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ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

OVERVIEW OF THE WEST VALLEY VITRIFICATION FACILITY TRANSFER CART CONTROL SYSTEM*

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ABSTRACT

Oak Ridge National Laboratory (ORNL) has designed the control system for the West Valley Demonstration Project Vitrification Facility transfer cart. The transfer cart will transfer canisters of vitrified high-level waste remotely within the Vitrification Facility. The control system will operate the cart under battery power by wireless control. The equipment includes cart mounted control electronics, battery charger, control pendants, engineer's console, and facility antennas.

BACKGROUND AND INTRODUCTION

The West Valley Demonstration Project is sponsored by the United States Department of Energy (DOE) and is located at the former Nuclear Fuel Services reprocessing plant site at West Valley, New York. West Valley Nuclear Services, Inc. (WVNS) is managing the project. The primary objective of the project is to solidify high-level waste stored in underground tanks into a form suitable for transportation and disposal. The existing HLW was produced from the chemical reprocessing of approximately 640 t of spent nuclear fuels. DOE has selected vitrification as the method of solidification and borosilicate glass as the waste form.

The vitrified waste is poured into stainless steel disposal canisters and cooled. The canisters are sealed, decontaminated, and transferred to the former chemical process cell (CPC) within the facility for interim storage. The main purpose of the transfer cart is to transfer the empty canisters into the vitrification cell (VC) and the filled canisters from the VC to interim storage in the CPC. Other future uses of the transfer cart have also been identified.

The design of the transfer cart has been a joint effort by WVNS and ORNL. Generally, ORNL has been responsible for the design of the transfer cart control system, which is summarized in this paper. A more detailed description of this work has been prepared [Bradley, 1993].

REQUIREMENTS

The transfer cart control system design requirements were determined by WVNS and documented prior to start of the design. This section contains a summary of significant design requirements; other requirements are discussed in later sections.

The transfer cart must move a load of four filled canisters (10.4 t) plus the cart over the full range of travel between the VC and the CPC. Additional capacity for loads up to 25 t is also required.

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The cart is required to operate on the existing rail design between the VC and the CPC and be powered with no trailing umbilicals. This ultimately means that battery power and wireless controls are required. A diagram of the cart travel path is shown in Fig. 1. The existing rail design has no provision for fixed power or signal conductors. Also, because of the three doors and radiation levels in existing cells, new construction to add power and signal transmission in the floor is not feasible.

The cart is required to have individual drives for each of the four drive wheels to increase redundancy and to reduce maintenance difficulties. The cart on-board electrical controls and batteries must be located in an enclosure that can be removed and reinstalled remotely. The batteries must be capable of being recharged both on the cart or off the cart at a separate location.

The cart will be remotely operated from two ex-cell control stations using general area remote closed-circuit television and shielded viewing windows. One station is located on the north wall viewing window of the VC, and the other station is located at the north CPC viewing window.

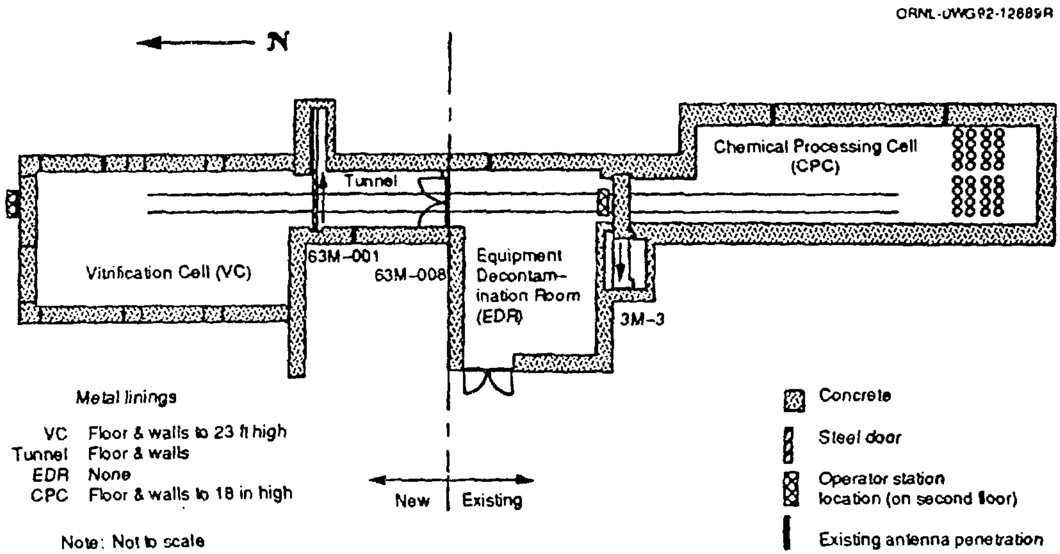

Fig. 1. Transfer cart travel path.

CONTROL SYSTEM DESIGN PHILOSOPHY

The Instrumentation and Controls Division at ORNL is one of the few organizations with experience in building communications systems for metal-lined hot cell applications which require not only radiation-tolerant component selection but also special radio frequency (rf) communication techniques to avoid the rf multipath problem.

Where possible, components used on the cart side of the control system were selected based on ORNL's experience with identical or similar components in radiation fields. In addition, for those components with which ORNL had no previous experience, radiation testing was performed at the Gamma Facility at Argonne National Laboratory.

Metal-lined walls are used in the hot cells at West Valley to facilitate decontamination and decommissioning (D&D) activities where mild acids may spray against the wall during equipment washdown. Metal lining is useful for D&D purposes, but when rf signals are transmitted within a cell, signal nulls result at node cancellation locations because of multipath reflections from the walls. West Valley had experiences with rf-based crane control systems where the crane would travel into an rf signal null and stop. Once inside the null, communications to the crane ceased and the crane could not be moved out of the null.

The rf system designed by ORNL for the transfer cart includes two cart antennas and four facility antennas (one in each cell of the cart's path). The antennas are set up in a diversity selection mode whereby the strongest signal received is selected. In this manner, if one antenna is in an rf null, another antenna can still be used for communication. Wide-band spreading of the modulated digital control signals is used so that if a null occurs in a small frequency range, the digital signal may still be recovered from the remainder of the frequency band. Finally, an algorithm is used on the cart system controller that will enable the cart to keep travelling a few inches if it stops receiving valid commands and if the last valid command it received was to drive. If both cart antennas are in a null, the additional few inches of travel will allow the cart to drive out of the null.

HARDWARE DESCRIPTIONS

Major equipment items in the control system design, as shown in Fig. 2, include the transfer cart control module, the battery charger, the north and south control pendants, the engineer's console, and facility antennas.

The design is a combination of off-the-shelf components and specially designed equipment. Early on in the design we recognized that a radiation-tolerant, battery-powered communications system did not exist commercially and, therefore, must be specially designed. Special interfacing cart electronics were also designed; however, a commercially available, embedded, microprocessor-based controller was identified and radiation tested for use on the cart. On the facility side, the communications system to match the cart side was designed in-house. A unique requirement to be able to switch charging polarity of the cart batteries led to a specially designed battery polarity interface circuit. The control pendants, although based on a commercially available, hand-held pendant, have a specially designed circuit board and faceplate decal. The programmable logic controller (PLC), the engineer's console computer, and the battery charger are all commercially available.

CONTROL PENDANTS

Operation of the cart will be controlled by one of two hand-held control pendants. One will be located near the north viewing window of the VC, and the other will be located near the north viewing window of the CPC. The functionality is the same for both pendants.

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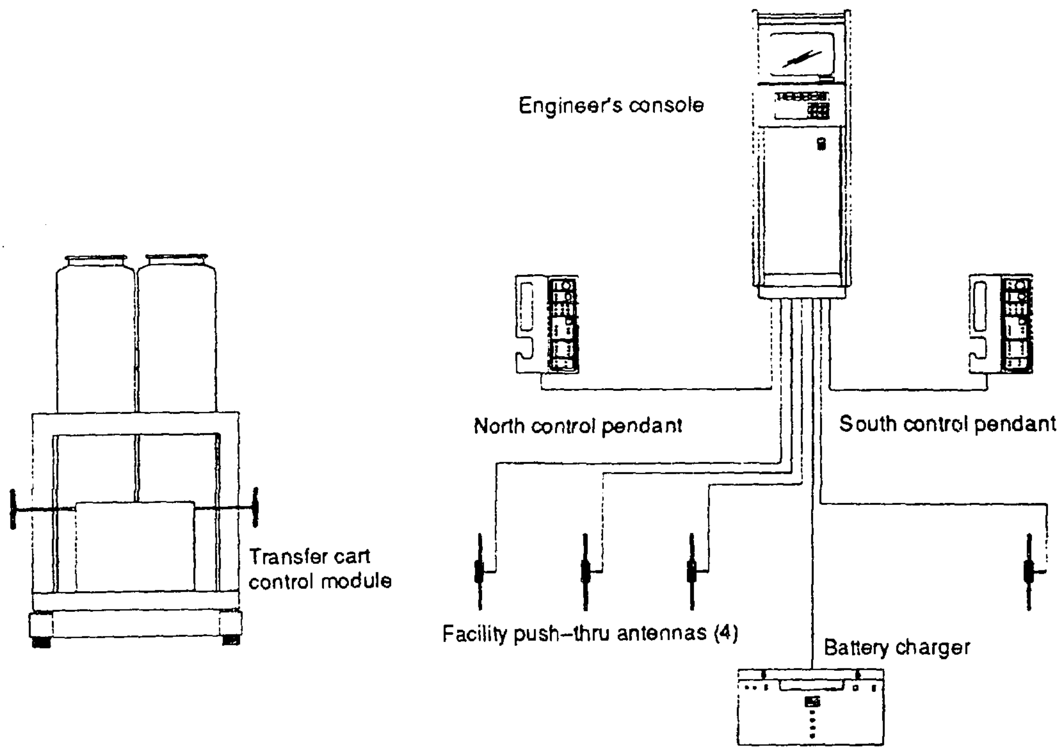

Fig. 2. Transfer cart control system.

Space is limited for the control pendants; therefore, instead of the typical wall-mounted, rectangular control panel with switches and indicator lights laid out in a matrix fashion, a human-engineered, hand-held control pendant was designed. A layout of the control pendant is shown in Fig. 3. The control pendant consists of switches, light-emitting diodes (LEDs), and an audible alarm. The switches and LEDs are divided among functional blocks on the front face of the pendant. The audible alarm is mounted on the top side of the pendant. The push-button switches are used for operator command inputs, and the LEDs are used for visual status indication. An oversized emergency-stop button is provided for stopping the cart and battery charger from either pendant. A three-position, return-to-center rocker switch is provided for cart drive.

The cart control system operates in two basic modes: battery charging and cart operation. During the battery charging mode, the cart is disabled completely; sending commands to the cart will have no effect, and the cart will not report the status of any of its normally monitored variables. During the cart operation mode, the battery cannot be charged unless it is located at the charging shoes.

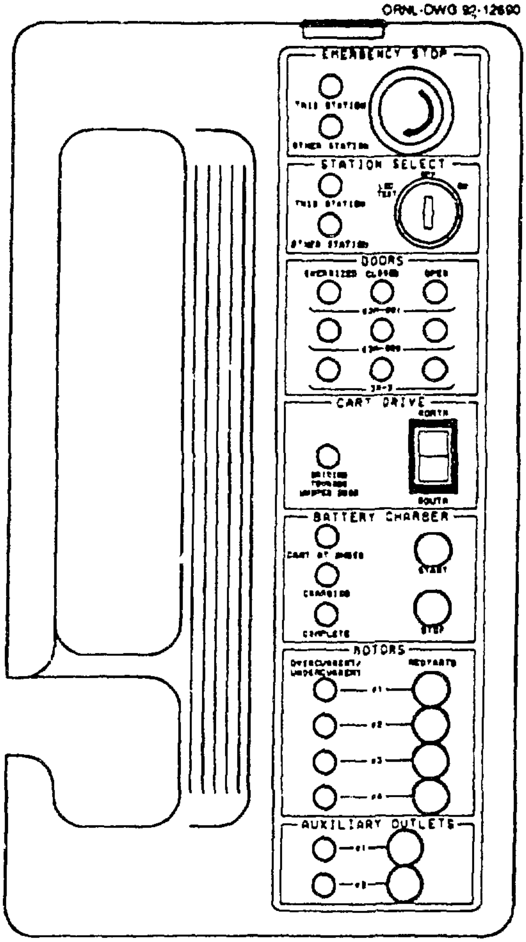

Fig. 3. Control pendant.

PLC

The PLC selected for this application is an Allen-Bradley PLC 5/15. Because of previous experience with Allen-Bradley at the West Valley site, West Valley personnel requested that Allen-Bradley be used as much as possible for control hardware. In the Allen-Bradley family, the PLC 5/15 model provides the lowest price per functionality ratio for this application. Besides the typical digital interfacing, this application is somewhat unique for a PLC in that it must interface the battery charger through an RS-232 link. Through the present architecture, the 5/15 interfaces directly to a Prolog standard (STD) bus based microprocessor using the Prolog 7514 Allen-Bradley interface card. The Prolog microprocessor acts as the communications controller. The PLC uses the Prolog RS-232 interface to communicate to the battery charger. High-speed communications tasks must be coordinated closely by the communications controller. The programming was written in C language on the Prolog communications controller microprocessor.

The PLC is the heart of the control system through which all control activities are coordinated. It will interface (1) to both control pendants through digital input/output (I/O) modules, (2) to the communications controller over the PLC's remote I/O link and a Prolog 7514 Allen-Bradley interface card in the communications controller, and (3) to the engineer's console computer over the Allen-Bradley Data Highway Plus link and a Sutherland-Schultz 5136 SD interface card in the engineer's console. The PLC also interfaces to the facility doors and to the enable/disable input of the battery charger interface through the PLC's digital I/O.

The PLC will physically reside in the engineer's console in a 19-in. rack. The engineer's console computer will be used to modify, download, and monitor ladder logic running on the PLC.

ENGINEER'S CONSOLE COMPUTER

The engineer's console computer resides in the engineer's console assembly. For an engineer, the engineer's console computer will be the window into the control system. Through the computer, an engineer can monitor cart activity and data, whether current or historical, and operational status of the control pendants, doors, and battery charger. A commercial man/machine interface software package has been used to develop the engineer/control system interface. In addition, the computer can be used to modify and download ladder logic in the PLC. It can be used to modify, compile, and download C programs to the Prolog communications controller. A switch in the back of the engineer's console, also makes it possible to interface the battery charger directly to the engineer's console computer through one of its serial communications ports. In this mode, configuration parameters of the battery charger can be interrogated and changed, and it would even be possible to operate the battery charger in this mode in situations when the control pendant, PLC, or communications controller had failed. The engineer's console computer will be capable of trending any of its inputs and providing alarm outputs based on the input value. It will also be capable of performing mathematical and logical operations on the cart data.

A Nematron model IWS-5386DX is specified for use as the engineer's console computer. The Nematron is an industrially rugged computer with a shock-mounted disk drive, NEMA 12 sealing, and optically isolated communications ports. It has a 19-in. VGA color monitor, an 80386DX 25-MHz processor, and a front-panel function keyboard. The intent is that routine operations with the computer could be accomplished using the front-panel function keys. More intense diagnostic or maintenance operations can be performed by folding down the panel, which exposes a full-function QWERTY-style keyboard.

The computer interfaces to the PLC with a Sutherland-Schultz 5136 SD card located in one of the computer's expansion slots.

BATTERY CHARGER

The battery charger specified and tested for the project is an Exide ERBC 24/30. It is a unique battery charger in that it includes a microprocessor for interfacing to the control system. Start and stop commands are issued to the battery charger, and status variables for battery charging current, voltage, and temperature are returned to the control system. The Prolog communications controller is the primary interface between the control system and the battery charger; however, a polarity interface circuit is also located between the battery charger and the batteries. The primary purpose of this circuit is to reverse charging polarity when the cart has been reversed on the tracks. A second key feature of the interface circuit is that it provides an emergency stop function that is available both locally and through the control system.

The battery charger connects to the cart through a set of spring-loaded charging shoes that will be located between the cart track rails. The shoes are designed to interface with a set of contact plates mounted on the base of the cart control module. A limit switch will indicate when the cart is in the charge location.

DOOR INTERFACES

Each door will be monitored for three conditions: (1) door open, (2) door closed, and (3) door energized. Door limit switches will interface to the PLC so that the status of door operations can be monitored. In addition, the PLC has the capability of disabling all doors when the cart is operating. Three outputs are provided from the PLC and must be interfaced to the door actuation circuit by interposing relays.

COMMUNICATIONS SYSTEM DESIGN

The communications system operates with a carrier frequency of 915 MHz in the industrial, scientific, and medical bands. Deviation of the carrier is adjusted to ± 10 MHz around the carrier. A total of eight communications system boards were designed and built in-house for this project. The rf boards and digital message encoder/decoder boards were built around the STD-bus form factor. Crutcher and Moore summarize the design of the communications system in a separate paper [Crutcher, 1993].

CART ELECTRONICS SYSTEM

Two 12-V, sealed lead-acid batteries, operating in series, power all the cart electronics, communications system, and motors. A commercial, STD-based, embedded controller manufactured by Winsystems serves as the cart systems controller. The Winsystems controller was tested for radiation tolerance at Argonne National Laboratory. The test showed that the controller would survive the 5-year lifetime criterion at the specified radiation dose. Lead shielding is used to attenuate gamma radiation received by the controller. In 5 years the controller will accumulate a 10^4-rad total integrated dose.

In-house developed electronics cards include an interface card and motor driver cards. The interface card connects the system controller to the cart communications system, the motor driver raw inputs, enclosure fan, auxiliary outlets, a position-sensing limit switch, and the battery charger through the charging shoes. Raw signals that must be conditioned by the interface card before passing on to the system analog-to-digital converter include battery temperature, voltage, and current; motor voltage and current; voltage and current of two auxiliary outlets that may be used to supply power to tools in the hot cells; and electronics temperature. All these variables are passed to the system controller, which, in turn, passes them to the communications system for transmission to the facility side using packet-type communications protocol. The electronics temperature is used by the system controller to actuate a fan when the enclosure temperature rises too high. The position-sensing limit switch is used to confirm when the cart has passed a cell-door threshold.

The motor drives are H-bridge circuits that operate in a pulse-width modulation (PWM) technique from a signal from the system controller. The cart motors will run at a pre-set speed. By using the PWM technique, the speed of the cart can be modified while operating. From the engineer's console, a request is made to increase or decrease motor speed. The request is passed to the cart system controller, which modifies the PWM-signal frequency to change the motor speed. This feature may prove to be beneficial to cart operation because of the wide range of loads planned to be transported by the cart. Without speed adjustments, the cart would run slower with greater loads and faster with less loads. For maintenance reasons a separate board is used for each of four cart motors. Over-current trips prohibit the motors from operating when the motor current exceeds a high limit.

CONTROL MODULE

The control module shown in Fig. 4, contains all of the on-cart controls and electrical equipment to perform all of the cart control functions within a single assembly. The control module is designed as a remotely replaceable module. The assembly is held in place on the cart by two captive bolts that can be operated by a remote impact wrench. A lifting bail is provided for remote handling by the crane for removal and installation. All of the electrical connections between the control module and the transfer cart are contained in a single remote electrical connector that couples when the control module is installed. In the event of failure of any of the cart controls, the entire module can be removed and replaced remotely using only the crane and impact wrench.

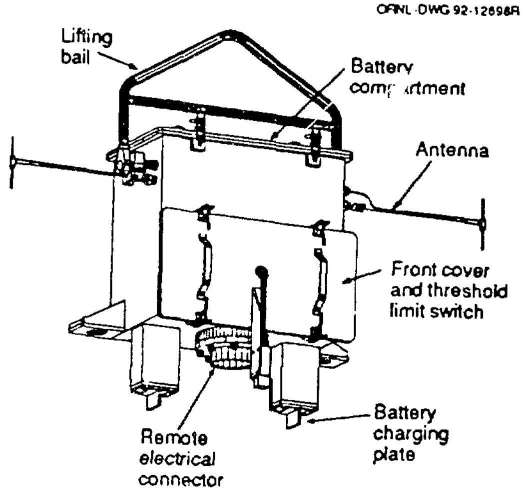

Fig. 4. Control module.

The control module enclosure is an all-welded structure made of type 304 stainless steel plate. The enclosure design provides two separately sealed compartments. The upper space is for the batteries, and the lower space is for electronics that require shielding from the radiation. Two removable covers provide access to the batteries and electronic components within the enclosure. The enclosure is completely sealed to prevent moisture or nitric acid vapor from entering inside the electronics or battery compartments. All components within the enclosure are designed to be contact maintained.

The battery compartment is integral with the top cover. A small high-efficiency particulate air filter is provided in the top of the battery compartment to allow venting of any hydrogen which may be generated during recharging. The front cover provides access to the wiring harness and the motor driver circuit boards. The front cover also supports the threshold limit switch. This limit switch is used to detect door threshold locations which provide error correction for the cart position algorithm.

On the bottom of the control module, two legs extend down for mounting the battery charging plates. Also on the bottom of the control module, between the legs, is the remote electrical connector. Two additional electrical connectors are located on the sides near the top to provide auxiliary power outlets.

The antennas are also mounted on each side of the control module near the top. The two dipole antennas extend past the edge of the transfer cart for line-of-sight communications with the facility antennas.

Electrical components incapable of withstanding 10 Mrad are protected in a shielded enclosure with the equivalent shielding of 3 orders of magnitude of reduction. The shielded enclosure is made of lead encased in a stainless steel liner. The top of the shield enclosure is removable for access to the electronics. Openings with shadow shielding are provided for wiring and ventilation. A fan provides forced air circulation through the electronics and within the control module enclosure.

FACILITY ANTENNAS

The facility antennas are dipole antennas which are designed to fit within existing cell penetrations. The antennas fold to fit inside a 1.25-in.-diam straight-through penetration. Four of the facility antennas will be used. Materials used for the antennas include type 304 stainless steel and PEEK (polyetheretherketone) thermoplastic for the insulator. PEEK is a high-temperature thermoplastic which also has good radiation tolerance.

Stainless steel corrugated hose is used to push the antenna through the cell penetration to deploy it in-cell and is used as a conduit for the antenna cable. Once inserted into the cell the dipole antenna unfolds and deploys to the vertical orientation for signal transmission with the cart.

SUMMARY

This paper documents the design of a control system for the West Valley transfer cart. At the time of this writing, detailed hardware design and prototype hardware testing are complete. Software has been developed to the stage that it was used for integrated hardware testing, but more development will be required to bring it to the level of being ready for the entire control system and to work out some problems that surfaced during integrated hardware testing. The results of the prototype hardware testing indicate that the system should operate as planned. However, minor modifications will almost surely be necessary when the control system is tested and installed at the West Valley site.

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