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Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
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REMOTE, AUTOMATED MATERIAL HANDLING OF RADIOACTIVE WASTE CONTAINERS

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I. INTRODUCTION

To enhance personnel safety, improve productivity, and reduce costs, the design team incorporated a remote, automated stacker/retriever, automatic inspection, and automated guidance vehicle for material handing at the Enhanced Radioactive and Mixed Waste Storage Facility - Phase V (Phase V Storage Facility) on the Hanford Site in south-central Washington State. The Phase V Storage Facility, scheduled to begin operation in mid-1997, is the first low-cost facility of its kind to use this technology for handling drums.

Since 1970, the Hanford Site's suspect transuranic (TRU) wastes and, more recently, mixed wastes (both low-level and TRU) have been accumulating in storage awaiting treatment and disposal. Currently, the Hanford Site is only capable of onsite disposal of radioactive low-level waste (LLW). Nonradioactive hazardous wastes must be shipped off site for treatment. The Waste Receiving and Processing (WRAP) facilities will provide the primary treatment capability for solid-waste storage at the Hanford Site.

The Phase V Storage Facility, which accommodates 27,000 drum equivalents of contact-handled waste, will provide the following critical functions for the efficient operation of the WRAP facilities:

- Shipping/Receiving
- Head Space Gas Sampling
- Inventory Control
- Storage
- Automated/Manual Material Handling.

II. DESCRIPTION

A. Shipping/Receiving

The Shipping/Receiving area will serve as the primary shipping/receiving point for Phase V Storage as well as for the WRAP facilities. This area includes battery charging for automated guided vehicles (AGVs), forklifts, and battery-powered manlifts. The equipment used in this area includes a 20-ton overhead crane to unload shipping casks and a 2-ton jib crane to arrange drums on pallets as they are unloaded into the facility. An administrative annex is attached to the Shipping/Receiving area for the main warehouse operations staff. It also houses the primary control system for the automated equipment.

B. Head Space Gas Sampling

Head space gas sampling (HSGS) is used to determine the composition and concentrations of flammable gases (hydrogen and methane), volatile organic compounds (VOCs), and certain standard gases of air that are in the void volumes (or head space) of waste containers. HSGS is used to ensure that each waste container meets applicable restrictions for concentrations of VOCs and flammable gases, as mandated in the No-Migration Determination (EPA 1990).

HSGS is required for all TRU containers before they are placed in a TRUPACT-II shipping cask to be sent to the Waste Isolation Pilot Plant (WIPP) for permanent disposal. The HSGS will sample for VOCs (must be stabilized at 500 ppm or less) and hydrogen to comply with TRUPACT-II shipping requirements.

Three types of sampling are used at this time.

Headspace sampling of the innermost layers of confinement (the polybag layer closest to the waste) is currently a requirement for the waste to be used in the Experimental Program. This requirement may not apply to the remainder of characterization during the Test Phase once sufficient data are gathered to show compliance with the restriction using empirical correlations.

Headspace sampling in the liner bags (the bags used to line the drums) is currently a requirement for the waste to be used in the Experimental Program. This requirement may not apply to the remainder of the characterization during the Test Phase once sufficient data are gathered to show compliance with the restrictions using empirical correlations.

Head space sampling under the drum lid (sampling outside the bags lining the drum) is anticipated eventually to be the only type of sampling required. Sampling all of the inner voids in the waste containers will be unnecessary. Head space sampling is the technique to be applied to the characterization of the WIPP waste inventory, unless the sites are specifically directed otherwise.

The U.S. Environmental Protection Agency (EPA) has imposed requirements during the test phase to sample every container sent to WIPP. It is anticipated that after an initial period, when enough data are gathered, perhaps only a representative number of containers of a particular lot will require sampling during the operational phase.

At this time, the length of time that a container can be stored after sampling before it is shipped is not restricted; however the maximum field holding time for the sample canisters is 4 days. This is defined as the time from sample collection to shipment to a laboratory. The laboratory holding time is approximately 28 days.

The head spaces will be sampled for analyte gases, nitrogen oxides, and VOCs. The head gas samples will be taken at a temperature of 25° C ± 5°. A 3-day temperature equalization period should be expected. This allows for the samples to be taken at the same temperatures to provide consistent data. The samples must be stored at specific temperatures depending on the sample type.

A 38-day sample is required for drums that exceed the decay heat loading limits and/or if the waste process cannot provide full characterization from either previous sampling or waste stream analysis.

C. Inventory Control

Inventory will be controlled using an onsite data management system integrated with the equipment control system. Each container will have a bar code to assist the data management system in tracking the container through the facility.

Storage will be provided in both manual and automated areas. The manual storage area will house both 55- and 85-gallon drums in a 3-drums-high 2-drums-wide configuration. The Washington State Department of Ecology (Ecology) requires the containers and the containment area to be inspected weekly. To help accomplish this task, Ecology requires at least 30 inches between aisles. Automating the inspection process is currently planned primarily to reduce radiological exposure to operating personnel. As the inventory grows, automated inspection will also reduce life-cycle operating costs. Drums that contain VOCs, free liquids, or pressurized containers will be placed in an area specifically design for low-flashpoint containers. All boxes received from both onsite and offsite generators will be placed in a separate box storage area.

Container Batching

One of the primary material-handling/inventory-control functions directly tied to the automated equipment is batching containers for processing and/or shipment to WIPP. The containers will be batched based on a variety of criteria; TRU gram loading content of the container will be the most critical.

D. Automated Storage

The automated storage area will provide up-to-90-day staging for drums that require processing through the WRAP facilities. The automated storage area will accommodate approximately 7,000 drums (both 55- and 85-gallon). This area is still under development;

however, it is expected that it will be an Automated Stacker Retriever System or a rack-supported system with AGVs. The material-handling function between the processing/treatment facilities, as well as the automated weekly inspection, will be provided primarily through the use of AGVs. Forklifts will transport drums to the manual storage areas; AGVs will transport drums between Shipping/Receiving, automated storage, and the TRU and Mixed Waste processing facilities via an enclosed transfer corridor.

E. Automated Guided Vehicles

The preferred AGV guidance system is the laser-guided vehicles that use a "dead reckoning" method to determine location. Using this type of system eliminates the need to disturb the floor surface; also it is not affected by dust or dirt.

The type of load deck being considered is a roller deck capable of carrying a pallet loaded with four drums. Single drums may be returned from the TRU processing area, so an AGV will be used that can transport two single drums instead of a pallet. Boxes will be handled on an infrequent basis and can be transported on a small trailer pulled by one of the pallet AGVs.

The minimum transfer corridor size for the drum and box transfers is determined to be 24 feet. This accommodates a maintenance access path on both sides of the corridor and a physical barrier between AGV paths.

The four general types of guidance systems available are: 1) Passive guidance systems, which have optical paths, chemical paths, or metal tape; 2) three-dimensional tracking systems, which use landmarks fixed to the walls as references; 3) the grid method, where the guidepath is laid out in a checkerboard pattern and the vehicle navigates from the reference grid; 4) inductive guidance systems, which use guidewires placed in the floor to provide a signal for the vehicle to follow.

When evaluating the preferred guidance method, the following attributes should be considered:

- Collision avoidance (people, vehicles, stationary objects)
- Accurate vehicle navigation
- Length of guidepath that can be accommodated by the technology
- Accuracy with which vehicles can track the guidepath
- Flexibility in moving the guidepath
- Guidepath reliability
- Difficulty of installation
- Equipment cost.

The passive type of optical guidepath uses fluorescent tape to stripe the floor. The vehicle uses an ultraviolet light to illuminate the stripe and a photocell sensor to track the tape. The photocell will sense when the vehicle strays from the path and the on-board controller makes steering corrections to keep the vehicle on the path. These systems are sensitive to dirt, direct sunlight, and damage to the tape, particularly in high traffic areas. If the fluorescent tape cannot reflect the light to provide feedback, the vehicle will shut down. However, the vehicles are designed to bridge small breaks in the path (up to 5 inches) to prevent unnecessary shutdowns. Another passive type uses fluorescent particles mixed into paint that is used to outline a guidepath onto the floor. With this system, the vehicle uses an ultraviolet light to illuminate the stripe. The unit uses this information and a microprocessor to change the steering commands as necessary. Ambient light and floor conditions have little effect on this type of guidepath.

Guidepath brightness needs to be monitored and when the brightness deteriorates, the path must be refreshed. Generally the system will last a year before needing renewal. The refreshing process is done by applying a new coat of paint over the old stripe. The main concerns with these two systems are 1) keeping the guidepath and sensors clean, 2) keeping the focal length between the sensor and guidepath constant, 3) keeping the guidepath from breaking under normal wear in high traffic areas.

Metal tape can be used with metal detectors as the sensor. This system works in the same basic way as the other two systems. The advantages of using metal are that it is more resistent to wear and tear and that the metal can be detected through dirt, paint, and normal floor sealant. Maintenance is minimal for this type of system; however, the cost of installing a metal tape system is roughly twice that of installing the optical systems.

With the 3-dimensional (3-D) system, vehicle scanners locate identifiable landmarks such as bar codes to triangulate the vehicle position. As the vehicle advances, it continually scans for different landmarks and, from these reference points, determines its relative position. Between landmarks the vehicle uses measuring-wheel technology to dead reckon its navigation. If the vehicle cannot locate a landmark, it will travel a specified distance, stop, and report to the controller that it needs assistance. Landmarks are generally located 30 to 50 feet apart. The advantage of a 3-D system is that the guidepath is flexible and easy to change. One system uses a laser scanner that searches for reflective bar code targets fixed to the building walls. The target locations are stored in the vehicle memory for tracking reference. The laser triangulates off any three targets to determine its precise location at P&D stations and any two points to navigate along a path. Paths are changed by entering software commands and adding bar code targets.

The grid guidepath is based on the vehicle being able to self-navigate over the entire work area using a work area map, dead reckoning, and calibration. The work area map is based on a rectangular coordinate system. An on-board computer stores positions and dimensions. The vehicle monitors its position by measuring the traveled distance using encoders. The grid is laid out in a checkerboard pattern with either alternating colors of tile, tile with dark edges or concrete blocks with metal edging. By referencing the grid, the AGV can correct for course deviations caused by wheel slippage or uneven floors. The advantage of a grid system is the flexibility of the guidepath. The AGV routes can be changed by editing the floor map via a graphics program.

An inductive guidepath provides vehicle routes by means of a network of wires imbedded in sealed grooves cut into the floor. The guidewire is energized with an alternating current of a specific frequency, which produces a magnetic field above the guidepath that is detected by the antennas on the vehicle. The on-board vehicle controls choose the correct guidance frequencies to follow at junctions, spurs, etc., without reference to the central control. A recent development in inductive guidepaths is to use magnets placed in the floor every few feet. The floor still needs to be cut, but not to the extent that the imbedded wire requires. The advantage to inductive systems is that they are the most proven technology and are currently the most used. They have been proven to be reliable and can accommodate heavy traffic and dirty environments. The disadvantage is the inflexibility of the guidepath. To change the path, a new groove has to be cut in the floor, wire laid, and the groove sealed. The installation cost for this is roughly three times that of an optical guidepath. Metal floor drains, metal shavings, etc. can also create problems by causing a loss of contact with the wire and the AGV stops.

The appropriate guidance system is selected based on the application and the plant environment. Wire-guided systems are the most widely used, but the guidance path flexibility is limited. Given the environment of Phase V Storage and the type of material handled, the feasibility of changing the guidepath by cutting new grooves in the floor is questionable. The process creates cement dust, poses a potential contamination concern, and requires personnel to spend a significant amount of time in restricted areas to cut the groove, lay the wire, and seal the groove. Using optical stripes or chemical guidepaths in Phase V would require good lighting where the guidepath is installed and a degree of dust control to keep the path clean. The path can be changed only by replacing the tape or painting a new stripe, both of which are fairly short tasks. The path should last a reasonably long time because of the limited number of AGV hours that will be accumulated during a year. The grid guidepath system is flexible and would not require anyone to spend a lot time in a restricted area to change or fix a guidepath. The grid guidepath requires the use of tile or concrete blocks. Both of these floor systems would be difficult to seal with the protective coating. The 3-D guidance system is the system best suited for the Phase V application. The guidepath can be changed by moving the wall-mounted barcodes and making software changes. This will limit the exposure to maintenance personnel when changes are required. The floor will remain undisturbed and other metal objects near the guidepath will not cause interference.

Various AGV installations and their susceptibility to breakdowns were studied. The types of failures were broken into four main categories: control systems, vehicle guidance systems, vehicles, and interfaces. Control systems caused the fewest problems; however, their problems took longer to resolve because the system generally required a complete restart. The number of breakdowns caused by interfaces is low, but each breakdown gains in significance as the installation becomes more complex.

The majority of breakdowns are caused by the guidance system. The most common errors are errors of data transfer, breakdown of individual components such as light switch barriers or circuit boards, and defective antennae or floor installations. The guidance system failures fall into four groups: mechanical, electrical, operating errors, and accidents.

Mechanical defects account for only 10 percent of the total number of breakdowns; however this number increases as the facility ages. Electrical defects account for approximately 80 percent of the breakdowns regardless of the age of the installation. The data transfer process is particularly susceptible to breakdown. Operating errors make up only 5 percent of the total breakdowns. Most of these errors are caused by obstacles placed in the AGV path. In the facilities that were studied, approximately 90 percent of the breakdowns were resolved in less than 10 minutes and very often in less than 5 minutes.

F. Automated Inspection System

An automated drum inspection system is not currently available commercially; however, one could be assembled from a commercial deployment system and a commercial inspection system. The integration effort could be performed in house or contracted to a systems integrator.

Automated and manual inspection systems were compared, including remote manual inspection. Remote manual inspection solves the as-low-as-reasonably achievable (ALARA) problem, but is slower than a human inspector walking through the facility. Automated inspection solves both the ALARA considerations and reduces the labor hours associated with the inspection.

The U.S. Department of Energy (DOE) has funded automated drum inspection systems at other facilities. A contract with Clemson/University of South Carolina has been initiated to investigate machine vision options.

Savannah River Technical Center (SRTC) is implementing a partial solution to the drum-inspection problem. They have procured a commercially available custom robot and mounted a camera to it. The camera frame grabs images and stores them to an optical drive. The images are not processed.

Martin Marietta has developed a prototype system based on their work for NASA. They have demonstrated a system designed using products they developed for space missions. This first system uses the Mars land-rover vehicle as a deployment system. Laser structured light is used to identify dents and bulges in the exposed surface of a drum. A color camera is used to identify streaking (a sign of a leak) and corrosion. The initial system was reported to perform well. The main drawback to this system is its size. The vehicle is 4 feet wide and requires a 6-foot aisle. Also, this system is currently tethered by a cable. DOE Morgantown is funding a development effort in which Martin Marietta is to redesign the system to work in smaller aisles and communicate remotely instead of via cable.

Several types of systems are available for positioning a sensor package to inspect storage drums. The overhead gantry system appears cost prohibitive, although such a system could provide access to areas not accessible from the floor. An additional drawback of the gantry system is that repairs and maintenance would be conducted within the facility, although, in some cases, these systems could be removed from the facility for repair and maintenance. In addition, most systems are unable to turn corners so each aisle would require a separate system, which may be cost prohibitive. Also, other overhead systems, such as rail-guided systems, have limited flexibility to change paths if the storage configuration is altered.

The wire, chemical, and optical guidance AGVs also have limited flexibility in path alteration. The vehicles themselves could be removed for repair and maintenance, but the guidance path can be damaged by traffic and require reinstallation. Other AGVs are available with self-guidance systems. They use dead reckoning, sensors, and other means to determine their position. Still other systems are controllable through an RF link. However, few systems are capable of operating within the 36-inch-wide aisle currently used at the Hanford Site.

The AGV appears to be the most practical means of delivering a sensor for drum inspection. The wireless AGV can provide access without interfering with manual inspection or operations. It also offers reduced exposure through both automated inspection and maintenance of the system outside the facility and requires no installation time.

SRTC chose a commercial robotic system as their drum inspection system. This commercial system is not designed for the harsh industrial environment, but for a clean hospital environment. However, a deployment system is commercially available that is 29 inches wide, expanding to 34 inches wide, with the safety bumper installed. This system was designed for tough industrial use.

The inspection technique is to frame-grab and store an image of each drum as it is introduced into the storage facility. This baseline image is stored on an optical drive.

Each week, a new image is captured and compared with the baseline image. The comparison involves translation (moving in the X and Y planes), scaling, and possible color or brightness correction to account for lighting. The image is then subtracted from the baseline image using pixel subtraction. The resulting pixels indicate changes in the appearance of the drum's surface. The software can then determine whether the drum passes inspection by applying a threshold to the differential image and despeckling. It has not been determined that color is required to detect all flaws on a drum. This determination may require testing.

Neural computing is a collection of mathematical techniques for analyzing data. The most practical applications for neural networks are pattern recognition. An advantage to this method is that when the neural network gets stuck and cannot make the proper determination, an operator can view the questionable image and decide the issue. The operator's determination is entered into the neural network's database. When the neural network sees similar image data, it will make the determination consistent with the operator. In this manner, a neural network learns from experience.

The most critical aspect of neural computing is the training sets, essentially, the data the network accesses to make determinations. A color image may be too much data to run through a neural network directly. This is especially true where the appearance of the drums (color, stenciling, labeling, etc.) is so varied and the types of defects being sought (corrosion, streaking, cracks, etc.) are so varied.

A practical implementation of neural networks is to have it process data from a color histogram. A color image is separated into its red, green, and blue components (an easy process). Shades of each of the three components are summed, resulting in three curves. The curves are then analyzed by the neural network.

Histogramming could also be used on a gray-scale images. This would greatly reduce the amount of data processed and the number of training set images needed. Flaws are independent of location on a drum. If the neural network has been given an example of a corroded drum (and is told that it is a bad drum), it will classify other drums with the same amount of corrosion as bad, regardless of where the corrosion appears on the drum.

CONCLUSION

Phase V Storage is designed to expand to meet the growing needs of the Hanford Site's solid-waste treatment and processing programs. The automated systems area required to ensure personnel safety and increase productivity in the areas of material handling and container inspection. Future facilities that may require the storage and material-handling functions provided by Phase V Storage are thermal treatment facilities and a hot-cell version of WRAP that processes primarily remote-handled wastes. These wastes would be processed and/or shielded to contact-handled status before being placed in the Phase V Storage facility.

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