ORNL/TM-13501

Chemical Technology Division

OUT-OF-TANK EVAPORATOR DEMONSTRATION: FINAL REPORT

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DISCLAIMER

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ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
BAT	bayonet augmented tube
BPE	boiling-point elevation
CRO	control-room operator
DF	decontamination factor
DOE	Department of Energy
EDS	Engineering Development Section
FY	fiscal year
GE	General Electric
GUI	Graphical User Interface
HAZWOPER	Hazardous Waste Operations and Emergency Response
HEPA	high-efficiency particulate air (filter)
ICP	inductively coupled plasma
LCD	limiting controls document
LGWOD	Liquid and Gaseous Waste Operations Department
LLLW	liquid low-level waste
MVST	Melton Valley Storage Tank
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
ORNL	Oak Ridge National Laboratory
OTED	Out-of-Tank Evaporator Demonstration
PID	proportional/integral/derivative
PLC	pump module operator
PPE	personnel protective equipment
PWTP	Process Waste Treatment Plant
QA	quality assurance
RCRA	Resource Conservation and Recovery Act
SSA	System Safety Analysis
TDS	total dissolved solids
TSR	Technical Safety Requirements
TSS	total suspended solids
WAC	Waste Acceptance Criteria
WMRAD	Waste Management and Remedial Action Division

ACKNOWLEDGMENTS

Successful completion of this project required the cooperation of more than 125 individuals representing 11 divisions at Oak Ridge National Laboratory (ORNL). Although the Engineering Development Section (EDS) of the Chemical Technology Division formed the core of the Out-of-Tank Evaporator project team, essential contributions were made by several personnel from the Office of Radiation Protection, Engineering Division, Plant and Equipment Division, Waste Management and Remedial Action Division (WMRAD), Analytical Services Organization, Purchasing Division, Metals and Ceramics Division, Industrial Hygiene Division, the Office of Environmental Compliance and Documentation, other sections within the Chemical Technology Division, the Office of Quality Programs and Inspection, Metals and Ceramics Division, and Instrumentation and Controls Division. The authors wish to specifically acknowledge M. I. Morris, S. E. Lewis-Lambert, L. L. Cobb, and R. D. Nipper, Jr., of ORNL, and D. G. Wygmans and D. B. Chamberlain, of Argonne National Laboratory, for their assistance and guidance. The evaporator system was designed and fabricated by Delta Thermal, Inc., Pensacola, Florida; and the concrete shielding modules were fabricated by Concrete Products, Inc., Memphis, Tennessee. This work was cofunded by DOE's Office of Technology Development (EM-50) and ORNL WMRAD (EM-30).

EXECUTIVE SUMMARY

As a consequence of past and present nuclear energy research and radiochemical production activities at Oak Ridge National Laboratory (ORNL), approximately 450,000 gal of liquid low-level waste (LLLW) is being held in twelve 50,000-gal underground storage tanks. This waste is similar to wastes being stored at Hanford and Savannah River. State-of-the art evaporators are being considered at these Department of Energy (DOE) sites to concentrate waste for interim storage prior to separations and/or solidification processes for waste disposal. The project reported here was conducted to demonstrate the use of a skid-mounted subatmospheric evaporator to process these wastes.

A single-stage subatmospheric evaporator rated to produce 90 gal of distillate per hour was procured from Delta Thermal, Inc., of Pensacola, Florida (formerly of Mobile, Alabama), an industrial firm that primarily manufactures equipment for nonnuclear applications. The system, which was shielded with concrete modules purchased from Concrete Products, Inc., Memphis, Tennessee was installed in an existing building.

The demonstration project was initiated to evaluate the use of modular skid-mounted equipment to process radioactive liquid waste such as that stored in ORNL's Melton Valley Storage Tanks (MVSTs). During the 8-day demonstration, 22,000 gal of LLLW (approximately 10% of the present MVST inventory) was concentrated by 25% using the evaporator system. Of this total, approximately 16,500 gal of concentrated liquid was returned to the MVSTs and 5,500 gal of distillate was disposed of at ORNL's Process Waste Treatment Plant (PWTP).

Decontamination factors (DFs) achieved in the evaporator averaged 5×10^6 (i.e., the distillate contained five million times less ^{137}Cs than did the feed), with maximum values of 9×10^6. Evaporator performance substantially exceeded design requirements and expectations based on bench-scale surrogate test data. Design specifications of 1.2×10^5 were based on the DF required to produce distillate that would meet PWTP waste acceptance criteria (WAC); however, changes in the waste composition increased the target DF to 2.5×10^6. Pilot-scale surrogate tests conducted at Argonne National Laboratory using a 3-gal/h evaporator indicated that DFs of up to 1.4×10^6 (based on sodium) could be expected from this type of equipment, which is somewhat lower than the target value. Special arrangements could have been made for disposal of the distillate produced at a DF of 1.4×10^6; however, DFs observed with actual waste in the full-scale system were consistently higher than needed. During both surrogate tests and operations with actual waste, minor foaming problems and a lack of heat exchanger fouling were experienced.

Out-of-tank evaporator demonstration (OTED) operations successfully addressed the feasibility of hands-on maintenance. Failure of a control-valve actuator in the system required a 2-day shutdown for repairs. After flushing the evaporator with tap water, workers performed hands-on repairs and received exposures of less than 10 mR. Upon completion of operations, only three water rinses were required to decrease the background radiation throughout the system by more than 98%. Final radiation background values measured less than 5 mR/h.

A computer model used to predict radiation fields proved very useful and accurate as compared with actual measurements taken during the demonstration. During the demonstration, only minor rearranging of lead shielding was required to moderate doses from "hot" spots. Radiation exposures to personnel were maintained well below the administrative control limits for the project.

When the radiation background was sufficiently reduced to allow direct access to equipment, approximately six areas were identified where small leaks (total volume, less than 20 mL) had contaminated exterior surfaces of equipment. These areas were decontaminated with water and dilute nitric acid rinses. The sources of the seepage were identified as valve stems and pump drain plugs. Minor modifications to address expansions and contractions due to temperature changes should eliminate leaks during future operations. Both of these activities indicate that (1) skid-mounted mobile equipment is a viable alternative for the treatment of ORNL LLLW and (2) hands-on maintenance and decontamination for movement to another site is achievable.

Results from the demonstration are being used to recommend minor upgrades prior to installation into Waste Management and Remedial Action Division (WMRAD) baseline operations at ORNL and/or procurement of similar systems at other DOE sites. These are primarily related to modifications of the valves mentioned previously and to updates made for the purpose of improving the energy efficiency of the system.

The OTED project was completed in 24 months at a cost of $3.1M (including equipment). After 8 days of operation, it had successfully concentrated 22,000 gal of ORNL legacy supernate by 25%. Ten percent of the demonstration costs will be immediately recovered by elimination of solidification and disposal costs for 9,000 gal of grouted waste at the Nevada Test Site. The entire cost of the demonstration can be recovered by processing the existing inventory of MVST waste and/or sluice water generated from sludge consolidation activities through OTED equipment prior to solidification. An additional savings of approximately $200K per year can be obtained by processing newly generated waste through the system. The demonstration results showed that bench-scale surrogate information can be scaled up to predict full-scale performance. The results also indicate that this type of evaporator system should be considered for application across the DOE complex for concentrating LLLW. With minor modifications, the OTED will provide a system that meets ORNL user needs and is suitable for long-term baseline operations.

1. INTRODUCTION

1.1 BACKGROUND

Oak Ridge National Laboratory (ORNL) has operated several facilities for nuclear energy research and radiochemical production activities since its inception in the 1940s. These activities have generated radioactive liquid low-level waste (LLLW), approximately 450,000 gal of which is held in twelve 50,000-gal underground storage tanks at ORNL. This waste, which is are similar to wastes being stored at Hanford and Savannah River, is being used as a surrogate in treatability studies for waste streams at the two sites. State-of-the art evaporators are being considered for concentrating LLLW at these Department of Energy (DOE) sites prior to separations and/or solidification or other processes for disposal. The project reported here was conducted to demonstrate the use of a skid-mounted subatmospheric evaporator to process such wastes.

1.2 OBJECTIVES

Hanford, Savannah River, and ORNL are interested in using skid-mounted, mobile evaporator systems to treat remote-handled low-level or high-level radioactive waste. Each site is interested in single-stage subatmospheric evaporators similar to those procured in FY 1994 at Argonne National Laboratory (ANL) for use in treating contact-handled process wastewater because the low operating temperatures tend to decrease the potential for scaling and fouling of the heat exchanger surfaces. Figure 1 shows a basic flow diagram for a single-stage evaporator. The primary information desired by potential DOE users from the demonstration of a subatmospheric evaporator can be summarized as follows:

1. Hanford, Savannah River, and ORNL are potentially interested in using skid-mounted, mobile units that can be easily moved between tank processing locations. Key information requested from the demonstration includes obtaining reliability/operating experience and determining the feasibility of decontaminating the system for hands-on maintenance and/or demobilization of the system for use at other locations.

2. All sites are interested in verifying that experiments with simulated waste in small-scale test units can accurately predict the performance of full-scale units operating with actual waste. Of specific importance are parameters such as scaling, foaming, and decontamination factors for overheads.

3. ORNL WMRAD planned to install a subatmospheric single-stage evaporator unit to process MVST waste, a 4 to 5 *M* sodium nitrate solution contaminated primarily with ^{137}Cs and ^{90}Sr, to near-saturation to increase limited storage capacity and reduce volumes of waste for treatment and disposal. Uncertainties, such as those described above, had driven the cost estimates for

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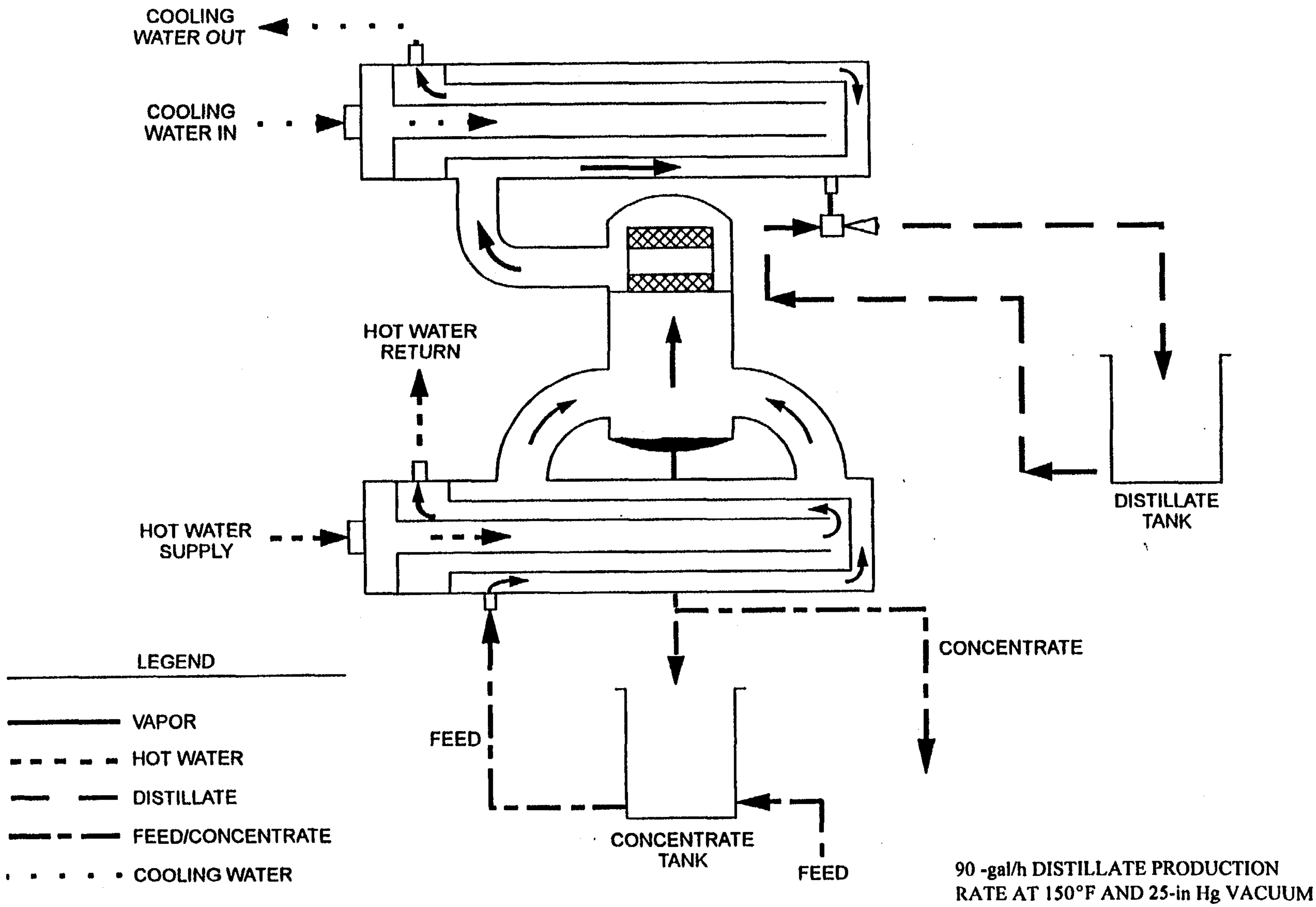

Fig. 1. Basic flow diagram for a single-stage evaporator.

installation of the unit to $6M. EM-30 was interested in cofunding a demonstration to set operating conditions and to reduce the uncertainties (and, hopefully, the costs) associated with the long-term installation/operation of such a unit.

4. Hanford and Savannah River are interested in obtaining experience regarding the documentation, safety, and facility requirements for use of mobile evaporator units. Although such experience will vary significantly from site to site and one waste stream to another, lessons learned from a demonstration at any site will be helpful to the other sites.

1.3 SCHEDULE

The OTED was initiated in FY 1994 with initial project planning, feasibility studies, and development of bid specifications. Efforts in FY 1995 were focused on acquisition of the system; shielding, preparation, and planning for installation; acquisition of necessary permits; preparation of safety documentation; and determination of additional requirements for operation of the system with radioactive waste. Activities in FY 1996 included installation of the evaporator system, development of operating procedures, completion of regulatory and safety documents, training, a readiness self-assessment, a series of demonstration operations, decontamination of the system; and transfer of ownership to EM-30.

2. DESCRIPTION OF THE SYSTEM

2.1 GENERAL ASPECTS

The system centers around a single-stage subatmospheric evaporator. Low operating temperatures corresponding to the low pressures tend to help reduce scale formation and heating requirements and to limit chemical degradation of the feed. The system automatically adjusts for changes due to ambient temperature, feed-flow temperature, and energy input (electric) to ensure maximum system throughput and minimum energy usage as well as allow the operator to actively interface with the evaporator or simply observe the Graphical User Interface (GUI), in real time, from a computer terminal.

During processing, the system requires minimal operator attention. All digital signals (pumps, solenoid valves, and motor valves) and analog signals (pressure, temperature, flow, levels and positioning valves) are coupled to the GUI via single-point digital/analog processing modules or a programmable logic controller. A programming strategy based on a real-time operating system with task prioritization enables the unit to continually seek and obtain its optimum heat balance while maximizing feedwater throughput and distillate production with minimal energy usage and highest possible distillate purity. Program adjustments to the heating, cooling, concentrate, and distillate loops of the evaporator are continually made by the processor, utilizing feedback from digital/analog signals and algorithms formulated to ensure system optimization. An operator can input changes to the evaporator's temperature, flow, and/or level setpoints while the system is operating, allowing for an increase/decrease in production or an increase/decrease in the concentration ratio during operation without interruption. The operation of the evaporator can be monitored via GUI with real-time data at the system CRT screen, over a network, or via a remote computer system using a modem connection. The program offers alarm-logging, trending of real-time or historical data, free format reports, and exporting of historical data to a spreadsheet. All system alarm parameters such as high temperature, pump-loss-of-pressure and/or flow, high/low tank levels, pump-motor status, high conductivity, and suspected sensor malfunction are monitored; the operator is alerted to a problem by a horn. The processor and all critical process valves and instrumentation are backed up by an uninterruptible power supply (UPS) to ensure an orderly system/process shutdown in the event of a power failure. The system is capable of remote operation, monitoring, and real-time data acquisition. If necessary, it can be monitored by Delta Thermal, Inc., engineers from their manufacturing plant in Pensacola, Florida.

The system consists of five skids, including the main evaporator skid, a feed/concentrate skid (concentrate tank, feed tank, recycle pumps, and feed pumps to the evaporator skid), an air-cooled heat exchanger skid (with pumps, expansion, and surge tanks), a heating skid (electric boiler, pumps, and pressurized bladder tank), and a distillate holding tank skid (assembled at ORNL).

2.2 PROCESS FLOW

2.2.1 General Features

Hot water is circulated through a bayonet augmented tube (BAT) bundle in the evaporator shell. The hot water ("tube-side") heats wastewater located on the outside of the BAT heat exchange tubes and inside the evaporator shell ("shell-side"). As the wastewater is boiled, water vapor passes through the vertical separator where contaminants coalesce and fall into the base of the separator. Distillate vapor passes through the separator and into the condenser shell, where it contacts cold condensing tubes.

Cooling water is circulated through the BAT condenser tubes to condense the vapor. Two hydraulic jet eductors extract distillate and noncondensables; distillate is collected in a recycle tank for discharge from the system. A conceptual flowsheet for the system is shown in Fig. 2.

2.2.1.1 Heating Loop

Energy in the form of hot water (at 190°F and approximately 190 gal/min) is supplied to the evaporator by an electric boiler (a self-contained, thermostatically controlled unit that incorporates flow-

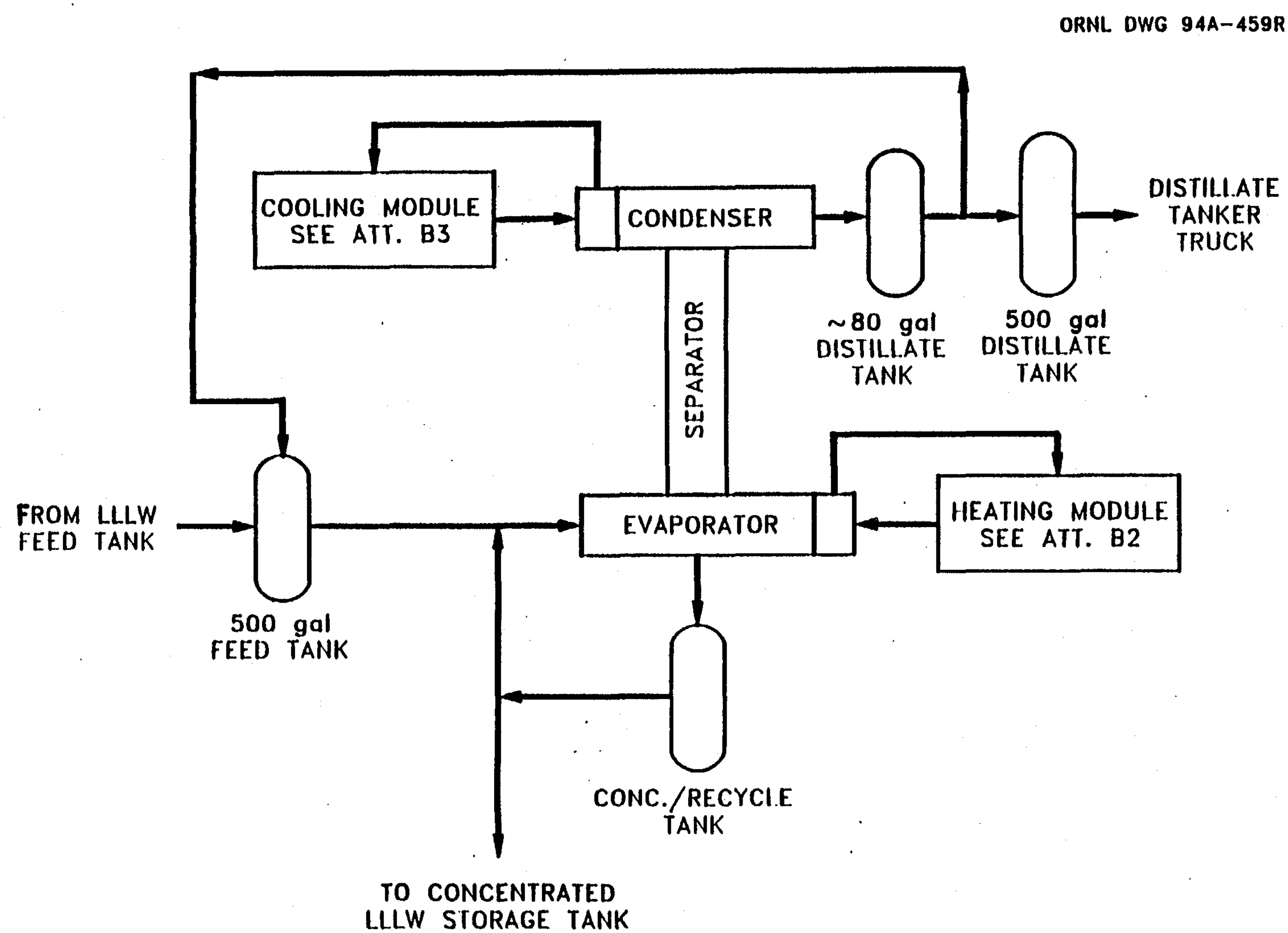

Fig. 2. Conceptual flowsheet for the evaporator system.

and temperature-sensing units) and a pressure relief valve. A conductivity element/transmitter monitors the heating fluid for any indication of a leak and signals a control valve, which stops flow to the boiler in the event that the conductivity should exceed a predetermined setpoint. Thermocouples monitor the temperature into and out of the BAT heat exchanger. A flow transmitter monitors the heating loop flow.

2.2.1.2 Cooling Loop

Cooling water is circulated through BAT condenser tubes at approximately 140 gal/min. The flow of cooling water through an air-cooled heat exchanger and the temperature of the condenser are controlled by a PID loop. As the temperature rises in the condenser, more cooling water is allowed through the air-cooled heat exchangers by a mixing flow control valve. The two blowers are also sequenced "on" with an increase in temperature. Pressure, flow, and temperature are monitored.

2.2.1.3 Distillate Loop

Operation of the distillate loop provides several services to the overall unit process: system vacuum, seal-water flow for concentrate recycle, reflux spray, unit rinsing, and distillate discharge to a holding tank. The distillate is pumped from a distillate recycle tank through eductors (serving as vacuum pumps pulling a vacuum on the shell, separator, and condenser assembly) and is then returned to the distillate tank.

Distillate discharge is controlled by four parameters--unit temperature, distillate conductivity, distillate tank level, and low-feed-tank recycle mode. Discharge temperature is initially set for 120°F. Once the distillate loop temperature, sensed by temperature element, reaches 120°F, a conductivity control valve will open and allow distillate to be discharged — providing the conductivity of the distillate meets or exceeds a preprogrammed conductivity setpoint. Until the distillate loop temperature reaches the discharge temperature setpoint, any distillate produced by the unit is routed back to the concentrate tank via another conductivity control valve. If at any time during the operation of the unit (while distillate is being produced and discharged) the conductivity of the distillate exceeds the preprogrammed setpoint, one conductivity control valve will close and the other will open to recycle distillate back to the concentrate tank. Should the unit sense a low feed tank level (sensed by a level switch), the same sequence of events will take place as those when a high conductivity level is sensed. Level in the distillate recycle tank is controlled by a PID loop consisting of a level transmitter and a flow control valve.

2.2.1.4 Concentrate Loop

Feed is delivered into the 500-gal feed tank via an existing pump module system previously used in solidification operations. Feed is then pumped out of the feed tank to a concentrate recycle tank on an as-needed basis sensed by another level transmitter in that tank. Feed in excess of that required by the concentrate tank is recycled to the feed tank. The feed in the concentrate tank is vacuum-dragged into the evaporator shell and then recycled to the concentrate tank. The recirculation rate and the level in the shell are controlled by PID loops. The recycle flow rate is sensed by a flow transmitter; the pump pressure is sensed by a pressure transmitter. Heat exchanged in the shell is sensed by temperature transmitters.

2.2.2 System Controls

The process flows discussed are normally directed from the Computer Interface Station but can be managed from a local maintenance panel. The entire unit is controlled by a GE Series 90-30 Programmable Logic Controller (PLC) using GE FANUC's 90-30 Logic Master Software and a 486/80-MHz personal computer with a 540-megabyte hard drive, 8 megabytes of RAM, 3.5 floppy drive, and a 15-in. SVGA monitor, using Intec Control's Paragon Software as a GUI.

The GUI has two main operational components: Normal Unit Operations and Unit Off Operations. The purpose of Normal Unit Operations is to interface the operator to the evaporator when it is in production. When the computer system is first turned on, the GUI will bring up the Main Menu Screen, which lists the major operational screens available. The Normal Unit Operations component consists of the following screens: Pump Select Screen, Start-Up Screen, P&ID Screen, Data Screen, and Alarm Screens (plus subscreens General Alarms, S/D Pending Alarm, and Shut-Down Alarms).

The purpose of the Unit Off Operations component is to interface the operator to the evaporator when the unit is not in operation and unit checks need to be done (e.g., draining of the unit or checking the calibration or movement of a control valve). The devices and/or push buttons illustrated on the graphic screens for Unit Off Operations are only operable when the unit is not operating. Selecting the System Off Operation graphic push button will bring up the Manual Ops Select screen. System Off Operations/Manual Ops consist of the Distillate Loop Screen (as well as subscreens Dist Loop#1 Manual Ops and Dist Loop#2 Manual Ops), the Concentrate Loop Screen (as well as subscreens Conc Loop#1 Manual Ops and Conc Loop#2 Manual Ops), and the Cooling/Heating Loop Screen (as well as subscreen Cooling/Heating Loop Manual Ops). Almost every device on the unit can be operated from these Unit Off

Operations screens. When the unit is off, the operator can use these screens to fill and drain the unit, check the operation of the control valves, and conduct pump checks. These screens are valuable maintenance tools when making repairs or calibrating unit analog devices.

3. PREPARATIONS

3.1 PROCUREMENT

Four of the five skids used for the evaporator system were purchased from Delta Thermal, Inc. — a heating skid, a cooling skid, a feed/concentrate skid, and the main evaporator skid. A separate distillate holding tank skid was assembled at ORNL. Radiation from the LLLW made shielding necessary for the feed/concentrate and the evaporator skids. Concrete modular shielding, consisting of four stackable, square concrete "rings" that surround each skid, was purchased from Concrete Products, Inc.

3.1.1 Bid Specifications

Specifications for OTED equipment, prepared by the Engineering Division at ORNL, were issued in July 1994. Core requirements were for a 90-gal/h horizontal-tube (for lower shielding height), single-stage subatmospheric evaporator with concentrate holdup tank, distillate tank, heating and cooling skids, all associated piping, and a computer control interface for the system. Additional requirements included the need for remote operation of individual pumps and valves, duplicity in pumps and valves, and data-gathering capability in real time. Materials specification was a significant issue. In addition to being radioactive, the MVST feed has a nitrate concentration of >4 *M* nitrates and a pH >12.0. Capability was also required to decontaminate the equipment with warm water or nitric acid rinses. Stainless steel (316L) was specified for all process piping and tanks, while carbon steel was sufficient for construction of the heating and cooling skids.

Motor drain valves that could remotely drain all radioactive fluids were specified for the drain system. All major pipe welds were to be seal-welded in an inert gas environment to eliminate significant structural flaws on the inside surfaces of piping along the weld. Flanges required a 150-lb working pressure rating.

3.1.2 Construction/Fabrication

Design plans were finalized, and fabrication of the four vendor-supplied evaporator skids was initiated at Delta Thermal, Inc., in the spring of 1995. On-site testing at Delta Thermal, Inc. of the complete system began in late September 1995, starting with city water and safety system tests. Safety system tests identified several minor programming problems that were immediately corrected. During city water tests, observed distillate production rates of up to 120 gal/h exceeded specifications. Surrogate testing followed in accordance with specification instructions using a formulation based on LLLW composition (Appendix A). The system was tested thoroughly using city water and surrogates, although the maximum DF attainable in the evaporator was not identified since concentrations of sodium in distillate approached analytical detection limits. However, results indicated that a DF of at least 1.0×10^5 was attained. Documentation, including complete copies of the *OTED Operations and Maintenance Manual*, instrument calibration plans, complete vendor cut-sheets, and spare parts lists, was provided by the vendor.

3.2 INSTALLATION

3.2.1 Site Preparation

The electrical supply to Building 7877 had been upgraded in July 1995 to supply increased power demands of the evaporator system. Installation of the system began in October 1995 with placement of heating and cooling skids on the west side of Building 7877 adjacent to the high-efficiency particulate air (HEPA) ventilation system. Once the heating and cooling skids were secured, the area was restricted for access. A temporary shelter was installed over the heating skid to protect the electric service system from the effects of weather.

The evaporator, feed/concentrate, and distillate holding tank skids were then installed in Building 7877. Positioning of the skids inside previously fabricated stainless steel drip pans was accomplished with an existing 5-ton overhead crane. Figure 3 shows the approximate layout of each skid inside and outside Building 7877. For initial city water and surrogate tests, only the bottom "ring" of each shielding module was installed (see Fig. 4). This approach allowed near-complete electrical and piping installation without creating confined spaces during system checkout and troubleshooting.

3.2.2 Electrical/Piping Connections

Electrical and piping installation required approximately 3 months to complete. During this time, repairs were made to the bay doors and the ventilation system to ensure that adequate negative pressure could be maintained within the building during OTED operations. Several electrical panels were required, and wiring was routed through conduit. Electric power supply to the system and a video camera system

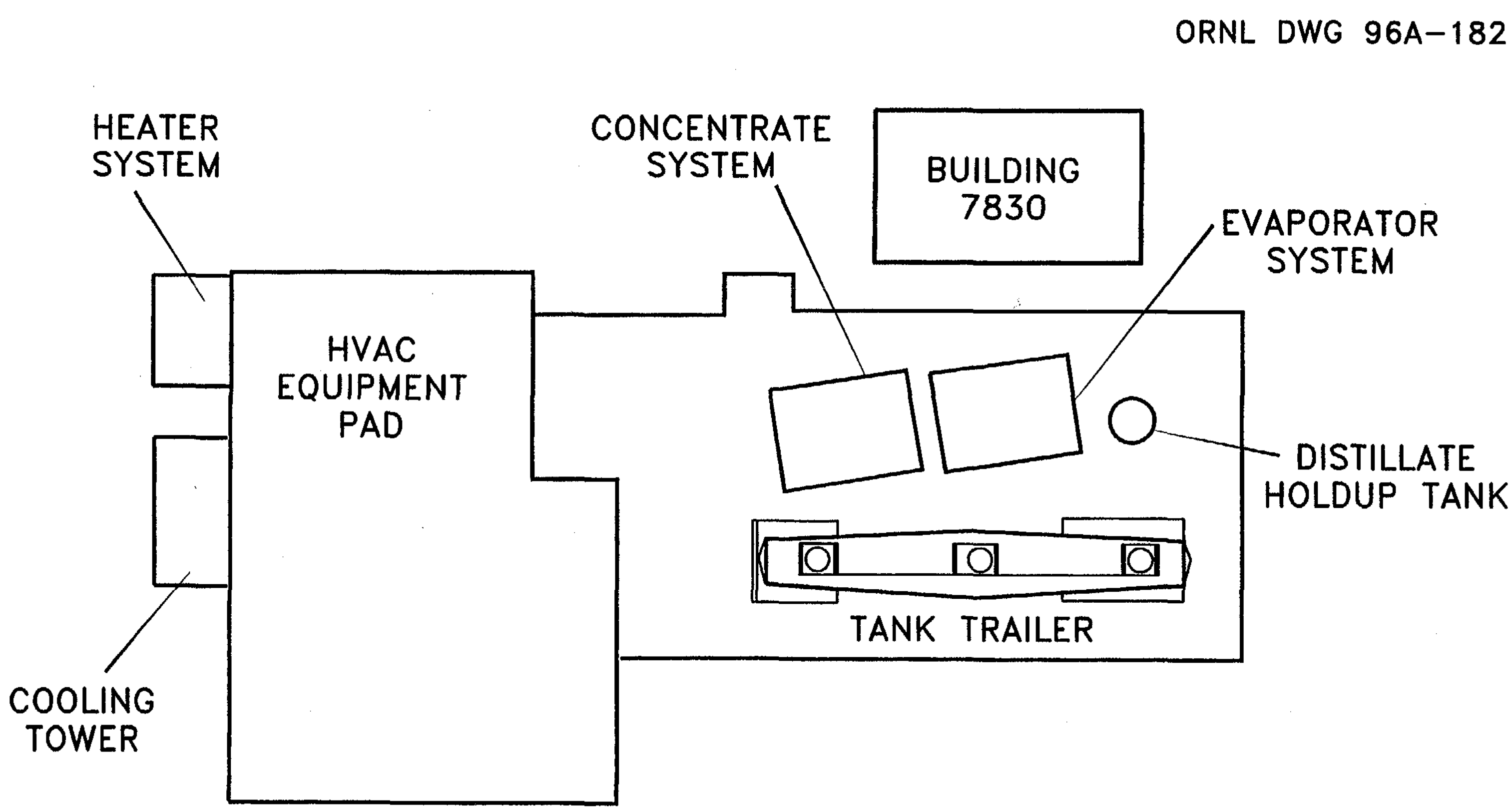

Fig. 3. Layout of evaporator system skids at Building 7877.

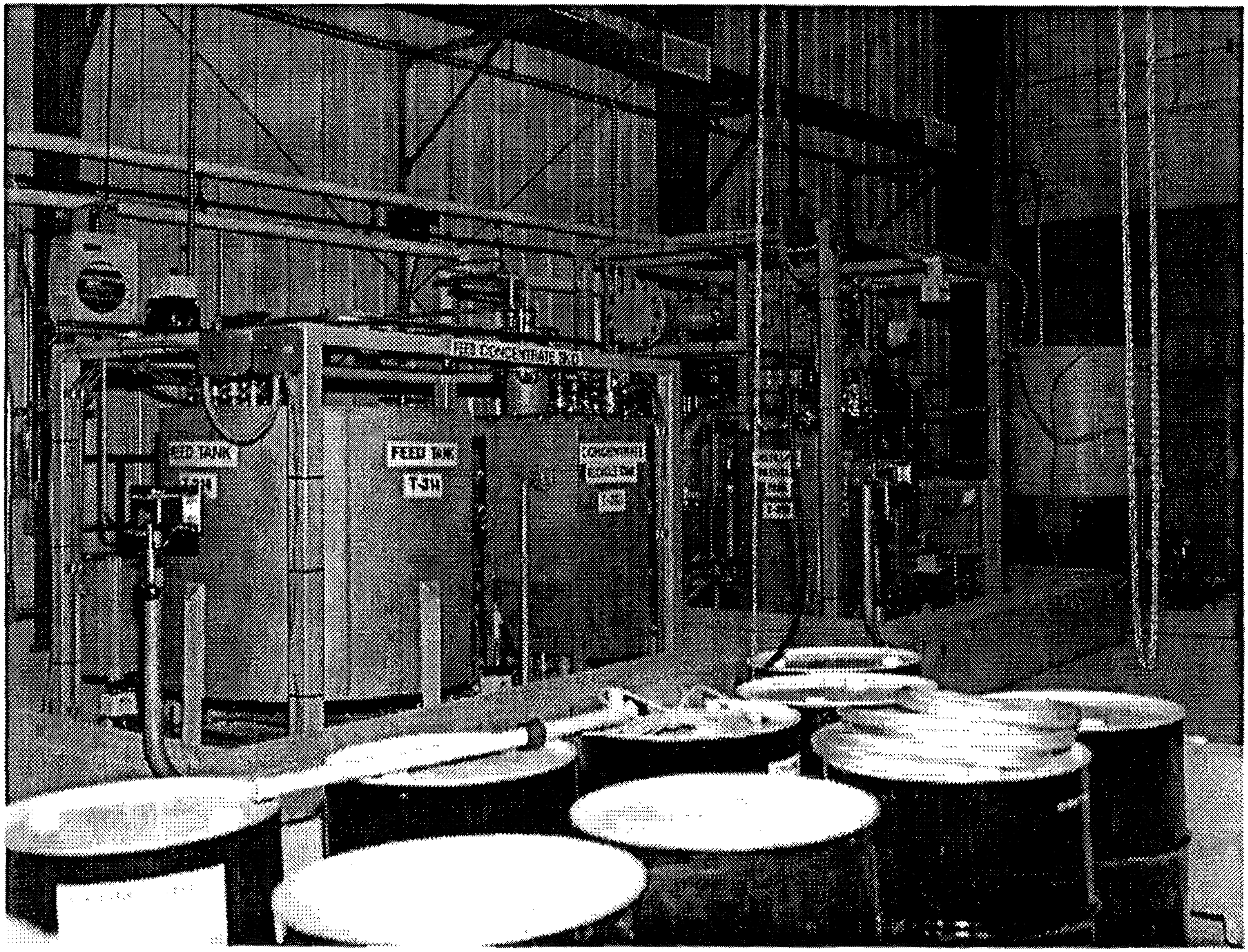

Fig. 4. Feed/concentrate skid and evaporator skid with bottom layer of shielding installed.

were installed. The remote operation computer terminal was installed in the control room in Building 7863 (approximately 125 ft away), with required connections to the evaporator system routed to Building 7877 through an existing underground conduit.

Interconnecting piping between skids was fabricated and installed. Feed, concentrate, and distillate samplers were installed with associated pumps and vents. Virtually all interconnecting piping between skids was "hard-piped" of stainless steel except for hoses connecting the heating and cooling skids to the evaporator skid and a hose used to pump distillate from the holding tank to the tanker. Double containment of piping between skids was not required since secondary containment was provided by drip pans and the building floor, which is sloped toward a sump. Hoses were used for heating and cooling fluids since they did not contain process fluids. A hose was also used for transfers of distillate to the tanker since its radioactive content was not significant. The evaporator system was deliberately left uninsulated so that potential leaks could be easily located and external surfaces could be decontaminated more readily.

During the installation of piping, oxidation of some welds was observed on terminal connections of the purchased equipment. It was theorized that this oxidation was caused by inadequate purging with an inert gas during welding. Additional information indicated that such oxidation could pose corrosion problems during nitric acid rinses of the system (a potential decontamination measure). Samples of the welds were submitted to the ORNL Metals and Ceramics Division for tests and inspection. Results indicated that sufficient unoxidized metal was present in the welds so that corrosion of the oxidized portion was not likely to result in failure of the weld (leaks) during dilute nitric acid rinses.

3.3 DOCUMENTATION

Where possible, documentation was developed so that minimal updates or modifications would be required for EM-30 to use the system for routine operation after completion of the demonstration. Several issues were identified which needed to be addressed with project documentation, including National Environmental Policy Act (NEPA) documentation; Resource Conservation and Recovery Act (RCRA) issues, nuclear criticality safety issues, modification of the facility safety basis (the System Safety Analysis and Technical Safety Requirements, SSA and TSR), radiation protection, and project-specific operational issues.

3.3.1 NEPA/RCRA

NEPA documentation is required for all research projects at ORNL. A categorical exclusion was obtained for the demonstration, based on NEPA documentation developed previously.

Since LLLW stored in the tanks contains regulated levels of heavy metals, RCRA issues were considered. The ORNL LLLW system is regulated by a National Pollutant Discharge Elimination System (NPDES) permit; OTED operations were covered by existing "Permit-by-Rule" documentation.

3.3.2 SSA/TSR

Building 7877 is classified as a category 3 nuclear facility because of the radionuclides present in the LLLW. This classification required modification of the facility safety basis (the SSA and TSR) for the demonstration. Transuranic elements such as ^{238}U are present in measurable quantities in the sludges in the tanks, requiring nuclear criticality safety issues to be addressed. Completion of these documents was essential to obtaining approval for the processing of radioactive waste in Building 7877. (These reports were developed by the ORNL Engineering Division.) The objectives of the SSA report were to (1) identify the hazards associated with the facility; (2) analyze and evaluate the potential accidents and their consequences; (3) identify and analyze the measures taken to eliminate, control, or mitigate the hazards; and (4) analyze the risk of operation of the facility. The existing SSA report for Building 7877 was modified specifically for the evaporator project and approved by DOE. The TSR report outlined the criteria necessary to show compliance with the requirements made in the SSA document and temporarily replaced the Limiting Controls Document (LCD) for Building 7877.

Two major concerns were raised regarding the OTED system in general: criticality potential and potential inhalation and ingestion risks for Melton Valley waste. Compliance regarding the criticality issue focused on the volume of liquid being processed in the OTED system. The MVST tanks hold a mixture of liquid and sludges; in general, the liquid has a gross alpha level of less than 200 Bq/L, while the sludges are transuranic wastes and, therefore, gross alpha levels are much higher. It was shown that the design of the MVST decant piping on the tanks used in OTED processing was such that solids would not be stirred up into solution and enter the OTED system. To remove the potential for a criticality issue, a TSR limit for gross alpha was determined by assuming a "worst-case scenario" that all the alpha activity was ^{238}U. Periodic sampling of the MVST feed was mandated to ensure that a gross alpha level of 350 Bq/L in the evaporator feed and concentrate liquids would not be reached during processing.

The second potential issue covered in the TSR was the possibility of inhalation or ingestion of radioactive material. A table was formulated to convert beta- and gamma-emitter concentrations to a ^{137}Cs equivalent (the predominant species in MVST liquids). Safety limits were established, based on the equivalent for both inhalation and ingestion hazards. The periodic sampling of the MVST feed and process concentrate was mandated to ensure that this safety requirement was fulfilled.

To guard against leaks and spills, the TSR required observation of the system and pumping lines during processing and pumping of MVST waste, as well as a qualified shutdown of feed transfer from MVST if the 10-gpm diaphragm pump exceeded 60 min in filling the feed tank in the OTED system. Other areas that were included in the TSR report involved contractor responsibility and organization, a mandate for formal procedures to be developed to demonstrate TSR compliance, and institution of several additional programs during the demonstration. These programs included radiation protection, criticality safety, fire protection, emergency preparedness, and facility safety analysis review. Each of these programs is defined in the *Energy Systems Policy Procedures, ORNL Standard Practice Procedures*, and/or the *Nuclear Criticality Safety Manual*. In addition to programs and compliance activities, the TSR report established periodic safety reviews of the facility use for OTED, a minimum requirement for operating records, and facility staff general qualifications.

3.3.3 Preoperational Review

The facility changes for the OTED and modification of the safety basis for the Nuclear Facility required the determination of applicability of DOE Order 5480.31, "Startup and Restart of Nuclear Facilities." A review of the requirements listed in this DOE order and in DOE STD-3006-93, "Planning and Conduct of Operational Readiness Reviews (ORR)," indicated that the OTED did not fall under the requirements of the order. It was determined that a Readiness Self-Assessment, consisting of a self-assessment and an independent management assessment, would be conducted to confirm readiness of the OTED team to safely operate the system with radioactive waste.

3.3.3.1 Self-Assessment

A checklist was prepared, based on previous readiness assessments for supernate solidification campaigns conducted in Building 7877. It consisted of 59 criteria to show that facilities and equipment, documentation (plans, procedures, and permits), and personnel were ready for operations. Modifications were made to specifically address the evaporator system and needs of a research demonstration project. All items in the checklist were addressed prior to operation with radioactive waste. Each item was addressed with documented evidence prior to operation with radioactive waste. The self-assessment required approximately 2 months to complete.

3.3.3.2 Management Assessment

An independent management assessment was conducted to confirm that self-assessment activities were sufficient to determine readiness for safe operation. The structure of the assessment was similar to that of a readiness assessment, as outlined in DOE Order 5480.31. During the process, criteria and requirements for satisfying each one were refined to define more specific needs for safe operation. Findings identified by the review were addressed prior to operation with radioactive waste. The review required approximately 2 weeks to complete.

3.3.4 Procedures/Work Plan

A comprehensive work plan was developed for the overall program; workaids or procedures were developed for tasks specified by SSA and TSR documents. The work plan contained general information about the OTED project and equipment, including objectives, a general demonstration schedule, a sampling plan, contingency action plans, and relevant contact lists. An overview of directions for distillate discharge, draining/flushing/decontamination of the system, filling the system, and a normal operations list was provided in the text, while detailed instructions and checklists were included in the appendixes.

Pump module operation, sampling, and TSR schedule requirements were developed as separate workaids. Instructions were given for system settings for feed delivery and concentrate discharge. Checklists were also provided for the operators to use while operating the system. A sampling workaid was written to describe use of the samplers installed on the OTED system, and a separate TSR workaid provided worksheets and checklists to completely document all criticality and inhalation/ingestion requirements of the TSR document. Other documents that became part of the *OTED Operating Manual* were QA procedures, instructions from the vendor, Delta Thermal, Inc., and the completed Self-Assessment Matrix.

3.3.5 Radiation Protection

Radiation protection was a high priority during the OTED. Radiation dose estimates to personnel for sampling operations in the demonstration were difficult to determine because of the variety of sources and their particular geometries. Initial dose estimates were made using simple geometries in Microshield 4.0. For each dose point, individual estimates were made from each contributing source term. These values were then added to give an overall dose rate at that point; however, the results were not satisfactory as they tended to vary greatly with relatively small changes in the location of dose or source term points in space. Substantial simplifying assumptions were often required when angles other than right angles were considered for radiation paths.

The Office of Radiation Protection was then consulted to provide more vigorous calculations of dose estimates for the OTED. Their modeling program (QADMOD-G) has several advantages over the

Microshield 4.0 software. It can use three-dimensional data describing multiple objects in space — for example, AutoCad simple three-dimensional objects — as its input for tanks, shielding, etc. In addition, the program can factor in the effect of reflection of radiation off angular and curved surfaces in three-dimensional space. Finally, it is a simple task using QADMOD-G to enter a batch of several dose-point locations. Once source terms are entered, almost any location can be chosen for the calculation of an estimate. Results of the computer model were used to finalize the design of engineering controls for radiation protection, determine ALARA and hold-point limits for exposure, and give early warning of potential high radiation areas within Building 7877.

3.4 TRAINING REQUIREMENTS

General training requirements were derived to comply with applicable state and federal laws and regulations, DOE Orders, Lockheed Martin policies and procedures, and concerns for employee safety and health. Project-specific training requirements were determined through meetings with the OTED team and reviews of SSA/TSR requirements and procedures and materials developed for operation by OTED personnel. As a result, a series of objectives, training forms, self-tests, and practical training checklists was generated. The OTED trainers then used these materials to document the completion of training for all OTED operating personnel.

3.4.1 General Training

General occupational training that was required for project personnel included 24-Hour HAZWOPER, Radiation Worker II, Respirator Qualification, Conduct of Operations for Liquid and Gaseous Waste Operations Department (LGWOD), and Off-Road Defensive Driving. Most of these requirements arose from the need to work with industrial-scale equipment with radioactive materials. All project personnel were qualified in respirator use due to the potential for dealing with radioactive contamination. Off-Road Defensive Driving was required since roads to the MVSTs were gravel.

3.4.2 Project-Specific Training

Facility training included discussion of the locations of local emergency manual, emergency exits, general site precautions, and access requirements. Operators took written examinations covering critical aspects of operating workaids and the Work Plan. On-the-Job training was also conducted and documented.

3.5 ANALYTICAL RESULTS

To test for DFs in the surrogate distillate, a project-specific standard method was developed for use of inductively coupled plasma (ICP) in detecting low levels of sodium and potassium. Anions were determined using ion chromatography. Other surrogate parameters, including pH, density, conductivity, and total dissolved and suspended solids (TDS/TSS), were determined by standard procedures. A full set of analyses for Waste Acceptance Criteria (WAC) parameters was performed for disposal of surrogates with a 4+ *M* nitrate content at a biodenitrification facility located in the Y-12 area.

During operations with radioactive waste, the following parameters were monitored in real time: gross alpha, beta, ^{134}Cs, ^{137}Cs, ^{90}Sr, and ^{60}Co activities. Following completion of the demonstration, these samples were analyzed for pH, conductivity, density, TDS/TSS, anions, and metals, including sodium and potassium.

3.6 PREOPERATIONAL TESTS (SAFETY)

During the preoperational phase of the project, all system controls, valves, and electronic instrumentation were checked for operability. The manual mode of the control program allowed testing of each individual valve and pump within different process control loops.

The evaporator system was filled with water and tested methodically for leaks. Both feed and concentrate tanks (vented to the building ventilation system) were filled to a high level with pumps on the skid and tested by recycling water between the two tanks. Once this skid had been checked and leaks had been identified and repaired, water was pumped to the evaporator shell and distillate tank on the evaporator skid. The distillate tank, also vented to the ventilation system for Building 7877, was filled to a high level and checked for leaks. Both distillate pumps were operationally checked and leak tested. The evaporator shell was tested hydrostatically by replacing a temporary isolation valve on the condenser with a pressure gauge and pressurizing to 3.0 psig with water. The evaporator normally operates at over 20-in Hg vacuum, but the slight pressurization allows leaks to be easily detected. Leaks identified under hydrostatic pressure were repaired by tightening flanges, and the condenser and separator were drained to a working level in the shell by pumping to the distillate tank.

Once levels were normal in all tanks and the evaporator shell, the second phase of leak tests began. The system was started and allowed to build up vacuum as distillate flowed through the twin eductors. Once the system had reached a vacuum of about 25.0 in. Hg, the evaporator, separator, and condenser were sealed off from the remainder of the system by closing the appropriate flow control and ball valves. After being monitored for 2 h, no loss of pressure was observed in the evaporator. Valves were opened and testing proceeded with a check of the safety features in the equipment. High- and low-level switches and alarms, analog high and low setpoints, flow/pressure/temperature setpoints and alarm setpoints, general system alarms, and control system logic were tested. Many of these features were simulated by manipulating alarm setpoints above or below normal operating conditions. During this time, the calibrations of tank level sensors, flow and pressure measurement devices, and thermocouples were verified or adjusted as necessary. The final phase of checkout consisted of 24 h of operation of the system with city water.

3.7 SURROGATE TESTS

After the tests with city water had been completed, the 500-gal feed tank was filled with surrogate solution (see Appendix A). Surrogate tests with the same solution had been previously conducted at ANL using a bench-scale (3-gal/h) evaporator. Results from those studies indicated that DFs up to 1.4×10^6 could be attained, and scaling and foaming were not expected to be significant during normal operation. Foaming was observed shortly after startup but disappeared soon thereafter. Boiling-point elevations of 7 to 10°F were observed by ANL.

Shifts were established to practice round-the-clock operation, including concentrate and distillate sampling. Every 2 h, ambient, outside, and feed-tank wall temperatures were taken and a concentrate and a distillate sample were obtained from the samplers located on the OTED skids. Every 4 h, the condenser temperature variable was changed to build a matrix of operating conditions using the surrogate feed. Initial results were poorer than expected, with DFs below 1×10^5; however, these results were considered to be caused by difficulties controlling the system. Temperature control for the heating loop was cycling constantly up to ±20°F around the setpoint. The temperature controller was replaced with an upgraded model to improve control and evaporator performance.

When a severe winter storm hit East Tennessee during early February 1996, the heating system in Building 7877 was unable to cope with the subzero temperatures, and some valving, pumps, and instrumentation were damaged due to ruptured lines. Over the next month, repairs were made to damaged sections of this system.

While the evaporator system was being repaired, it was discovered that the glass septum bottles used for sampling had contaminated the samples with a small amount of sodium (just over 1 ppm). This observation rendered distillate concentrations from previous experiments (which were expected to be in the 100-ppb range) useless for determining DFs. It was then decided to continue using glass bottles for the concentrated samples but to switch to plastic precleaned bottles for distillate collection. Additional troubleshooting revealed that the flow rate through the concentrate sampler was very low. Therefore, a sampling pump was installed in the concentrate sample line to provide supply pressure and flow for the concentrate sampler.

A second series of tests was performed using the same surrogate feed as before. For this set of experiments, the condenser temperature setpoint was varied (120, 130, 140, 150, and 160°F) every 6 h. Condenser temperature and reflux spray were expected to have the most significant effects on the DF achieved in the evaporator. The reflux spray in the condenser was alternated on and off every 3 h, with a 3-h delay between temperature and spray condition changes. The system was allowed to operate at least 3 h between changes to allow sufficient time to pass to ensure that concentrations measured were indicative of that set of operating conditions. A concentrate sample and a distillate sample were taken at 1.5-h intervals. These samples were analyzed for the same parameters as were those in the first surrogate run — TDS/TSS, density, conductivity, pH, metal ICP, and ion chromatography. Results from this surrogate run were very favorable; based on sodium the DFs were greater than 1.7×10^6, and based on potassium they exceeded 7.5×10^5. The difference between the results for the two metals was attributed to difficulties in analyzing distillate samples, where the sodium and potassium concentrations consistently approached or were below detection limits. Suspended and dissolved solids were also below detection limits in distillate samples. On average, distillate was produced at 60 gal/h. The results shown in Fig. 5 indicated that the highest DFs were obtained with the system operating with a condenser temperature of 140°F and appeared to be unaffected by reflux spray (the single low DF observed resulted from the only distillate sample collected in a glass bottle). No indication of significant scaling or foaming was observed. These observations compared favorably with results obtained in bench-scale experiments conducted at ANL.

During removal of the surrogate feed from the system, the drainage design from the evaporator and feed skids to the sump pit (which routes to the MVSTs) was determined to be inadequate due to anticipated problems associated with decontaminating a large open sump pit. Therefore, an intermediate sump container and pump were added to allow liquid to be routed to tank W-30 instead of draining directly to the open sump.

4. DEMONSTRATION OPERATIONS AND RESULTS

Throughout the planning and implementation phases of the demonstration, personnel radiation protection was a high priority. Early in the planning stages, radiation exposure and the potential for contamination were identified as the primary drivers for engineering controls and procedural requirements for operation of the system with radioactive waste. Concrete and lead shielding, personnel training, remote

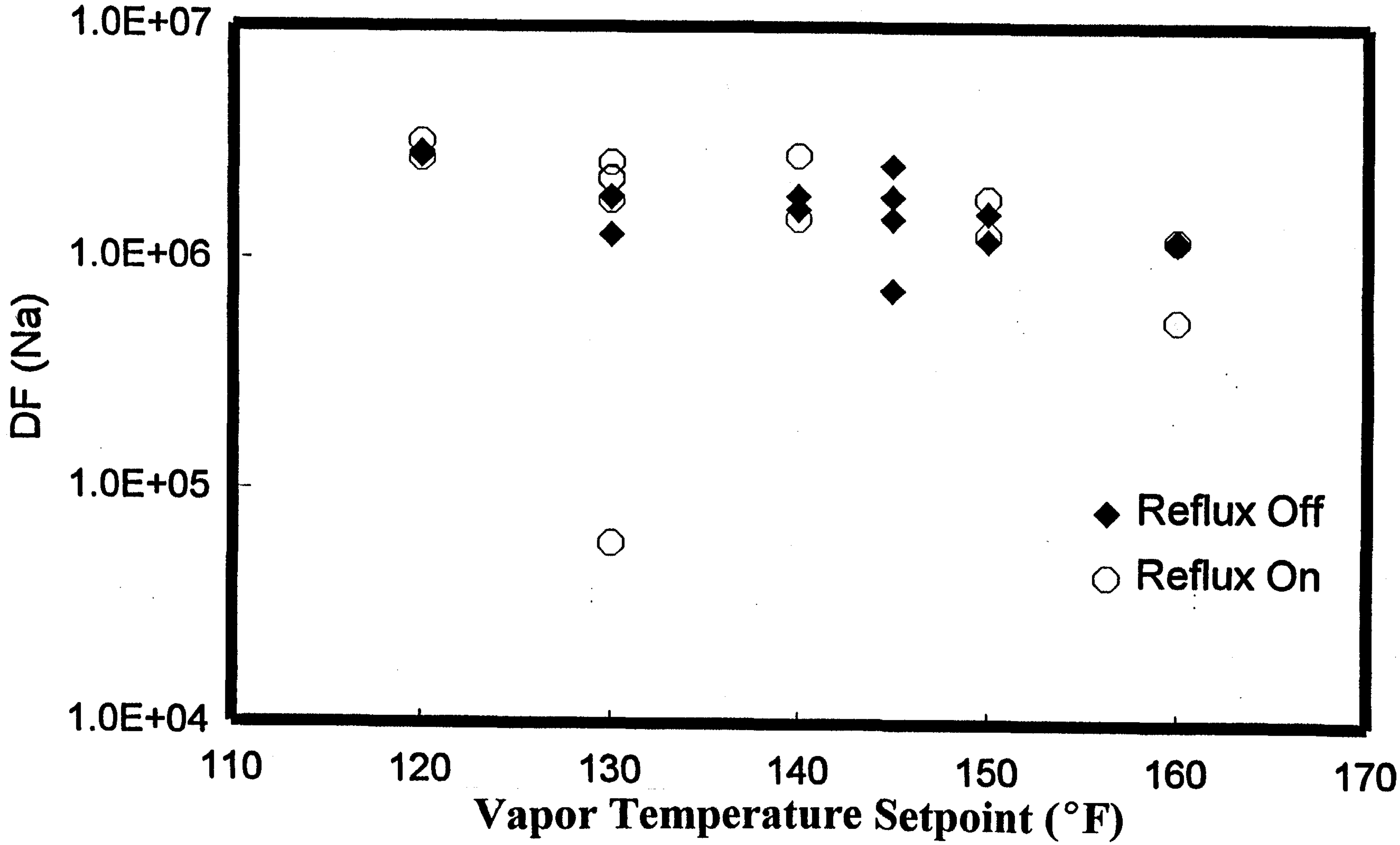

Fig. 5. Decontamination factors obtained in surrogate tests at ORNL.

operation, and several other measures were implemented for the protection of operators. During surrogate tests, "mock-run" sampling activities had been conducted using personnel protective equipment (PPE) required for operation with radioactive waste (level C). These tests allowed practice with donning/doffing procedures and identified potential logistic problems. During operation, PPE required company clothes, Tyvek suits, double gloves, and shoe covers. During sampling and many other activities, full-face respirators were also required.

After surrogate experiments had been completed, the remaining modules of concrete shielding were installed (see Fig. 6). Lead was installed on the north side of the shielding to decrease radiation doses in an adjacent building. Since the source of radioactivity during operations was primarily from the feed/concentrate tank skid, additional lead shielding was installed on that module (Fig. 7).

4.1 RADIATION DOSE MEASUREMENTS

Upon initiation of LLLW processing, a feed sample was taken from tank W-29. After confirmation that the gross alpha, beta, ^{60}Co, ^{90}Sr, ^{134}Cs, and ^{137}Cs activities met TSR requirements, the evaporator feed tank was filled (490 gal) and dose rates were measured around the building. All dose rates were in sufficient agreement with, or were less than, predemonstration estimates. QAMOD-G predictions tended to be somewhat higher than those observed; however, lead shielding was increased slightly after reviewing the predictions. Figure 8 shows both predicted and measured (during operation) radiation dose rates.

4.2 LLLW PROCESSING

Operations with LLLW continued 24 h/day with shift changes at 7:00 a.m. and 7:00 p.m. A radiation protection technician was present to assist with all radioactive sampling activities. During normal operation, three persons were normally present. This allowed one control-room operator (CRO), one pump module operator (PMO), and another individual to act as backup operators for sampling, emergencies, obtaining supplies, etc. Worksheets were completed to document most activities, including pump module access, sampling, and shift turnover. Abnormal conditions and routine operations in Building 7877 for distillate transfer (setting of valves) were recorded in the Operations Logbook in Building 7863.

Operation of the system proceeded smoothly. Every ten batches, samples of feed, concentrate, distillate recycle, and the distillate holding tank were obtained and submitted for analysis. Feed and concentrate analyses were used to verify TSR requirements, and comparison with distillate recycle results

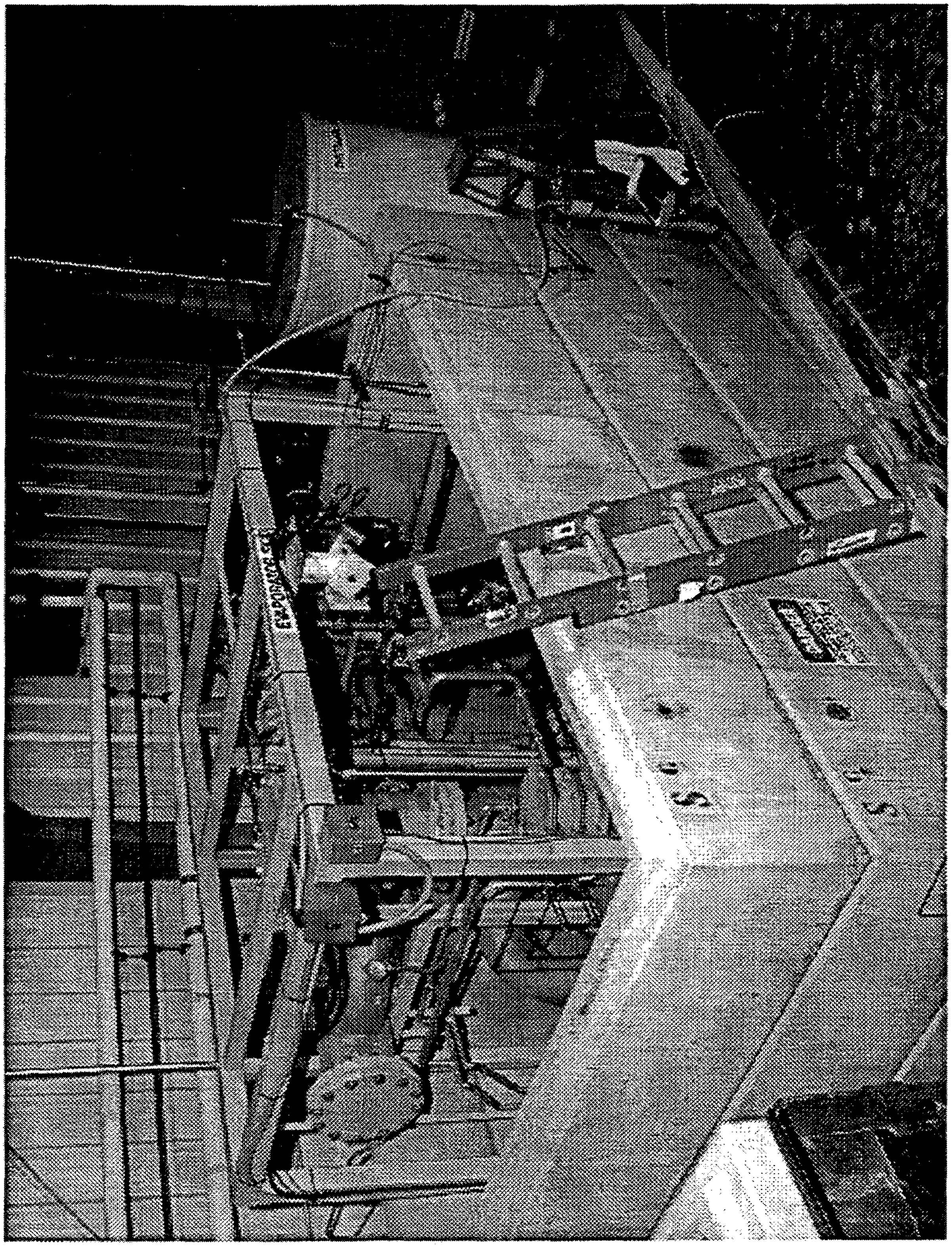

Fig. 6. Evaporator skid with concrete shielding completely installed.

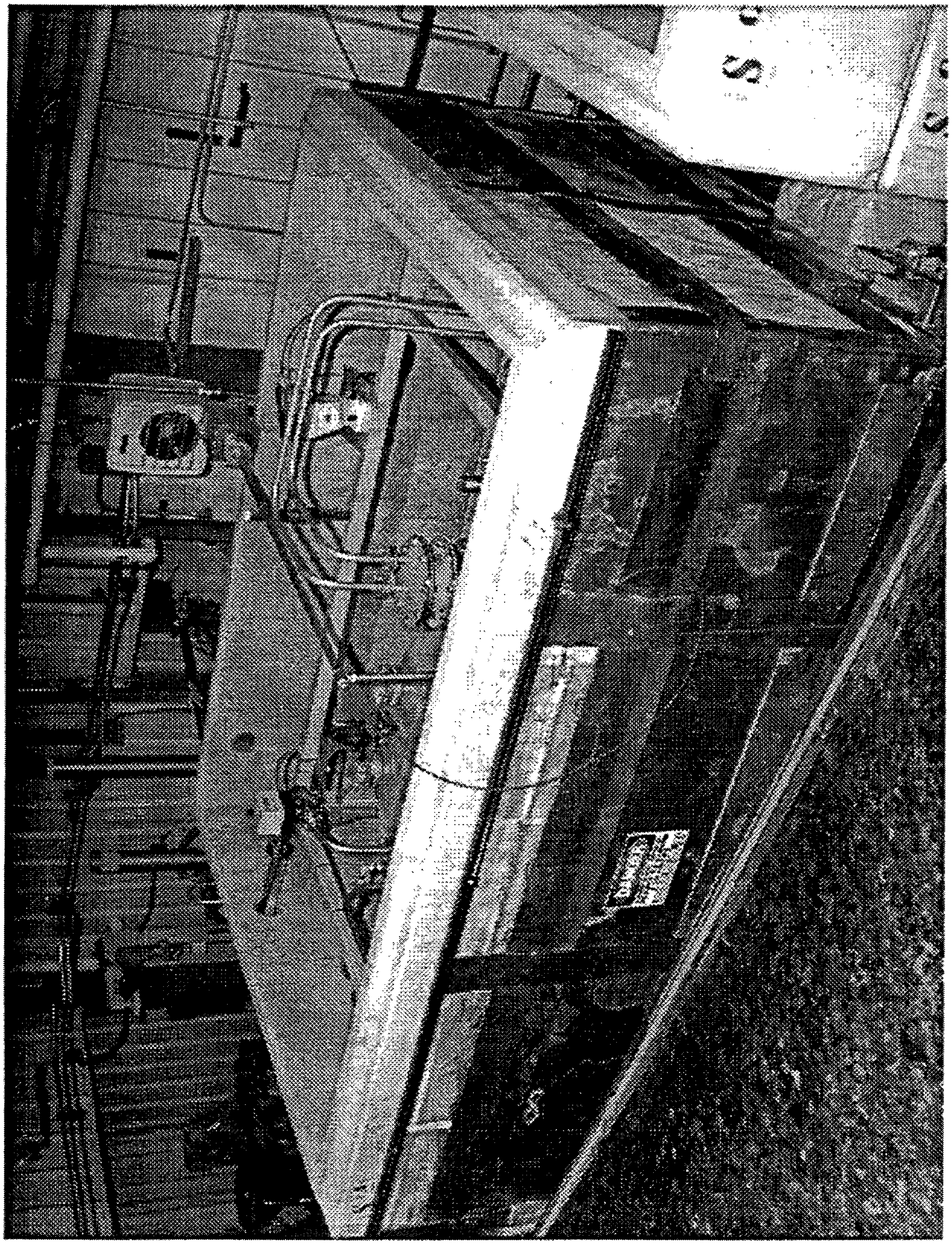

Fig. 7. Lead sheet attached to concrete shielding around feed/concentrate skid.

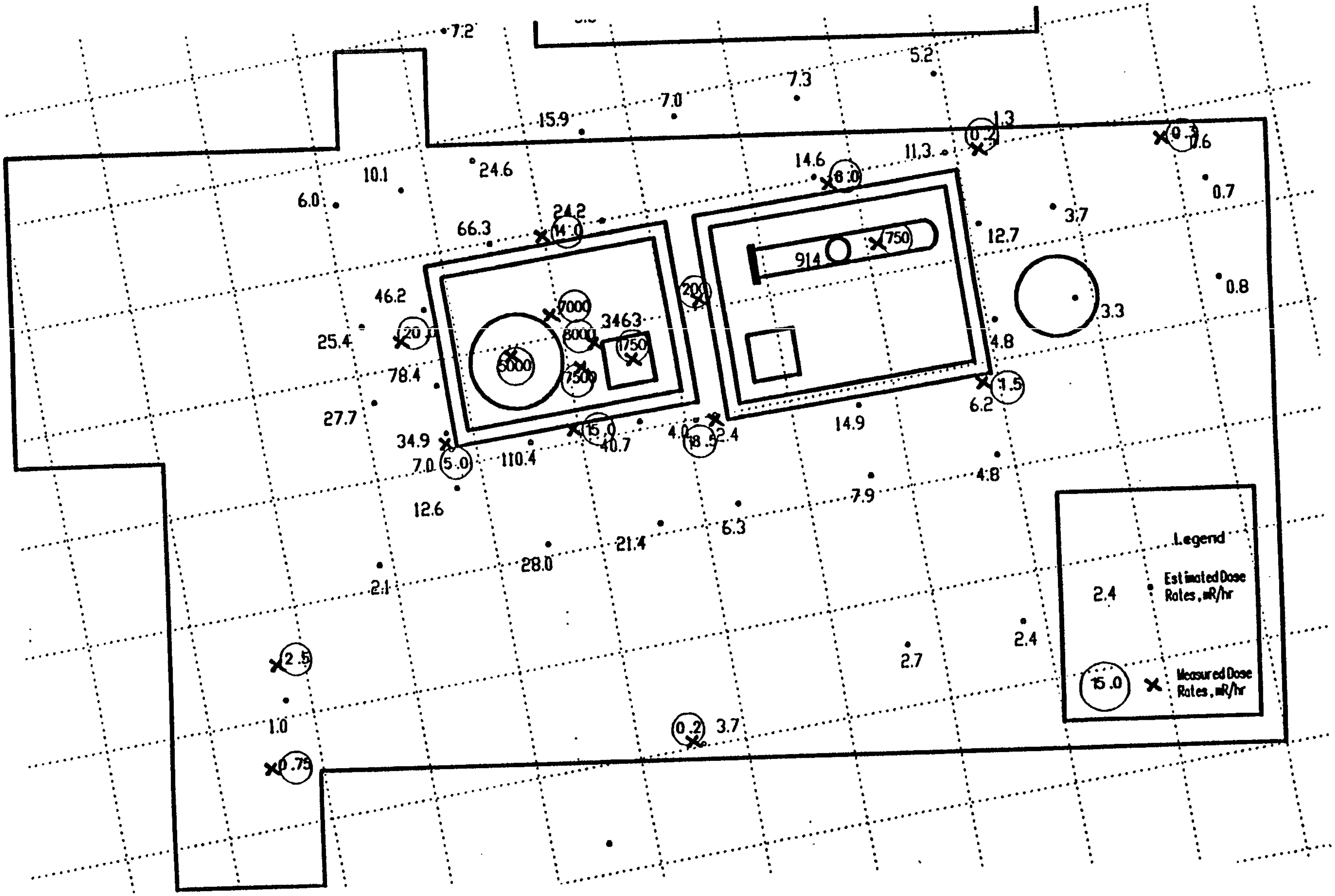

Fig. 8. Predicted and measured radiation dose rates around the evaporator system.

allowed the evaporator performance to be evaluated. Separate distillate samples from the holding tank were taken every five batches, and the contents of the distillate holding tank were transferred to a transport tanker after samples were confirmed to be below PWTP WAC limits for radioactivity. The separate distillate samples allowed two methods for determining evaporator performance. Distillate holding tank samples represented an average distillate produced during five batches of feed. Distillate recycle samples were used to determine an "instantaneous" DF value, which gives an indication of the evaporator performance at a particular time.

A failure of a control valve actuator required a 2-day shutdown of the system for repairs. A fusible link failed inside the actuator, which operates a valve to control the level in the distillate recycle tank. Prior to the attempt to repair the actuator, the volume of LLLW present on the evaporator skid was reduced; then the remaining liquid was diluted with process water. The repair required work inside the shielded area of the evaporator skid.

Dose rates were approximately 70 mR/h, but exposure to workers was limited by limiting the time spent inside the shielding. No worker received more than 10 mR during the repair, showing that hands-on maintenance was achievable. Operation proceeded smoothly for the remainder of the demonstration.

The gross alpha content of the feed remained fairly constant in the 100 to 250-Bq/L range during the entire demonstration. No visible solids buildup occurred in the evaporator during processing. Occasionally radioactive-salt deposits would build up on the shell tubes, but they were quickly redissolved when the shell level was changed and the tube surfaces wetted. Solids could have potentially become a concern if volume reduction had occurred much closer to the saturation point of the salts or any measurable uptake of solids or slurry from W-29 sludges had occurred during refilling of the system. Another potential area of concern was the scaling of the evaporator tubing and inner concentrate pipe surfaces. Although there was no visible evidence of scaling on the evaporator shell tubes, it is difficult to determine the scaling effect over the course of the demonstration. The overall heat-transfer coefficients (see Sect. 4.4) apparently remained about the same during radioactive processing. This would indicate a general lack of scaling on the heat-transfer surfaces in the evaporator system.

4.3 FINE-TUNING THE SYSTEM

Four key flow loops operate the evaporator system. A distillate loop provides vacuum on the condenser as it flows through eductors and also serves as a source of seal water for the concentrate recycle pumps. A concentrate recycle loop maintains a flow of concentrate through the evaporator shell and keeps the concentrate tank level constant. The heating loop adjusts the concentrate recycle inlet temperature to the setpoint boiling temperature. Finally, the cooling loop provides a cooling medium for the vapor condenser.

The system PID controls were fine-tuned initially during the experiments with surrogate formulations in January and February 1996. With these settings, the evaporator system performed more efficiently at night when temperatures were below 50°F ambient. The cooling loop flow rate required adjustment since difficulties were encountered in maintaining the condenser setpoint. Heating loop setpoints (heating reservoir temperature setpoint) ranged from 170 to 190°F, depending on the ability of the cooling loop to maintain its desired setpoint. (The controller on the heating loop was upgraded after the surrogate tests.) In addition, level parameters such as the evaporator-shell level setpoint were adjusted as necessary.

The most significant adjustments required during operation were PID tuning parameters for the condenser temperature (controlled by the cooling loop). Due to increased ambient temperatures, these adjustments were needed to maintain the condenser temperature setpoint identified during surrogate experiments.

4.4 HEAT TRANSFER ANALYSIS

As mentioned previously, the evaporator system was deliberately left uninsulated for the demonstration. The additional heat lost to the environment was recognized as a potential cause of reduced efficiency; however, the ability to more easily locate and correct potential leaks was judged to be more important. Generally, a similar well-insulated system could be expected to lose 5% or less of its heat input to the environment. Experimental data indicated that heat lost from the OTE system was as high as 30%. As expected, heat lost to the environment decreased during the day and increased at night due to changes in ambient temperature.

The analysis of heat transfer data identified two areas for improvement. Temperature readings around the evaporator shell indicated an apparent negative boiling-point elevation (BPE), the temperature of the boiling solution minus the temperature of the vapor. Results of small-scale surrogate tests conducted at ANL had predicted that the system should have a positive 7 to 10°F BPE. Examination of the evaporator skid revealed that part of the concentrate recycle flow bypassed the shell due to the placement of drain lines — which resulted in the observed anomalous temperature readings. Assuming that the BPE was 7°F, more than 90% of the concentrate recycle flow bypassed the shell. This observation is significant because the local concentration ratio inside the shell would have been over twice the achieved concentration ratio through the system, thereby increasing the potential for forming precipitates and fouling heat exchangers.

Overall heat transfer coeficients for the evaporator were calculated using the 7°F boiling-point elevation obtained from surrogate tests at ANL. Figure 9 shows heat transfer coeficients obtained during the demonstration, neglecting any heat lost to the environment from the evaporator shell. Little change was observed over time, indicating that heat exchanger surfaces did not foul significantly during operations. The heat transfer coefficients appeared to slightly increase with time, which was due to warming ambient temperatures (and less heat loss to the environment) during operations.

The second area identified for improvement resulted from difficulties experienced in tuning the cooling loop and from temperature data observed in the distillate recycle loop. A vent condenser present in the distillate recycle tank is designed to slightly subcool the condensed distillate to ensure that the eductors operate properly. Manufacturers' information indicates that the temperature of liquid pumped through each eductor should be 5 to 10°F less than the vapor temperature for efficient operation. Temperature data revealed that distillate pumped out of the tank was 20°F less than the vapor temperature, indicating that the cooling capacity was wasted with excessive subcooling (about 32 gal/min of distillate 10 to 15°F more than necessary). Assuming that this capacity could be utilized in the condenser, an extra 0.5 gal/min of distillate could be condensed, thereby increasing the throughput of the system by 50%. Figure 10 illustrates the difficulties in maintaining control of the vapor temperature and in subcooling the distillate stream. Two changes are recommended to improve the efficiency of the evaporator system: (1) the drain from the inlet pipe to the evaporator shell needs a motorized valve to prevent concentrate recycle from bypassing the shell; and (2) a control valve is recommended for coolant flow to the vent condensers so that cooling capacity will not be wasted with excessive subcooling of the distillate recycle stream.

4.5 EVAPORATOR PERFORMANCE RESULTS

Concentrate and distillate samples were taken and analyzed after each series of ten batches of material had been processed. The data were then used to calculate a DF, (feed ^{137}Cs concentration)/(distillate ^{137}Cs concentration). Analyses of MVST supernate in 1994 indicated that a DF of 1.2×10^5 would be required to produce distillate that would meet PWTP WAC. The DF was included in the specifications for the evaporator system. Analyses of the supernate in 1995 indicated that changes in the composition of LLLW resulted in a required DF of at least 2.5×10^6 to meet PWTP WAC. Experience with ANL's bench-scale unit indicated that DFs of over 1.4×10^6 (based on sodium) were attainable (Wygmanns and Chamberlain, 1995). Results from previous surrogate tests from ANL's large-scale units indicated that DFs of 10^5 up to 10^6 were attainable (personal communication from D. B. Chamberlain,

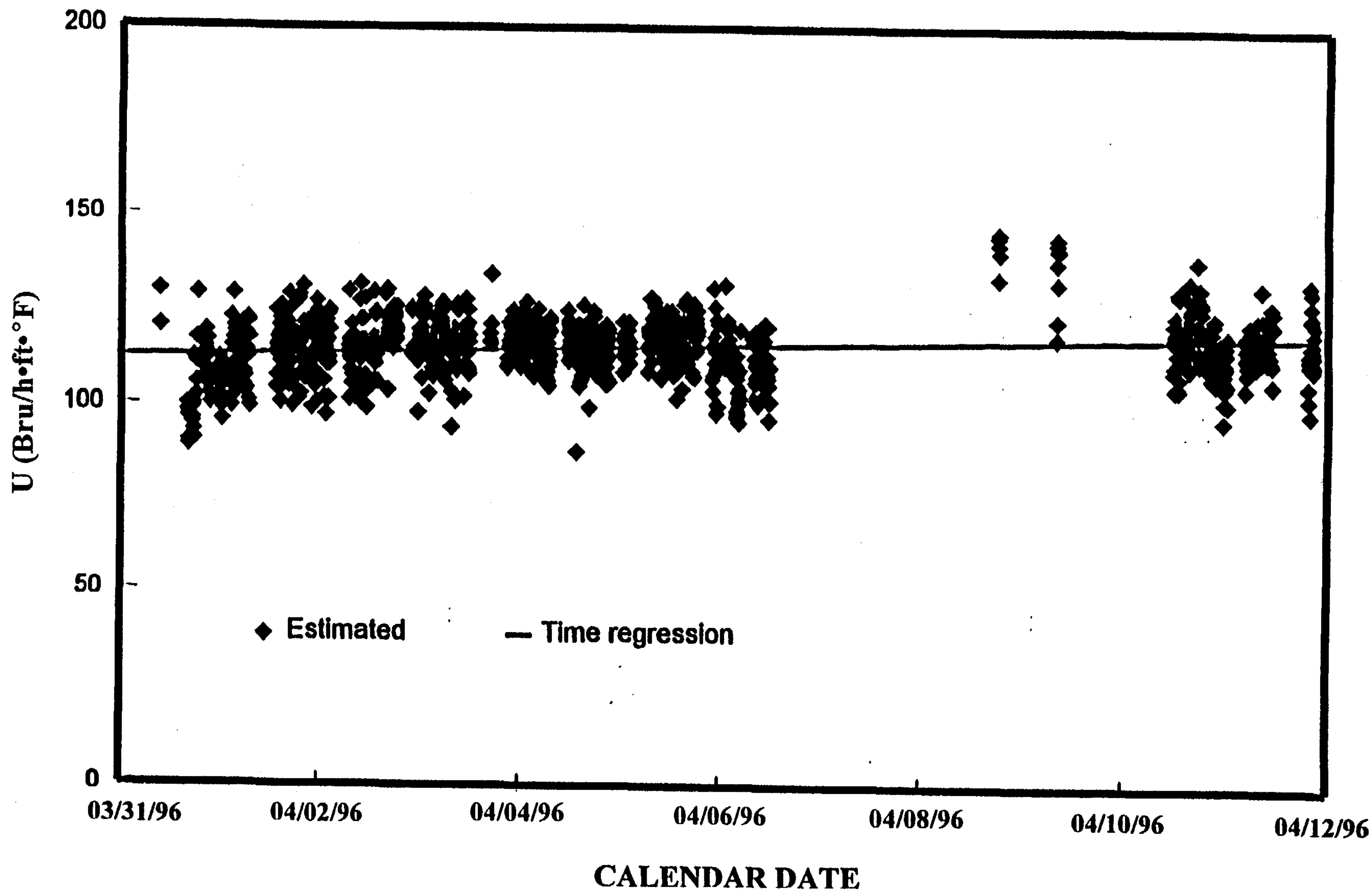

Fig. 9. Overall heat transfer coefficients for the evaporator during the demonstration.

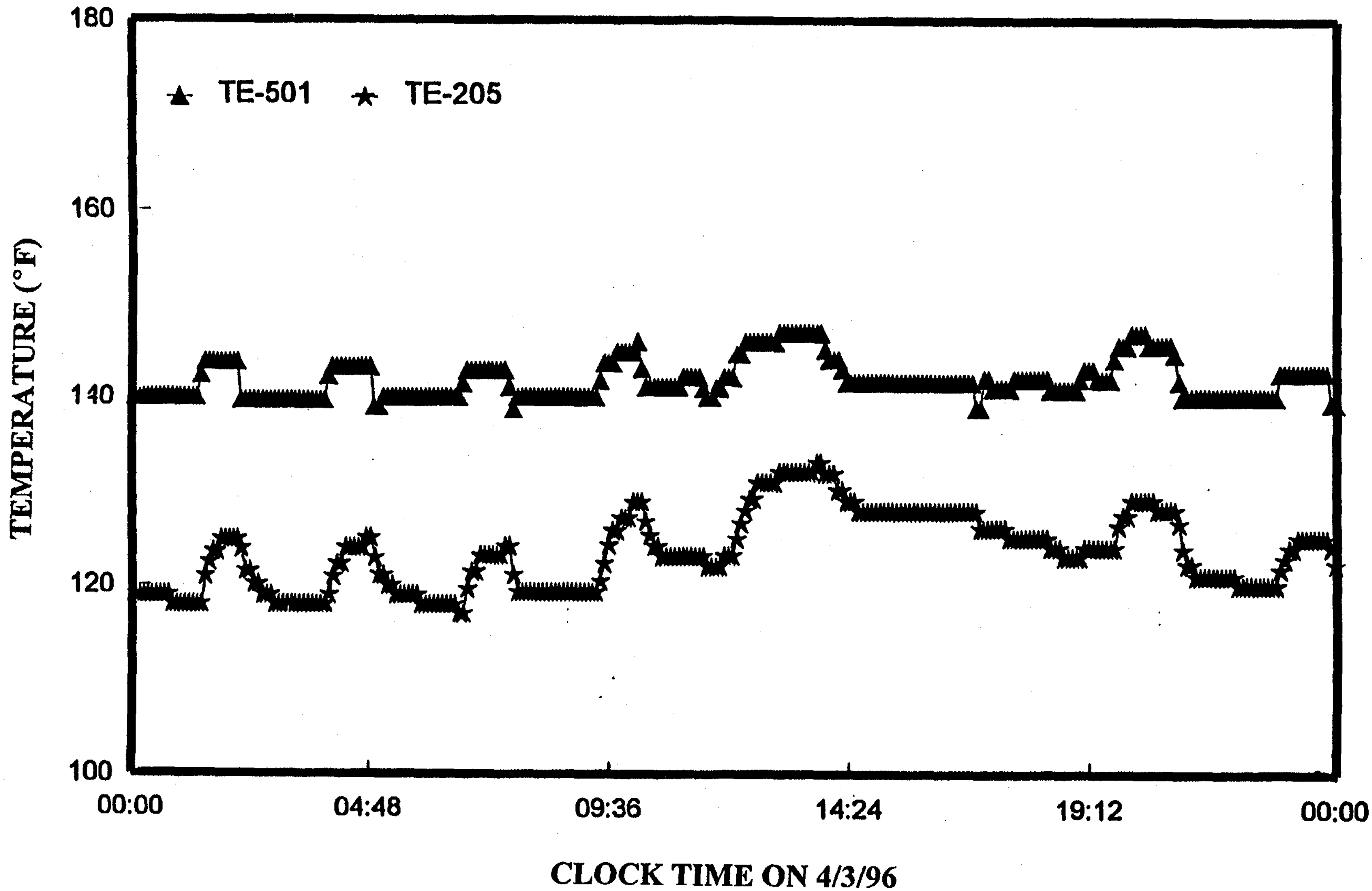

Fig. 10. Vapor temperature (TE-501) and distillate temperature (TE-205) during operation on April 3, 1996.

1994). In surrogate tests on the ORNL evaporator system, DFs reached at least 1.7×10^6. Special arrangements could have been made for the disposal of distillate produced with a DF of 1.7×10^6, but they were not necessary.

The OTED evaporator consistently performed above the level that was expected. The DFs averaged more than 5.0×10^6, with some values approaching 9.0×10^6. Figure 11 shows excellent average decontamination factors for ^{137}Cs during the demonstration (^{137}Cs was the primary radioactive contaminant in the LLLW). Analyses of distillate recycle samples allowed an "instantaneous" DF to be calculated, thus providing an indication of operation at the time of sampling. These values differed from the averages somewhat; however, this was expected because the evaporator system entered the recycle mode after each batch of feed was processed. Without the addition of cold feed (40–50°F), the cooling system experienced difficulties in maintaining the desired vapor temperature. It is believed that the DFs decreased while the system was in recycle and increased while the system was introducing fresh feed. Increased distillate conductivites observed during recycle support this observation. Even with these difficulties, average concentrations of 140–200 Bq/L in the distillate produced easily met PWTP waste acceptance criteria of 400 Bq/L. Table 1 shows average concentrations of the major constituents of the LLLW during the demonstration.

Table 1. Average concentrations of major constituents of LLLW during the OTED

	Feed	Concentrate	Distillate
^{137}Cs, Bq/mL	9.0 E05	1.2 E06	1.7 E-01
Na^+, mg/L	7.6 E04	9.9 E04	2.8 E-02
K^+, mg/L	2.3 E04	3.1 E04	3.4 E-02
NO_3^-, mg/L,*M*	2.3 E05 [3.7]	3.0 E05 [4.8]	2.8 E-01
Cl^-, mg/L	4.1 E03	5.4 E03	2.1 E-01
TSS, mg/L	2.6 E05	3.6 E05	<5.0
TDS, mg/L	7.8 E04	8.0 E04	7.0
Density, g/mL	1.21	1.27	1.0
Conductivity, µS	9.9 E04	1.1 E05	1.1 E01
pH	13	13.1	7.2

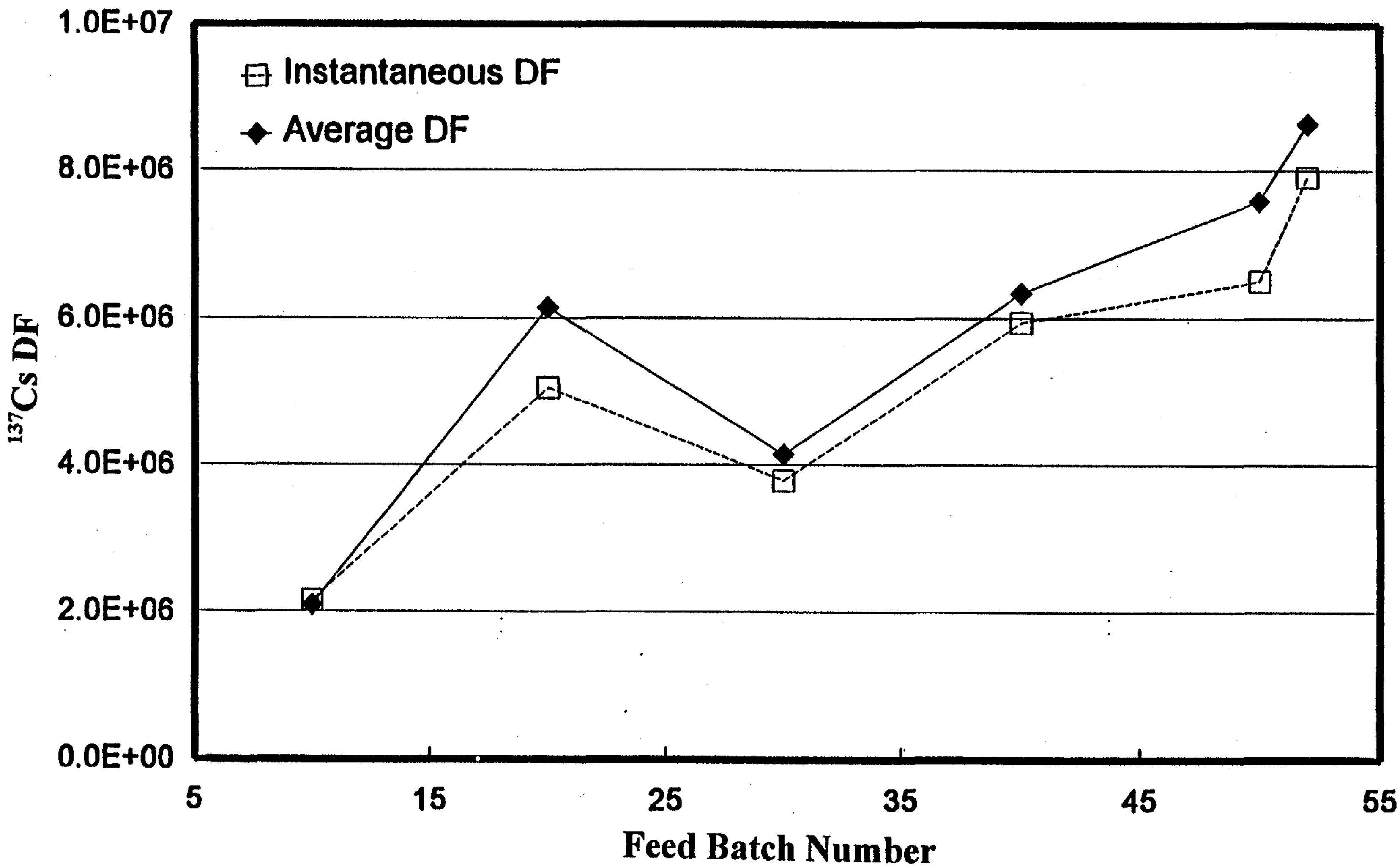

Fig. 11. Decontamination factors for ^{137}Cs during demonstration operations.

4.6 DECONTAMINATION OF SYSTEM

4.6.1 Internal Flushing

The evaporator system was designed to drain and rinse essentially all areas that contained process fluids. Rinses could be performed with distillate, process water, or nitric acid. The addition of flush or rinse water caused significantly increased foaming and bubbling in the evaporator shell. Foaming had increased slightly during operation when the system entered the recycle mode, but the effect was much more extensive during flushing. This observation was noted during operation with either surrogate or MVST supernate. Two possible explanations could account for the increased foaming: dilution decreased the boiling-point elevation, leading to increased, more vigorous boiling, or the process water had introduced particles for nucleation. The shell level was normally decreased during rinse cycles, from 6+ in. to 3 in., to prevent contamination carryover.

The basic steps involved in reducing background radiation and flushing internal system contamination were: (1) pump as much LLLW out of the system as possible, (2) rinse the feed tank with 200 gal of water, (3) process this water in the evaporator system at a high concentration factor, (4) obtain radiation dose measurements, and (5) repeat the procedure until background readings are decreased sufficiently. Following this procedure, the system was drained and pumped to tank W-30 in the MVST system. Radiation surveys determined "hot" spots, and the above procedures were repeated. Three rinses of the system reduced background radiation doses by over 98%. Results of each individual decontamination measure are shown in Table 2. Rinses with water proved to be highly efficient in reducing radiation levels, but difficulties were encountered with the interface between the OTE PLC and the pump module PLC for draining to tank W-30 in the manual mode.

4.6.2 External Flushing

After rinses of the system had reduced the radiation background sufficiently to allow closed visual inspection of the system and radiation surveys, approximately six areas were identified where small leaks (estimated, <20 mL) had contaminated exterior surfaces of equipment. These areas required decontamination to reduce the potential for creating airborne radioactive contamination. OTED personnel dressed out in protective clothing and decontaminated these surfaces with damp cheesecloth wipes. Some areas of the drip pans required rinsing with water to sufficiently decrease transferrable contamination levels. The sources of contamination were identified for repair prior to future operation of the system.

Table 2. Decontamination dose rates (mR/h)

	Dose rate during operation	Dose rate after emptying system	Dose rate after flush with 300 gal distillate	Dose rate after 500-gal flush	Dose rate after third flush
Evaporator skid					
Outside evaporator		3.0	1.75	0.3	< 5
Top, inside shielding		29.0	18	2.0	< 5
East end, shielding	250	35	390	25	< 5
Center, shielding	400	63	495	28	< 5
West end, shielding	300	55	28	20	< 5
Concentrate line	1100	860	38	42	< 5
Vacuum drag line				72	< 5
Feed/concentrate skid					
Outside shielding		1500		0.1	< 5
Top in front	370	140	68	10	< 5
Top in back	300	120	46	10	< 5
West end, opening		38	17	6.5	< 5
Top of feed tank	1500	390	165	28	< 5
East side, feed tank	4500	2000	765	87	< 5
West side, conc. tank		3500	2200	250	< 5
North side, conc. tank	8500	5000	1700	212	< 5

5. RECOMMENDATIONS

The OTED operational experience resulted in a list of recommended upgrades to the system prior to future operations to improve efficiency and reduce radiation exposure. Recommended improvements include additions to computer controls, addition of one video camera to improve visual leak detection on the feed skid, and use of a larger number of plastic drip pans underneath leak-prone areas (as a precautionary measure after fixing the leaks encountered during the OTED). Based on the experience gained in repairing the failed control valve actuator inside the shielding, actuators on each control valve inside shielded areas could be replaced or rewired with "plug-in" connections. This approach will allow an actuator to be easily and quickly removed for repair or replaced, thus minimizing the amount of time spent in a radiation area in the event of failure during operation

It is recommended that the interface between the pump module PLC controller and the OTE system be reexamined to allow automatic shutoff of the feed pump upon filling the feed tank. Although the safety shutdown operates properly, it sends the entire system into an emergency shutdown mode if activated.

Analysis of heat transfer data identified two additional piping "runs" that require additional motorized valves to improve operating efficiency. The drain from the inlet pipe to the evaporator shell needs a motorized valve to prevent concentrate recycle from bypassing the shell. A control valve is recommended for the coolant flow to the vent condensers so that cooling capacity will not be wasted with excessive subcooling of the distillate recycle stream.

6. CONCLUSIONS

Comparisons of dose estimates and data from the actual demonstration indicated that the simple dose model reasonably predicted a range for simple cases such as sample bottles; however, it failed to accurately predict radiation doses for complex cases such as the background at the concentrate sampling station. The more complex QAMOD model allowed significant improvements in dose estimates for improved planning for sampling and other events.

Operations flowed smoothly during the 8-day demonstration in which 22,000 gal of MVST supernate was successfully processed. Rinses with water reduced radiation doses by over 98%. The evaporator performance significantly exceeded requirements, with DFs as high as 9.0×10^6 being achieved for ^{137}Cs. Operation of both small and large evaporator systems, using surrogates, adequately predicted performance with the full-scale system on LLLW.

The results obtained during the demonstration indicate that this type of evaporator system should be considered for application across the DOE complex for concentrating LLLW. With minor modifications, the OTED will provide a system that is designed for long-term baseline operations and will meet ORNL user needs.

7. REFERENCES

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8. APPENDIXES

8.1 APPENDIX A

OTED Surrogate Formulations

Component	A[a]: Concentration (g/L)	A[a]: Concentration (*M*)	B[b]: Concentration (g/L)	B[b]: Concentration (*M*)
Sodium nitrate	369.80	4.35	281.00	3.31
Potassium nitrate	28.30	0.28	61.90	0.613
Sodium carbonate	15.90	0.15	10.60	0.100
Sodium chloride	4.27	0.07	3.51	0.0601
Calcium nitrate 4-hydrate	0.05	0.00	0.03	1.27E-04
Magnesium chloride 6-hydrate	0.01	0.00	0.007	3.44E-05
Sodium silicate 9-hydrate	2.48	0.01	0.185	1.51E-03
NaOH	Added to adjust pH to 13.10		Adjust pH to 12.8	

[a]Used in LICON bench-scale tests and in Delta Thermal, Inc., surrogate tests.

[b]Used in ANL bench-scale tests and in ORNL on-site surrogate tests.

8.2 APPENDIX B

ORNL/CF-96/07
April 16, 1996

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MANUAL

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