# Application of Robotics and X-ray Radiography to the Examination of Large Contact Handled Transuranic (TRU) Waste Containers

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## ABSTRACT

The US Department of Energy, Savannah River Site is storing a large number of transuranic (TRU) waste containers that are to be shipped to the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. Radiographic examination of waste containers is required prior to shipment. This paper will discuss the TRU waste container positioning system and safety system provided by PaR Systems, Inc., Shoreview, MN, to the inspection system prime contractor, Hytec, Inc., Los Alamos, NM.

Most containers will be over-packed in large metal shipping containers (TRUPACT-III). The largest containers are 2.8 m x 1.9 m x 1.9 m and weigh 5600 kg. In addition, smaller containers and drums are inspected. The containers are manipulated to view the contents from various directions. The motions of the container, X-ray source and X-ray detectors are coordinated to obtain a constant viewing area relative to the item of interest in the container.

## INTRODUCTION

DOE, Savannah River Site, has over 2000 containers to be shipped to the Waste Isolation Pilot Plant (WIPP) in Carlsbad New Mexico. These containers include wooden boxes, drums, concrete containers, and various small metal containers. The largest containers are 2.8 m x 1.9 m x 1.9 m and weigh 5600 kg.

The containers will be radiographically inspected prior to shipment. To avoid opening the containers and the accompanying contamination, the containers will be X-rayed to determine the contents. In addition to identifying the contents, the system will ensure that all aerosol containers have been punctured to relieve pressure. Shipping of containers containing more than 3% liquid is prohibited.

A separate system will use radiation spectrographic analysis to determine the amount and type of transuranic material. That system will not be addressed in this paper.

PaR Systems, Inc. supplied the positioning system to HYTEC, Inc. HYTEC is the prime contractor and supplies the X-ray source, imaging equipment, imaging software, supervisor controls, safety systems and overall systems integration.

## SYSTEM REQUIREMENTS

The system must perform a cursory scan of the entire container and a then subsequent higher resolution scans of areas of interest. To provide adequate imagery of items of interest, a second detector must image a small area at high resolution and real-time rates.

The positioning system must manipulate the 5600 kg container in four axes to view contents at various viewing angles. The system must accommodate a range of container sizes and shapes.

The system is designed to be relocated to other sites. While some modifications and additions to the facilities are necessary, facility modifications are to be kept to a minimum. Figure 1 is a photograph of the actual system. Figure 2 provides system side and plan views.

To verify that containers do not contain more then 3% liquid, it is necessary to detect 3 tablespoons of liquid in a one gallon container. The container must be accelerated at 0.25 G in order to agitate the fluid while it is being viewed in real-time.

The motion of the X-ray source, the container, and the high resolution detector must be coordinated. This ensures that the item of interest remains in the viewing area as the container is manipulated.

The positioning system must be rigid enough to reduce any vibration to a level that will not affect image quality.

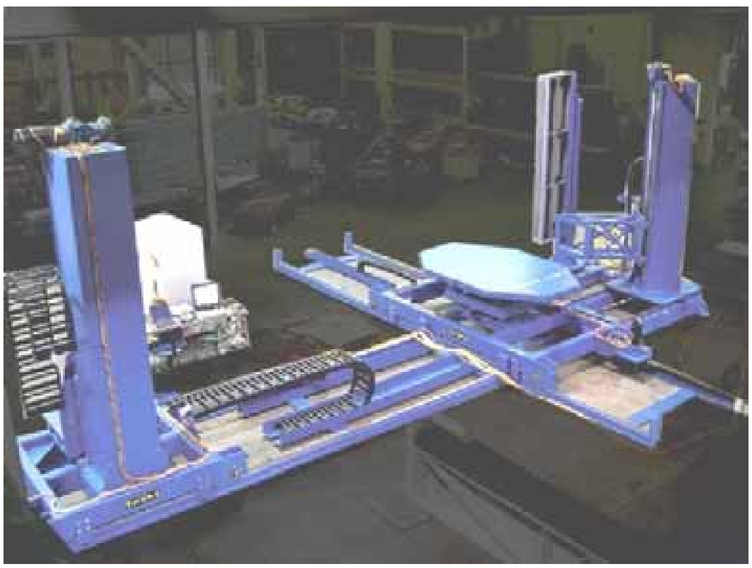

**Fig. 1. TRU Waste container positioning system**

## CELL DESCRIPTION

The equipment is located in one of 12 unused bays in a low level waste repository at Savannah River Site. Each of the 12 bays is 42 m x 15 m x 5.8 m high. One end wall is to be poured after the bay is filled and therefore is not currently in place. The walls are approximately 1 m thick concrete. The positioning system and source are located in the second bay. The source is directed so that the wall between the bays and the outside wall of the adjacent bay serve as the backstop.

The back wall has two small access holes used for ventilation. The cabling from the positioner and X-ray system passes through those holes to two trailers outside the cell. One small trailer contains the power supply for the X-ray source and other system electronics.

The second trailer contains the positioner power center, and the imaging control system, and the operator controls. The operators are seated at a console with the various monitors and controls.

The floor of the bay is sloped. Since the positioner is designed for use at other sites, its mounting pads are level. A sloped support structure beneath the positioning system is therefore used to create level surface upon which the positioning system sits. This support structure incorporates jacking screws to level the positioning system's rails.

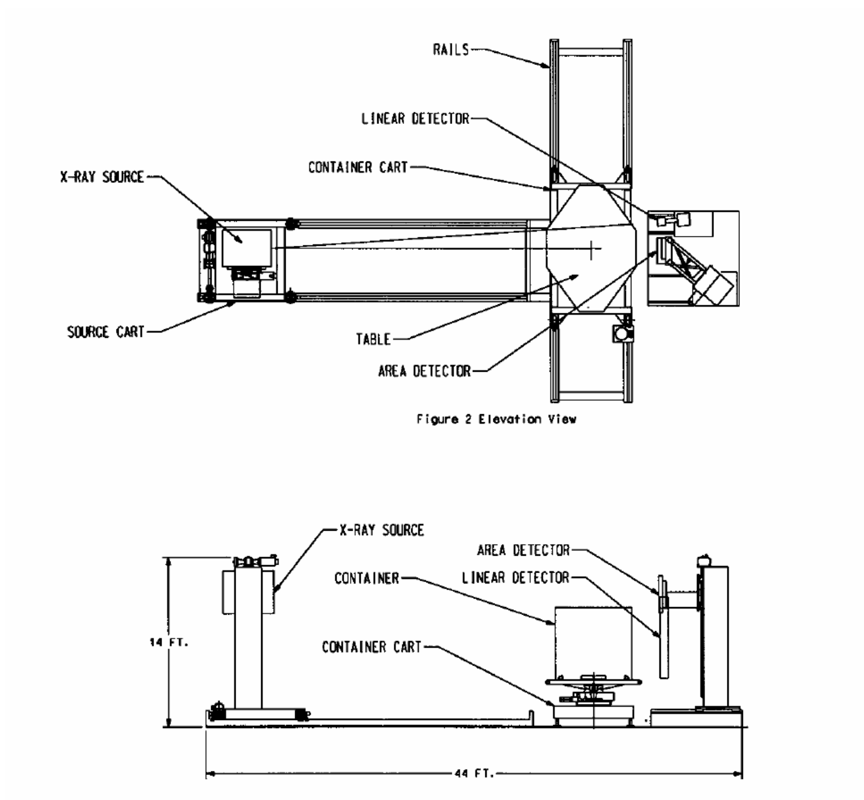


**Fig. 2. System side and plan view**

## Positioning System

The positioning system includes:

- Rail system
- Source cart and column
- Container cart

- Detector base and columns
- Control system

The rail system supports both the X-ray source cart and the container cart. The source cart moves the 3 MeV linear accelerator head (X-ray source) vertically to align with the target area and horizontally to vary the distance from the target area. The container cart supports the container being X-rayed, provides a transverse motion and includes the rotate and pivot motions to manipulate the target area. The detector base includes two columns, which support both the linear and area X-ray detectors. These columns move horizontally to vary the distance to the target area. The area detector moves vertically to align with the target area.

**Rail System**

The rails are arranged in a "T". One section supports the container cart and the other supports the source cart and column. The rails are composed of simple rectangular rail with protrusions that engage the hold down brackets on the carts and gear racks used to drive the carts. The footprint of the assembled system is approximately 12 m x 12 m.

The two rails for one cart are connected by bars welded in place. This ensures the alignment of one rail to the other and simplifies installation. The end of the source cart rail is bolted to the container cart rail. The detector base is bolted to the container cart rail. This ensures the alignment of the three structures and simplifies installation. The two rail systems also support trays which guide the carts' cable tracks.

**X-Ray Source Cart and Column**

The source cart incorporates wheels that ride on the rails. The lateral position is controlled by guide rollers on either side of the rails. The cart is driven by a motor reducer and pinion gear which meshes with the gear rack. The drive assembly is mounted on a linear bearing to allow it to float and accommodate the rail's inaccuracies. A cam follower holds the pinion in engagement with the gear rack. Hold down brackets attached to the cart engage protrusions on the rails and prevent overturning in case of an accident.

The source is mounted on a carriage, which in turns moves vertically on the column. Rails on the column and linear bearing slides on the carriage guide the source. The elevator motion is provided by a recirculation ball screw, gear reducer, and motor. The elevator drive uses redundant brakes as an accidental drop of the source would cause significant damage.

The 3 MeV linear accelerator is shielded to reduce the radiation emitted, which increases its weight to 4000 kg. A movable two position collimator is mounted on the front. In the position used for the area detector, the beam is approximately 250 mm square and directed straight ahead. In the position used for the linear detector, the beam is approximately 15 mm wide and 2000 mm tall and at a $5^0$ angle.

**Container Cart**

The container cart uses a similar wheel, drive and rail system to that of the source cart, but has a longer wheel base. A shear-ball turntable bearing is mounted on top of the cart and supports the cart table and pivot drive. A rotating mechanical stop allows full $360^0$ rotation. The table rotates about a vertical axis by means of a motor reducer and pinion driving a bull gear integral with the turntable bearing. The pivot axis is mounted on top of the rotate axis and is driven by a lever arm, ball screw, motor and reducer.

The table is a rectangle approximately 2800 mm by 1900 mm. A section of each corner is removed to allow rotation when the ADA is cantilevered over the table to inspect small containers. Sockets and pins on the edge of the table restrain large containers. Angle stops with tie down eyes are bolted to the table at multiple locations to restrain smaller containers. Straps attached to the various tie down eyes and passing over the containers will prevent tipping.

**Detector Base and Columns**

The detector base is bolted to the container cart rails to ensure its alignment and ease installation. The area detector column and the linear detector column are both mounted on linear bearing slides driven by balls screws and motors. The linear detector is mounted to a column at a $5^0$ angle and aligned with the X-ray source beam. Since the beam alignment is achieved at only one position, the linear detector slide has only retracted and extended positions and is not coordinated with the other axis.

The area detector moves vertically on a carriage. The column and elevator drive is similar to that of the source column. The column is orientated at a $45^0$ angle and the area detector is cantilevered by means of a lattice structure. This reduces X-rays reflecting off the column and support back to the area detector and affecting the image.

Each of the area detector and linear detector are protected by a continuous ring of contact ribbon switch surrounding the detectors. The switches trigger an emergency stop when activated. The ribbon switches are compliant to allow over travel as the system decelerates to a stop.

**Control System**

The positioning system is controlled by a PaR Systems CIMROC$^{tm}$ robot controller. Position sensing is achieved by motor mounted encoders. All axes are equipped with brakes, end of travel limit switches, and mechanical stops.

When the container is rotated to view an object of interest at different angles, the container cart must move to keep the object of interest in the viewing area. When it is pivoted, both the area detector elevator and the source elevator must move to keep the object in the viewing area. In either case, to achieve a constant magnification, the source cart and the area detector slide must move to remain at a constant distance from the object of interest. Therefore seven axes (the area detector slide, area detector elevator, container cart, table rotate, table pivot, source cart, and source elevator) all must be coordinated.

Since the two elevators must always be at the same elevation, the area detector elevator is slaved to the source elevator and essentially becomes one axis. This reduces the coordinated axes and removes the possibility of singularities. A singularity occurs when there are multiple solutions to positioning the "end of arm" at a particular point and orientation.

The mechanical configuration creates some challenges. Normally, a robot control system coordinates multiple axes to place a single end effector at some point is space at some orientation. This system has three entities, source, area detector, and table that are coordinated to achieve alignment and relative distances. In addition to the motion control software, changes to the CIMROC$^{tm}$ host software were required.

The CIMROC$^{tm}$ controller commands a preprogrammed move when performing the initial linear scan. When manipulating the container for the area detector scans, the controller will be in a teach mode and the operator will control the motion by means of a space mouse.

The whole examination has 3 subsystems. The CIMROC$^{tm}$ controller controls the positioning equipment. The Linear Scan Subsystem (LSS) and Real-Time Image Process Subsystem (RTIPS) provide the higher level control and are provided by HYTEC. Only the LSS needs to communicate with the CIMROC$^{tm}$ controller to set some motion parameters and make some of the inspection operations. The LSS communicates to the CIMROC$^{tm}$ controller through an Ethernet port with TCP/IP protocol and a socket mechanism. All commands between the 2 subsystems are ASCII strings. A single point of control mechanism is also implemented. The LSS must specifically request control access with a command from the CIMROC$^{tm}$ controller, then can issue any motion related commands after the control access is granted. The CIMROC$^{tm}$ controller host initiates motion operations only after the LSS gives up the control or after the CIMROC$^{tm}$ controller forcedly overrides the LSS control access when it is necessary.

### Safety Systems

The HYTEC safety system incorporates several elements to avoid energizing the source when an operator is in the cell. The open end of the cell and the adjacent empty room are protected by fencing and gates. The power to the source passes through interlock switches on the gates that prevent operation if they are open. Radiation sensors monitor the level in the cell and the surrounding area and shuts down X-rays through the interlock system if radiation levels exceed preset levels. Visual and audible indicators are used to warn people when X-rays are both about to turn on and are on. Emergency stop buttons are located throughout the cell and on the equipment for added safety. Close circuit TV is used to verify that no one is in the cell before operation.

## OPERATION SEQUENCE

The container is loaded onto the table by means of a fork lift and tied to the table by straps. The worker leaves the area and engages the X-ray safety interlock system.

The linear detector and X-ray source are moved forward into scanning position. The cart then moves the container between the source and linear detector, which generates a single large radiograph of the entire container for the operator to view on the monitor in the trailer. The operator determines if further examination is required. If not the container is removed.

If an object of interest is detected and further examination is required, the handling system positions the object of interest between the area detector and the source. The operator then uses the space mouse to manually control the positioning system to view the object at different angles in real-time and at very high resolution.

If an object is encountered that the operator determines may contain a fluid, the positioner control system oscillates the container cart at 0.25 G and 2.5 cm amplitude. This sloshes any fluid and the operator can detect its motion.

The container scan from the linear detector, any high resolution area detector images acquired, and real-time imagery is saved to DVD for reporting and archival purposes.

## CONCLUSIONS

The combination of digital radiography and robotics will greatly increase the efficiency of inspecting containers. It will shorten the time required as the operator can move the target and view to item of interest in real time. It will reduce contact as the worker will be in the cell for only loading and unloading.

## ACKNOWLEDGEMENTS

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