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The Emergency Avoidance Solidification Campaign of Liquid Low-Level Waste at Oak Ridge National Laboratory

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THE EMERGENCY AVOIDANCE SOLIDIFICATION CAMPAIGN OF LIQUID LOW-LEVEL WASTE AT OAK RIDGE NATIONAL LABORATORY

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CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	v
INTRODUCTION	1
PROJECT SCOPE AND PROCESSING STRATEGY	1
WASTE CHARACTERIZATION, WASTE FORM CERTIFICATION, AND VENDOR SELECTION	2
FACILITIES DEVELOPMENT	4
FACILITIES CHECKOUT AND OPERATION	6
POST CAMPAIGN SAMPLE ANALYSES AND WASTE FORM MONITORING	14
OVERALL EASC PROJECT SCHEDULE AND COST	17
REFERENCES	21

LIST OF TABLES

Table		Page
1	Summary results of the LLLW characterization effort in support of EASC waste form certification	3
2	Processing and storage summary for EASC liners	15
3	Summary schedule for the Emergency Avoidance Solidification Campaign	18
4	EASC cost summary	20

LIST OF FIGURES

Figure		Page
1	Basic EASC process flow sheet and facilities.	5
2	Cross section of the cask with the enclosed waste form.	7
3	EASC processing and interim storage site.	8
4	Schematic layout of LN Technologies processing equipment for the EASC.	10
5	ORNL EASC baseline processing schedule.	11
6	Temperature profile for typical liner of solidified LLLW.	13

INTRODUCTION

Since the beginning of nuclear research and development activities at the Oak Ridge National Laboratory (ORNL) in 1943, the generation, collection, treatment, storage, and disposal of the liquid low-level waste (LLLW) stream has been an integral part of ORNL's waste management operations. This waste stream, consisting principally of a high nitrate (4.5 molar), high pH (pH 13-14) mixture of reactor, hot cell, and research laboratory liquid radioactive wastes (<5 Ci/gal), has been treated and disposed of in a variety of ways over the years. Most recently, the hydrofracture technology had been used for deep-well disposal of a grout mix of LLLW, cement, fly ash, and other additives. In 1984, this disposal technique was discontinued due to regulatory permitting issues and the need for extensive facility modifications for future operations. With loss of this disposal capability and the continued generation of LLLW by ORNL research activities, the limited tank storage capacity was rapidly being depleted.

Beginning in October 1985, the ORNL Waste Management Operations staff initiated the study of treatment alternatives for the accumulating LLLW. By October 1986, ORNL and the Department of Energy, Oak Ridge Operations (DOE-ORO) management had selected "reference" and "backup" flow sheets for detailed design and implementation planning. Both flow sheets involved the solidification of the liquid waste into a stable waste form, either bitumen- or cement-based. The reference flow sheet included filtration and decontamination steps ahead of the solidification operation in an effort to minimize the hazard associated with the final waste form. The backup flow sheet involved simple decanting and solidification of the LLLW without preprocessing. In February 1987, after detailed assessment of the reference flow sheet feasibility, the decision was made to implement the backup processing technique, as the schedule and cost for application of the reference flow sheet was not compatible with the near-term need for process start-up. By that time, even after significant gains had been made in LLLW generation reduction, the available storage capacity was reduced to 2 years routine generation.

PROJECT SCOPE AND PROCESSING STRATEGY

To avoid the potential emergency conditions that would be associated with loss of LLLW storage capacity, a campaign was launched consisting of solidification of approximately 50,000 gal of LLLW utilizing the backup flow sheet. This campaign, called the Emergency Avoidance Solidification Campaign (EASC), was to involve (1) the construction of new facilities for the decanting of 50,000 gal of LLLW from two storage tanks at the Melton Valley Storage Tanks (MVSTs), (2) construction of a new process building adjacent to the MVSTs for conducting the solidification steps, (3) modification of the existing Building 7863 to serve as the remote control room for the solidification campaign, (4) construction of a gravel storage pad and fabrication of concrete storage casks for the interim storage of the solidification waste forms, and (5) selection and certification of subcontractor services for the solidification processing step. This was to be the first major project to be conducted at ORNL under the new DOE Model concept of involving commercial vendor capabilities in the solving of DOE waste management problems.

The processing strategy employed for the EASC consisted of the batch solidification of LLLW into vendor-supplied steel liners using commercial solidification equipment operating within the ORNL-provided processing buildings. ORNL waste management staff responsibilities included transfer of the waste to the vendor equipment, oversight of the vendor's solidification operations, analysis of process control samples, and transfer of the solidified waste forms into their interim storage casks. In addition to the solidification processing responsibilities, the vendor was also required to develop and certify, up front, an appropriate solidification mix for the LLLW stream, utilizing Nuclear Regulatory Commission (NRC)-equivalent performance requirements for waste form stability.

WASTE CHARACTERIZATION, WASTE FORM CERTIFICATION, AND VENDOR SELECTION

In October 1987, LN Technologies of Columbia, South Carolina, was selected as the primary qualified source for the on-site solidification of the waste and Chem-Nuclear, also of Columbia, South Carolina, as the alternate. Both firms had demonstrated experience with the in-container solidification of typical nuclear power station radwaste in cement and also had NRC-approved topical reports on their mobile solidification system. Contracts were signed with both the primary and the alternate solidification sources to proceed with waste form demonstration work to develop the formulations to solidify the ORNL high nitrate LLLW and to certify that the resulting waste form would meet the performance requirements of 10 CFR 61 and yield a minimum leach index of eight for nitrates.

The vendors utilized a surrogate waste formula provided to them by ORNL for development of their respective waste form mixes. The surrogate constituents concentrations were based on previous sampling and analysis of the MVSTs, although not specifically from the two tanks to be used in the campaign (W-29 and W-30). Later tank sampling and analysis from the subject tanks confirmed the bounding nature of the surrogate formula and detailed the controlling constituents of the liquid waste (pH, nitrates, heavy metals, radionuclides). A summary of the LLLW characteristics for the campaign is provided in Table 1. Of particular note is the presence of heavy metals, lead and mercury, above the Resource Conservation and Recovery Act (RCRA) limits and the confirmation of the high pH of the waste, making the waste characteristically hazardous under the RCRA regulations. The high concentrations of beta-gamma emitters Sr-90, Cs-137, and Co-60 defined the radiation shielding and contamination control requirements of the project, while the lack of significant concentrations of transuranic (TRU) nuclides ensured that no TRU wastes would be generated by the campaign. It was known that the sludges in the bottom of both W-29 and W-30 storage tanks contained high concentrations of TRU nuclides, and special effort was made throughout the processing campaign to observe and control the TRU content of the decanted LLLW.

Chem-Nuclear completed their formula development and waste form certification work in April 1988 (ref. 1). Their recommended binder consisted of 55% standard Portland Cement, Type I, and 45% low-calcium Class F fly ash. Mix ratios from 13.3 to 20.0 lb of binder per gallon of LLLW were tested; all produced acceptable waste forms and were certified as meeting the 10 CFR 61 and nitrate leach requirements. LN Technologies completed similar work in June 1988 (ref. 2), and their recommended binder consisted of 40.4% Portland Cement,

Table 1. Summary results of the LLLW characterization effort in support of EASC waste form certification (Tanks W29 and W30)

TANK NUMBER / SAMPLE NUMBER	W29-333-1	W29-333-2	W29-333-3	W29-500-1	W29 500-2	W29 500-2D	W29 500-3	W29 666-1	W29 666-2	W29 666-3	W30-333-1	W30-333-2	W30-333-2D	W30-333-3	W30-500-1	W30-500-2	W30-500-3	W30-666-1	W30-666-2	W30-666-3
DENSITY, g/ml	1.24	1.24	1.24	1.24	1.24	1.26	1.24	1.25	1.25	1.25	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
pH	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
TOTAL URANIUM, ug/ml	7.23	7.03	7.42	7.45	7.57	7.73	7.55	6.82	7.55	7.62	9.67	9.73	9.45	9.67	9.55	9.58	9.33	9.32	9.35	9.33
TOTAL ORGANIC-CARBON, ug/ml	509	562	548	562	535	509	509	446	496	490	357	357	398	386	350	350	361	326	329	354
INORGANIC CARBON, mg/ml	1.46	1.56	1.59	1.72	1.59	1.64	1.51	1.51	1.54	1.53	1.42	1.39	1.23	1.25	1.30	1.42	1.20	1.31	1.31	1.35
NITRATES, NO_3, M (mg/ml)	4.68 (290)	4.52 (280)	4.68 (290)	4.52 (280)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.68 (290)	4.35 (270)	4.52 (280)	4.68 (290)	4.52 (280)	4.52 (280)	4.52 (280)	4.52 (280)
CARBONATES, CO_3, M	0.14	0.14	0.14	0.15	0.14	0.14	0.15	0.15	0.14	0.14	0.14	0.13	0.14	0.12	0.14	0.13	0.13	0.14	0.13	0.13
HYDROXIDE, OH, M	0.25	0.24	0.24	0.24	0.25	0.25	0.23	0.24	0.24	0.24	0.47	0.48	0.48	0.50	0.49	0.49	0.50	0.48	0.49	0.49
GROSS ALPHA, nCi/ml	0.065	0.062	0.059	0.062	0.078	0.078	0.086	0.081	0.078	0.070	0.054	0.051	0.049	0.041	0.054	0.062	0.0105	0.059	0.062	0.039
(with Fe precipitation)			(0.108)				(0.122)			(0.035)				(0.062)			(0.059)			(0.070)
BETA EMITTERS, nCi/ml Sr-90	131	125	141	128	141	130	129	122	114	115	98	106	96	93	91	115	107	109	107	109
C-14	0.032	0.051	0.030	0.041	0.041	0.049	0.041	0.043	0.041	0.035	0.130	0.132	0.168	0.146	0.119	0.149	0.143	0.149	0.143	0.149
H-3	7.92	8.16	8.22	8.30	8.27	8.32	8.35	8.46	8.54	8.43	6.03	6.00	6.11	5.97	6.03	6.03	6.03	6.08	6.11	6.00
GROSS GAMMA, cts/min/ml	2.37E6	2.37E6	2.20E6	2.38E6	2.39E6	2.38E6	2.39E6	2.39E6	2.40E6	2.37E6	131.E6	1.30E6	1.30E6	1.29E6	1.29E6	1.29E6	1.30E6	1.29E6	1.30E6	1.28E6
GAMMA EMITTERS, nCi/ml CS-137	6510	6490	6220	6325	6110	5920	6435	6350	6430	6460	3515	3570	3540	3430	3540	3515	3325	3570	3460	3325
CS-134	218	193	191	191	181	182	196	189	185	202	105	111	112	111	111	106	109	115	111	99
Co-60	34	30	28	25	32	21	33	32	34	25	25	22	18	21	23	23	17	26	22	24
RCRA METALS, ppm (5.0) Ag	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
(5.0) As	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0		<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
(100.0) Ba	1.5	1.6	1.6	1.7	1.3	1.7	1.7	1.9	1.7	1.4	1.0	1.0	1.0		1.0	0.93	0.91	1.0	0.95	0.87
(1.0) Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
(5.0) Cr	2.4	2.6	2.6	2.6	2.2	3.0	2.9	3.1	2.9	2.2	3.5	3.6	3.5		3.6	3.4	3.5	3.5	3.4	3.5
(0.2) Hg	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6		<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
(50.0) Ni	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
(5.0) Pb	10.0	11.9	10.9	12.5	9.7	12.6	13.2	13.1	13.0	10.1	14.9	14.3	13.9		14.1	13.8	14.6	13.9	14.5	13.6
(1.0) Se	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0		<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
(0.9) Tl	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3		<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Cations, ppm Al		13.6			13.4			14.0				47.3	47.0					50.0		
B		0.59			0.51			0.60				0.66	0.60					0.61		
Ca		4.22			4.04			4.01				4.36	3.53					3.31		
K		11,100			9,720			10,500				7,890	8,440					8,820		
Mg		0.018			0.012			0.019				<0.01	<0.01					<0.01		
Na		103,000			103,000			104,000				111,000	104,000					111,000		
Si	12.0			13.0				12.0			31.0				31.0			34.0		
Sr		1.12			1.06			1.00				1.00	0.86					0.83		
Th		<1.35			<1.35			<1.35				<1.35	<1.35					<1.35		
U		<10.2			<10.2			<10.2				<10.2	<10.2					<10.2		
Zn		65.6			68.5			67.4				42.8	41.8					41.7		

Type I, 40.4% blast furnace slag, Grade 120; 3.8% celite (a moisture absorbent); and 15.4% Type F fly ash. The recommended mix ratio was 10.8 lb of binder per gallon of LLLW. This formulation was certified as meeting all the 10 CFR 61 requirements and the ORNL nitrate leach indices. Since both vendors' formulas qualified against the performance criteria, LN Technologies, as the primary vendor, was requested to make preparations for the processing campaign utilizing their qualified mix.

FACILITIES DEVELOPMENT

As outlined previously, new decant, solidification, and interim storage facilities were required for implementation of the EASC. The facilities development, design, construction, and testing were accomplished principally through two capital funded General Plant Projects (GPPs) and through an expense-funded site development project. The two capital projects were approved for construction in March 1987, consisting of an FY 1986 LLLW Solidification Facilities Defense Program GPP and an FY 1987 MVST Decant System Defense Program GPP. A brief description of the facilities provided through these projects is given below, with a schematic of the basic process flow sheet provided in Fig. 1.

The LLLW solidification facilities provided a confinement structure and supporting utility services for the vendor's mobile solidification process. The structure is a preengineered metal building approximately 33-ft wide by 60-ft long by 33-ft tall. It is insulated and sealed to provide for negative pressure operations with a high efficiency particulate air (HEPA) filtration system. The building floor is 1-ft thick reinforced continuously poured concrete sealed with an epoxy coating. The floor drains to a sump with an overflow back to the pipe tunnel within the MVST. The building was provided with a 5-ton electrically operated crane with a 25-ft clearance from the floor to the crane hook. Electrical services were extended to the building and a new distribution system was provided for pumps, fans, monitoring equipment, lights, and outlets. A new dry-pipe sprinkler system was installed for fire protection. Process water was provided from existing services in the general area.

The MVST Decant System provided a pumping and piping system from the MVST facility to decant the LLLW from the tanks and transfer it to the vendor's system. The decant system consists of a pump module (a shielded stainless steel box which contains the transfer pump and associated process valving) located on the roof of the MVST vault, dip pipes which extend to the centerline of tanks W-29 and W-30 (well above the sludge region of the tanks), approximately 200 ft of lead shielded 1-in.-diam stainless steel pipe contained inside a 2-in.-diam stainless steel pipe, a pressurized-annulus leak detection system for the double-walled piping system, new liquid-level monitors, and associated instrumentation.

Completion and checkout of the GPPs for the confinement and liquid decanting and transfer facilities were completed in April 1988. In addition to the general plant facilities, requirements were also identified for general purpose equipment (GPE)--a diesel generator, uninterruptible power supply, and stack monitor--to support the campaign. These were provided as GPE and were installed and operable by September 1988.

ORNL-DWG 88M-7830

Solidification will be Performed with the Solidification Liner Positioned Inside a DOT Approved Shipping Cask

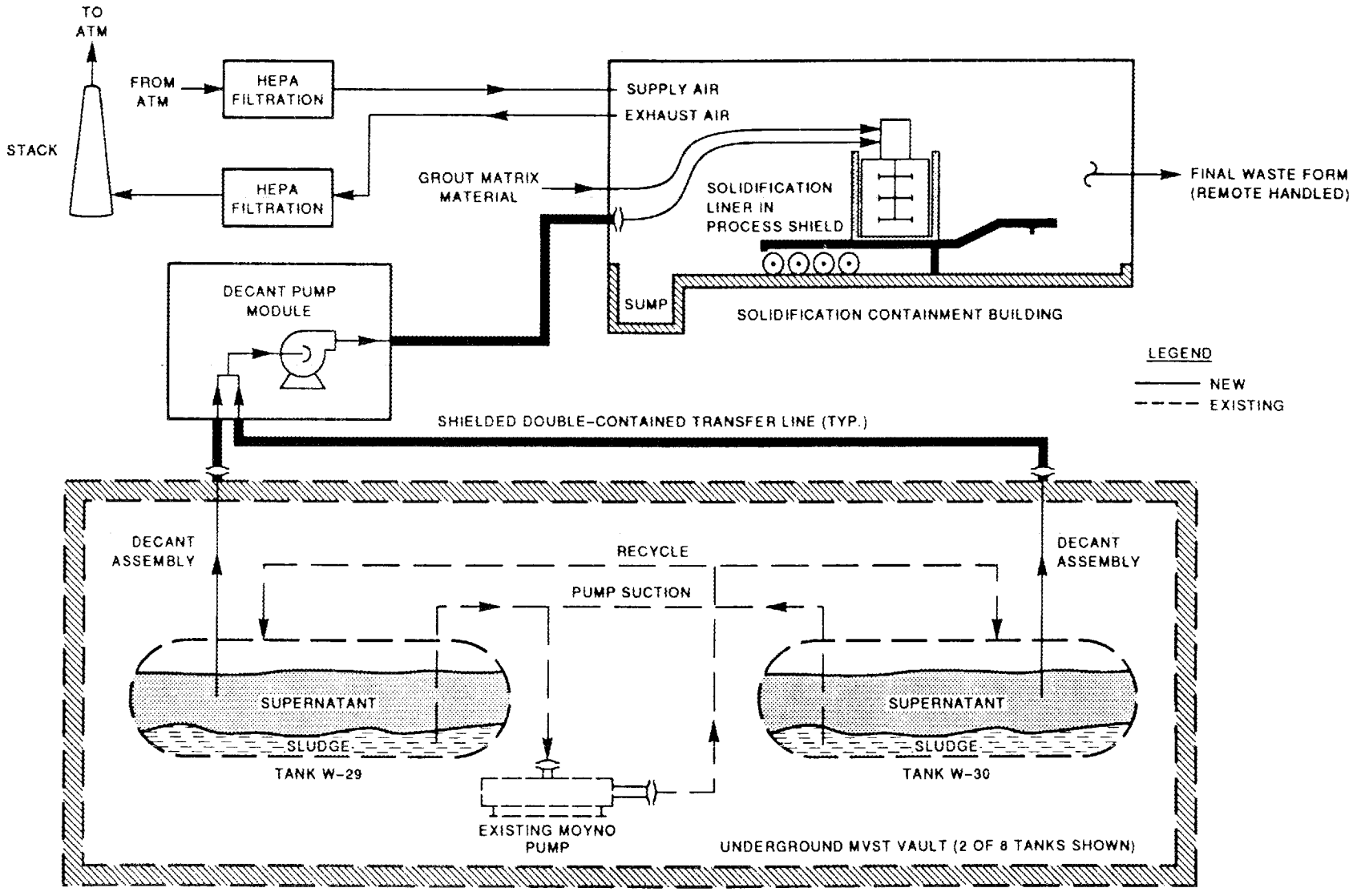

Fig. 1. Basic EASC process flow sheet and facilities.

When the decision was made in February 1987 to implement the EASC, the plan was to transport the solidified waste forms from the solidification confinement structure inside a Department of Transportation (DOT) approved shipping cask to Solid Waste Storage Area (SWSA) 6 for disposal either on the tumulus or in greater confinement silos. However, in December 1987, the Tennessee Department of Health and Environment (TDHE) indicated to DOE-ORO that the plan to dispose of EASC solidified waste on the tumulus could not be endorsed. Immediately upon learning of this situation, an alternative analysis to look at other ways of handling the near-term management of the solidified waste was undertaken by Martin Marietta Energy Systems, Inc., staff. The results of the analysis were presented to TDHE in February 1988 and approval for the modified waste storage concept received shortly thereafter. The alternatives analysis recommended redirecting the original plan to provide for on-site interim storage of the waste in monitored casks rather than for tumulus or silo disposal of the waste until the plans for final disposal could be implemented over the next few years as part of the overall Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program. A maximum 5-year storage period was agreed to, consistent with similar short-term storage activities at commercial nuclear power plants.

The interim storage casks design provided for multiple containment barriers for the solidified waste form, adequate shielding for the high-activity waste, and sampling capabilities for both entrained liquids and gases. The casks were fabricated of 1-ft-thick steel reinforced concrete with an inner liner of corrosion-resistant synthetic, vinyl ester, fiber reinforced plastic (FRP) laminate. The cask is about 9-ft diam and about 9-ft tall on the outside. The cask cavity is sized to accommodate one liner of solidified waste and provide 1 ft of concrete shielding (see Fig. 2). Once a waste liner was placed in the cask, the inner vinyl ester FRP liner was capped with a lid made of the same FRP materials. Finally the cask was closed with a waterproof reinforced concrete cask lid which was also 1-ft thick. The cask design provides for two monitoring tubes--one to monitor the bottom of the cask for any moisture and the second one located in such a way to facilitate monitoring of the inner cavity for off-gassing during storage. The casks were fabricated locally, with initial delivery provided in June 1988. A total of 70 casks were constructed in support of the campaign.

An area adjoining the EASC processing facilities on the south side of the site was selected for the graveled pad interim storage yard for the loaded casks (see Fig. 3). The area, which is about 300-ft wide by 400-ft long, required some clearing and grading to level the area. It was covered with a layer of geotextile fabric on top of the soil layer. A 6-in. lift of number 57 size crushed limestone was then placed directly over the geotextile fabric and capped with a 6-in. layer of compacted crushed limestone. The entire graveled area was sized to accommodate a maximum of about 160 casks and was enclosed with a chain link security fence to control personnel entry. Site development was completed in August 1988, just prior to start-up of the campaign.

FACILITIES CHECKOUT AND OPERATION

Preoperational checkout and testing of the facilities and equipment constructed for the EASC occurred in several distinct phases, extending from initial facilities construction in January 1988 through the end of the Readiness

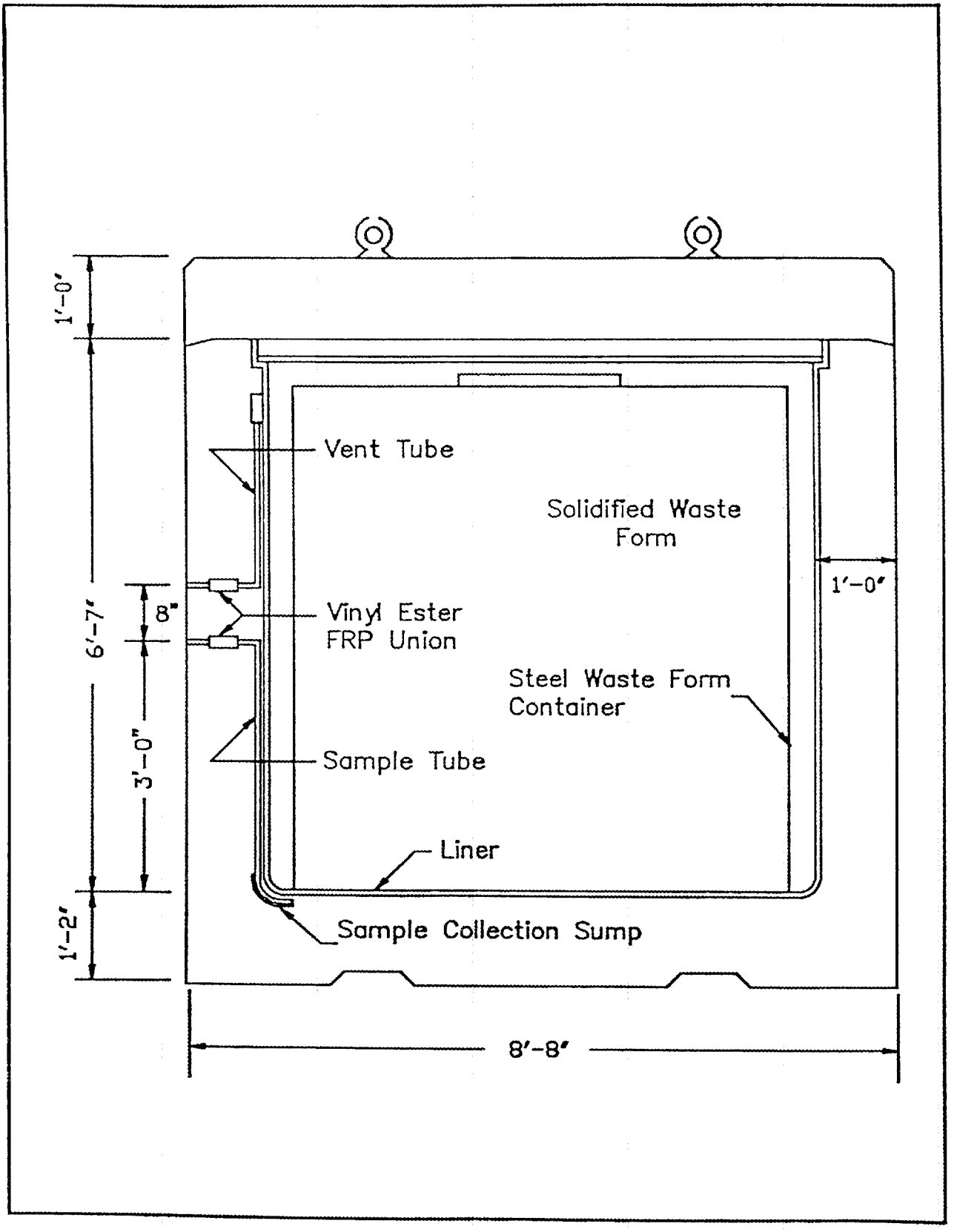

Fig. 2. Cross section of the cask with the enclosed waste form.

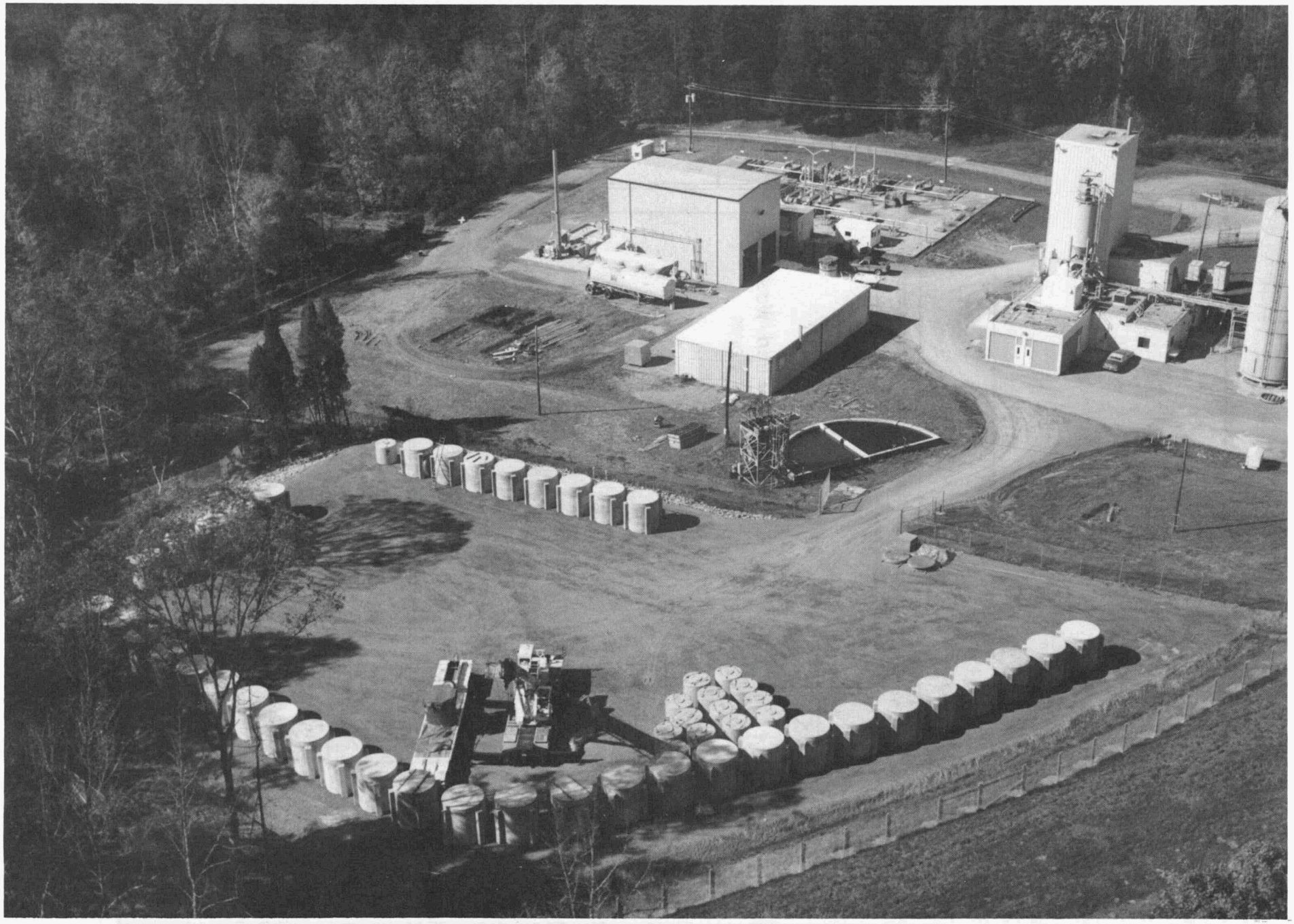

Fig. 3. EASC Processing and Interim Storage Site. Note the Melton Valley Storage Tanks and EASC processing buildings in top center of photo and the interim storage casks and staged liners in foreground.

Review process in September 1988. The major phases of system checkout included (1) integrated systems tests by Energy Systems Engineering for components included in the two GPP construction projects, (2) preoperational system checkout and operator training by the ORNL Waste Management staff to ensure system readiness prior to contractor arrival on-site, (3) setup and checkout of the LN Technologies processing equipment, including demonstration of system interlocks between the ORNL and LN process controls, (4) "cold" testing of the complete system operations with both process water (2 liners) and nonradioactive surrogate liquids (2 liners), and (5) a formal internal ORNL Pre-Operational Readiness Review that addressed the complete physical, operational, and administrative readiness of the project. References 3-6 document this series of facilities checks and reviews, with ref. 6 including documentation of the final approval for campaign start-up, received on September 21, 1988.

With successful completion of the facilities checkout, the full complement of vendor solidification equipment was brought on-site and set up for hot operations. As outlined schematically in Fig. 4, the baseline operating mode involved the positioning of two low-boy trailers supporting a combination processing liner, fillhead, and processing shield unit on each trailer. Appropriate air, liquid, and solids transfer hoses were connected to the supply lines and vendor plant connection skid for controlled filling and operation of the process units. Both units were connected to off-gas collection and filtration systems that exhausted through the facility HEPA filtered exhaust system. Two bulk-solids trailers were positioned outside the processing building for storage and transfer of the cement, fly ash, blast furnace slag, and celite for the solidification mix. The control panels for both the LN Technologies processing units and the ORNL waste transfer and facility containment and radiation protection systems were remotely located in an adjacent building.

The processing schedule initially established for the solidification campaign (see Fig. 5) was to (1) process two liners of LLLW on the first day of the week, (2) allow for solidification to go to completion on the second day, and (3) remove the solidified liners on day three, transport those liners to their storage locations, and process another two liners on that long day. This basic pattern repeated on an every-other-day basis would have resulted in a six liner per week solidification rate. At approximately 800 gal of LLLW per liner, a total of 62 liners were expected to be processed over a time frame of about 11 weeks. Early operational difficulties and vendor equipment availability constraints resulted in less than this ideal processing rate, although by the end of the campaign, the six liners per week average was routinely achieved.

On September 28, 1988, LLLW was transferred from MVSTs W-29 and W-30 to processing liners 1 and 2 to initiate the EASC. The waste transfer went smoothly, with a pumping rate exceeding expectations. The TRU analysis for the first two liners and for every liner thereafter indicated gross alpha concentrations less than 1 nCi/g, a level well below the 100 nCi/g limit for designation as TRU waste.

Additional samples for detailed radiochemical analyses and for the LN Technologies Process Control Program (PCP) were also pulled for these liners (and for approximately every eight liners thereafter). The PCP samples were solidified (in a glove box provided in the solidification building for this purpose) with the certified solids formula in order to ensure that any waste characteristics changes during the campaign would not affect the solidification

ITEM	DESCRIPTION
1	FILLHEAD & BATCH CHAMBER ASSY.
2	DISPOSABLE LINER
3	DOT TRANSPORT/PROCESS SHIELD CASK
4	PLANT CONNECTION SKID
5	CONTROL PANEL
6	VENT FILTRATION SKID
7	VENT BLOWER PRE-FILTER
8	HYDRAULIC SKID
9	PCP TABLE
10	BULK CEMENT TRAILER
11	AIR CONTROL SKID
12	BLOWER SKID
13	DUST COLLECTOR SKID
14	CELITE HOPPER
15	WASTE TRANSFER LINE

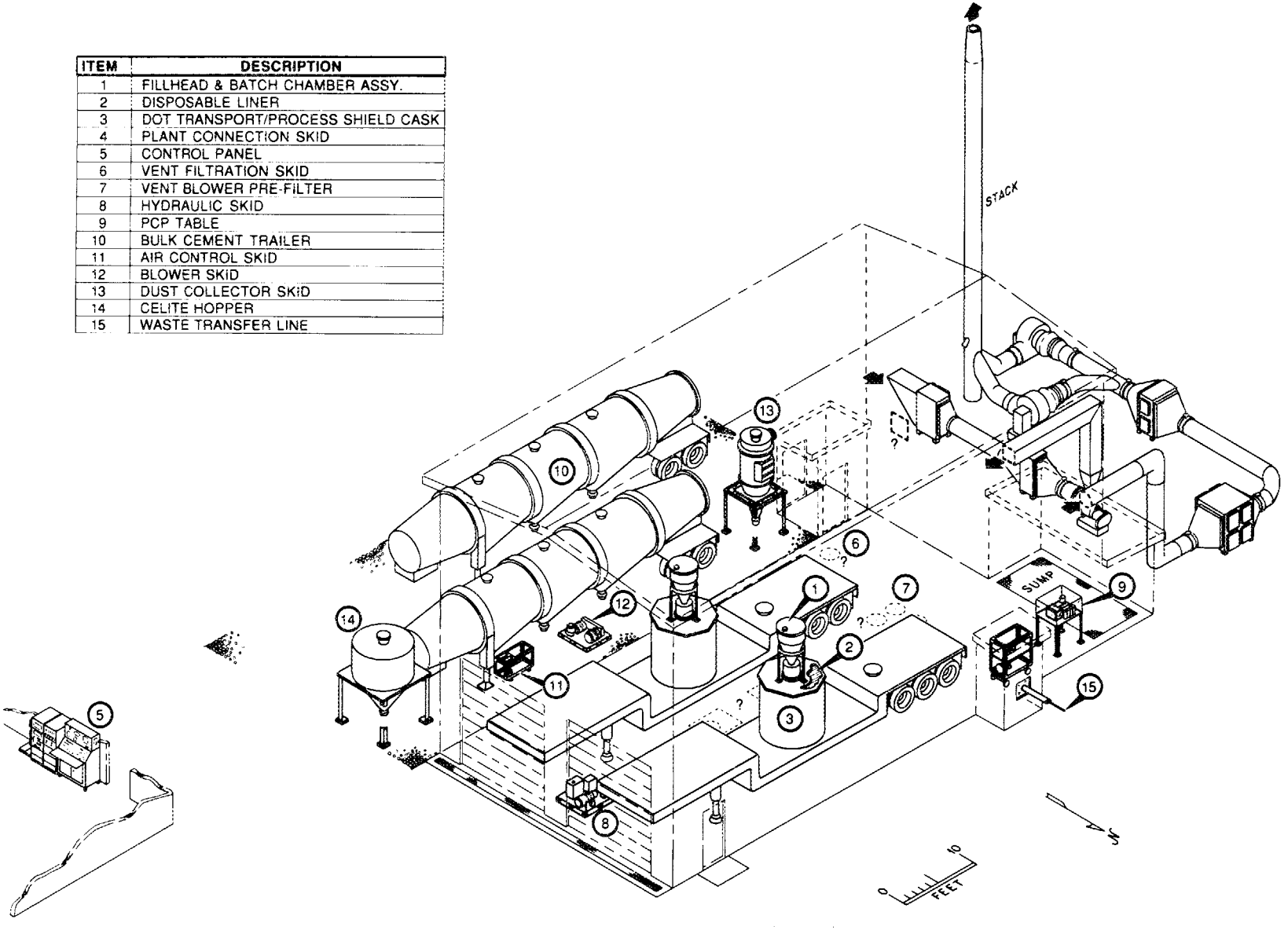

Fig. 4. Schematic layout of LN Technologies processing equipment for the EASC.

process. PCP samples from the first two liners solidified according to the processing criteria (as did all others during the campaign) and solids addition and mixing occurred on September 29-30, 1988, for the first two liners.

On October 3, after checking the temperature curves for the heat/cool solidification cycle (see Fig. 6) against the predicted temperature cycle and ensuring that the temperature peak had occurred, the fillheads were removed and the waste forms inspected. As in all liners eventually solidified, the top of the solidified waste form was dry and the billet was hard. Radiation levels for the liners ranged from 1.1 to 1.8 rem/h on contact with the waste and 0.6 to 1.1. rem/h at the surface of the steel liner. These readings remained consistent for the liners from each tank (W-29 exhibiting higher radiation levels than W-30 throughout) for the entire campaign. Based on average radionuclide concentrations, each liner from W-29 contained approximately 18 Ci of radioactivity, and liners from W-30 contained approximately 12 Ci. The curie totals consisted primarily of Cs-137 (94% of the total), with lesser quantities of Cs-134, Sr-90, and Co-60. The total number of curies processed during the campaign is estimated at roughly 875 Ci.

Upon completion and thorough operational review of the first hot processing run, routine solidification operations got under way. Liners were processed at a 4-liner/week rate for the first 6 weeks or so of the campaign, finally reaching the 6-liner/week rate for the last several weeks of operation. Liquid transfers from the storage tanks to the liners went smoothly throughout the campaign, with no equipment failures or leaks occurring. As the outdoor temperatures cooled down in the late November-early December time frame, additional heat and weather protection had to be provided for the outdoor pump module to eliminate air line "icing." This turned out to be the only problem experienced on the liquid transfer portion of the system. Similar success was achieved with all the support systems operations, including the radiation monitoring, building containment and ventilation, and remote process controls systems.

Problems with the solids transfer system, however, were experienced from the beginning and were the principal factor in the less than expected waste processing rate. Even though the problems were minor in scope, they were time-consuming to alleviate and were extremely frustrating to the operating staff. Some of the problems encountered included (1) solids leaks through transfer system lines, elbows, and fittings; (2) improper operation of solids system valves and controls due to humid process air supplies; and (3) plugging of solids transfer hoses and bulk storage tanks. By the end of the campaign, most of the causes of the problems were eliminated and/or the corrective actions for the problems became routine enough that an acceptable processing schedule was maintained.

On the interim storage side of the operations, the waste transport, transfer to storage casks and reloading of processing casks efforts were conducted flawlessly throughout the campaign. Liner and cask deliveries, staging, and preparations maintained pace with the solidification operations to the end. No transfer incidents occurred and the rigger operations were conducted in a very professional manner, due in part to the intensive up-front training provided for the storage team. Waste form certification documentation and storage records were generated and maintained throughout the campaign and are now permanently filed and entered into the ORNL Solid Waste Information Management System computer data base.

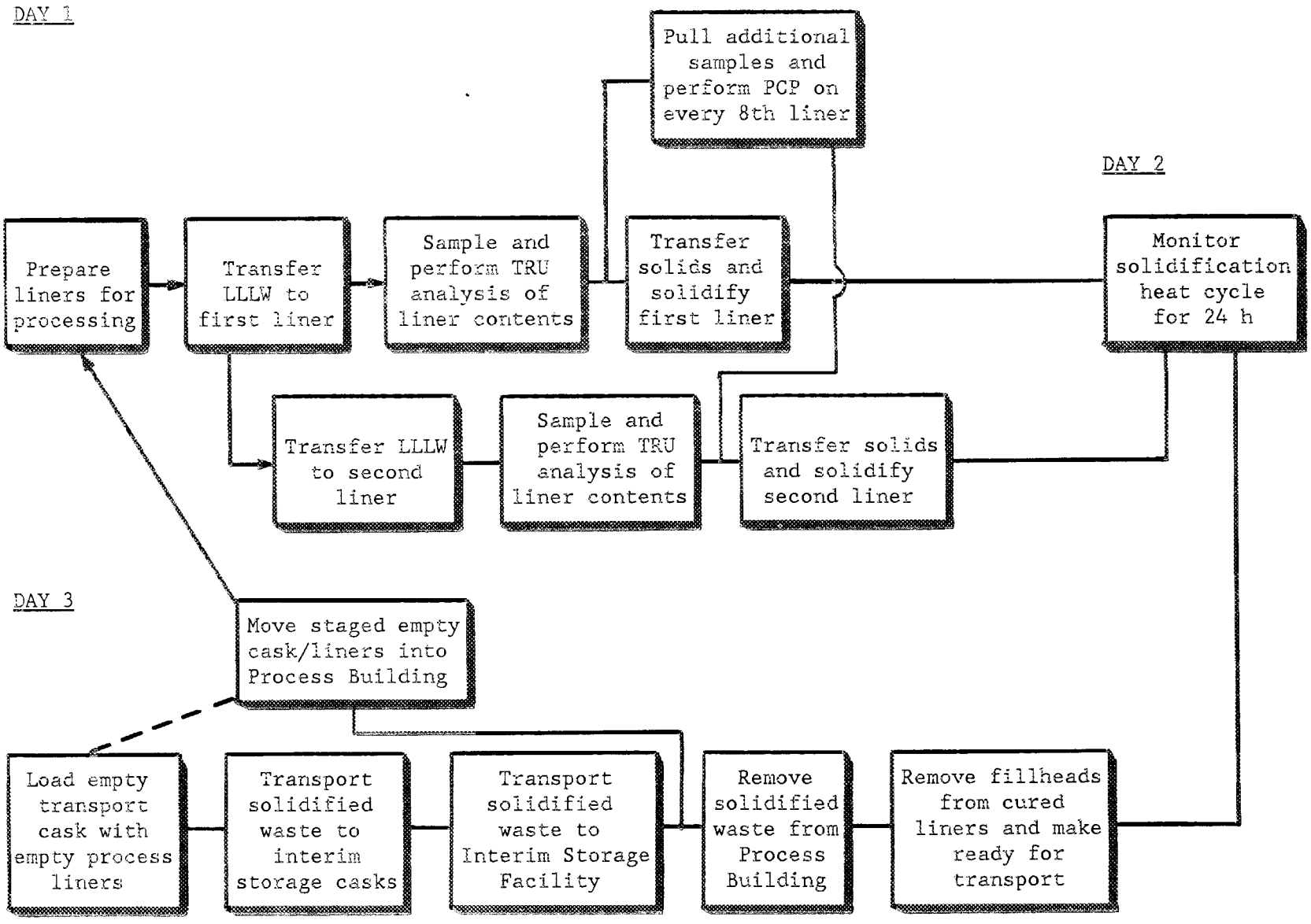

Fig. 5. ORNL EASC baseline processing schedule.

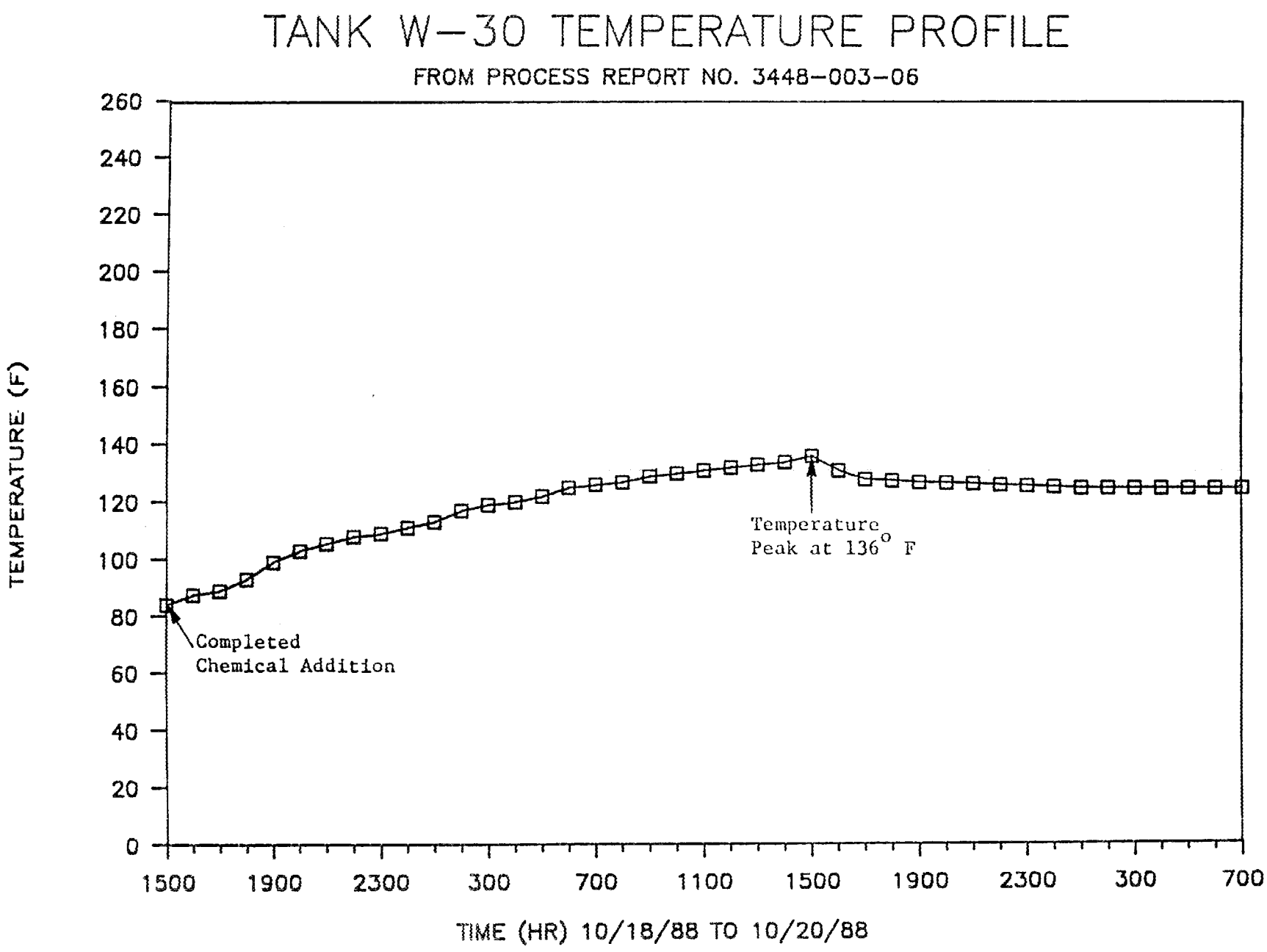

Fig. 6. Temperature profile for typical liner of solidified LLLW.

Liners 57 and 58 were being filled on December 22, 1988, when the transfer pump lost suction while pumping from tank W-30 to liner 58. Liner 57 had already been filled from tank W-29. After valving back to tank W-29 to continue filling liner 58, liquid transfer could not be accomplished from that tank either, signifying the end of the campaign. The transfer pump and piping was then flushed with water and solids added for these last two liners. A special solids mix was calculated for the final liner, since it contained less than the standard LLLW volume. After the Christmas holiday, the last two liners were capped and transferred to the interim storage facility. LN Technologies personnel then decontaminated and packaged their system for transport back to Columbia, South Carolina, with the equipment shipped out the first week of January 1989. The project completion report (ref. 7) covering the LN Technologies portion of the EASC was submitted in February 1989 as the final deliverable on their contract.

Table 2 summarizes the basic processing and storage data for the two surrogate and 58 LLLW liners solidified during the EASC. The total volume processed is estimated at 6,231.5 ft^3 (46,615 gal). Radiation protection records maintained throughout the campaign showed that the total exposures for Energy Systems personnel were negligible and that the exposure for the LN Technologies operating staff was well below the DOE guidelines. The total exposure for Energy Systems personnel is estimated to be less than 100 man-millirems, and the total for the LN Technologies staff was approximately 2,060 man-millirems. This compares favorably with the safety study estimated exposures of approximately 4,000 man-millirems. The doses received per liner were higher at the beginning of the campaign but were reduced week to week as the operating personnel became more familiar with the operations and containment constraints. Several factors, both operating and engineered, helped to hold down the exposures. Lead shielding around the waste transfer pump module and piping kept the Energy Systems liquid waste operations personnel exposures negligible as they performed the valving necessary to transfer waste from the tanks to the liners. The solidification project's use of remote controls and closed circuit TV systems allowed the solidification processes to be observed remotely, thus reducing exposure tremendously. The modifications made in the methods used to contain the radionuclides within the LN systems eliminated the necessity to constantly decontaminate filled liners, thus reducing exposures dramatically. Other administrative and operational controls, including full-time health physics coverage, maintained the exposures received as low as reasonably achievable. In addition, the isokinetic sampling station installed on the facility ventilation stack confirmed that airborne releases of radioactivity were negligible during the campaign.

POST CAMPAIGN SAMPLE ANALYSES AND WASTE FORM MONITORING

Periodically throughout the processing phase of the EASC, samples of LLLW were taken for subsequent radiochemical analyses. This sampling was undertaken to serve two basic purposes: (1) to confirm the findings from the preoperational waste characterization and waste form certification efforts and (2) to provide archive samples for any later confirmatory tests or regulatory questions on the waste characteristics. Archive samples were taken from every liner of waste solidified and detailed analysis completed for samples from the eight special PCP liners identified in Table 2. These eight samples underwent the same

Table 2. Processing and storage summary for EASC liners

Liner	Date waste transferred	Waste volume (ft^3)	Storage cask number	LL number[a]	Date liner stored
Surrogate 1	08/30/88		1[b]	3378	09/27/88
Surrogate 2	09/02/88		2[b]	3379	09/27/88
1[c]	09/28/88	110.00	3[b]	3454	10/03/88
2[c]	09/28/88	110.00	4[b]	3455	10/03/88
3	10/04/88	107.50	9	3466	10/07/88
4	10/04/88	107.50	10	3467	10/07/88
5	10/07/88	107.50	11	3468	10/10/88
6	10/08/88	107.50	12	3469	10/10/88
7	10/10/88	107.50	13	3472	10/13/88
8	10/10/88	107.50	14	3473	10/13/88
9	10/13/88	107.50	15	3478	10/17/88
10	10/13/88	107.50	16	3479	10/17/88
11	10/17/88	108.75	17	3482	10/20/88
12[c]	10/17/88	108.75	5[b]	3483	10/20/88
13	10/20/88	108.75	18	3488	10/24/88
14	10/20/88	108.75	19	2489	10/24/88
15	10/24/88	108.75	20	3492	10/27/88
16	10/24/88	108.75	21	3493	10/27/88
17	10/27/88	108.75	22	3596	10/31/88
18	10/27/88	108.75	23	3597	10/31/88
19[c]	10/31/88	108.75	6[b]	3601	11/03/88
20	10/31/88	108.75	24	3600	11/03/88
21	11/03/88	108.75	25	3602	11/07/88
22	11/03/88	108.75	26	3603	11/07/88
23	11/07/88	108.75	27	3617	11/11/88
24	11/07/88	108.75	28	3616	11/11/88
25	11/10/88	108.75	29	3616	11/11/88
26	11/10/88	108.75	30	3619	11/14/88
27	11/14/88	108.75	31	3626	11/16/88
28	11/14/88	108.75	32	3627	11/16/88
29	11/16/88	108.75	33	3629	11/18/88
30[c]	11/16/88	108.75	34	3630	11/18/88
31	11/18/88	108.75	35	3638	11/21/88
32	11/18/88	108.75	36	3639	11/21/88
33	11/20/88	108.75	37	3640	11/22/88
34	11/20/88	108.75	38	3641	11/22/88
35	11/22/88	108.75	39	3644	11/28/88
36	11/22/88	108.75	40	3645	11/28/88
37[c]	11/28/88	108.75	41	3646	11/30/88
38	11/28/88	108.75	42	3647	11/30/88
39	11/30/88	108.75	43	3648	12/05/88
40	11/30/88	108.75	44	3649	12/05/88
41	12/05/88	108.75	45	3651	12/07/88
42	12/05/88	108.75	46	3652	12/07/88
43	12/07/88	108.75	47	3654	12/10/88

Table 2. Continued

Liner	Date waste transferred	Waste volume (ft^3)	Storage Cask Number	LL Number[a]	Date liner stored
44	12/07/88	108.75	48	3655	12/10/88
45	12/10/88	108.75	49	3656	12/12/88
46	12/10/88	108.75	50	3657	12/12/88
47	12/12/88	108.75	51	3660	12/14/88
48[c]	12/12/88	108.75	7[b]	3661	12/14/88
49	12/14/88	108.75	53	3668	12/16/88
50	12/14/88	108.75	52	3667	12/16/88
51	12/16/88	108.75	55	3671	12/19/88
52	12/16/88	108.75	54	3670	12/19/88
53	12/18/88	108.75	57	3673	12/20/88
54	12/18/88	108.75	56	3672	12/20/88
55[c]	12/20/88	108.75	8[b]	3679	12/22/88
56	12/20/88	108.75	58	3678	12/22/88
57	12/22/88	108.75	59	3680	12/27/88
58	12/22/88	40.25	60	3681	12/27/88

[a]Low-level (LL) waste package identification number for input to ORNL Solid Waste Information Management System.

[b]Liners stored in specially instrumented casks for detailed monitoring.

[c]Process Control Program (PCP) and special analysis sampling conducted on these liners.

analysis as the preoperational sampling effort, except for the EP-tox and ANSI6.1 waste form tests which were completed only for one representative sample from each tank of waste. In general, the results of the post-operational sample analysis confirm the preoperational findings for all the measured sample characteristics. The EP-tox testing of the solidified waste forms showed all RCRA constituent in the leachate to be below the detection limits, signifying the non-RCRA status of the stored wastes. Documentation of these pre- and post-operational sample analyses is provided in ref. 9.

The most significant post-campaign activity, however, is the monitoring of the stored waste forms. The scope of the regulatory-approved monitoring plan for the EASC casks (ref. 8) reflects the facts that the storage period will be limited to five years and the casks are impervious to liquids and most gases. The monitoring effort includes (1) measurements of the quantity and composition of the liquids collected from inside the casks; (2) soil sampling at selected points at the storage site; (3) routine visual inspection of the casks; (4) measurement of temperature, pressure, relative humidity, and gas composition inside the eight specially instrumented casks; (5) measurement of ambient outside temperature, relative humidity, and solar radiation; (6) periodic removal of surrogate waste forms to assess waste form container performance; and (7) measurement of radiation levels outside the casks.

Soil sampling at the storage site began prior to emplacement of the first cask to establish baseline data. The cask monitoring program was initiated for the first quarter of 1989, with data collection, analysis, and storage to be provided as part of the routine ORNL Waste Management Operations monitoring activities. The monitoring effort may be modified as more is learned about the volumes of gas and liquid available for sampling, the composition of the samples and the performance of the storage technology.

OVERALL EASC PROJECT SCHEDULE AND COST

As described in the Introduction section of this report, the definition and planning of the EASC began in 1985 in response to the loss of disposal capability for the LLLW stream. From that point in time, until the completion of the post-operational sample analyses in October 1989, a total of 48 months of project-related time elapsed. Activities beyond the October 1989 date will include the routine monitoring of the stored waste for a period up to 5 years as well as the ultimate disposition efforts for that waste either on-site or at a yet-to-be-determined off-site location.

A summary of the schedules associated with the major EASC project phases is provided in Table 3. Phase durations have been documented for the project definition, facilities development, operations planning, solidification services, and post-operational analysis and monitoring phases of the project. Although the evolution of the project resulted in significant changes in scope and direction during some of these project phases and there were significant milestone achievements all along the line, the three principal milestones tracked by DOE (completion of GPP Facilities Construction - April 1988, Initiation of Solidification Campaign - September 1988, and Completion and Documentation of the EASC - March 1989) were all completed on schedule.

Table 3. Summary schedule for the Emergency Avoidance Solidification Campaign

EASC project phase	Month/year Start	Month/year Finish	Months duration
I. Project Definition	10/85	02/87	17
II. Facilities Development			
General Plant Projects	03/87	04/88	14
Design	03/87	08/87	6
Project approval	08/87	09/87	1
Construction	09/87	03/88	7
System tests	03/88	04/88	1
Interim Storage	12/87	01/89	14
Approve concept	12/87	03/88	3
Fabricate first article liners and casks	01/88	06/88	6
Fabricate next 69 liners and casks	06/88	01/89	7
Develop storage site	05/88	08/88	4
General Plant Equipment	09/87	10/88	14
III. Operations Planning	02/87	09/88	20
QA and safety documentation	02/87	09/88	20
Systems testing and operator training	04/88	09/88	6
Operating procedures development	10/87	09/88	12
Readiness reviews	07/88	09/88	3
IV. Solidification Services	09/86	12/88	28
Develop Statement of Work	09/86	02/87	6
Award contract	02/87	11/87	9
Certify waste forms			
LN Technologies	12/87	06/88	7
Chem Nuclear	11/87	04/88	5
Mobilize and cold checkout	08/88	09/88	1
Solidify 47,000 gal	09/88	12/88	4
V. Post-Operational Analysis	01/89	10/89	10
PROJECT TOTAL	10/85	10/89	48

The project costs for EASC implementation are summarized in Table 4 according to the major program phases listed above and the funding types utilized. Programmatic (DOE Defense Programs) and ORNL waste generator charge-back expense funds were used in combination to support all of the project planning and operations phases. GPP and GPE funds were both used for facilities development activities. The project total estimated cost of $5.47 million represents the best available accounting of project costs over the 48-month effort. Of this amount, almost $700K was spent on vendor-supplied solidification services, $350K in vendor-support studies and support documentation, and over $1.0 million in vendor-constructed facilities and equipment, for a total vendor involvement of over $2.0 million in the campaign. Dividing the total estimated project cost by the 47,000 gal of waste solidified yields a per-gallon cost of approximately $115/gal of concentrated LLLW. If the costs associated with the initial project definition, facilities development, and majority of the operations planning phases are removed from the processing cost analysis, then the total solidification cost is roughly $40/gal of LLLW concentrate.

This was the first major application of waste generator charge-back funds for special waste processing at ORNL. These funds were used for all direct waste treatment and storage costs, including all waste certification and solidification service subcontracts, and the development of the interim storage facility and casks. These funds had been collected over a period of approximately 2 years and held in a reserve account for this application. In addition to these solidification costs, the cost associated with the long-term storage cask monitoring will be paid for through charge-back funds as part of the routine ORNL solid waste operations program. The funding source for the final waste disposal costs, expected to be in the $0.5-1.2 million range, has not yet been identified since those costs are not expected to be incurred for up to five years and no reasonable charge can be levied against current generators without knowing the ultimate disposition of the waste.

Rough estimates of the costs and schedules for future solidification campaigns, if needed, can be drawn from the EASC experience with some qualification. Assuming that essentially the same solidification operations are conducted in a reasonably near-term time frame (2 to 3 years) and that no significant facility modifications or changes to project safety/QA documentation is required, then the cost of solidifying another ±50,000 gal of LLLW should be on the order of $2.5 million ($50/gal of concentrate), excluding waste disposal costs. It is anticipated that implementation of such a campaign would take from 18-24 months to complete. If significant changes are required (i.e., incorporation of the reference flow sheet into the project) for a follow-on campaign, then the timing will extend into the 24-48 month time frame, with total project costs likely to exceed the EASC totals.

With successful completion of the EASC, the viability of the concept of using commercial vendor services for help in solving DOE waste management problems has been demonstrated. The ability to interface the ORNL facilities and staff with the vendor's equipment and management team was proven. Although the overall management strategy for the ORNL LLLW stream (ref. 10) does not rely on continued, routine application of the solidification process, the success of the EASC certainly provides a good reference and recommendation for future use.

Table 4. EASC cost summary

EASC project phase	Estimated cost by funding type ($000)				Total
	Expense		Capital		
	Charge-back	Programmatic	GPP	GPE	
I. Project Definition	0	450	0	0	
SUBTOTAL	0	450	0	0	450
II. Facilities Development					
Project Management	0	225	0	0	
Studies and Estimates	0	160	0	0	
As-Built Drawings	0	40	0	0	
LLLW Solidification GPP	0	0	740	0	
MVST Decant System GPP	0	0	505	0	
General Plant Equipment	0	0	0	205	
Interim Storage Facility/Casks	710	0	0	0	
SUBTOTAL	710	425	1,245	205	2,585
III. Operations Planning					
Test Plans and Procedures	0	35	0	0	
Quality Plan	0	100	0	0	
Operations Planning and Procedures	0	315	0	0	
Safety Studies	0	445	0	0	
Monitoring Plan	0	25	0	0	
SUBTOTAL	0	920	0	0	920
IV. Solidification Services					
Statement of Work Preparation	0	50	0	0	
Waste Characterization	0	200	0	0	
Waste Form Certification	170	130	0	0	
Mobilize and Cold Checkout	70	165	0	0	
Solidification of 47,000 gal	540	0	0	0	
Energy Systems Solidification and Analysis Support	90	0	0	0	
SUBTOTAL	870	545	0	0	1,415
V. Post-Operational Analysis	100	0	0	0	100
TOTAL	1,680	2,340	1,245	205	5,470

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