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WASTE INSPECTION TOMOGRAPHY (WIT)

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DISCLAIMER

2.2 Waste Inspection Tomography (WIT)

CONTRACT INFORMATION

Contract Number	DE-AC21-93MC30173
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Contract Program Manager	Richard T. Bernardi
Principal Investigators	Richard T. Bernardi Kyung S. Han, Ph.D.
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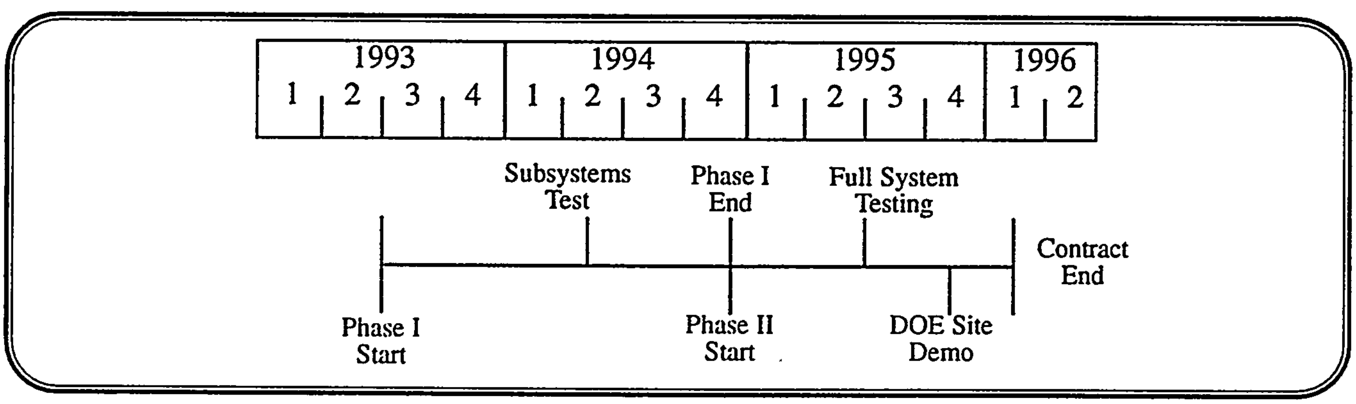
Period of Performance	June 22, 1993 to December 22, 1995

Schedule and Milestones



OBJECTIVES

The WIT program will provide an inspection system that offers the nuclear waste evaluator a unique combination of tools for regulatory-driven characterization of low-level waste (LLW), transuranic waste (TRU), and mixed waste drums. WIT provides nondestructive, noninvasive, and environmentally safe inspections using x-ray and gamma ray technologies, with reasonable cost and throughput.

BACKGROUND INFORMATION

X-ray imaging is an established method for waste container inspection. However, the technique generally used, real time radiography (RTR), has limited density discrimination and does not provide much information about the contents of dense objects such as cement-solidified drums. The RTR system couples a TV camera to a two-dimensional, light-producing x-ray detector, and thus provides a TV image that is viewed on a monitor during x-ray exposure. The dynamic range of such a system is usually from 6 to 12 bits (64 to 4096 gray levels in the image), meaning that contrast resolution in a single exposure is very limited. Also, no quantitative evaluation of the image is possible, since it is not in digital form.

Emerging technologies for nondestructive evaluation (NDE) of low level, transuranic, and mixed nuclear waste include x-ray computed tomography (CT) and digital radiography (DR). The solid-state detectors used in CT/DR imaging have enough dynamic range to provide contrast sensitivity approaching 12 to 16 bits (up to 65,536 gray levels). The higher the dynamic range, the greater the advantage in examining denser waste forms such as a grout matrix. In CT, x-ray data are collected through a thin plane of the object, using a linear detector array, while the object rotates in the x-ray beam. The data are then mathematically combined to form a cross sectional image of the irradiated plane. In DR, the object is moved past the linear detector array while projection data are collected a line at a time. The lines are then displayed as a two-dimensional projection image.

Two emission imaging techniques will be employed for characterizing materials in waste containers. The first of these is gamma emission tomography, commonly called single-photon emission computed tomography (SPECT). Rather than using an external radiation source, SPECT uses the emission of radioactive materials within the object of interest for imaging. In this case, emission from actual nuclear waste within a container will provide a three-dimensional image of the radioactive substances in the container.

The second emission technique will use high-purity germanium detectors for gamma ray spectroscopy. This technique, called nondestructive assay (NDA), can identify the emitting isotopic species and strength. Work in emission tomography and assay of nuclear waste has been undertaken at Lawrence Livermore National Laboratory using a technique called Passive Tomography.

PROJECT DESCRIPTION

Waste Inspection Tomography (WIT) is a research, development, and demonstration project funded by DOE to develop CT NDE/NDA capability for characterizing drums of low-level waste (LLW), transuranic (TRU) waste, and mixed nuclear waste. WIT combines three characterization technologies on a mobile trailer platform to identify drum content. The WIT inspection system includes a transmission CT imaging system with a 2 MeV x-ray source and a linear array of solid-state detectors of cadmium tungstate crystals. The CT system produces two-dimensional axial images through the drum, which can be viewed as an image stack for precise three-dimensional display of the drum's internal structure. The CT system can also be used for two-dimensional projection imaging in a technique known as digital radiography.

The WIT single photon emission computed tomography (SPECT) system uses large area sodium iodide crystals in two-dimensional detector arrays for locating the position of gamma-ray emissions within a drum. SPECT can provide slice views as well as two-dimensional projection images. Energy-sensitive gamma ray spectroscopy with a high efficiency, high purity germanium (HPGe) detector identifies the emitting gamma-ray isotopic species and its activity level on the outside of the drum.

RESULTS

The following images are examples of ongoing WIT development and recent experimental results designed to demonstrate CT and SPECT capabilities. Figures 1, 2, 4, and 5 show experimentally acquired images of phantoms that simulate nuclear waste in a 55 gallon drum with gamma ray emission. Figures 3 and 6 are 2x zoomed images that fuse transmission with emission images in the projection and slice modes, respectively.

Figure 1 is a 2 MeV transmission DR projection image of a 55 gallon drum phantom. Clothing in the top layer simulates low density combustible waste. Cans of liquid as well as rods of metal and plastic in the mid-section simulate higher density heterogeneous waste. Cement in the bottom part of the drum simulates solidified high density waste in a grout-type matrix. Hollow Plexiglas tubes penetrate all levels of the drum for insertion of isotope phantom test samples at any layer.

Figure 2 is a series of 16 gamma emission projection images taken every 22.5 degrees of rotation from a centered radioactive test source. The emission source was ^{133}Ba with a 360 kV peak and 250 microcuries of activity. The window used was 30% and the integration time was 1 minute for a single view. Shorter data collect times are possible.

Figure 3 is a 2x zoom of Figure 1 with fusion of a single view from Figure 2. This fused image shows the emission source in line with the center Plexiglas phantom tube within the 55 gallon drum. The dots, more apparent in this zoomed mode, are the locations of actual photon counts, which are denser near the actual emitting source location.

Figure 4 is a 2 MeV transmission CT slice 10 mm thick through the combustible upper level of the drum from Figure 1, with a 1024 x 1024 reconstruction. The Plexiglas tubes are evident, as is the clothing.

Figure 5 is a SPECT reconstruction 10 mm thick with a 256 x 256 image showing the ^{133}Ba radioactive emission location.

Figure 6 is the data fusion result of combining the transmission CT data with the emission SPECT image. The narrowed window and scaled data used in Figure 6 show progressive bands of counting statistics near the emission source. The dots in the fused image are air overflow artifacts from the transmission CT reconstruction.

Figure 7 shows a zoomed CT image of a section of a drum wall that has been thinned to simulate corrosion and imminent leakage.

Figure 8 is a volume display of transmission CT data taken from a drum phantom built by Lawrence Livermore National Laboratory. Three-dimensional visualization software has been used to cut away the front portion of the drum to reveal its internal structure.

Figure 9 is a fused volume display of emission and transmission CT data of a drum phantom built by BIR. In the center of the large tube in the top layer is a ^{133}Ba source with an activity of 250 μCi.

Figure 10 shows the results of an experiment using active and passive CT to measure internal radioactivity from a mock 55 gallon waste drum.

Figure 11 is a photograph of the trailer housing the WIT inspection system. The trailer includes the 2 MeV CT/DR system as well as the equipment for SPECT and spectroscopy inspection. An operator's room contains all the necessary computing and image analysis facilities for waste container inspection.

These early results illustrate the visualization capabilities possible with fusion of transmission and emission images from computed tomography and projection radiographic imaging. The WIT system's combination of inspection technologies lets inspectors choose an appropriate level of characterization for each site or waste container.

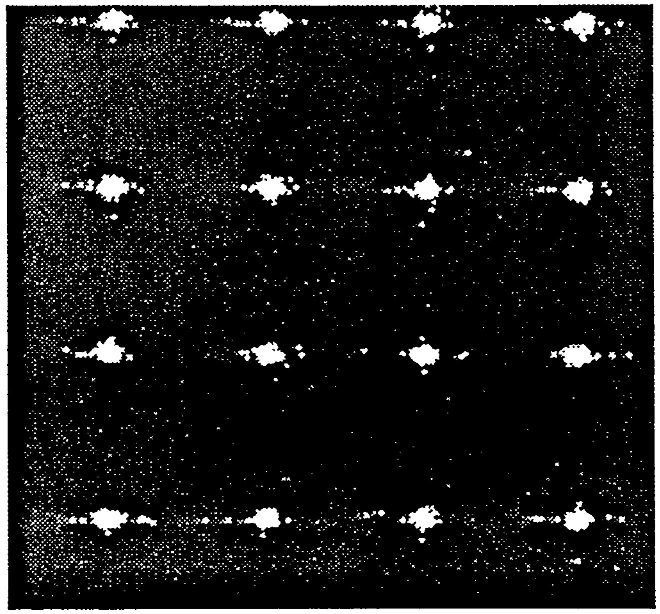


Figure 2. This photograph shows 16 views of a ^{133}Ba gamma emission with the gamma source rotating 22.5 degrees between views.

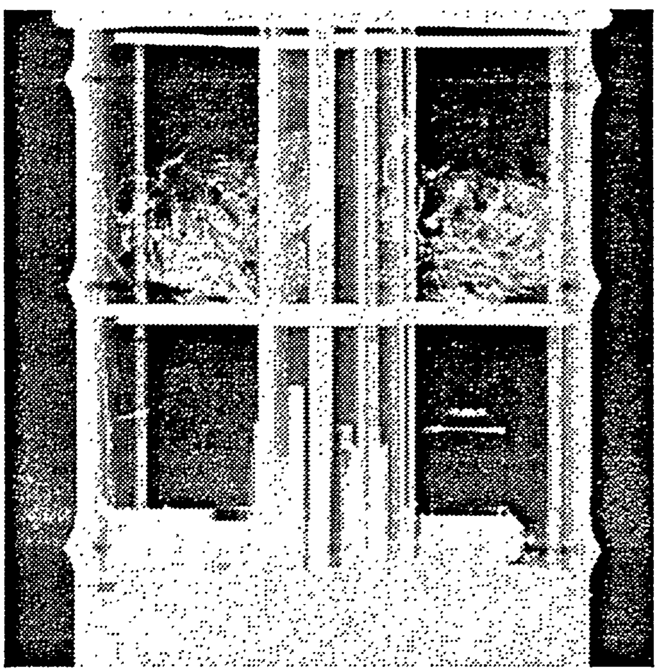


Figure 1. This is a 2 MeV digital radiography (DR) image of a 55 gallon drum phantom, showing clothing in the top section and aerosol cans and high density objects in the lower section. The center is an assembly of Plexiglas tubes used for inserting radioisotopes for emission imaging.

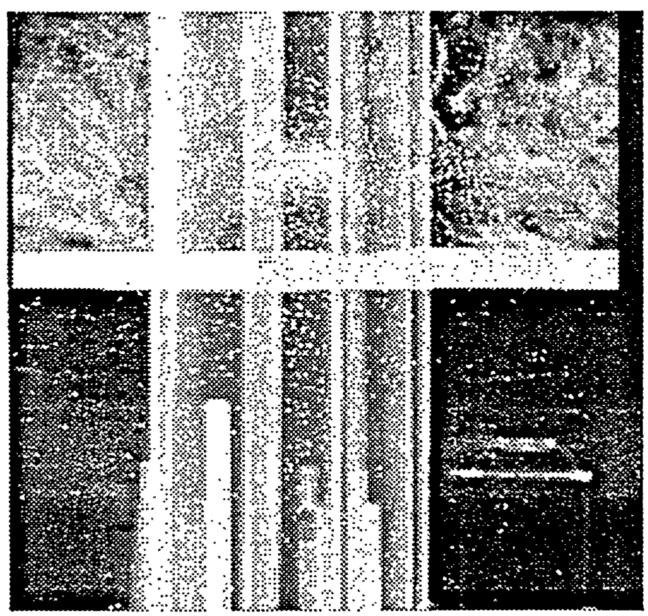


Figure 3. This is a 2x zoomed DR image of the drum phantom fused with a single gamma emission view, shown by the dots indicating photon counts.

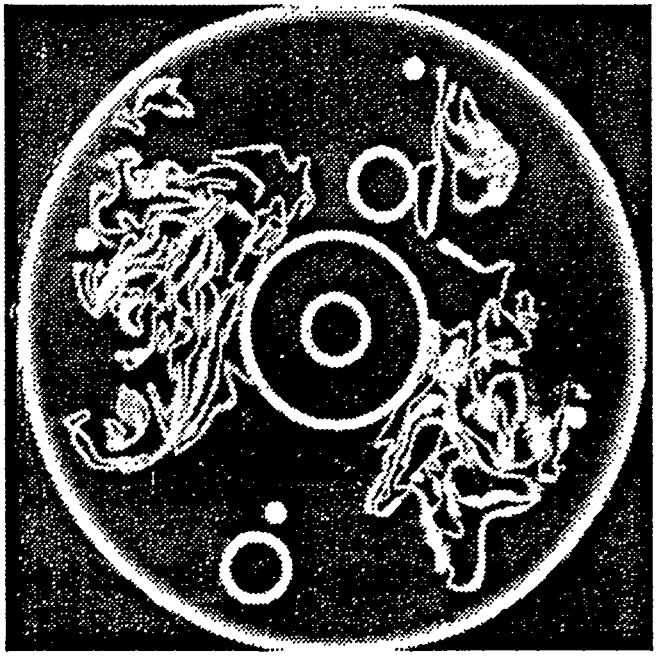


Figure 4. This is a 10 mm thick CT slice, taken with 2 MeV x-ray energy, of the upper level of the phantom drum.

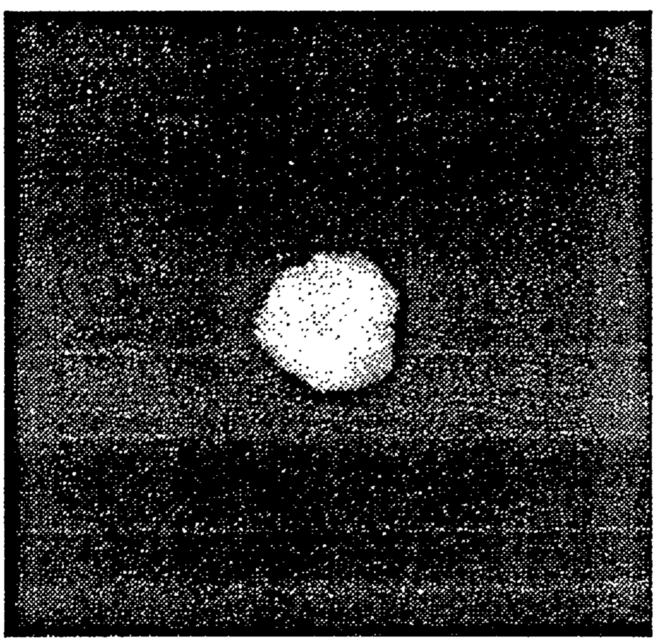


Figure 5. This is a 10 mm thick SPECT image slice of the ^{133}Ba radioisotope.

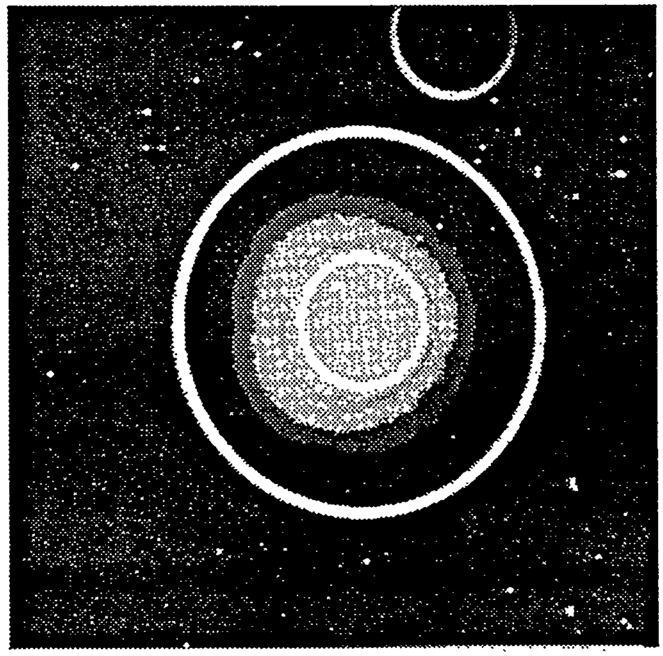


Figure 6. This is a fused display of the CT image and the SPECT image showing the location of the ^{133}Ba. The image is zoomed 2x.

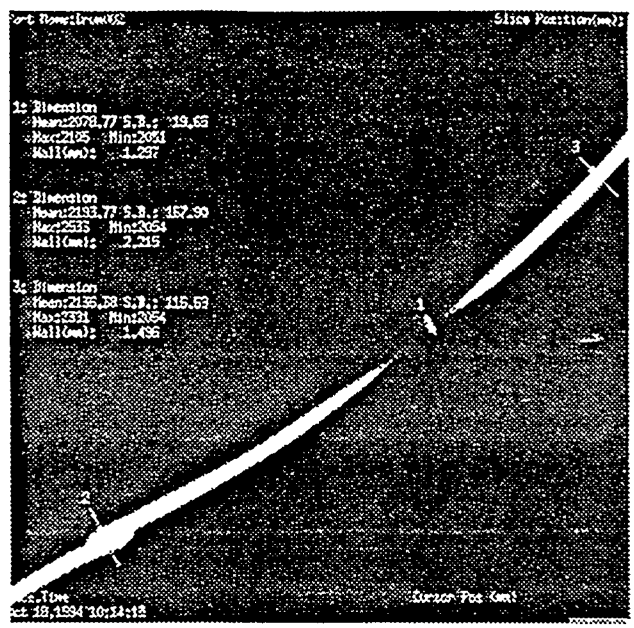


Figure 7. This zoomed CT image shows a thinned section of a drum wall, where potential corrosion could lead to leaking of fluids from the drum. The weld bead in the drum is also visible.

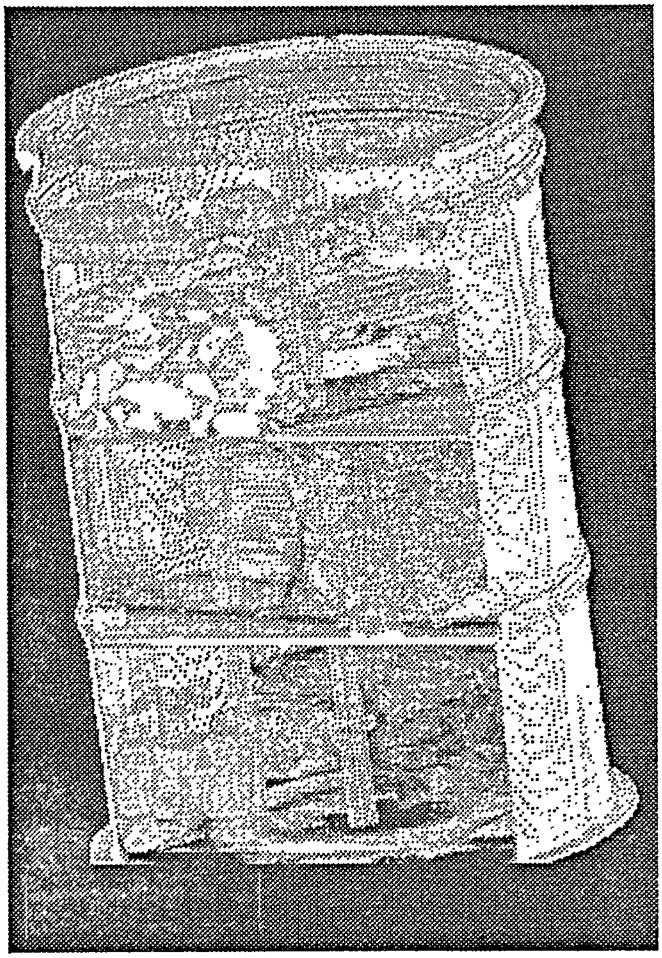


Figure 8. This is a volume display of transmission CT data taken from a drum phantom.

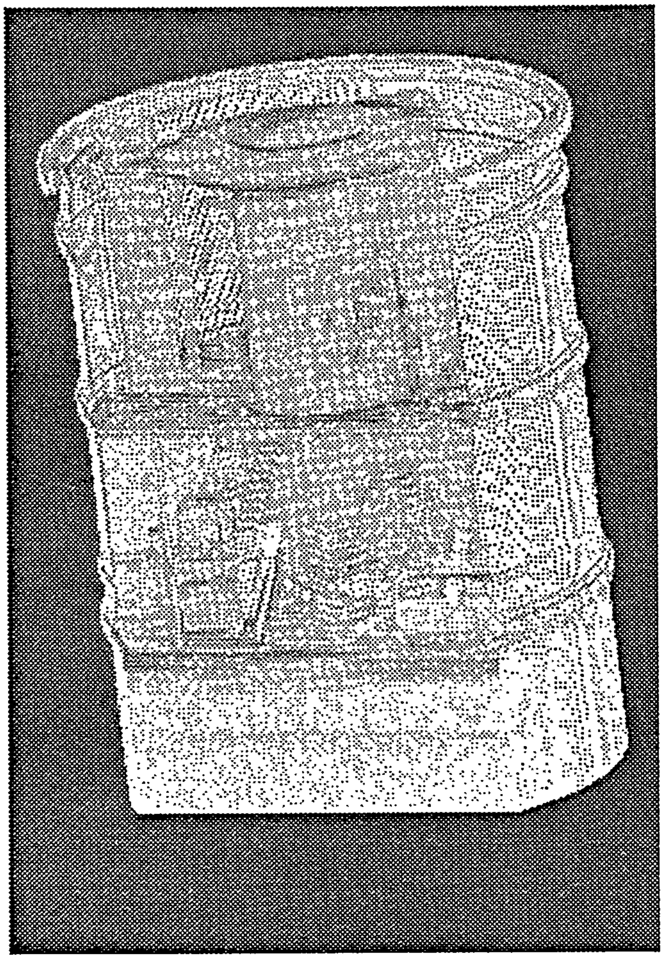
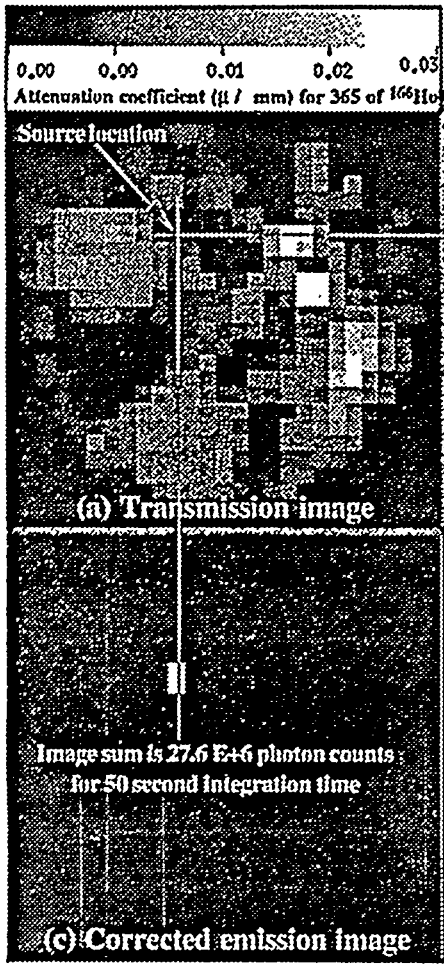
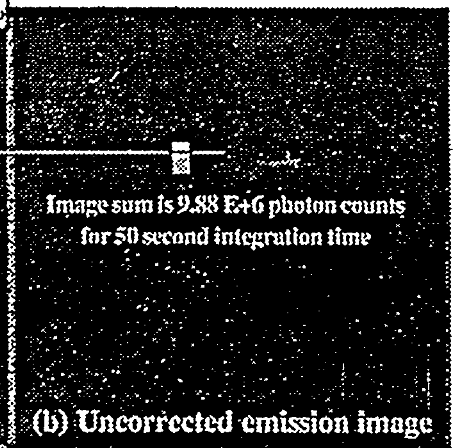


Figure 9. This is a fused volume display of emission and transmission CT data of a drum phantom. A barium 133 source is visible as a white sphere in the tube at the top of the drum.





Midsection of TRU drum with roughly 65% average attenuation for 356 peak of ^{133}Ba emission source

	Activity	Photon Counts	Error
Ideal	68.2 μCi	26.19 E+6	
Measured	71.9 μCi	27.6 E+6	+5.4%

Figure 10. These images and the table show active and passive CT determination of measured internal radioactivity from a mock 55 gallon waste drum.

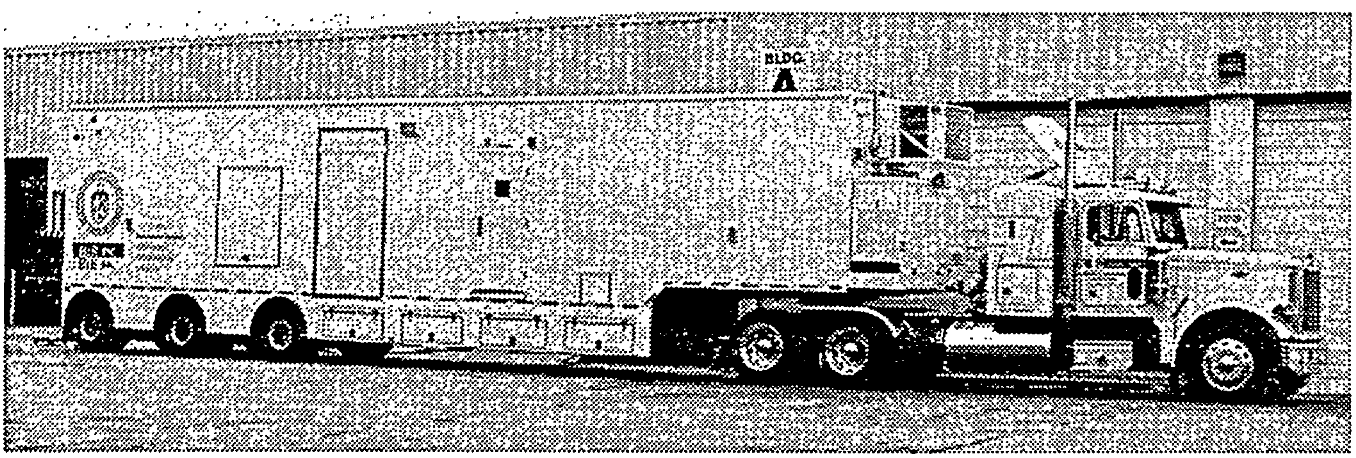


Figure 11. The photograph shows the WIT trailer designed and built during Phase I.

FUTURE WORK

The WIT system is currently being fabricated at BIR's facility in Lincolnshire, IL. After system integration and testing, the trailer will be driven to three sites for demonstration and evaluation, which will continue through December 1995. The three sites are Lawrence Livermore National Laboratory, the Idaho National Engineering Laboratory, and the Savannah River waste processing site. The demonstrations will involve characterization of real waste to validate the system's ability to identify contents of containers and to verify system throughput.