Conf-9103238--1

WSRC-MS--91-073

DE92 013194

PROPERTIES OF SLAG CONCRETE FOR LOW-LEVEL WASTE CONTAINMENT (U)

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A Paper for presentation at American Concrete Institute Spring Meeting, March 17-21, 1991

Derivative Classifier: WEStevens Level 4
(Name and Title)

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ABSTRACT

Ground granulated blast furnace slag was incorporated in the concrete mix used for construction of low-level radioactive waste disposal vaults. The vaults were constructed as six 100 x 100 x 25 ft cells with each cell sharing internal walls with the two adjacent cells. The vaults were designed to contain a low-level radioactive wasteform called saltstone and to isolate the saltstone from the environment until the landfill is closed. Closure involves backfilling with native soil, installation of a clay cap, and run-off control.

The design criteria for the slag-substituted concrete included compressive strength, 4000 psi after 28 days; slump, 6 inch; permeability, less than 10^{-7} cm/sec; and effective nitrate, chromium and technetium diffusivities of 10^{-8}, 10^{-12} and 10^{-12} cm^2/sec, respectively. The reducing capacity of the slag resulted in chemically reducing Cr^{+6} to Cr^{+3} and Tc^{+7} to Tc^{+4} and subsequent precipitation of the respective hydroxides in the alkaline pore solution. Consequently, the concrete vault enhances containment of otherwise mobile waste ions and contributes to the overall protection of the groundwater at the disposal site.

INTRODUCTION

Recent developments in environmental regulations pertaining to disposal low-level radioactive waste and mixed waste (hazardous and radioactive) have prompted design and construction of engineered disposal facilities at the Savannah River Site (SRS).[1] SRS is owned by the U.S. Department of Energy (DOE) and has been managed by the Westinghouse Savannah River Company (WSRC) since April 1989. The primary mission of SRS is to produce nuclear materials for defense.

Several low-level disposal sites are being designed and constructed to support plant operations. They include: G-Area, the solid low-level waste disposal facility; Z-Area, an industrial low-level waste disposal facility; and Y-Area, a mixed waste disposal facility. A second mixed waste facility will be included in G-Area to dispose of prepackaged waste that is both hazardous and low-level radioactive. See Table 1.

Concrete vaults have been identified as design components in each of the disposal facilities listed above. Advantages of concrete vaults were originally identified in the G-Area Environmental Information Document[2] (EID) and Environmental Impact Statement[3] (EIS), and in the initial performance modeling for Z-Area[4]. Subsequently, DOE issued a Record of Decision for SRS low-level waste disposal which required concrete vaults in the design of these engineered disposal units.

The purpose of low-level waste disposal vaults at SRS is to provide discrete units for confinement which can be observed, monitored, and maintained. The vaults thus serve to enhance public acceptance by isolating the waste from the environment. They also facilitate long-term maintenance of the disposal site.

The Z-Area disposal facility is a special case in which the vaults also serve as forms for casting the treated waste. Z-Area is also the only controlled release disposal site. The concrete vaults in Z-Area serve as a diffusive barrier to control the migration of soluble contaminants into the environment. Special design features for the Z-Area vaults include: diffusivity of waste ions through the concrete, hydraulic conductivity of the concrete; and crack control of the structure. Since three Z-Area vaults have been built, two are receiving waste at the present time, the design and construction of these structures will be reviewed in this paper. Lessons learned from these existing vaults are currently being incorporated in the design of second generation Z-Area vaults and the other vaults listed in Table I.

Z-AREA VAULTS

The Z-Area facility was designed to treat and dispose of low-level radioactive waste generated in the nuclear materials separation process at SRS. The wasteform is referred to as saltstone and is emplaced as a slurry prepared from alkaline salt solution, 46 wt%, and pre-blended hydraulic solids, 54 wt%. The waste solution contains 71 wt % water and the salts are primarily sodium nitrate, nitrite, sulfate, and aluminate in addition to sodium hydroxide. The activity of the waste solution is very low, and averages less than 230 uCi/l. The treatment and disposal processes are operated as hands-on-maintenance facilities. The blended solids contain 47 wt% ground granulated blast furnace slag (BFS); 47 wt% Class F fly ash; and 6 wt% Portland Type II cement.

The saltstone is pumped approximately 2000 ft to the disposal vault and is placed in layers up to eight inches thick. Consecutive layers are emplaced until each cell is filled to within one foot of the top. The saltstone gels within 10 to 20 minutes and sets within 48 hours to form a monolithic unit with more than 1000 psi compressive strength. The vault walls are coated with a sealant to prevent direct contact between the vault concrete and the saltstone.

Z-AREA CONCRETE VAULT MIX DESIGN

One objective of these vaults is to provide a diffusion barrier for soluble contaminants, in particular, nitrate, NO_3^-, chromate, $CrO_4^=$, and pertechnetate, $T_cO_4^=$. The effective diffusivity of concrete is primarily controlled by the properties of the binder, provided that the aggregates are non-porous. Initially, the standard SRS 4000 psi concrete was specified for the Z-Area vaults. See Table II. However, the mix designed was modified after leaching experiments indicated that blast furnace slag in the matrix enhanced the pore structure. BFS also chemically reduces chromium and technetium, thereby, resulting in precipitation of insoluble compounds in the alkaline matrix. The effective diffusivities for these containments are greatly improved as the result of lowering the concentrations of these ions in the matrix pore solution.

Leaching experiments were used to identify the binder for the Z-Area concrete. These experiments involved casting a mortar shell, with the same ingredients as the concrete being evaluated for use in the thin vaults. However, the course aggregate was not included in the thin-walled shells. The shells were 7-8 mm thick on the sides and 8-10 mm thick on the bottom. After the shells were cured 7 days, they were filled with saltstone and the shell top was cast in place. After these samples were cured 28 days, they were leached by the ANS 16.1 procedure. Effective diffusion coefficients were calculated according to the ANS 16.1 procedure. Results for the matrix in the SRS standard 4000 psi concrete and the slag substituted matrix actually used for Z-Area (Z-2) are summarized in Table 3.

Z-AREA VAULT DESIGN AND CONSTRUCTION

Construction of vault 1 started in 1986 and construction of vaults 6 and 7 (the next two built) began in 1988. The first concrete was placed in 1989 and continued through 1989. The concrete was supplied by an on-site vendor. The batch plant was located approximately 10 minutes from the vaults. The quality control program entailed testing four compressive strength cylinders and taking a unit weight for every 100 cubic yards. Slump, air, and temperature (maximum of 90°C) measurements were also made on every 50 cubic yards.

Each vault is actually built in two segments arranged end to end with a three inch separation between segments. Eleven vault pairs are planned at this time. Additional vaults will be added to the disposal facility as needed. Each segment measures 100 feet by 300 feet by 25 feet high. The walls are 1.5 feet thick. The floor is 2 feet thick and was built on a 4 inch working slab. Each segment is subdivided into three cells. There are six cells per vault pair. A design sketch of a vault is shown in Figure 2. A photograph of the vault under construction is shown in Figure 3.

The slab concrete placements were limited to 30 x 33 feet. Vertical construction joints in walls were at the same location as the floor. The walls were placed in two lifts with the construction joint located at approximately 15 feet above the floor. Wall construction was not allowed to begin until the foundation concrete had reached 75% of its specified strength. Forms were stripped after 24 hours. The concrete was water cured for 7 days after which it was cured by the liquid membrane method. The concrete was emplaced by bucket and crane.

Due to the time of year the concrete was placed, concrete temperature was a major problem. Ice was used in cooling the concrete. High early compressive strengths (5000PSI @7 days) reflected the accelerated hydration process.

The vaults are reinforced concrete tanks and were designed to withstand five feet of hydrostatic load from unset saltstone slurry (about ten feet of true hydrostatic load).

A concrete cover, a minimum of three inches thick, was provided to protect the rebar from corrosion. Testing to date indicates that the rebar is passivated by the high alkalinity in the saltstone.

A weather protection cover was designed to cover two cells at one time. One cell is covered during the saltstone emplacement. An adjoining cell is covered to provide weather protection while previously emplaced saltstone cures. After the saltstone has set, a one foot thick layer of non-radioactive concrete will be poured over the filled cell. The weather protection cover, which rests on rails running the entire 600 feet of the vault pair, can then be rolled to the next cell with a motorized winch assembly. The weather protection cover is a truss assembly with cat walks and a prefinished uninsulated metal roofing. Four lifting lugs on the weather protection cover are provided for the removal and placement on adjoining vaults. There are four openings in the roof of the weather protection to allow emplacement of the saltstone. Only the central discharge point is currently in use since the saltstone is self leveling.

LESSONS LEARNED

The original design for the Z-Area vaults did not identify crack control as a requirement. Laboratory experiments and modeling studies indicated that leaching of chromium and technetium was dependent on the chemistry of the concrete binder and independent of vault surface area. Nevertheless, vault design did specify that through-wall cracks and cracks greater than 5 mils would be evaluated for repair.

Vertical hairline cracks (up to 20 mils) did form in the vault walls shortly after the forms were stripped. The cracks were spaced about every ten feet and propagated from bottom to top and in many cases extend the entire height of the wall. The decision was made to repair the through-wall cracks to prevent direct access of rainwater to the wasteform during emplacement and curing. A patching material, Polybane 197, was applied to cracks after preparing the interior wall surface. Some were also repaired from the exterior side by injection of epoxy resin directly into the cracks.

Although both crack repair methods have been relatively successful to date, new vaults will be designed to eliminate through-wall cracks. Construction practices, such as, extending the length of time forms are left in place (1 to 7 days minimum) and lowering the acceptable delivery temperature from 90 to 60° C are under consideration. The concrete mix design will also be modified to control cracking. For example, aggregate size may be increased from 3/4 to 1 1/2 inches, and the percent of actual binder may be decreased to control the accelerated strength development which leads to high temperatures in the Z-2 mix. In addition, the second generation Z-Area vault design will specify installation of contracting joints with water stops spaced to compliment the shrinkage properties of the new Z-Area concrete mix.

SUMMARY

Concrete vaults are required components in future engineered disposal facilities for low-level radioactive waste and mixed waste at SRS. The vaults will provide discrete units for waste confinement. In one special case, the Z-Area Facility, they also function as a diffusion barrier which controls the release of soluble species. Performance of the Z-Area vaults as diffusion barriers depends primarily on the chemistry of the concrete matrix. Ground granulated blast furnace slag was substituted for 40 wt% of the Portland Cement in the mix design of a 4000 psi concrete. The chemical reducing capacity of the slag and the high alkalinity of the concrete and wasteform resulted in precipitation of insoluble compounds. Formation of chromium hydrated and technetium sulfide by these reactions greatly reduces the leachability of these contaminants.

Performance of the vault as a diffusion barrier is much more dependent on the chemistry of the concrete matrix than on the structural integrity of the vault walls. However, vault cracks, if present, will require repair since isolation of the waste in discrete units is a design objective.

Consequently, future Z-Area vaults and all other SRS waste disposal vaults will be designed to eliminate through-wall cracking. In the event that cracks do form, they will be repaired.

REFERENCES

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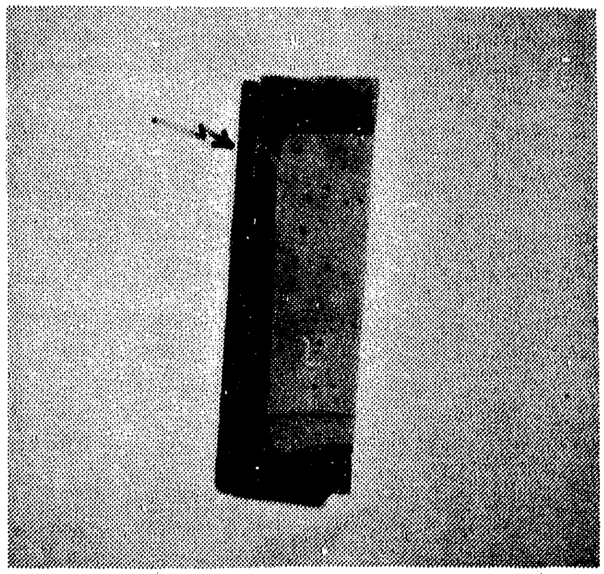

Figure 1. Cross section through a leaching sample used to evaluate binders for Z-Area vault concrete. The light gray portion is the salt-stone waste form and the dark gray material is the grout shell used to simulate the concrete matrix.

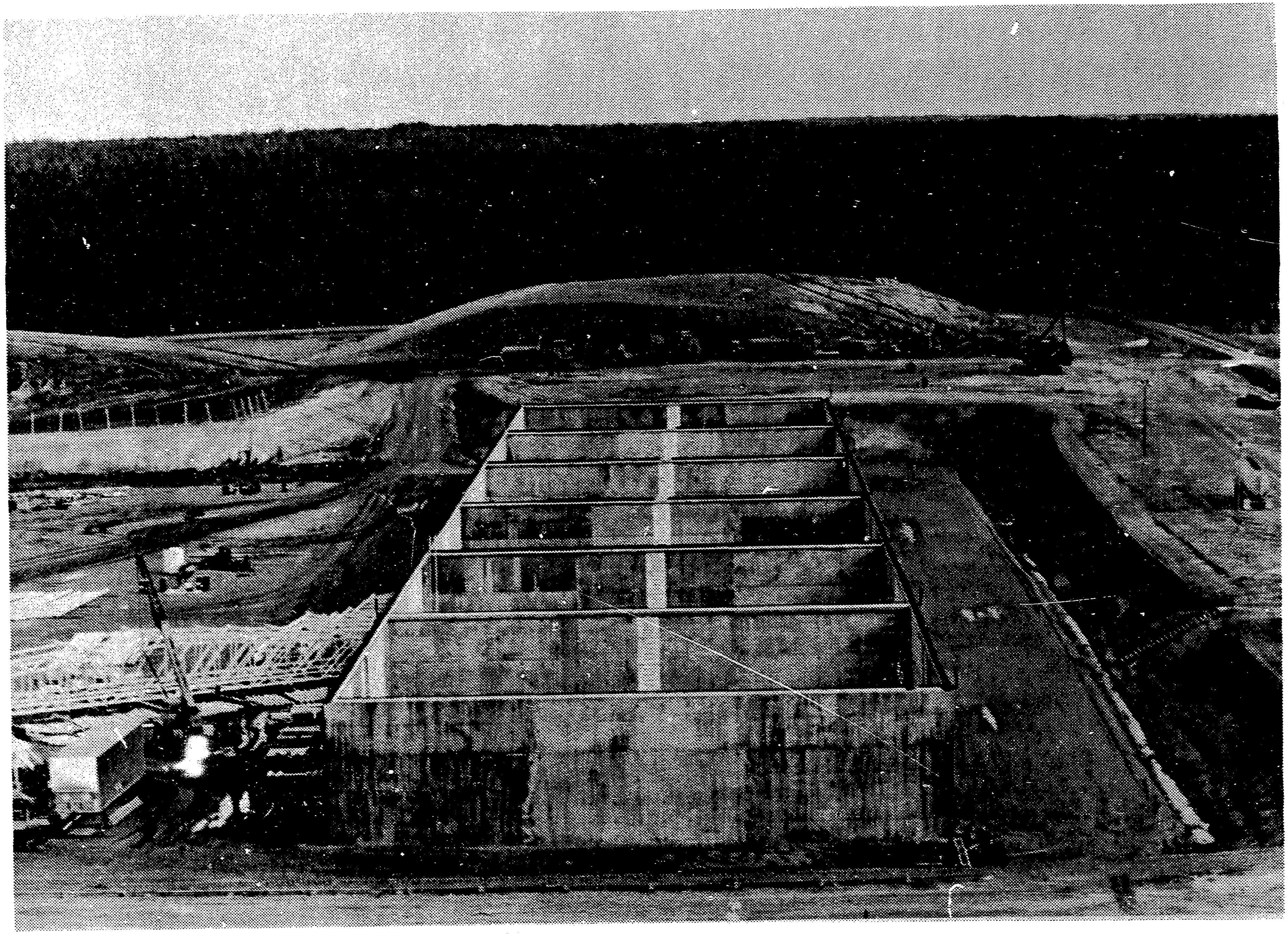

Figure 2. Photograph of a Z-Area vault pair; dimensions of each of the six cells are 100 x 100 x 25 feet.

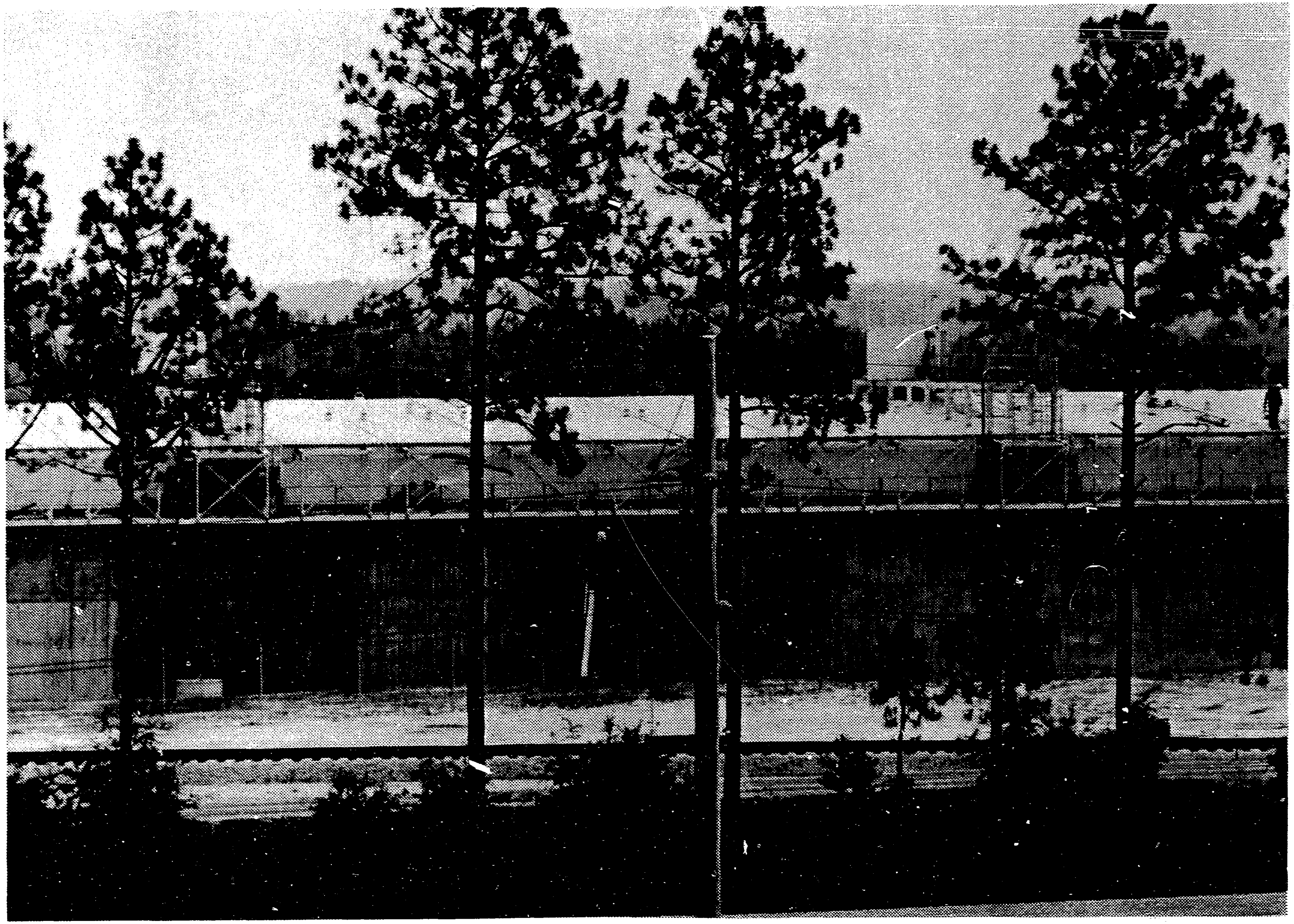

Figure 3. Photograph of a Z-Area vault with movable weather protection roof.

TABLE 1. SUMMARY OF SRS WASTE DISPOSAL VAULTS

Disposal Facility	Number of Vaults Planned	Vault Size (ft)	Cell Size (ft)	Leachate Collection	Waste Type	Purpose of Vault
Z-Area	11 (3 built)	100x600x25	100x100x25	None	Cast in place hydraulic wasteform	1) Diffusion Barrier 2) Emplacement Form 3) Confinement Unit
Y-Area	20	53x208x27	53x52x27	Yes includes synthetic liner	Cast in place hydraulic wasteform	1) Diffusion Barrier 2) Emplacement Form 3) Confinement Unit 4) Form for leachate collection
G-Area Low-Level <300 mr/hr	20	145x535x25	145x53x25	None	Solid Waste pre-packaged in B-25 boxes (96 cw ft)	Confinement Unit
G-Area low-level >300 mr/hr	10	50x190x28	50x26.5x28	None	Same	Same
G-Area low-level <300 mr/hr with tritium	10	145x535x25	145x53x25	None	Same	Same
G-Area >300 mr/hr with/tritium	10	52x57x25	52x57x25	None	4x3x23 ft steel crucibles	Same
G-Area mixed waste	10	48.5x202x23	48.5x49x25	Yes includes synthetic liner	Containerized waste	Confinement unit form for leachate collection system

TABLE 2. Z-AREA BINDER PLUS SAND AND CONCRETE MIXES EVALUATED IN LEACHING EXPERIMENTS

	Compressive Strength (28 days)	Saturated Hydraulic Conductivity	Slump (in)	Portland Type II Cement	Slag 120	Water	Fine Quartz Aggregate	3/4 inch Schist Aggregate	Water reducing agent oz/hundred wt	Air entraining agent	w/cement slag
J-Mix Binder	-	-	-	1000g	-	460g	2176g	-	-	-	0.46
Z-2 Mix Binder	-	-	-	600g	400g	430g	2212g	-	-	-	0.43
J-Mix Concrete	4000	$3.1x10^{-7}$	2-4	612 lb	-	283 lb	1334 lb	1706 lb	31	as req'd	0.46
Z-2 Mix Concrete	4000	$9.0x10^{-8}$	2-4	350 lb	233 lb	251 lb	1290 1b	1774 lb	23	as req'd	0.43

TABLE 3. EFFECTIVE DIFFUSION COEFFICIENTS OF CEMENT SAND MORTAR AND HYDRAULIC SLAG - CEMENT SAND MORTAR

Binder	NO_3^-	Deff (cm^2/sec) TcO_4^-	CrO_4^{-2}
Cement (Type II)	$5x10^{-8}$	$5x10^{-8}$	$5x10^{-8}$
60% Cement (Type II) 40% Grade 120 Slag	$1.7x10^{-8}$	$<6x10^{-10}$	$<6x10^{-10}$
Improvement	~3x	>100x	>100x

END

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