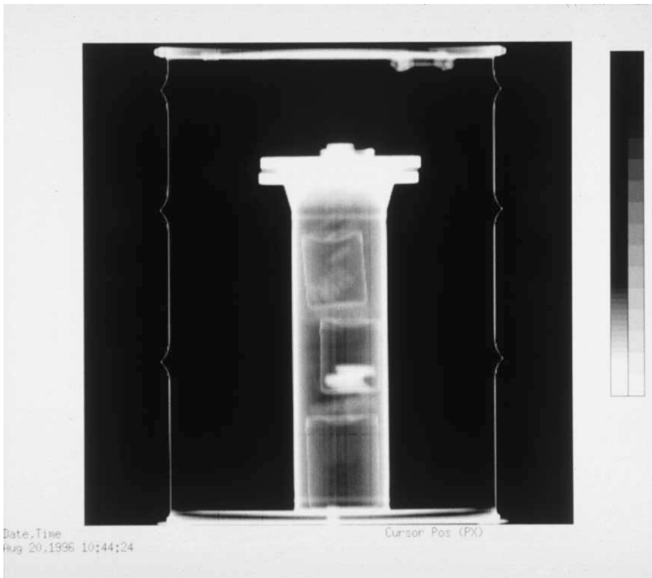

Figure 7. Above is a WIT 2 MV DR image of a steel pipe overpack in a 55-gal. drum from RFETS. The pipe contains three “coffee” cans; one is empty, one contains plastic bags, and one contains three aluminum plates. Because of the thick walled steel pipe, RTR would have imaging difficulties with this drum.

APPENDIX D
ACRONYMS AND ABBREVIATIONS

A&PCT	Active and Passive Computed Tomography
AK	Acceptable Knowledge
BIR	Bio-Imaging Research, Inc.
CAO	Carlsbad Area Office
CEP	Capability Evaluation Program
CGS	Collimated Gama Scanning
CT	Computed Tomography
DOE	Department of Energy
DR	Digital Radiography
EM	Environmental Management
Eu	Europium
FETC	Federal Energy Technology Center
HLW	High Level Waste
HPGe	High Purity Germanium
INEEL	Idaho National Engineering and Environmental Laboratory
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LLW	Low Level Waste
M&O	Management and Operating
MDC	Minimum Detectable Concentration
MOU	Memorandum of Understanding
MV or MeV	Million Volt (or Millions of Electron Volts)
MWFA	Mixed Waste Focus Area
nCi/g	Nanocurie per Gram
NDA	Non-destructive Assay
NDE	Non-destructive Examination
NETL	National Energy Technology Laboratory
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
PDP	Performance Demonstration Program
PMT	Photo Multiplier Tube
Pu	Plutonium
QA	Quality Assurance
QAO	Quality Assurance Objective
QAPP	Quality Assurance Program Plan
RCI	Rapid Commercialization Initiative
RFETS	Rocky Flats Environmental Technology Site
RSD	Relative Standard Deviation
RTR	Real-Time-Radiography
SBIR	Small Business Innovative Research
SGS	Segmented Gamma Scanning
SPECT	Scanning and Single Proton Emission Computed Tomography
SRS	Savannah River Site
TGS	Tomographic Gama Scanner
TMU	Total Measurement Uncertainty
TMS	Technology Management System
TRU	Transuranic
VR	Volume Rendering
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WIT	Waste Inspection Tomography
WITCO	Waste Inspection Technology Company, A division of BIR, Inc