MAY 04 1995
St (36) (77)

ENGINEERING DATA TRANSMITTAL

1. EDT 604126

2. To: (Receiving Organization) MWTF Project/W236A Jill Light	3. From: (Originating Organization) Structural Integrity Assessment/K. V. Scott	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: W235A	6. Cog. Engr.: E. B. Schwenk	7. Purchase Order No.: N/A
8. Originator Remarks: For review and approval.		9. Equip./Component No.: N/A
		10. System/Bldg./Facility: N/A
11. Receiver Remarks:	RECEIVED JUN 01 1995 OSTI	12. Major Assm. Dwg. No.: N/A
		13. Permit/Permit Application No.: N/A
		14. Required Response Date: 05/01/95

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-WM-ER-432	–	0	Evaluation of Remaining Life of the Double-Shell Tank Waste Systems	N/A	1,2	1	

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
(See Impact Level for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.
1	1	Cog./Proj.Eng E. B. Schwenk	E B Schwenk	4/27/95	H5-52	Central Files			L8-04		
1	1	Cog./Proj.Eng.Mgr. K. V. Scott	K V Scott	4/28/95	H5-52	OSTI (2)			L8-07		
1	1	M. A. Scott	M A Scott	4/28/95	H5-52						
1	1	D. C. Lindsay	D C Lindsay	4/28/95	R1-30						
1	1	E. J. Walter	E J Walter	4/28/95	H5-52						

18.	19.	20.	21. DOE APPROVAL (if required)
E. B. Schwenk E B Schwenk 5/1/95 Signature of EDT Originator / Date	J. M. Light J M Light 5/1/95 Authorized Representative for Receiving Organization / Date	K. V. Scott EBS for K V Scott 5/1/95 Cognizant/Project Engineer's Manager / Date	Ltr. No. [] Approved [] Approved w/comments [] Disapproved w/comments

BD-7400-172-2 (07/89) (EF) GEF097

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

RELEASE AUTHORIZATION

Document Number:	WHC-SD-WM-ER-432, Rev. 0
Document Title:	Evaluation of Remaining Life of the Double-Shell Tank Waste Systems
Release Date:	May 3, 1995

This document was reviewed following the procedures described in WHC-CM-3-4 and is:

APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:

V.L. Birkland   May 3, 1995

V.L. Birkland

A-6001-400.2 (09/94) WEF256

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DLC

SUPPORTING DOCUMENT

1. Total Pages 63 ~~6~~		
2. Title Evaluation of Remaining Life of the Double-Shell Tank Waste Systems	**3. Number** WHC-SD-WM-ER-432	**4. Rev No.** 0
5. Key Words Material Degradation Aging Double-Shell Tank Transfer Piping Corrosion Concrete	**6. Author** Name: E. B. Schwenk E B Schwenk Signature Organization/Charge Code ~~Structural Integrity Assessments/W236A~~ 6A500/P13[illegible]H03	

7. Abstract

A remaining life assessment of the DSTs and their associated waste transfer lines, for continued operation over the next 10 years, was favorable. The DST assessment was based on definition of significant loads, evaluation of data for possible material degradation and geometric changes and evaluation of structural analyses. The piping assessment was based primarily on service experience.

8.

10. RELEASE STAMP

EXECUTIVE SUMMARY

A remaining life assessment was conducted on the Double-Shell Tank (DST) Waste System in the 200 West and 200 East Areas. The life assessment was divided into two major parts: the DSTs and the transfer piping. The DSTs were evaluated for their ability to maintain the prime functions of leak tightness and structural stability. The piping transfer lines were assessed primarily through a review of their service experience. These tasks were undertaken with the understanding that the information available for such a life assessment is not complete. More information will be forthcoming from additional structural analyses and tank examinations; this information should be used during future DST Waste System life assessment reviews.

All of the DST Waste Systems performed satisfactorily, thus far. The question of their continued service resides in determining or estimating the service conditions that could degrade their capacity. Various types of metal corrosion are the dominant aging mechanisms for steel tanks and piping. Thermal degradation of concrete is the primary aging mechanism for the tank outer structure. The potential for additional loads, particularly on the concrete, is also important.

The DST life assessment determines structural margins by defining all significant loads and comparing them to structural acceptance criteria. Concurrent with this structural margin assessment is a detailing of initial material properties and an assessment of the potential for aging degradation mechanisms to produce geometric changes in structural elements and to produce material property changes. Their importance is evaluated using degradation data and service experience, and where possible, their effect on accepted structural margins is assessed. The DST Service Life Assessment and the Transfer Piping Life Assessment follow in that order.

DOUBLE-SHELL TANK REMAINING LIFE ASSESSMENT

The life assessment consists of three basic elements: (1) defining all significant loads, (2) evaluating data for possible material degradation and geometric changes, and (3) assessing the tank structure.

Significant Loadings

The tanks are designed to withstand several continuously present loads and some periodic loads. Soil overburden, thermal, hydrostatic, and vapor space pressure are essentially continuous loads. Periodic loads include snow and vehicle traffic. When combined with concrete aging, with creep and with time, a change in tank capacity can occur. This new capacity is used when evaluating the tank's capability to withstand abnormal and extreme loads that occur infrequently such as an earthquake or a hydrogen burn.

Analyses agree that the DSTs can withstand the expected loads and still maintain an acceptable safety margin. In addition, the analyses show the degradation of concrete strength with temperature and concrete creep are

unlikely to limit the life of the concrete shell and, although the primary steel tank may have high local stresses that would increase the chance for stress-corrosion cracking, the primary tank will not collapse. Soil loads and temperature place the greatest demand on the concrete structure. However, the available analyses do not thoroughly address temperature effects or through-wall temperature gradients. Future analyses must more fully address thermal cycling, a wider range of creep rates, and the large difference in the thermal expansion of the concrete and steel.

Material Properties and Geometric Changes

Initial material properties for each DST were reviewed and presented as a basis for initial structural assessment. These are separated into two categories : liner metals and reinforced concrete.

Liner Metals

Corrosion is the dominant aging degradation mechanism that could lead to geometric changes in liner metals. Limited radiation conditions, composed mainly of nonstructurally damaging alpha, beta, and gamma radiation, and relatively low tank temperature levels preclude any significant changes in metal properties.

Stress-Corrosion Cracking and Pitting-Crevice Corrosion--are the dominant corrosion mechanisms that could lead to future leakage. None of these mechanisms will likely alter structural stability. Any future in-tank processing, particularly in the more stress-corrosion cracking-sensitive DSTs, should be done within the present chemical corrosion controls.

Present chemical corrosion controls, coupled with future ultrasonic examination of the inner liner for thinning, pits, and cracks, provide a realistic approach for both controlling and periodically assessing geometric changes due to corrosion damage. If any of the mechanisms are active, crude rates of attack should be measurable allowing adequate time to prepare for pumping to another tank. The outer liner is unlikely to be strongly affected by corrosion. The outer liner will be subject to the same UT examination as the inner liner.

Several aging degradation mechanisms are unlikely in the inner or outer liner: brittle fracture, thermal embrittlement mechanisms, hydrogen embrittlement, liquid metal embrittlement, excessive uniform corrosion, erosion-corrosion, fatigue, fretting-corrosion, and creep.

Reinforced Concrete

The significant aging degradation mechanisms or threats to structural stability of reinforced concrete are the effects of elevated temperature, aggressive chemical attack, and corrosion of the embedded steel.

None of these three mechanisms should be a threat to the reinforced concrete structure. However, the combination of a low coefficient of expansion of Hanford concrete, if coupled with significant temperature cycling resulting from waste-height fluctuations, could cause degradation of the concrete-reinforcing steel bond. Further study of potential thermal cycling effects should be done to determine if dome concrete sampling should be considered.

TRANSFER PIPING REMAINING LIFE ASSESSMENT

The piping life assessment approach differs from that of the DSTs. The piping remaining life assessment was based on a review of the piping failure history and identification of the principal factors that contributed to those failures. Also, the 200 West and 200 East Area piping systems were reviewed for the effect of single- and double-line failures on waste transfer options.

Significant Loadings

Significant piping loadings are hydraulic pressure, thermal expansion, soil overburden and earthquake load. No accident condition loads were considered. Because most piping failures were not inspected or analyzed, only a limited history exists to allow one to determine the particular effects of mechanical or thermal loading on failure.

Material Properties and Geometric Changes

Corrosion, plugging, and possible mistransfer of aggressive chemical solutions are the primary mechanisms that could lead to geometric changes and piping failures. No significant changes in metal properties should result from radiation or thermal effects. Pitting-crevice corrosion and stress-corrosion cracking along with possible erosion effects should be the dominant corrosion failure mechanisms.

Present chemical corrosion control limits should be adequate for preventing any significant general corrosion. To limit the occurrences of plugging, waste solution density maximums should continue to be controlled to minimize precipitation of solids during waste transfer.

The 200 West and 200 East piping systems were also analyzed for the presence of pinch points. A pinch point is a restriction in the DST piping system that, if a single or a double failure were to occur, would seriously jeopardize future waste transfers.

Facilities with single pipeline pinch points in the 200 West area are U Plant, Building 222-S, and the 244-U-DCRT. In the 200 East Area they are the 244-BX DCRT, CR Vault and the 204-AR Rail Car Facility. None of these facilities are major waste producers; however, loss of the 204-AR facility would be significant. This would prevent waste receipt from the 200 West area lab (221-S), the 300 Area labs and the T Plant decontamination facility.

Intrasite waste movement in each area should not be significantly pinched. Intersite movements could be a problem as the present cross-site line has only two pipes remaining. Also, some single-shell tank farms and facilities (e.g., the Plutonium-Uranium Extraction [PUREX] Plant) could be important if waste movements were ever restricted to a single direction.

Future decommissioning of some plants could also reduce available piping systems. Tank Farms is proceeding with plans for decontamination and decommissioning of the 244-AR facility, which would reduce the number of pipeline transfer paths. Further study on the effect of decommissioning of plants or facilities associated with waste transfer is necessary to ensure minimal loss of future waste transfer capability.

The current failure rate of about one line per year is tolerable. Future piping failures should be inspected and evaluated to determine the reasons for failure. This will help ensure that present and future piping systems are designed and operated in such a way to preclude most failures.

LIST OF TERMS

ACI	American Concrete Institute
α	coefficient of thermal expansion
ASME	American Society of Mechanical Engineers
AWF	Aging Waste Facilities
DBE	design basis earthquake
CC	crevice corrosion
CP	cathodic protection
DCRT	Double Contained Receiver Tank
DB	diversion box
DOE	U.S. Department of Energy
DST	double-shell tank
Evap	evaporator
J_{IC}	The engineering estimate of fracture toughness near the initiation of slow stable crack growth
K_{IC}	Critical plane strain stress intensity factor; also plane strain fracture toughness
K_{Iscc}	Plane strain stress intensity factor at which stress-corrosion crack growth initiates
MIC	microbiologically induced corrosion
PC	pitting corrosion
SCC	stress corrosion cracking
SIA	structural integrity assessment
TWRS	Tank Waste Remediation Systems
UBC	Uniform Building Code
UC	Uniform corrosion
UT	ultrasonic testing
VPC	vapor phase corrosion
WHC	Westinghouse Hanford Company
ZPA	zero period earthquake

LIST OF FIGURES

LIST OF TABLES

CONTENTS

EVALUATION OF REMAINING LIFE OF THE DOUBLE-SHELL TANK WASTE SYSTEMS

1.0 INTRODUCTION

The double-shell tank (DST) waste system in the 200 West and 200 East Areas provides successful storage of nuclear waste (in DSTs) and provides safe, periodic transfer of these and related wastes through interconnected piping. Westinghouse Hanford Company (WHC), in conjunction with the U.S. Department of Energy (DOE), recently reevaluated the need for new DSTs in light of budgetary restrictions; WHC and DOE are assessing the implications and risks of no new DSTs for the next 5 to 10 years. If no new DST systems are built, the life of the existing systems becomes more important.

This life assessment focuses on the 28 DSTs and their associated transfer lines. This assessment determines, using the available information, whether the DST system should be available for the next 10 years. To support the near-term need for waste volume projections and planning for additional storage capacity, this task was undertaken without complete information. Additional structural analyses and DST examinations will provide more information.

The DST system life assessment comprises two major components: DSTs and transfer lines. DSTs are evaluated for their expected ability to maintain the two prime functions: leak tightness and structural stability. The piping life assessment is based primarily on service experience.

Because these components have performed acceptably, their continued service depends on those service conditions that degrade their underlying capacity (such as concrete strength loss or steel corrosion) and on the potential for additional loads. The following sections identify important aging mechanisms and loads and then evaluate their importance by using service experience or by assessing their effect on accepted structural margins.

1.1 DOUBLE-SHELL TANK REMAINING LIFE ASSESSMENT

The DSTs serve as caustic, radioactive waste storage and may be used for some limited in-tank treatment. Their design loads define their service demand. The DSTs are designed to store up to 1.1 Mgal of 350 °F radioactive waste with a specific gravity of up to 1.7, and withstand soil overburden up to 8 ft, concentrated equipment loads, thermal transients, and seismic loads. The DSTs must remain leak tight and structurally stable during their remaining service period. The primary steel tank and secondary steel liner confine the waste while the reinforced concrete structure carries the large soil loads.

Aging degradation is evaluated by exploring possible aging degradation mechanisms and screening out nonsignificant mechanisms. The conditions required for the remaining mechanisms to be potentially operative and damaging are identified and effects estimated. Various types of corrosion are the dominant aging mechanism for steel DSTs and piping. Thermal degradation of reinforced concrete is the aging mechanism for the outer structure.

The structural assessment of the DST consists of applying the loads to a DST model capable of capturing the material degradation, the elastic response of the steel DST, and the creep and cracking response of the concrete structure. The DST response is compared to the DST capacity as defined by the American Society of Mechanical Engineers (ASME) or American Concrete Institute (ACI) code. A range of loads and material conditions is assessed to ensure the DST response is appropriately represented and to estimate the structural margins after extended service. Existing analyses show the structural margins are positive and should remain positive. However, the effect of temperature and thermal transients on the concrete structure must be appropriately assessed by analysis to provide confidence in the prediction.

1.2 PIPING REMAINING LIFE ASSESSMENT

The assessment of the transfer lines is based on a review of service experience rather than structural analysis. The review shows that effective actions were taken during the last 40 years to design reliable transfer systems. The current rate of failure, slightly more than one line per year, is tolerable.

The background section describes the general subjects to be discussed in the two useful service life assessments: Double-Shell Tanks in Section 3.0 and Piping Systems in Section 4.0. The accompanying appendices provide backup information.

2.0 BACKGROUND

The DST waste system remaining life estimation begins with assessing the system's structural integrity, which is ensured through leak-tightness and structural stability.

2.1 TECHNICAL BASIS FOR A LIFE EVALUATION

A structural integrity program (i.e., remaining life evaluation) consists of three basic elements:

1. Define all appropriate loadings.
2. Define possible material and geometric changes (i.e., the degraded state of the structural materials).
3. Analytically evaluate the structure based on appropriate models and compared with appropriate structural acceptance (performance) criteria.

Loading definitions are used to calculate expected structural demands, which are compared to structural capacity. The DST systems were designed and constructed using prevailing design codes, which provided a significant failure margin. After the system is in service, the actual service demands on the structure and the amount of material degradation will be used to more reliably estimate DST system life. In fact, future degradation estimates will be incorporated into the life estimate. In cases where degradation is expected to be significant, nondestructive testing can be used to determine the degree of structural degradation and, where applicable, material property degradation.

2.1.1 Loadings

DSTs design loadings include those associated with normal operation: dead, live, hydrostatic, thermal, soil overburden, and peak earthquake. An extreme load, the flammable gas burn event, may fail the DST without material degradation; thus, the burn event's effect on DST life depends on the event occurrence probability, which is beyond the scope of this study (LANL 1994). The next section presents load details. (Section 3.2.1).

2.1.2 Geometry

Chemical limits applied to the waste control changes in DST geometry resulting from corrosive aging mechanisms (e.g., uniform corrosion, pitting corrosion, and stress-corrosion cracking). If crevice corrosion exists (i.e., an advanced form of pitting corrosion), it is more likely to be found around water-line crustal deposits or around bottom-lying deposits associated with solids or large-scale corrosion products. The ultrasonic testing (UT)-robot system should be used to assess the potential for these degradation mechanisms too but will only be able to view the DST bottoms, in the air slots, near the liner periphery.

Ongoing visual examinations of the DST annuli with video cameras and periodic photographing of DST interiors are used to determine if any gross structural irregularities exist or if any leaks have occurred. A sump fluid detection system and humidity monitoring of DST vapors in vent lines are also used to determine if any significant leaks have occurred.

Interconnecting piping systems are periodically pressure tested for leakage. Visual examination devices are also used in selected regions of reasonably accessible piping to confirm the presence of any large breaches in the piping walls.

2.1.3 Analysis Techniques and Acceptance Criteria

A structural stability assessment consists of selecting proper acceptance (performance) criteria, using representative DST models with appropriately applied load combinations, and assessing the safety margins.

No national standard provides rules for design evaluation of underground radioactive waste storage DST systems. However, a combination of standards was used for the design of the existing 28 DSTs: the ASME (ASME Section III), ASME Section VIII) for the primary and secondary DST liners and the ACI (ACI

1992, ACI 1986) for the concrete structure. A design code history of the DSTs based on applied codes is summarized in Table 1. The construction period and applicable codes provide a good sense of the design features of the DSTs.

For the waste transfer piping system, the design standard was either the Power Piping Code (ANSI 1973) or the Chemical Plant and Petroleum Refinery Piping Code (ANSI 1987). For this application, these two codes are essentially equivalent. "Coal-Tar Protective Coatings and Linings for Steel Water Pipeline-Enamel and Tape-Hot-Applied" (AWWA C203) is the standard used for the coating of buried carbon steel piping. Cathodic protection (CP), where required, is installed according to the standards and requirements specified in "Upgrade of Hanford Site 200 Areas Cathodic Protection Systems" (B-234-C-1). Typically, polyurethane is used where insulation is required and is tested for conductivity (ASTM C 177), compressive strength (ASTM D 1621), and water absorption (ASTM D 2842). The many project specifications released specify the acceptance criteria for these tests.

The techniques employed for DST structural analyses are summarized for each DST farm and each special case analysis in Appendix A.

2.2 TECHNICAL LIMITATIONS IN A REMAINING LIFE EVALUATION

The limitations associated with any remaining life evaluation are described below and ultimately result in the need to exercise engineering judgement.

2.2.1 Design Analysis Limitation

Design analyses are used to verify that the stresses or structural demands resulting from specified design loads do not exceed limits specified in the applicable codes. The code limits are set at a fraction of the ultimate structural capacity; therefore, the allowable stresses or demands on the structure are typically in the regime where the structure behaves elastically and are more easily and accurately calculated. Exceeding a code allowable does not mean the end to DST life but instead directs our attention to that part of the DST for further evaluation. Alternatively, one could attempt to predict the failure load on the structure but this is a difficult path to take because nonlinear material data is sparse and computations are onerous. In this report, the life of the DST with respect to its structural capacity is limited to comparisons to the code allowable.

Another limitation of the design analysis in assessing remaining life is analysis documentation. Most DST design analysis reports do not contain the detailed stress results and do not address the sensitivity of the analysis results to variations in the material properties or loads. Consequently, most of the conclusions in this life evaluation are derived from the most recent and limited analyses (Fisher et al. 1994; Scott and Peterson 1995).

Comparisons of structural analysis results to code allowables are not a complete answer to life assessment. Although analyses are valuable to ensure the as-built structure has sufficient structural capacity to withstand the applied loads, local weaknesses in the material or local stress concentrations often cause failure. To compensate for this limitation in the analyses, good engineering judgement and an appropriate testing and examination program are required. For the transfer lines, analyses are of limited value predicting service life. Instead, experience and failure investigations are used.

2.2.2 Degraded State Limitation

A closely related second limitation, requiring engineering judgement, is the general lack of knowledge of the degraded state of the DST inner liner and the DST outer liner-reinforced concrete structure. Periodic visual inspection of DST interiors and their annuli by photographic and video means show no significant overall deterioration of the tanks. It is not possible to visually access the concrete. Some pipelines failures were investigated and were shown to be caused by corrosion. The number and extent of the investigations are limited.

A recent development, however, will substantially increase the knowledge of the DST inner liner including its bottom knuckle and selected regions of its bottom. A robotic device has been designed and built for traversing selected regions within the annulus of a given DST. The device will interrogate the inner liner (and outer liner too) for wall thinning, pitting, and crack-like defects using a multisensor ultrasonic probe. The device is nearly completed and will be checked out using a series of performance demonstration tests and "calibrated" against a range of simulated DST wall thinning, pits, and actual stress-corrosion cracks. Application to the DSTs is expected by the end of the calendar year.

3.0 USEFUL SERVICE LIFE ASSESSMENT: DOUBLE-SHELL TANKS

3.1 DOUBLE-SHELL TANKS DESCRIPTION

Six DST farms are located in the 200 East (five farms) and 200 West Areas (one farm). The DST farms became operational between 1971 and 1986. For efficiency during construction and operation, the million-gallon DSTs are grouped into these six DST farms: 241-AN, 241-AP, 241-AW, 241-AY, 241-AZ, all in 200 East Area and 241-SY, in the 200 West Area. The 241-AY and 241-AZ are referred to, collectively, as the Aging Waste Facilities. Table 1 lists the various DST farms.

The various DST farms contain a total of 28 DSTs. Each DST can hold between 1 and 1.16 Mgal of high-level mixed waste for a maximum combined storage capacity of 32.8 Mgal for up to 50 years. Figure 1 shows the typical DST configuration.

Since 1971, DSTs have been used to store liquid radioactive waste (transuranic, high-level, low-level, and Hanford Site Facility waste). DSTs have been used exclusively for receiving liquid waste since 1980, when single-shell tanks (SSTs) were retired from waste-receiving service. Several operating plants in the 200 East and 200 West areas of the Hanford Site transfer mixed wastes from the facility through buried transfer lines to the

1-Mgal underground DSTs. The liquid waste accumulates in the DSTs until it can be disposed of in the future.

Table 1. Double-Shell Tank Farms.

Tank farm (area)	Tanks in farm	Tank volume (Mgal)	Year constructed	Reference drawing
241-AN (200 East)	7	1.16	1977-79	H-2-71901
241-AP (200 East)	8	1.16	1983-86	H-2-90436
241-AW (200 East)	6	1.16	1978-80	H-2-37701
241-SY (200 West)	3	1.00	1974-77	H-2-64301
Aging Waste Tank Farms				
241-AY (200 East)	2	1.00	1968-70	H-2-64301
241-AZ (200 East)	2	1.00	1971-77	H-2-68353
Total	28	--	--	--

3.2 LOADINGS AND MATERIAL PROPERTIES

3.2.1 Loads

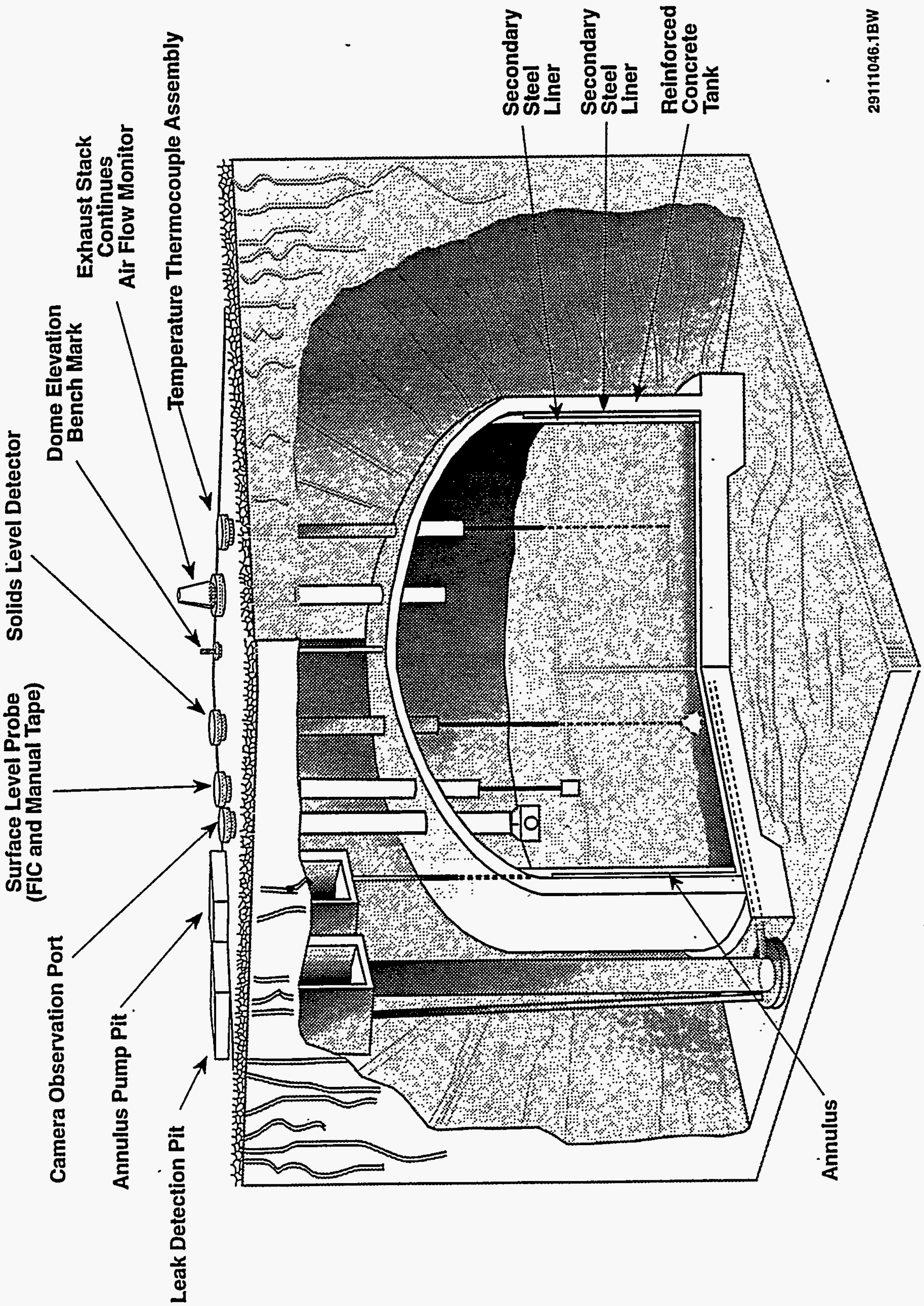
Based on their load classification in the source documents and best engineering judgement, loads have been grouped into three categories: normal, abnormal, and extreme.

1. Normal Loads--Loads encountered during normal operation. For the primary steel tank, the major contributors to DST stresses during normal operation are the hydrostatic load and the soil overburden. The other loads contribute a relatively small amount to the overall stress state. For the secondary steel liner and the concrete structure, the major demand comes from the thermal loads, the soil loads, and the concentrated live load. The normal loads are listed below.

a. Dead Loads--Structure weight and permanent equipment loads.

b. Live Loads--Movable equipment loads and other loads that vary with intensity and occurrence, except soil pressures, which are included separately.

Figure 1. Double-Shell Tank and Ancillary Equipment Configuration.



c. Hydrostatic Load--Hydrostatic pressure, including cyclic variations.

d. Thermal Loads--Thermal effects and loads from differential thermal expansion and thermal gradients.

e. Soil Overburden Loads--Soil overburden and lateral soil pressure.

f. Operating Pressure Loads--Pressures in the primary DST vapor space and the annulus determined from the operational safety document and operational safety requirement defined values.

g. Pump Loads--Weight, vibration, and thrust loads from pump operation (normally evaluated on a DST-by-DST basis).

2. Abnormal Loads--Abnormal loads place demands on the DSTs that are a fraction of the normal loads.

a. Pressure Loads--A sudden release of gases causing a brief increase in the primary DST vapor pressure.

b. Wind Loads--Objects acting as missiles.

c. Pump Loads--Maximum pump vibration (impeller plugged), maximum pump thrust (one nozzle plugged), wasteberg striking the pump column, installing and removing loads, discharge pipe assembly failure (pump loads are addressed on a DST by DST basis).

d. Earthquake Loads--Loads generated by the Design Basis Earthquake with a Zero Period Acceleration of 0.25g. Only the actual dead load and existing live load need be considered in evaluating seismic response forces.

e. Seismically Induced Hydrodynamic Effects--The underground storage DSTs will contain liquid; therefore, the seismic event will produce a hydrodynamic response in the liquid, imposing loads on the DST structure. Hydrodynamic forces must be evaluated for a horizontal component of ground motion, a rocking motion of the DST base, and for a vertical ground motion. The resulting convective and impulsive pressures must be evaluated.

f. Pressure from Soil-Vault Interaction--The DSTs must be evaluated for seismic loads resulting from soil-structure interaction analysis with actual soil properties accounting for the variabilities in the soil properties as directed in American Society of Civil Engineers (ASCE 1986).

3. Extreme Loads--These loads are imposed on the DSTs as a result of various extreme conditions identified in either the functional design criteria or in the safety analysis report. These loading conditions are typically dynamic in nature and demand is typically compared to failure criteria rather than design criteria.

a. Hydrogen Burn--Very rapid pressure pulse caused by deflagration of nitrous oxide and hydrogen gas. Before active mitigation, measured gas release events in DST 241-SY-101 (commonly referred to as DST 101-SY) were sufficient, if properly concentrated and ignited, to cause DST failure (LANL 1994). Active mitigation for the other five hydrogen watch list DSTs will be decided after characterization of the slurry gas compositions. In the meantime, there is a small, but finite, probability that a gas burn could damage one of these DSTs.

3.2.2 Steel and Concrete Properties

The initial structural material properties of all the DST farms are detailed in each DST design specification and related engineering documents. Table 2 presents a compilation of the major material specifications, welds, concrete, and reinforcing steel.

Construction materials for ancillary components including DST risers and other openings, suspended components, and insulating concrete, are also detailed in the specific design and engineering specification documents for each DST farm.

All ancillary materials exposed to the waste are carbon steel, thus eliminating failure mechanisms associated with galvanic (two-metal) corrosion.

<u>Other Important Metal Properties.</u> Measures of the sensitivity of DST liners to stress corrosion cracking (SCC) and fracture are provided by K_{ISCC} and fracture toughness [K_{IC} (or J_{IC})] data.

Fracture toughness data are important but are not critical to the future operation of DSTs. While charpy impact fracture data and fracture toughness data can only be inferred from the American Society for Testing and Materials (ASTM) metal specifications, the carbon steel construction metals typically display ductile-to-brittle transition temperatures well below that of the lowest ambient soil temperature (about 50 °F).

DST fracture, in general, is highly unlikely for several other reasons. First, the DST liner metals all have low- to medium-low strength, which generally ensures high toughness. Based on Pellini (1989), the liner metals have fracture toughness (K_{Ic}) levels that likely exceed 100 Ksi$\sqrt{in}$ with the result that a ductile failure is the likely fracture mode (Shurrab et al. 1991). In the absence of gross SCC or gross wall thinning in the DSTs, some undefined, excessive loading would be necessary to produce a DST fracture.

Table 2. Specifications for DST Farm Metallic and Concrete Materials.

DOUBLE SHELL WASTE TANKS															
TANK FARM 241-	CONSTR. DATES START END	HANFORD CONSTRUCTION SPEC.	STEEL LINERS (PRIMARY/SECONDARY)					CONCRETE			REINFORCING STEEL			SEISMIC CRITERIA
			DESIGN CODE		STEEL SPEC	WELDS		SPECIFICATION			REBAR (ASTM)	XTIES (ASTM)	WELD	
			PRIMARY LINER	SECONDARY LINER	ASME YIELD STRESS	PROC.	QUAL.	COMPRESSIVE STRENGTH						
								DOME	WALL	FDN				
AY	1968 1970	HWS-7789 TO HWS-7791	ASME	ASME	A515-65 GR 60 F_y=32 ksi	*NRA*	ASME SECT IX	ACI 318-63			A15-65 FDN GR 40 A432-66 SHELL GR 60	A432-66 GR 60	*NRA*	UBC TID-7024
								3ksi	3ksi	3ksi				
AZ	1971 1977	HWS-8981 HWS-8982	ASME SECT III	ASME SECT III	A515-69 GR 60 F_y=32 ksi	*NRA*	ASME SECT IX	ACI 318-63			A615-68 GR 60	A615-68 GR 60	*NRA*	TID-7024
								3ksi	3ksi	3ksi				
SY	1974 1976	B-101- C1, C2 & C3	ASME SECT III	ASME SECT III	A516-65 GR 65 F_y=35 ksi	HPS-220-W	ASME SECT IX	ACI 318-71			A615-72 GR 60	A615-72 GR 40	AWS D12.1	TID-7024
								4ksi	4ksi	3ksi				
AW	1978 1980	B-120- C3, C4, C5 & D1	ASME SECT VIII DIV 2	ASME SECT VIII DIV 2	A537-74a CLASS 1 F_y=50 ksi	HPS-220-W	ASME SECT IX HPS-210-W	ACI 318-71			A615-76a GR 60	A615-76a GR 40	AWS D12.1 HPS-220-W	SDC 4.1 TID-7024
								5ksi	5ksi	4.5ksi				
AN	1980 1981	B-130- C1, C3, C4 & D1	ASME SECT VIII DIV 2	ASME SECT VIII DIV 2	A537-75 CLASS 1 F_y=50 ksi	HPS-220-W	ASME SECT IX HPS-210-W	ACI 318-71			A615-75 GR 60	A615-75 GR 40	AWS D12.1 HPS-220-W	SDC 4.1 TID-7024
								5ksi	5ksi	4.5ksi				
AP	1983 1986	B-340-C3, C4 & D1	ASME SECT VIII DIV 2	ASME SECT VIII DIV 2	A537-80,79 CLASS 1 F_y=50 ksi	AWS D1.1	ASME SECT IX	ACI 318-77 & 349			A615-81a GR 60	A615-81a GR 60	AWS D1.4	SDC 4.1 TID-7024
								5ksi	5ksi	4.5ksi				

*NRA--Not readily available from onsite records reviewed to date.

In addition, the DSTs experienced essentially no neutron irradiation. Only gamma, beta, and alpha radiation exist and have decreasingly, but vanishingly, small effects on bulk mechanical properties including ductility and toughness (Blackburn 1989).

3.3 GEOMETRY AND MATERIAL DEGRADATION MECHANISMS

3.3.1 Inner Liner Degradation Mechanisms

Corrosion is the dominant aging mechanism or threat to the leak tightness of the Hanford DST inner liners. While all corrosion mechanisms must be considered for all construction materials, past Hanford, Savannah River, Idaho Falls, and West Valley site studies and historical experience show general corrosion, SCC, and pitting-crevice corrosion are the corrosion mechanisms of consequence (significant age-related degradation mechanism) for Hanford DSTs and are described below.

Other DST metal aging mechanisms are considered insignificant and include hydrogen embrittlement (Anantatmula et al. 1994; Bandyopadhyay et al. 1994) thermal embrittlement, radiation embrittlement, wear, fatigue, erosion, erosion-corrosion and creep (Bandyopadhyay et al. 1994; Schwenk 1992a; Schwenk 1992b; Shurrab et al. 1991). No evidence exists that microbiologically induced corrosion (MIC) has occurred in the inner liner, and it is believed to be unlikely. MIC might conceivably occur in the outer liner and is discussed below (Section 3.3.3.5).

3.3.1.1 General Corrosion. General or uniform corrosion (UC) is characterized by a chemical or electrochemical reaction that proceeds uniformly over the entire exposed area. The metal becomes thinner and eventually fails. Uniform corrosion has not been reported to be a cause of failure in any of the Hanford DST inner liners. Several studies show that general corrosion is not expected to be significant at the typical temperatures and pH conditions of operation for the DSTs. Specifically, corrosion experiments, using synthetic DST wastes, yield very low general corrosion rates that differ little among various liner carbon steels (Dacres 1993; Lini 1975; Mahidhara 1992; Mahidhara et al. 1992). Values were generally less than 25 micron/year (1 mil/year). Corrosion controls (Kirch 1984) based on corrosion experiments (Divine et al. 1985) are believed to have maintained in-DST uniform corrosion rates <1 mil/year.

Uniform corrosion in the vapor phase is possible as the waste-borne chemical controls probably do not extend to the vapor space above the waste. Corrosion rates of several mils/year in humid environments are possible (Schwenk 1992a). Some DST wastes, however, emit ammonia (NH_3) which can act to inhibit vapor phase corrosion (VPC) as long as vapor concentrations do not become excessive (Graver 1985). For DSTs that do not contain ammonia, and that were only partially filled for relatively long periods, some wall VPC could have occurred. However, once the DST is filled, the chemical corrosion inhibitors would act to reduce any corrosion. In addition, future UT inspection of the DST walls would provide both a measure and check on the amount of initial corrosion and any change that would occur between inspections. VPC above the maximum fill line is unlikely to affect structural stability or leak tightness of areas below the fill line.

3.3.1.2 Pitting/Crevice Corrosion. Pitting is a form of extremely localized attack that results in cavities and, ultimately, holes in the metal. Pitting is one of the more destructive forms of corrosion. It is often difficult to detect pits because of their small size and because the pits are often covered with corrosion product. The density of holes produced by pitting generally does not remove enough material to seriously compromise the overall strength of a structure made of ductile metal (e.g., the DST liners).

Pitting is difficult to predict by laboratory tests. Pitting usually requires an extended period (i.e., an incubation time ranging from months to years) before visual pits appear. Pitting is a localized and intense form of corrosion, which is particularly harmful because once it starts it can penetrate the metal at an ever-increasing rate. Pitting is usually associated with stagnant conditions such as a liquid in a DST or liquid trapped in a low part of an inactive pipe system. Pitting could also occur in water-line crustal deposits where liquid waste chemistry changes may occur or under liner surface deposits.

Crevice corrosion (CC) is a more advanced form of pitting corrosion (PC). It is an intensive localized form of corrosion that frequently occurs within crevices and other shielded areas on metal surfaces exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and rivet heads. Examples of deposits that may produce crevice corrosion are sand and dirt, corrosion products, and other solids such as "sludge and settlement." The deposit acts as a shield and, like pitting, corrosion proceeds in the highly occluded environment (Fontana 1968).

Laboratory testing in synthetic wastes often yield high-pitting growth rates above the liquid level. Pitting has been reported on coupons that occurred in different waste environments associated with Hanford SSTs. No leakage resulting from pitting or crevice corrosion has been reported at the Hanford facility DSTs. The extent of pitting and crevice corrosion is expected to be evaluated in the near future by annulus-based, UT-inspection methods.

An program is developing remote equipment for automated UT of the primary and secondary DSTs of the DSTs from the annulus regions. These examinations are being designed to measure wall thickness (general or uniform corrosion) and detect the size of cracks and pits resulting from localized corrosion mechanisms. Particular attention will be paid to regions that are typically prone to these corrosion effects, such as weld seams, vapor-liquid interface, and the highly stressed bottom knuckle area (Pfluger 1994).

Although no reported evidence of crevice corrosion in the DST inner liners has been reported, all of its propagation elements exist, mainly in two areas: under sludge or corrosion product layers on the DST bottoms and in the unsealed backup bars remaining after the roof seam welding. The UT-robot system is expected to assess potential bottom sludge-layer effects through the air slots near the outer periphery of the bottom. Future, in-DST, magnified image viewing of the backup bars is expected to clarify their corroded state although their failure is not believed to be significant to either leak tightness or structural stability as stated above.

Corrosion Monitoring. The Materials and Corrosion Engineering section of Tank Waste Remediation System Specialty Engineering is working toward installing a prototype corrosion monitoring probe in at least one DST. The probe should be capable of detecting and discriminating between uniform corrosion, SCC, and pitting as they occur (i.e., in "real time"). Development activities focus on two promising probe technologies: Electric Field Pattern and Electrochemical Noise analysis. Task funding provides a prototype probe assembly and its incorporation into a standard-level detection tree already scheduled for insertion into a DST by September 1995. This first probe assembly will provide actual in-DST corrosion monitoring under actual service conditions and will identify areas for design improvement for future assemblies. The probe choice is contingent on successfully completing in-progress proof-of-technology studies. Information from this probe assembly should provide further evidence that corrosion will not limit DST life (Lindsay et al. 1994).

3.3.1.3 Stress-Corrosion Cracking. SCC is a brittle failure that can occur at relatively low, constant tensile stress in an alloy that is exposed to a corrosive environment. Such tensile stress levels can be less than design stress; fortunately, design stress requires a simultaneous interplay of (1) tensile stress, (2) a corroding media (not usually aggressive to the metal as a whole), and (3) a multitude of "normal," built-in, crack-sensitive paths associated with the boundaries of the metal crystals or grains. Absent any one of these conditions, SCC will not occur.

SCC Control in DSTs. SCC (including pitting corrosion and uniform corrosion) has been successfully controlled specifically through maintenance of proper levels of chemical inhibitors with elevated temperature limitations (Kirch 1984) and a decrease in residual stresses through a DST post-weld heat treatment, also called a stress-relief treatment. Like PC, SCC also displays an incubation time. The incubation time can exceed the typical time-of-testing, which frequently does not exceed 1-year. The short-term tests have another limitation: they cannot readily measure very slow crack growth rates, which could be associated with Stage I growth in an inner liner. These are additional reasons why an annulus-based UT inspection will be very helpful for at least determining the approximate size of possible SC-cracks; periodic UT measurement or on-line acoustic emission monitoring might be used to determine if the crack is growing.

In addition, a flaw (crack) could deepen enough to influence the solution's local chemistry at the crack tip. As a result, the local, crack-tip environment could differ from the waste solution bulk chemistry, thus influencing in-DST SCC growth. The depth at which a local chemistry alteration might occur in a caustic solution is not known.

SCC Causes. The environmental causes of SCC that could apply to steel DSTs individually, are high levels of nitrates, carbonates, phosphates, and caustic. Extensive studies indicate that adding nitrite and controlling the hydroxide percentage and temperature inhibit SCC as well as reducing pitting and uniform corrosion to satisfactory low levels. Short-term SCC tests, as noted earlier, can be misleading concerning long-term incubation periods and potential local chemistry variations within a given DST.

No leakage in the stress-relieved DST inner liners has been reported. Video inspection of all the DST annuli confirm this claim. Five of the 28 DSTs are nominally out-of-specification with respect to the caustic-nitrate balance.

Conclusions on Corrosion Failure Mechanisms for the Inner Liner

Corrosion is the dominant aging mechanism or threat to the leak tightness of the Hanford DSTs; while it is not possible to guarantee no breaching of the confinement barrier during the next 10 years, previous corrosion experiments and the present lack of leakage in DSTs, suggest that failures are not imminent. Future UT liner inspection will provide a measure of any significant corrosion attack caused by the four corrosion mechanisms.

General Corrosion. General corrosion (DST plate thinning) is not expected to be significant providing the temperatures and chemical conditions (viz., hydroxide and nitrite concentrations) of operation, presently specified, are maintained. UC in the vapor phase, termed VPC, is not expected to be detrimental to structural integrity or leakage. There does remain the possibility that a DST which was maintained in a low-fill position for a number of years, could have suffered more VPC than the region below the prior water line, but its extent would be measurable during future UT-monitoring.

Pitting/Crevice Corrosion. Because pitting is typically an extremely localized attack, hole-through could occur rapidly (as short as months) once its incubation time has been exceeded. Total leakage rates however, are unlikely to exceed annulus pumping rates thereby allowing for prompt remedial action. Local metal removal by pitting generally will not affect fracture stability in ductile liner metals.

Stress-Corrosion Cracking. SCC, which also displays an incubation time, might be slowly occurring for two reasons: very slow crack growth could be occurring because typical one-year tests do not reflect 20 or more years of in-DST chemical exposure, and localized crack-tip chemistry variations could act independent of the bulk chemistry controls used to subdue corrosion in general, once a crack exceeded some undefined depth. DST annulus inspections with a UT-robot system are expected to provide a satisfactory measure of the adequacy of the chemical corrosion controls that are being used to minimize damage by both pitting and SCC. Additional K_{ISCC} data would be beneficial for assessing the relative severity of UT-detected cracks.

It is not possible to make more definitive reliability predictions until DST waste characterizations have progressed further and the UT-Robot inspections have completed examination of the signal DSTs.

3.3.2 Outer Liner Degradation Mechanisms

The welded outer liner is typically made of the same steel as the inner liner; because it is supported by the reinforced concrete outer structure, the outer liner has one thickness from top to bottom, nominally 3/8- to 1/2-in.

Few corrosion mechanisms should exist here. Some UC and PC could occur if rainwater were to diffuse through cracks in the reinforced concrete and settle in the narrow region between the liner and the contiguous concrete. In addition, the water would have to settle for a significant amount of time. MIC could also occur here, but is believed to be unlikely. Like the inner liner, the UT-robot system will be able to interrogate areas of the outer liner from near its top down to the bottom of the annulus.

Should waste ever leak into the annulus, it should not be left there for an indefinite amount of time. The outer liner was not stress-relieved because of the reduced thermal resistance of normal portland cement concrete. Thus, the outer liner will be more sensitive to SCC. Normal chemical inhibition of the waste may be adequate to restrain significant amounts of SCC.

None of the other failure mechanisms (e.g., fatigue, creep, thermal embrittlement) noted in Section 3.1.3.1 are significant to the outer liner.

3.3.3 Reinforced Concrete Degradation Mechanisms

The significant aging degradation mechanisms or threats to the structural stability of concrete are the effects of elevated temperature, aggressive chemical attack, and the corrosion of embedded steel.

Inspection and testing of samples of concrete removed from SSTs, concrete test data, and inspection and testing of concrete removed from other Hanford facilities indicate that most reinforced concrete degradations mechanisms at Hanford should be insignificant. The combination of thermal cycling resulting from waste height variations and the low expansion coefficient of Hanford concrete could promote a cyclic fatigue effect that could both significantly alter the concrete-steel shear load-carrying capacity and induce further cracking of the concrete. Further analysis should be done to determine the significance of the latter effect and to determine whether to perform sampling inspections. Aging mechanisms and Hanford concrete test data are described below.

3.3.3.1 Elevated Temperature Effects. The thermal degradation threshold for concrete is about 200 °F. At higher temperatures, concrete exhibits a significant departure in its elastic and inelastic behavior from that observed at lower temperatures. This is also evidenced by the degradation of the elastic modulus with time at constant temperature. In addition, the compressive strength, tensile strength, and creep compliance degrade with time under increasing or constant temperature so that the material response is highly nonlinear and exhibits a complex dependence on the time-temperature history of a given DST (Kassir et al. 1993).

The high-level waste in some DSTs is reported to have reached a temperature range of 302 to 356 °F; the long-term exposure to elevated temperature could be a significant age-related degradation mechanism for the concrete enclosure of the storage DSTs. However, concrete laboratory tests and concrete core samples removed from selected Hanford Site Facilities often did not show significant deterioration; these are briefly described below.

3.3.3.2 Concrete laboratory and Core Sample Test Results

Concrete Laboratory Tests

Rockwell Hanford Operations (RHO) sponsored an extensive test program with the Portland Cement Association to determine various properties of laboratory casts of concrete that simulated concrete used in Hanford Site waste DSTs. These tests were reviewed and are described briefly (Blackburn et al. 1992).

Concrete exposed to temperatures between 250 and 450 °F produced some degradation in mechanical properties, but mainly at the higher exposure temperatures and times.

Heat-induced strength losses did not reduce Hanford Concrete mixes's compressive strengths below minimum design levels except for a near 10% decrease for the highest temperature and longest time (i.e., 450 °F and 920-day exposure).

In addition, the relative sensitivity to heat exposure degradation was greatest on the modulus of elasticity decreasing in order with splitting strength and compressive strength with poisson's ratio changing the least. The high-temperature, longest time (i.e., 450 °F and 920-day) exposure decreased the modulus of elasticity of heated concrete about 30% compared with that measured with unheated concrete. At the maximum temperature (450 °F) the decrease in mechanical properties did not appear to approach limiting values even after more than 2-1/2 years of exposure. This last noted effect should be studied further.

Thermal expansion of Hanford Concrete mixes was only about one-half of that reported for normal-weight structural concrete. Such decreased α values could cause a larger internal stress in steel-reinforced concrete in a heated structure. A number of cyclic temperature changes in a reinforced concrete structure might compromise the concrete-reinforcing steel bond as noted earlier.

Cyclic varying temperatures produced smaller changes in concrete-only properties than an equivalent exposure to a fixed maximum temperature. Property losses generally increased with the increasing number and length of temperature cycles. This indicates that both the steel-concrete bond and the concrete properties alone could both be affected by thermal cycling.

The above information indicates that if any DSTs have undergone a number of temperature swings resulting from significant increases and decreases in waste level (or variations in heat load for whatever reason), it should be reviewed concerning possible damage to the reinforcing steel-concrete bond. If the review confirms any significant cyclic temperature condition, consideration should be given for obtaining some concrete cores for evaluation.

Concrete Core Samples

Concrete core samples were taken from a number of Hanford site Structures and subjected to various examinations and tests with good results.

Concrete cores from Building 221-A and the Plutonium-Uranium Extraction (PUREX) Plant were exposed to elevated temperatures (121 and 232 °C [250 to 450 °F]) for 920 days. No detectable effects of stress or time on microstructure and no detectable signs of chemical reaction or physical damage were found. Some thin sections showed evidence of carbonation. Thus, no significant deterioration had resulted from elevated temperature exposure for as long as 2-1/2 years (920-days).

DeFigh-Price (1982) summarized results of modulus of elasticity, splitting tensile strength and compressive strength from samples taken from SST and PUREX Plant. These structures are 25 to 30 years old. Strength values were compared with laboratory results and showed no signs of degradation after about 29-years service (RHO 1981).

Forty-five year old concrete from B Plant and 35-year old concrete from the 105KE/105KW fuel pool storage basins showed no significant cracking from corrosion of reinforcing steel.

3.3.3.3 Aggressive Chemical Attack. The high alkalinity of concrete (pH >12.5) is degraded by strong acids whenever the concrete is exposed to such solutions (Troxell et al. 1968). Sulfates in the soil and groundwater, carbon dioxide in the air, and possible degradation resulting from internal reactions, are potential sources of chemical attack on concrete. Chemical attack usually increases the porosity and permeability of concrete, reduces its alkaline nature, and subjects it to further deterioration which can result in reduced compressive strength and stiffness. No evidence of any significant chemical attack has occurred in Hanford Concrete (see below).

Sulfate Attack

Protection against sulfate attack is obtained by using a low cement-water ratio and a portland cement having the needed sulfate resistance (ACI 1990). For a sulfate content in the soil below 0.1%, no special protection is required. The maximum sulfate content in soil from nine wells (depth between 3 and 60 feet below the surface) in the 200 East Area was 0.027% (Blackburn et al. 1992). This is far below the level at which protective measures would be used.

In addition, most of the DST farms were made using sulfate-resistive concrete. According to Blackburn et al. (1992), Type II cement was used in DST Farms AN and AP while Type V cement was specified for SY and AZ. The AY farm concrete was not specified. The low sulfate in the soil and the general use of high sulfate-resistance concrete significantly reduces any tendency for sulfate attack.

Carbonation Attack

Because concrete is alkaline, carbonation reactions from the acid atmospheric agent CO_2, can react with it. Atmospheric CO_2, dissolved in rain water can permeate concrete. In contrast, decomposition of hydrated cement compounds, caused by carbonation, can increase concrete strength by as much as 100% (Blackburn et al. 1992). Retrieving samples of soil-contacting concrete would be useful to see if any serious carbonation reaction has occurred in areas that may have experienced periodic rainfall or heavy snow melt conditions.

When reactive aggregates are employed, the use of a "low alkali" cement, the avoidance of sea water or alkali soil water for mixing, and prohibition of sodium or potassium chloride additions protects against deterioration (ACI 1990). A review of DST construction specifications revealed that low-alkali cement was required only for the 241-AN and -AP DST farms. However, examining concrete from other Hanford site structures, which should be similar to DST concrete, indicate that cement aggregate reactions do not occur within a 25 to 35-year period (Blackburn et al. 1992).

3.3.3.4 Corrosion of Embedded Steel. This section was excerpted from Blackburn et al. (1992). The document provides a very satisfactory description of the processes (and chemicals) that can lead to Hanford Site reinforced concrete corrosion. In addition, the Hanford Site is generally low in concrete depassivating agents and that limited investigation of concrete core samples removed from Hanford structures show little corrosive attack. Because possible temperature cycling in the DSTs remains to be resolved, future periodic inspection of reinforced concrete in DSTs should be considered if DST fill analysis and temperature records show any significant thermal cycling effects.

Good-quality concrete provides an ideal environment to protect the steel reinforcement. Chemical protection is provided by concrete's high alkalinity and physical protection occurs as a result of concrete acting as barrier to the access of aggressive species.

Despite these inherent protective qualities, corrosion of steel reinforcement has become the most common cause of failure in concrete structures (Rosenberg et al. 1989). Corrosion of reinforcing steel occurs under severe exposure conditions and when the concrete cover is not thick enough. Corrosion is generally not a problem at inland sites, except for bridge decks for which salt is applied for freeze-control problems.

Concrete Pore Structure Importance. The structure, size, size distribution, and interconnection of pores in the cement phase determine the availability of oxygen and moisture at the surface. Both oxygen and moisture are necessary for the maintenance of a passive film on the reinforcing steel. High pH and the availability of oxygen lead to a passive state in which the steel is essentially noncorroding. The highly soluble sodium and potassium salts present in cement give the pore solution of ordinary portland cement a pH of greater than 13 (Rosenberg et al. 1989).

The structure, size distribution and interconnection of pores also determine the rate of penetration of aggressive species that can destroy passivity and lead to corrosion of embedded steel. Cracks in the concrete are not necessary for damage by corrosion, but cracks extending in from the surface can clearly contribute to corrosion by giving improved access to moisture, air, and other aggressive chemicals. Thermal cycling would act to increase the amount of cracking.

Primary Causes of Reinforcing Steel Corrosion. The two major causes of the corrosion of embedded steel are the presence of chloride ions, either included in the mix or resulting from penetration from the environment, and a decrease in the pH value of the aqueous solution in the concrete pores. The latter can occur because of reaction of the cement paste with carbon dioxide (carbonation). Neither carbonation nor chlorides are expected to be of concern.

The chloride ion is not used up in the corrosion of reinforcing steel, and corrosion is not stifled by the high concentration of iron ions in the vicinity of the steel. Thus, the process can continue with iron ions migrating away from the steel and reacting further with oxygen to form higher oxides or hydroxides. Instead of spreading laterally along the reinforcing bar, the corrosion continues at the local anodic areas, causing the development of deep pits and eventual severance of the bar.

Either carbonation or the presence of excessive amounts of chloride can produce a general loss of passivity. The corrosion process is then widespread and homogenous, leading to a general reduction in the cross-sectional area of the steel.

Environmentally Aggressive Effects of Reinforcing Steel Corrosion. The most aggressive environment related to concrete deterioration via reinforcement will be alternating semidry and wet cycles. During the semidry periods, the carbonation front advances, and during the wet periods, the steel corrodes. Periodic heavy rains, subsoil runoff and concentration, and rapid snow melt, particularly, might, in extreme cases, cause such conditions at Hanford.

A permanently dry environment will produce passivation when the carbonation front reaches the steel, but no significant corrosion will occur. In contrast, constantly wet conditions will avoid carbonation, and the steel will remain passive as long as no other depassivating agent is present.

The expansive force generated by iron as it is transformed to higher oxidation states is the major cause of concrete failure from reinforcement corrosion. The specific volume of the hydrated iron oxides can approach seven times the volume of the iron from which they were formed. The resulting stresses generated lead to cracking and spalling of the concrete cover. Although general corrosion can reduce the reinforcement cross section, cracking of concrete by the expansive forces often occurs before the loss of section becomes important to load-carrying capacity.

The service environment for Hanford site DSTs is not severe. The chloride level in the soil from nine different wells near the grout vault site in 200 East Area was generally less than 0.003% (DOE-RL 1988). Examination of reinforcing steel in an old Hanford site, above-ground structure (see Concrete Core Sample Section, above) showed no evidence of corrosion.

If concrete samples are ever taken from DSTs to determine possible cyclic temperature effects, then these same samples could be economically evaluated for possible rebar corrosion effects. Otherwise, removal of concrete samples only for the study of rebar corrosion effects, does not appear necessary.

3.3.3.5 Microbiologically Induced Corrosion. Biological corrosion is not a type of corrosion; it is the deterioration of a metal by corrosion processes that occur directly or indirectly as a result of the activity of living organisms. These organisms include microscopic forms of bacteria and have been observed to live and reproduce in mediums with pH values between 0 and 11, at temperatures between 30 and 180 °F, and under pressures up to 15,000 $lb/in.^2$ (Fontana 1968). If any concrete cores are to be removed from Hanford structures in the future, Hanford biologists should be consulted to see if an adequate base exists for the growth of microbes that could lead to MIC. MIC was shown to have been involved in a failure of a buried stainless steel pipeline. In that work, a Kadlec Hospital biologist was able to show that the wet solution in contact with the corroded stainless steel part did contain bacteria which were believed to be responsible for the failure (Mollerus 1950).

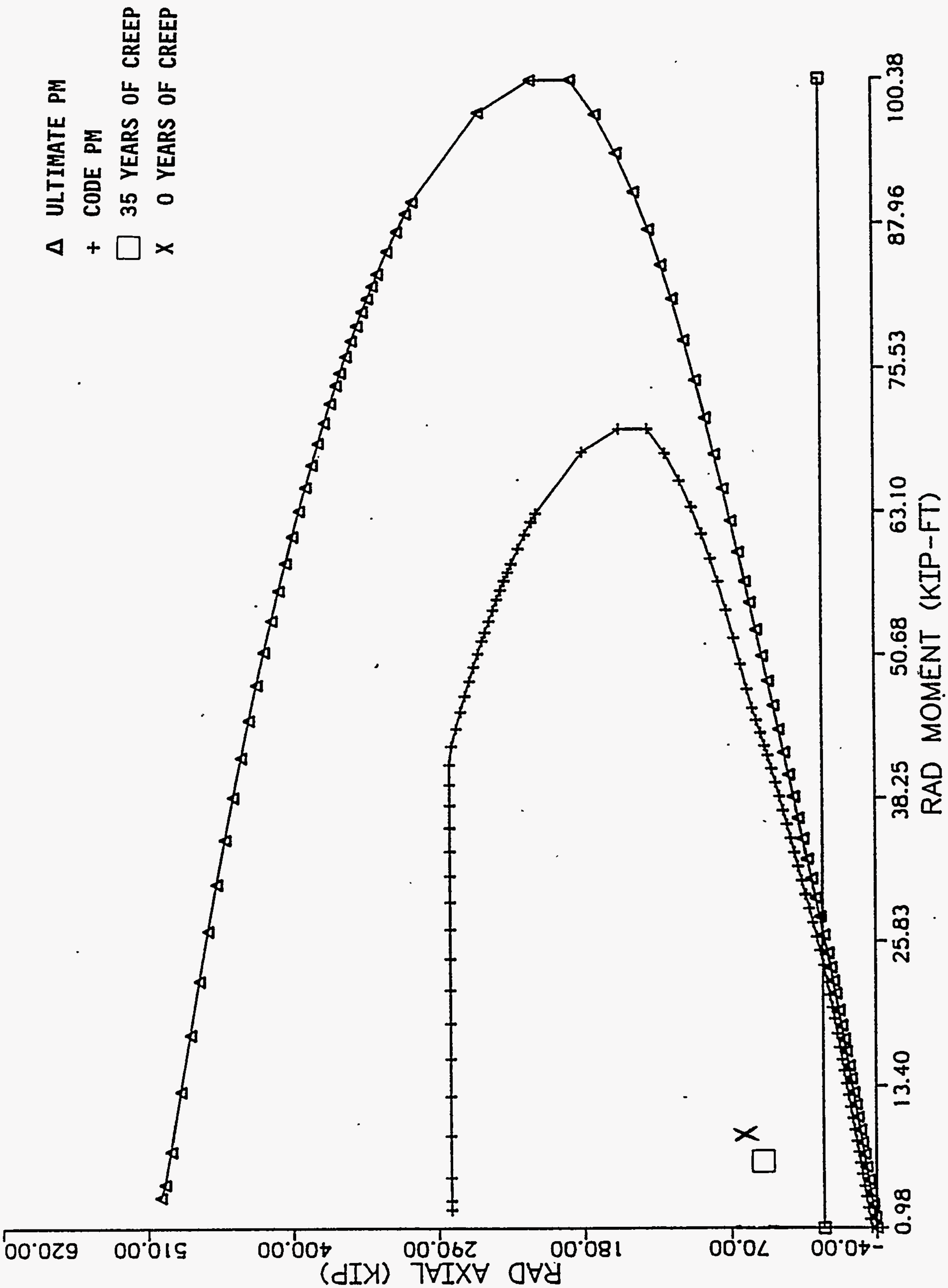
3.4 COMPARISON OF INTEGRITY ANALYSES TO ACCEPTANCE CRITERIA

A synopsis of the models, assumptions, and results from each of the DST analyses is presented in Appendix A. The appendix also includes a synopsis of SST analyses because the SST concrete shell is similar to the DST shell and both must withstand the same kind and magnitude of loads. The results of each analysis were reviewed to identify the relative load demand and to determine what load type, analysis assumptions, and material degradation estimates reduce DST structural capacity as a function of time in service.

The analyses served their intended purpose using the available data and methods at the time of evaluation. No implication is made to justify the validity of the analyses or to discredit the findings.

The analyses related to normal and operational loadings on the DSTs demonstrate adequate bases for continued service when evaluated using the simple concrete degradation and creep analytical techniques. In the past year, additional structural analyses were conducted. The first are a set of interim analyses (Julyk 1994a, 1994b, 1994c; ARH 1994) to evaluate the effect of additional gravity loads on the reinforced concrete DSTs. The analyses used static, linear analysis techniques (no concrete creep, no concrete strength degradation, no concrete thermal cracking) and determined the DSTs can withstand additional soil overburden depth, increased soil density, and increased concentrated load. Thermal and seismic loads were evaluated qualitatively.

Figure 2. Demand in the Upper Tank Wall Section.



The other recent analysis (Scott 1995) used the generic DST model from the Accelerated Safety Analysis--Phase I (Fisher et al. 1994) to verify the current DST analysis of record for the maximum normal load combination. The concrete dome, haunch, and upper wall were evaluated and compared to the ACI allowable limits. The DST model included concrete creep and tensile cracking elements, and elastic rebar elements. The results of this analysis are comparable to the other recent analyses when the same material assumptions are made. Both analyses show the DSTs are within ACI allowables. Figure 2 is a load-moment diagram for the upper wall near the haunch and compares the demand with creep and without creep.

Analyses have shown concrete creep and the degradation of concrete strength are important for establishing the demand on and capacity of the DST. However, although creep affects the structure early, after several years of operation the creep rate diminishes (see Figure 3). Early in operation, concrete stresses are reduced and the load is picked up by the steel reinforcement and the steel liner. Later, and for the remaining life of the DST, creep is no longer a significant contributor to changes in structural demand. In Figure 2, the change in structural demand that occurs as a result of creep is small and beneficial. This is typical of other sections in the DST as well. The long-term effect of concrete strength degradation on structural capacity is similar. The strength loss is rapid and primarily a function of temperature. Only a small amount of additional strength degradation occurs with time as shown in Figure 4. Hence, creep and strength degradation are not expected to significantly influence DST life estimates unless the DSTs see higher temperatures or higher loads than previously experienced. The calculated DST life could also be affected if the creep properties are significantly more severe than expected.

The stresses in Table 3 are from the ASA Phase II Double Shell Tank load combination evaluation (Scott, 1995) and are the result of a load factored ultimate strength analysis of only the concrete sections. The horizontal soil loads that produce the high stresses in the concrete wall and reinforcing steel are from the highest range of the horizontal soil pressures (Rankine Coefficient = 0.7) and have a load factor of 1.7 applied to the soil loads. The temperature profiles applied to the tank sections are the steady state temperatures resulting from thermal analysis. The temperatures are not factored which result in the thermal stress increases not being factored. The resulting stresses in the primary and secondary steel tank and liner have load factors applied to the soil, uniform and concentrated loads but not to the application of temperature and creep. The resulting steel liner factored stresses should not be compared to the ASME allowable stresses. The resulting stresses do show that there is a considerable increase in the stresses in both the primary and secondary liners resulting from the temperature and creep application. These stress increases should compared to the analyses of record and the unfactored stresses evaluated to the appropriate ASME allowable stresses.

A measure of the relative contribution of each load type to stresses in the dome, upper haunch, upper wall, and steel liners is presented in Table 3. The soil load (8.1 ft), uniform dead load (40 lbf/ft), concentrated load (50 tons), thermal load (323 °F at the DST bottom and 212 °F at the dome), and creep (35 years) are included in the table. By far, the two largest

Figure 3. Concrete Creep in Compression (Stress = 1500 psi).

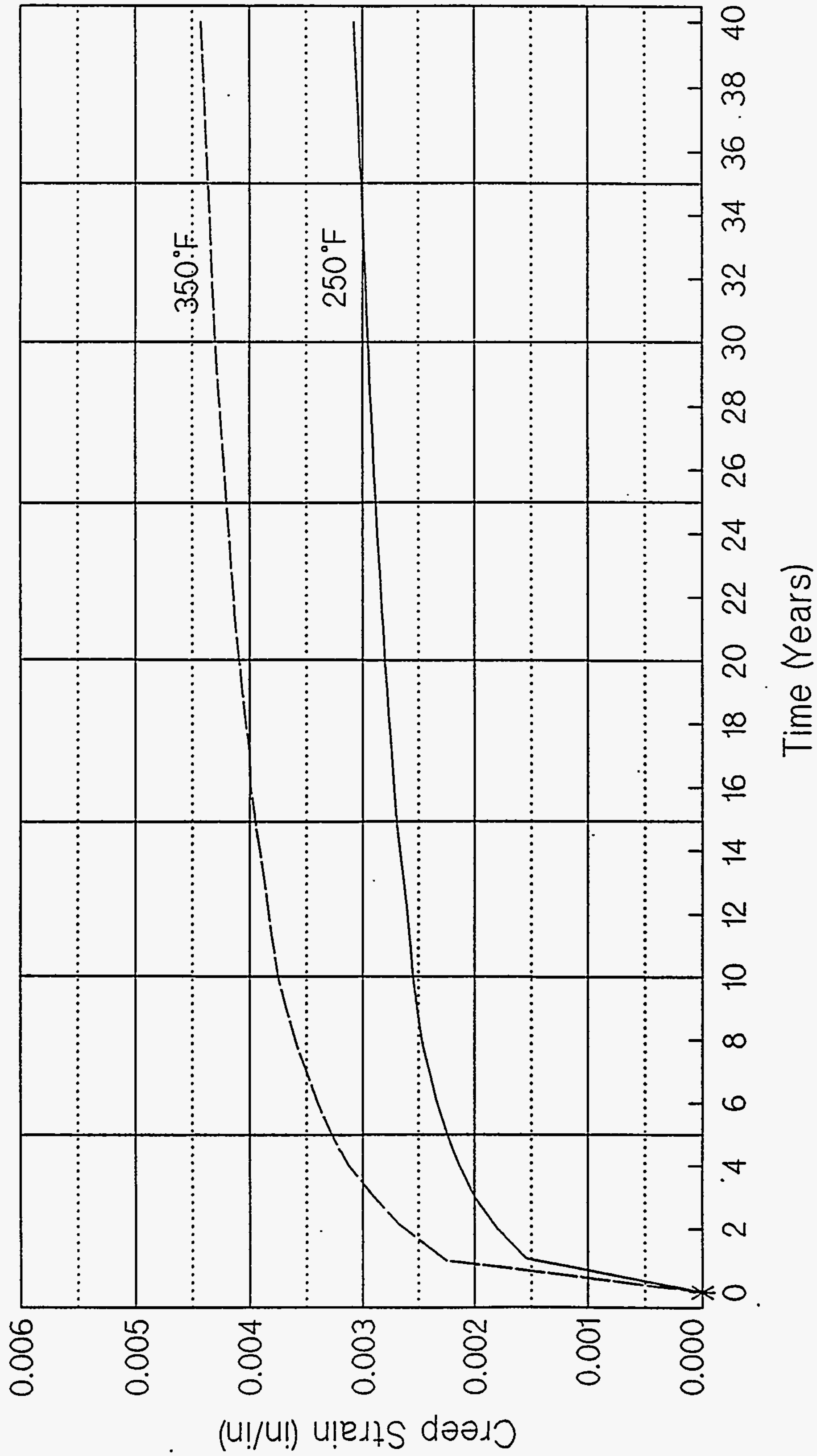


Figure 4. Effect of Time on Concrete Strength at 350°F.

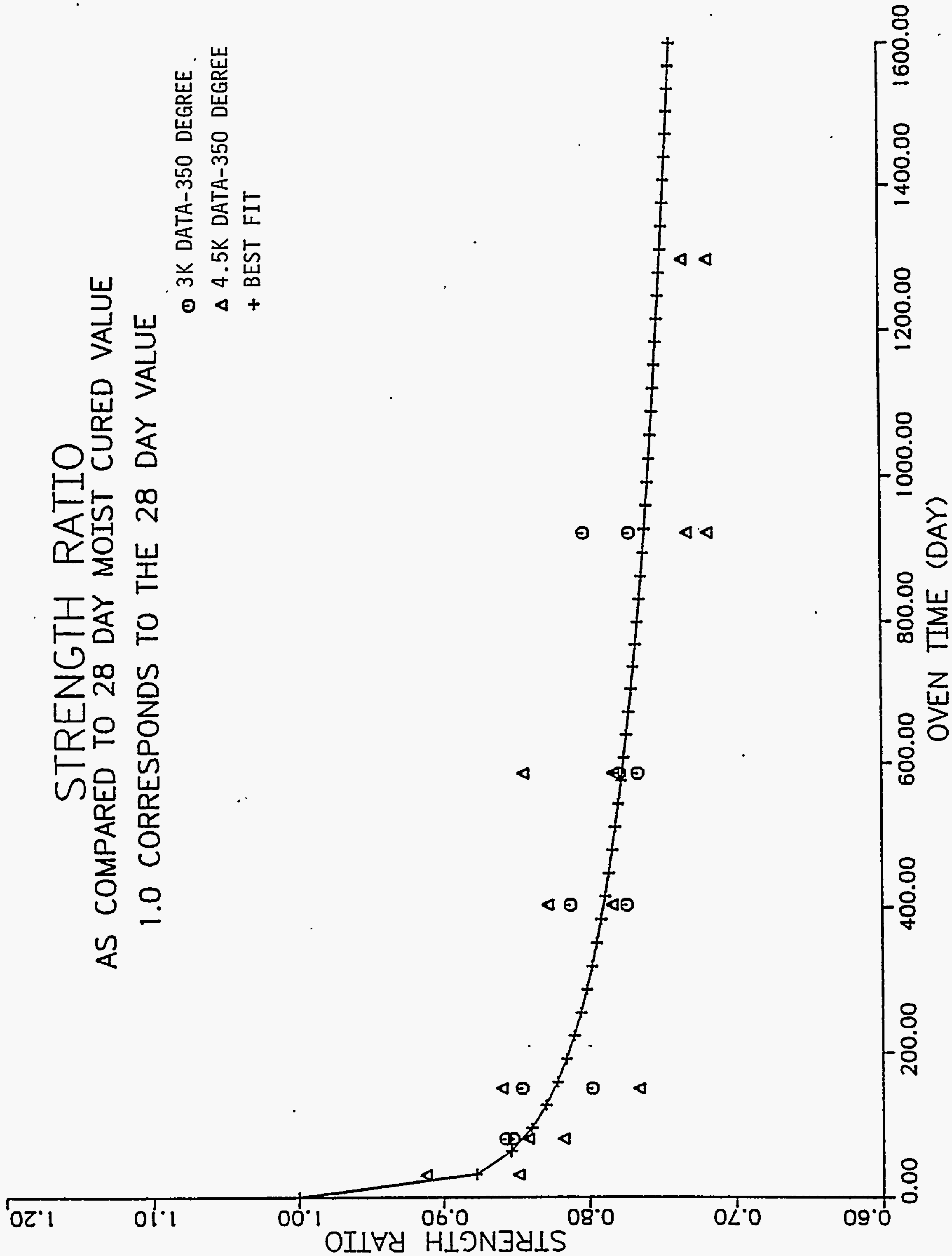


Table 3. Component Stresses (psi).

DST Component	Load Case			
	SOL	SOL+DL+CL	SOL+DL+CL+T	SOL+DL+CL+T+Creep
Principal Compressive Stress				
Dome Concrete	-623	-910	-767	-520
Upper Haunch Concrete	-728	-746	-593	-377
Wall Concrete	-1390	-1390	-1023	-579
Radial Steel Equivalent Stress				
Dome	4399	6561	20510	20346
Upper Haunch	4983	5192	19471	20296
Wall	2207	2309	17969	9563
Hoop Steel Equivalent Stress				
Dome	4163	6558	20509	20338
Upper Haunch	1070	1353	7658	7088
Wall	13192	13166	31489	48120
Primary DST Steel Liner	25027	25044	32461	26569
Secondary DST Steel Liner	28347	28690	69088	86986

SOL = Uniform Soil Load
SOL+DL = Uniform Soil Load plus Uniform Dead Load
SOL+DL+CL = Uniform Soil Load plus Uniform Dead Load plus Concentrated Load
SOL+DL+CL+T = Uniform Soil Load plus Uniform Dead Load plus Concentrated Load plus Temperature

4.0 USEFUL SERVICE LIFE ASSESSMENT: PIPING SYSTEMS

4.1 INTRODUCTION

The DST waste piping system in the 200 West and 200 East Areas has historically provided for the safe, periodic transfer of liquid waste (and related wastes) through a system of interconnecting piping and associated facilities.

The service life assessment of the piping transfer lines is based primarily on service experience rather than structural analysis. From this review a rate of failure is established. In addition, piping pinch points, in both the 200 West and 200 East areas, were reviewed. The effect of some single-, and particularly double-, pipeline failures could preclude major waste transfers.

4.2 OBJECTIVE

The assessment's objective includes several steps:

1. Review the failure history of the waste transfer piping system at the 200 Areas.
2. Identify the principal factors contributing to waste transfer piping failures.
3. From the failure history, existing operating and maintenance practices, and the piping design features, project the waste transfer piping performance during the next 10 years.
4. Identify areas or lines where the consequence of failure and the probability of failure are high.

4.3 SCOPE

The failure history review includes all waste transfer piping used outside of process facilities in the 200 Areas.

The waste pipe performance projection only applies to waste transfer piping, encased and direct buried, that is part of the DST system.

4.4 DESCRIPTION

The DST waste system provides containment, transfer, and other waste process support functions for continuance of the waste remediation program. The ability of the DST waste system to functionally support the remedial program and comply with the requirements of the Washington Administrative Code of the Department of Ecology is being questioned. The incidence of waste transfer piping failures during the past few years and the lack of encasement of a significant part of the buried piping are among the factors being questioned. Portions of the waste transfer system that do not comply with the Washington State Department of Ecology requirements are scheduled for upgrade during the next several years. However, to avoid interrupting the progress of the program it is necessary to continue use of the existing system.

4.4.1 Transfer Piping Design

The underground transfer piping design is normally one of three types:

1. Direct-Buried Piping--2- or 3-in, schedule 40, carbon steel, insulated in polyurethane and buried 3 to 4 ft underground. The pipe has a bituminous coating and is bubble wrapped to allow free movement between the piping and the insulation, which is poured and allowed to expand around the bubble-wrapped piping. Where the range of the design temperature is significant, expansion loops are provided in the piping. Trace heat is provided, in some cases, to prevent precipitation as the waste cools during transfer.

Note: Only a small portion of the piping exists in the DST system. Most of the direct buried piping is found in the SST farms.

2. Encased Piping--2- to 3-in, schedule 40, carbon steel, encased in 4- or 6-in, schedule 40, carbon steel pipe. The encasement is coated with a bituminous substance, insulated with polyurethane, and may be heat traced.

3. Enclosed Piping--3-in, schedule 10, stainless steel, supported by vitrified clay spools, enclosed in concrete pipeways or trenches.

Some examples of each of the above piping descriptions do not meet the specific description; however, these descriptions should be adequate for this review.

4.4.2 Approach and Assumptions

4.4.2.1 Approach. The approach and sequence of activities follows:

1. Study the objective and scope and review alternatives for achieving the objective.

2. Review the physical layout of the transfer systems and the types of piping, plans for upgrades, and regulatory requirements.

3. Research failed waste transfer pipe records. Failure information sources include interviews with personnel, review of past failure analyses and reports, reviews of unusual occurrence reports, drawings, engineering change notices to drawings, and other design documents.

4. Prepare a database using the waste transfer pipe failure information found during the research. This database is intended to contain information that would enable anyone to access the available information for any identified failure without repeating the extensive research required to accumulate the information in this original database.

If at a later date anyone chooses to perform more extensive analysis on a failure or chooses to verify the information found in the database, the design documents and reports provide a starting point.

5. From the information in the database and the waste transfer piping available for service, project the potential failure rate that may be expected during the next 10 years during normal service.

This analysis did not consider the effects of natural disasters (e.g., tornados, volcanic eruptions, sabotage) or operator actions.

4.4.2.2 **Assumptions.** Several assumptions were made:

1. The characteristics of the waste, chemistry and physical, will be controlled according to the requirements found in the operational safety requirements and other operating requirements documents.

2. The available waste transfer piping was installed according to the requirements of the respective project.

3. As a result of transfers of waste having characteristics outside the required limits, for whatever reason, there may be piping segments with the potential for imminent failure.

4.5 FINDINGS

The waste transfer record line failures were reviewed. The review findings are divided into three intervals: 1940s to 1955, 1955 to 1975, and 1975 to 1995. Specific event failure data to 1955 were not entered into the table because the information identifying specific failure incidents was not found; however, the studies, which were issued in 1954 and 1955, provide a general description of the problems and recommendations to resolve or minimize these problems (see below).

4.5.1 1940s to 1955

Many reported piping failures; a large portion of these failures were related to the local environmental conditions and construction practices. Investigations and inspections of these failures resulted in recommended design adjustments. Four studies evaluated the failures experienced and the recommendations made to minimize these failures:

1. HW-24500, "Protection of Exterior Buried Waste Lines," (October 15, 1952)--Investigated and evaluated the methods of protecting underground waste lines, discussed the effects of waste line failures, and provided the following recommendations for buried steel lines:

a. Cathodically protect all exterior buried process lines according to HW-3946.

b. In congested areas (e.g., roads), enclose all exterior process lines carrying high-activity solution in a reinforced enclosure.

c. Do not provide special concrete finish or waterproofing, except in special cases, for the enclosures.

d. Only in congested area, enclose all exterior buried waste lines carrying low-activity solutions.

e. Analyze the solution carried during the detail design stage, and determine the need for an enclosure.

f. Ensure that the enclosure for single exterior buried waste lines is similar to that recommended for multiple lines.

2. HW-33504, "Cathodic Protection of Stainless Steel Waste Lines, Interim Report No. 1, Underground Pipeline and Structure Corrosion Study Program," (November 15, 1954)--Prepared to demonstrate the practical aspects of CP of stainless waste lines and collect in a brief form the information and thinking used as a basis for the present concept.

This document recommended that the design shall stipulate the continued use of cathodic protection (CP) on all buried stainless process lines, enclosed or directly buried, according to HW-3946-S. This document had several conclusions:

a. Stainless steel (as used for waste lines) has a complicated technology governed in part by imperfectly established theory.

b. Such of the theory and practical aspects that are understood indicate that pit type corrosion to failure can occur readily in stainless steel, not only when buried in the soil, but in damp unventilated areas where ready access to oxygen is impaired.

3. HW-35009, "An Evaluation of Buried Waste Line Design Practice Interim Report No. 2 Underground Pipeline and Structure Corrosion Study Program," (April 1, 1955) provides a review of the design for buried waste transfer lines.

This document recommended that new waste line construction at Hanford conform to the following general policy:

a. Construct all lines in the areas to provide unimpeded access to major process facilities. This access is essential to economic operation. The individual method should suit the material to be transported and the extent of encasement should be reduced to a bare minimum.

b. Generally, the design for waste lines shall stipulate the use of Somastic-coated construction to take best advantage of reduced first cost and the possibility of leak detection and repair. Where special purpose lines are constructed for conveying highly valuable or toxic fluids such as dissolver solution, re-evaluation of this requirement should be made to correlate such designs with the end purposes of the proposed facility.

c. Temporary lines or lines internal to DST farms and highly contaminated areas are most economically installed bare. This practice is proper and should continue wherever practical.

d. All stainless lines regardless of construction shall be cathodically protected according to Hanford Standards.

e. Acid lines shall be separated from waste lines wherever practical to increase access for purposes of repair.

4. HW-33911, "Evaluation of Soil Corrosion at Hanford Atomic Products Operation Summary Report - Underground Pipeline and Structure Corrosion Study Program," (April 15, 1955) provides recommendations to minimize external corrosion to underground piping at Hanford; for example:

a. Bare carbon steel should be avoided except for temporary construction or nonprocess facilities of limited capital value. All process lines operating with fluids at ambient temperatures should be coated with a good grade of regular or synthetic coal tar enamel according to the specifications of the American Water Works Association. The joint construction of wrought steel pipe is optional, but is best limited to standard methods with a minimum of projections that can serve as discharge points for current leakage.

b. CP should always accompany the use of any buried installation using stainless steel. Coatings of any sort should not be used indiscriminately unless essential to the operation of leak detection devices or for minimizing the current requirements for CP.

c. Applications where the temperature of the soil will be elevated should be viewed with caution. CP of major process lines should be strongly considered where soil temperatures exceed 130 °F. Coatings would be applied in all cases and should consist of synthetic resins or bituminous enamels especially compounded for operation at the elevated temperature. It is difficult to see how improper materials can be deliberately specified or used, but the long history of such misapplications has produced unfavorable or negative results in every case. It is essential that special coatings and their technology be followed by the organization responsible all the way to the acceptance tests.

d. Before final acceptance of new facilities, tests for circulating direct currents should be conducted as part of such acceptance.

4.5.2 1955 to 1975

The detail data relating to the failures during this interval may be found in Appendix E. Failures and failure causes in this period are sketchy. The records for this period are relatively poor. No evidence of large numbers of failures were found; however, an appreciably larger number of failures may have occurred than are noted in Appendix E.

4.5.3 1975 to 1995

The detailed data relating to the failures during this interval may be found in Appendix E. Of the 25 failures in this period, 17 occurred in 241-S and 241-SX farms . Of the remaining eight failures recorded in the table, four were detected during a short time period in a route between B Plant and TK 101-AY. Five failures occurred in this route, four during a short period in 1984 and one in October 1994. "Metallurgical Analysis of Leak Failure of 241-A-B Valve Pit Jumper," SD-RE-TI-148, provides a detailed analysis of one of the two jumper failures in this route. Photographs and wall thickness measurements of the failed jumper show that significant internal corrosion over a large area had occurred.

4.5.4 Estimation of Double-Shell Tank Piping System Pinch Points

A pinch point is a restriction in the DST Waste Piping System such that, if a failure occurred, future waste transfers could be jeopardized.

If the new cross-site waste transfer line is not built, then the remaining lines must be relied on for continuing those transfers. Failure of a single pipeline would cause a problem for some lesser-used waste generating facilities and make some vaults unavailable for interim waste storage. Failure of two pipelines, in a given routing, however, could cause the cessation of some critical waste transfers. Such failures would be detrimental to progress on waste remediation at Hanford. Thus, a brief review was made of the various piping systems relative to both cross-site transfers as well as intrasite transfers, to assess the number and nature of pinch points.

The piping pinch points were reviewed systematically. First, individual pinch points were determined for both the 200 West and 200 East areas, respectively. Second, failure-induced pinch point paths were reviewed for transfers from the 200 West site to the cross-site line and, correspondingly, for transfers from the 200 East area to the cross-site line. Third, intra-site pinch points were reviewed for movements only within the 200 West and 200 East areas, respectively.

The following review was limited in scope and should be periodically revisited as further waste transfer operations information becomes available.

4.5.4.1 Pinch Points in the 200 West and 200 East Areas. From basic piping hardware drawings, the WHC Structural Integrity Assessment Section prepared Figure 5, "200 West Area DST Waste System and Pipeline Pinch Points," and Figure 6, "200 East Area DST Waste System and Pipeline Pinch Points."

Fig 5 - 200 West Area DST Waste System & Pipeline Pinch Points

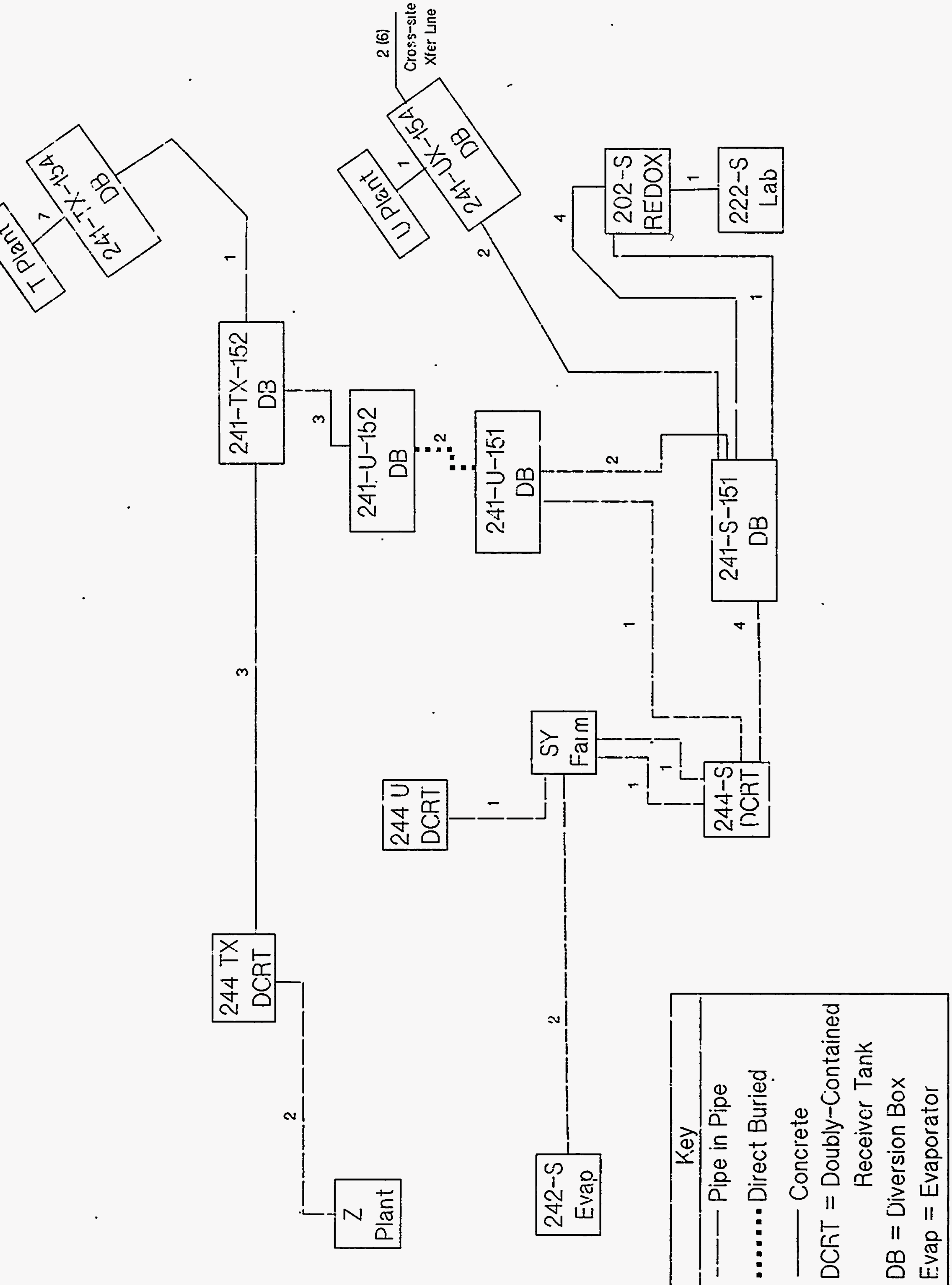


Fig. 6 - 200 East Area DST Waste System & Pipeline Pinch Points

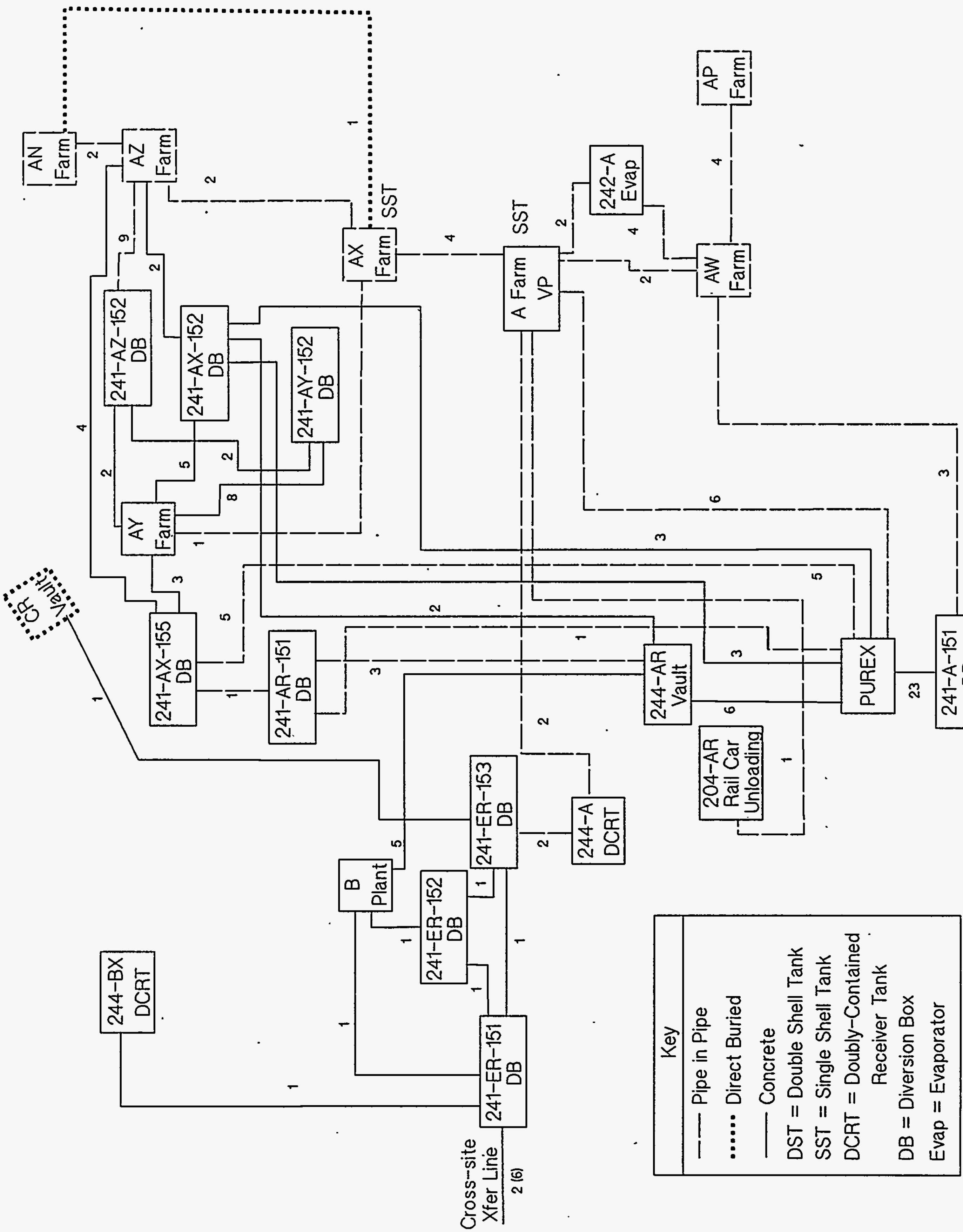


Figure 5 shows salient piping systems, the cross-site line(s), waste recovery-generation facilities and DST farm 241-SY. Evaporator 242-S is not running, but is shown for completeness. DCRTs are included because they could act as emergency interim waste storage DSTs. The arabic number located at each pipeline represents the number of pipes in the given line. The type of pipe (e.g., pipe-in-pipe, direct buried, or concrete) are also noted.

Figure 6 is the counterpart to Figure 5 showing the similar 200 East Area piping and facilities associated with waste transfers. The 241-AX and -AY SST farms are also shown because certain transfer piping pass through them. Also included are DCRTs, vaults, valve pits, diversion boxes and the railcar facility. Evaporator 242-A is the only operating evaporator. Like Figure 6, the arabic numbers indicate the number of available pipelines in a given route.

Three single-line pinch points are located in the 200 West Area:

- U Plant (through 241-TX-154)
- Laboratory 222-S
- 244-U DCRT

These facilities are not large-scale waste producers.

Three double-line pinch points are located in the 200 West Area:

- Plutonium Finishing Plant (PFP)
- 242-U-151 and -152 diversion boxes (for access to T Plant)
- Cross-site transfer line.

Loss of the 204-AR Rail Car facility would be significant. This would prevent waste receipt from the 200 West Area Lab (221-S), the 300 Area Labs, and the T Plant Decontamination Facility.

Although they generally have at least two pipeline paths passing through them, some 200 East Area diversion boxes (e.g., 241-TX-152, 241-U-152, 241-U-151 and 241-UX-154) could effectively act as a pinch point if they, as facilities, became nonoperational.

Three single-line pinch points are located in the 200 East Area (see Figure 7):

- 204-BX DCRT
- CR Vault
- 204-AR Railcar Facility.

None of these facilities represent large-volume waste transfers, assuming that Hanford receives no significant offsite railcar waste shipments.

4.5.4.2 Pinch Points Between 200 West and the Cross-Site Line. Movements from potentially large-volume waste facilities such as the 241-SY DST farm, generally have two (or more) pipeline paths with which to reach the cross-site line. The few, noncritical single pipeline pinch points were noted in

Section 4.5.4.1. If diversion box 241-UX-154 became inoperable, all transfers to the cross-site line would halt.

4.5.4.3 Pinch Points Between 200 East and the Cross-Site Line. Movements from potentially large-volume waste facilities include DST farms 241-AN, -AP, -AY, -AW, and -AZ. At this location, there are at least two pipeline paths between these facilities. If either PUREX Plant or the 244-AR vault were only able to transfer waste in one direction (either in or out, but not both), the pipeline path number for the various DST farms would be reduced, perhaps significantly. This potential restriction should be studied further.

Specific diversion boxes (e.g., 241-ER-151) could also be pinch points if they, as a "facility," became nonoperational

4.5.4.4 Intra-200 West Area Waste Movements. Pipeline pinch points were noted in Section 4.5.4.1, specifically T Plant (through 241-TX-150), U Plant and Laboratory 222-S).

The 241-SY Tank Farm and the 242-S Evaporator (should it become operable) display no single pipeline pinch points. Waste movements to and from Evaporator 242-S are limited to the pipelines in each facility with the 241-SY Tank Farm pipelines needed to transfer waste through to Evaporator 242-S. Thus, the 241-SY Tank Farm and its serial 244-S-DCRT facility are singular facilities whose inoperability could negate waste movements to and from either the 241-SY Tank Farm and Evaporator 242-S. In addition, diversion boxes 241-U-152 and -151 DB are singular facilities. That is, failure of either of them would interrupt flows from PFP and T Plant to the 241-SY Tank Farm.

4.5.4.5 Intra-200 East Area Movements. The single-line pinch points for the 200 East Area were noted in Section 4.5.4.1.

In general, a relatively large number of pipeline paths are available for major intra-200 East waste transfer.

As noted earlier, the PUREX Plant and the 244-AR Vault could be important to waste transfers, particularly if wastes could only be transferred through them in a singular direction (i.e., either in but not out or out but not in). Also, the 241-A Farm VP could be important for the same reason. If 241-T became inoperable, then, like the 244-AR Vault and the PUREX Plant, the number of available intra-200 East Area paths would be reduced substantially. Further study is needed to determine if both inflow and outflow are possible; also, future decontamination and decommissioning of such facilities could also act to restrict the number of pipeline paths available.

Tank farms is proceeding with plans for decontamination and decommissioning of the 244-AR Facility, which would reduce the number of pipeline paths.

4.6 CONCLUSIONS

The constraints of time and available documentation make it necessary to base these conclusions and recommendations on a less-than-desirable amount of evidence and data.

The evaluations and studies ending in 1955 provided design changes and recommendations that generally remain applicable today. The frequency of buried waste transfer line failures since 1955 appears to have decreased in proportion to the implementation of those design changes and recommendations. The piping failures before and since 1955 have resulted principally from external or internal corrosion, with external corrosion more prevalent than internal corrosion. The review of the unusual occurrence reports, failure analyses, studies, and evaluations lead to this conclusion, though material defects, physical damage, overpressurization, subsidence, and overburden may have been factors in isolated cases. These documents indicate the following to be the major factors in transfer piping failures.

1. External Corrosion. Failures resulting from external corrosion:

   Stainless steel
      Lack of CP or

      Improperly applied CP.

   Carbon steel
      Lack of CP or

      Lack of adequate coating or

      Operating at temperatures that degrade the coating.

2. Internal Corrosion. Failures resulting from internal corrosion:

   Stainless steel
      Low spots in piping where chlorides or other degrading materials are allowed to concentrate over a period of time.

   Carbon steel
      Chemistry of the waste being transferred is not within limits of the requirements.

4.6.1 Piping Degradation Mechanisms

In addition to the general corrosion, SCC, pitting-crevice corrosion identified as the corrosion mechanisms of consequence for the Hanford Site DSTs, MIC, galvanic corrosion, and erosion-corrosion have been documented in the Hanford Site waste transfer lines. The intermittent operation often leaves inaccessible areas of the transfer lines exposed to undefined concentrations of waste, humidity, and/or residual stresses.

Although both internal and external corrosion occur, corrosion predominantly occurs on the external surfaces of the Hanford site transfer lines. CP exists on most, but not all, of the DST transfer line system. Where they exist, the C systems mitigate external corrosion only. Internal corrosion of transfer piping occurs while in standby mode as well as in service. Failed piping has generally been isolated and abandoned in place, with the cause of failure(s) not thoroughly investigated or reported. The limited number of lines excavated after leakage and the prevalence and rate of corrosion cannot be reliably established. As an example, the SL 503 line in the 241-AP DST farm has a leak, which cause at this time is unknown.

1. **MIC**--Biological corrosion is not a type of corrosion; it is the deterioration of metal-by-corrosion processes that occur directly or indirectly as a result of the activity of living organisms. This form of corrosion was described earlier in Section 3.3.3.5.

   Bacteria have been cultured from pit material from failed stainless steel waste lines at the Hanford Site (Mollerus 1950). After applying CP to the Hanford systems, failures in the old areas stopped completely for the time period studied. C has been successfully used for more than 40 years on radioactive waste lines at the Hanford Site. It has been effective on both stainless and carbon steel (Tefankjian 1989).

2. **Galvanic (electrochemical) Corrosion**--Galvanic corrosion is an electrochemical corrosion. Corrosion of most buried carbon steel piping is the result of electrochemical reactions involving metals, chemicals, and water, which combine to form cells capable of generating electricity. For electrochemical corrosion to occur, an anode and a cathode must be electrically connected and immersed in a conducting medium, such as soil, with a potential difference between them. Metal is consumed where currents leave the pipe to enter the surrounding electrolyte. The rate and type of corrosion that occurs, whether it is uniformly distributed or localized as in the pitting type, are complicated by soil characteristics and environmental factors. Because of the variability in the environmental factors such as oxygen and moisture, extreme variations in the rate of attack are possible. Some major contributors to electrochemical corrosion are the close proximity of dissimilar metals, and the pipeline running through dissimilar soils which cause differentials in electrical potential at different portions or the pipe. Other causes establishing corrosion cells in the pipe lines include a mixture of different soils, dissimilar surface conditions on the pipe, new pipe electrically connected to old pipe, difference in temperature on the pipe, and the previously mentioned bacterial action.

3. **Erosion-Corrosion**--Erosion-corrosion is the acceleration or increase in rate of deterioration or attack on a metal because of relative movement between a corrosive fluid and the metal surface. Beside the influence of the pH level and elevated temperatures, the fluid flow velocity and solids content effect the mechanical wear. Most metals and alloys are susceptible to erosion corrosion damage. Stainless steels, for example, depend upon the development of a surface film of some sort (passivity) for resistance to corrosion. Erosion corrosion results when these protective surfaces are damaged or worn and the metal or alloy are attacked. Erosion corrosion is characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits a direction pattern (Fontana 1968).

After reviewing the failures and the operation of the waste transfer piping system, two concerns arise:

a. The design and fabrication in some of the projects may not have been adequate

b. The operation of the transfer system may not have been within the limits of the design.

4.6.2 Design and Fabrication

In some cases, no design and fabrication requirements exist for CP of carbon steel piping. In addition, the design temperature of the piping and the use of the trace heating exceeded the design temperature of the pipe coating. If the coating design temperature is exceeded, the coating protection is diminished and the potential for the initiation of corrosion through contact with the soil, conduit, or foreign materials is increased. A single failure is defined as the failure of a single uniquely identifiable pipe. Two major factors are considered contributors to piping failures: (1) inadequate protection of the external piping surface and (2) waste and piping material compatibility. Design requirements to minimize these factors as major contributors were established in 1955; however, it is difficult to determine whether the various projects since that date have implemented these requirements acceptably. For many projects, the available information is inadequate to determine whether the proper design requirements were specified or implemented.

4.6.3 Operations

The chemistry may not always be maintained within the limits of the procedural requirements. An example of a suspect case is the noted route between B Plant and DST 101-AY. There is always a possibility that through a valving mistake, a leaking valve, or some other problem, this condition could recur.

The table in Appendix E shows 28 piping failures, including two jumpers, during the past 40 years. Additional failures may have occurred during this period, but no applicable records have been found. The 28 piping failures, which is an average of less than one failure per year, included failures in both the SST farms and the DST system. The failure frequency during the past 10 years has been 1.2 failures/year, and the rate for the preceding 10 years has been 1 failure/year.

About 200 uniquely identifiable pipes are available for waste transfer in the DST system. The projected failure rate during the next 10 years in the DST system is not expected to exceed 1.5 failures/year. This projection excludes the piping failures that may occur within 241-S and 241-SX farms. Because the cross-site lines have not been used recently, it is possible that these lines may fail the leak test, which would result in 200 East Area being isolated from the 200 West Area. However, further discussion of these cross-site lines will await the results of the leak tests. A number of locations, perhaps seven or eight, would allow the failure of a pipe to isolate a facility from the DST transfer network. Should there be a waste pipe line failure that isolates a facility from the waste transfer network, many options may be exercised depending on the remaining function of the isolated facility. If the failed waste transfer line must be restored, the following two options have been given preliminary review: (1) repair the section of failed pipe or (2) replace the defective section of pipe with a new overground line, which complies with the requirements of Chapter 173-303-640 of the Washington Administrative Code.

The repair option cost is estimated at $100 to $150,000. A new section of overground pipe, 300 feet in length, is estimated at $300,000, which includes engineering and construction costs. Either of these options could be accomplished within 12 months, following the decision to commit the necessary resources.

4.6.4 Pipeline Pinch Points

The 200 West and 200 East Area piping systems were analyzed for the presence of pinch points. A pinch point is a restriction in the DST piping systems that, if a single or double failure were to occur, would seriously jeopardize future waste transfers.

Loss of the 204-AR Rail Car Facility, through failure of its single pipeline, would be significant. It accepts waste from a number of waste producing facilities across the site. Failure of two pipelines in the cross-site line would negate al interarea transfers.

Some facilities in the 200 East Area are critical to major waste movements as a passthrough: Purex Plant and the 244-AR Vault. Tank Farms is planning to decontaminate and decommission the 244-AR Vault which would reduce the number of available pipeline paths.

5.0 SUMMARY

A remaining life assessment of the DSTs and their associated waste transfer lines, for continued operation during the next 10 years, was favorable. The DST assessment was based on definition of significant loads, data evaluation for possible material degradation and geometric changes and evaluation of structural analyses. The piping assessment was based primarily on service experience.

Structural analyses of record show that the DSTs can withstand their expected loads and still maintain an acceptable margin of safety. They show that the degradation of concrete strength with temperature and concrete creep are not likely to limit the life of the concrete shell. Soil loads and temperature place the greatest demands on the concrete structure. Past analyses; however, do not thoroughly address temperature effects or through-wall temperature gradients and possible thermal-cycling effects.

Aging degradation mechanisms typically associated with DST outer concrete structure--the effect of temperature, aggressive chemicals and corrosion of reinforcing steel--do not appear life-threatening. However, thermal fluctuations or cycling associated with waste height variations, coupled with the low coefficient-of-expansion of Hanford Site concrete, could prematurely degrade or crack the concrete-reinforcing steel bond. No significant degradation of the outer steel liner is expected although it remains more sensitive to SCC, particularly if the inner liner were to leak.

Aging degradation mechanisms expected to be associated with the DST inner liner are SCC and pitting-crevice corrosion. Future periodic UT interrogation of the inner and outer liner metal and weldments in the sides, the bottom knuckle, and portions of the nearby bottom are expected to provide warning if any corrosion mechanisms are active. Maintenance of chemical controls on corrosion should be adequate to maintain low rates of any attack on the inner liner resulting from uniform corrosion and the other three corrosion mechanisms. Some DSTs may be more SCC-sensitive than others and may deserve a greater frequency of inspection.

Piping system integrity is expected to be tied to corrosion, plugging, and possible, but unlikely, mistransfer of aggressive chemicals. Maintenance of chemical corrosion limits in transferred waste coupled with periodic inspection of accessible regions of the piping systems should be adequate to maintain system integrity. Control of waste solution density levels should help minimize plugging failures. Some 200 West and 200 East facilities have only one or two pipelines associated with them, including the remaining two pipelines in the cross-site waste transfer line. Some waste transfers could be precluded if failures occurred in any of these critical lines. Failure of the single pipeline in the 204 AR Rail Car Facility would be significant as it accepts waste from a number of facilities throughout the Hanford Works. Future decommissioning of selected plant and facilities could further decrease the available pipeline paths. Future piping failures should be inspected, analyzed, and catalogued to ensure that present and future piping systems are designed and operated in a manner that will minimize further failures.

6.0 CONCLUSIONS

The initial life assessment conducted in this study the following conclusions are made:

1. The DSTs should maintain their integrity for the next 10 years.

2. Future nondestructive inspection and analysis of the DST inner liner are necessary to assess their present degraded state and to follow possible changes in their status.

3. Chemical controls on corrosion should be diligently maintained, particularly on some DSTs that may be more sensitive to stress-corrosion cracking than others.

4. The waste transfer piping system should be able to maintain integrity for the next 10 years; however, some facilities or systems are limited to one or two pipelines and their failure would preclude waste transfers.

5. Chemical controls on corrosion and control on fluid density levels, coupled with periodic inspection of accessible regions, and analysis and cataloguing of all piping failures should help minimize future failures.

7.0 REFERENCES

ACI, 1990, "Guide to Durable Concrete," ACI 201.2R-77(Reapproved 1982), ACI Manual of Concrete Practice, Part 1-1990, American Concrete Institute, Detroit, Michigan.

ACI 1992, "ACI Manual of Concrete Practice, Code Requirements for Nuclear Safety-Related Concrete Structures," ACI 349-8, American Concrete Institute, Detroit, Michigan.

ACI 318, "Building Code Requirements for Reinforced Concrete," American Concrete Institute, Detroit, Michigan.

Anantatmula, R. P., E. B. Schwenk, and M. J. Danielson (PNL), 1994, "Characterization of the Corrosion Behavior of the Carbon Steel tank Liner in Hanford Site Single-Shell Tanks," WHC-EP-0772, Westinghouse Hanford Company, Richland, Washington.

ANSI B31.1, "Power Piping," The American Society of Mechanical Engineers, 345 East 47th St, New York, New York.

ANSI B31.3, "Chemical Plant and Petroleum Refinery Piping," The American Society of Mechanical Engineers, 345 East 47th St., New York, NY.

ARH, 1994, "Analysis of Underground Waste Storage Tanks 241-SY at Hanford Washington," ARH-R-172, Rev. 0B, URS/John A. Blume and Associates, Engineers, Atlantic Richfield Hanford Company, Richland, Washington.

ASCE, 1986, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety-Related Nuclear Structures," ASCE 4-86, American Society of Civil Engineers, New York, New York.

ASME Sec III, "Rules for Constructions of Nuclear Power Plant Components," The American Society of Mechanical Engineers," 345 East 47th St; New York, New York.

ASME Sec VIII, "Rules for Construction of Pressure Vessels,", The American Society of Mechanical Engineers, 345 East 47th St., New York, New York.

ASTM C 177, "Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus, American Society for Testing and Materials, Philadelphia, Pennsylvania.

ASTM D 1621, "Test Method for Compressive Properties of Rigid Cellular Plastics," American Society for Testing and Materials, Philadelphia, Pennsylvania.

ASTM D 2842, "Test Method for Water Absorption of Rigid Cellular Plastics,", American Society for Testing and Materials, Philadephia, Pennsylvania.

AWWA C203, "Coal-Tar Protective coatings and Linings for Steel Water Pipeline-Enamel and Tape-Hot-Applied, American Water Works Association, Chicago, IL.

Bandyopadhyay, K., et. al., 1994, "Guidelines for the Development of Structural Integrity Programs for DOE High-Level Waste Storage Tanks," (Draft), December 1, 1994.

Blackburn,, L. D., 1989, "Radiation Damage ASssessment for PFP Ducts," SD-CP-ER-022, Westinghouse Hanford Company, Richland, WA.

Blackburn, L. D. and H. L. Benny, Feb 1992, "Inservice Inspection of Double-Shell Storage Tanks at the Hanford Site", WHC-EP-0505, Westinghouse Hanford Co., P.O. Box 1970, Richland, Washington.

Dacres, C. M., "Corrosion Evaluation and Protection Programs of External Surfaces for High-Level Waste (HLW) Underground Storage Tanks and the Hanford and Savannah River Sites," DACCO SCI Inc., Report for DOE 03/93

DeFigh-Price, C., 1982, "Status of Tank Assessment Studies for Continued In-Tank Storage of Hanford Defense Waste," RHO-RE-ST-4P, Rockwell Hanford Operations, Richland, Washington.

Divine, J. R., et. al, 1985, "Prediction Equations for Corrosion Rates of A-537 and A 516 Steels in Double Shell Slurry, Future Purex, and Hanford Facilities Wastes," PNL-5488 UC-70, Battelle Pacific Northwest Laboratory, Richland, Washington.

DOE-RL, 1988, "Grout Treatment Facility Dangerous Waste Permit Application," DOE-RL 88-27, vol. 4, Appendix 5A-2, U.S. Department of Energy Richland, Field Office, Richland, Washington.

Fisher, T. W., L. L. Hyde, C. J. Moore, W. S. Peterson, W. W. Chen, 1994, "Structural Sensitivity, Evaluation of Single- Double-Shell Waste Tanks for Accelerated Safety Analysis - Phase I," WHC-SD-WM-DA-150, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Fontana, M. G., 1968, Corrosion Engineering, Library of Congress, Washington, D.C.

Graver, D. L., 1985, Corrosion Data Survey, Metals Section, 6th Edition, p. 10, National Association of Corrosion Engineers, Houston Texas.

Julyk, L. J., 1994, "Tank 241-C-106 Structural Integrity Evaluation for In situ Conditions (2 volumes), WHC-SD-W320-ANAL-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Julyk, L. J., 1994a, "241-AW/AN Waste Storage Tanks: Supplemental Gravity Load Analysis," WHC-SD-WM-ANAL-035, Rev. 0, vol. I, and vol. II, Westinghouse Hanford Company, Richland, Washington.

Julyk, L. J., 1994b, "241-AP Waste Storage Tanks: Supplemental Gravity Load Analysis," WHC-SD-WM-ANAL-033, Rev. 0, vol. I and vol. II, Westinghouse Hanford Company, Richland, Washington.

Julyk, L. J., 1994c, "241-AY/AZ Wast Storage Tanks: Supplemental Gravity Load Analysis," WHC-SD-WM-ANAL-034, Rev. 0, vol. I and vol. II, Westinghouse Hanford Company, Richland, Washington.

Kassir, M. K., Bandyopadhyay, K. K., and Reich M., "Thermal Degradation of concrete in the Temperature Range from Ambient to 315C (600F)," BNL-52384, Brookhaven National Laboratory, Long Island, New York, March 1993.

Kirch, N. W., 1984, "Technical Basis for Waste Tank Corrosion,", SD-WM-TI-150," Rockwell Hanford Corporation, Richland, Washington.

LANL 94, "A Safety Assessment for Proposed Pump Mixing Operations to Mitigate Episodic Gas Releases in Tank 241-SY-101: Hanford Site, Richland, Washington," LA-UR-92-3196, Rev. 13, November 1994, Technology and Safety Assessment Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Lindsay, D. C., R. P. Anantatmula, J. H. Haberman, J. L. Nelsen, 1994, "TWRS Corrosion Monitoring Program Plan," WHC-SD-WM-PAP-60, Westinghouse Hanford Company, Richland, Washington.

Lini, D. C., 1975, "Compilation of Hanford Corrosion Studies," ARH-ST-111, Atlantic Richfield Hanford Company, Richland, Washington.

Mahidhara, R. K., "Corrosion Failure Processes in Low Carbon Steels," North Carolina State University for LANL, November 25, 1992.

Mahidhara, R. K., et. al., "Corrosion and Failure Processes in High-Level Waste Tanks," North Carolina State University for LANL, November 25, 1992.

Mollerus, F. J., 1950, "Cathodic Protection of Stainless Steel Buried in the Ground," General Electric Company, Richland, Washington, unpublished.

Pellini, W. S. , 1989, "Guidelines for Fracture-Safe and Fatigue-Reliable Design of Steel Structures,", The Welding Institute, Abington Hall, Abington, Cambridge, CB26AL, England.

Pfluger, D. C., "Tank Waste Remediation system Tank System Assessments Program Plan," WHC-SD-WM-AP-017 Rev. 1, June 1994.

Ramble, 1983, "Single Shell Waste Tanks Load Sensitivity Study," SD-RE-TI-012, Rev. A-0, Rockwell Hanford Operations, Richland, Washington.

Rashid, Y. R., 1979, "Modeling and Analysis of Underground Nuclear Waste Containments," Anatech International Corporation, La Jolla, California.

RHO, 1981, "Effects of Long-Term Exposure to Elevated Temperature on the Mechanical Properties of Hanford Concrete," RHO-C-54, prepared by Portland Cement Association for Rockwell Hanford Operations, Richland, Washington.

Rosenberg, A., C. M. Hanssen, S. C. Andrade, 1989, "Mechanisms of Corrosion of Steel in Concrete," Materials Science of Concrete Journal, J. S. Kalny, Editor, The American Ceramic Society, Inc., Westerville, Ohio.

Schwenk, E. B., 1992, "Tank Wall Measurement Technical Study and Specification,", WHC-SD-W151-ES-002, Re 0, Westinghouse Hanford Company, Richland, Washington.

Schwenk, E. B., 1992, "A Study of Methods for Assessing Tank AZ-101 Component Structural Integrity," WHC-SD-W151-ES-003, Rv. 0, Westinghouse Hanford Company, Richland, Washington.

Scott, M. A. and W. S. Peterson, "Accelerated Safety Analyses Structural Analyses Phase II ACI Code Evaluations of the Maximum Loads in Concrete Dome, Haunch, and Upper Wall of Double-Shell Waste Storage Tank," WHC-SD-WM-SARR-032, Rev. 0, April 1995, Westinghouse Hanford Company, Richland, Washington.

Shurrab, M. S, M. D. Thomson, Westinghouse Hanford Co., J. W. Friley, M. R. Garnich, M. W. Rinker and F. A. Simonen, Pacific Northwest Laboratory, WHC-EP-0508, Vol 1, Westinghouse Hanford Company, P.O. Box 1979, Richland, Washington.

Tefankjian, R., Application of Cathodic Protection - Corrosion and Cathodic Protection Fundamentals, Gulf Coast corrosions Control Seminar, revised, January 3, 1989.

Troxell, G. E., H. E. Davis, J.W. Kelly, Composition and Properties of Concrete, Second Edition, McGraw Hill, 1968.

Upgrade of Hanford Site 200 Areas Cathodic Protection Systems, B-234-C-1

APPENDIX A

ANALYTICAL HISTORY OF DOUBLE-SHELL TANKS

The Hanford Site has 28 double-shell tanks (DSTs) that were constructed between 1968 and 1986. The DSTs are located in six separate DST farms (241-AY, -AZ, -SY, -AW, -AN, and -AP) in the 200 East Area and 200 West Areas. These DSTs have a nominal capacity of 1 Mgal. These DST farms have been seismically qualified using the seismic design criteria in effect during their design phase.

This section provides the reader with the historical structural design analyses and code evaluations performed in support of the high-level waste DSTs. These descriptions include the design loads considered, analysis assumptions employed, methods of modeling used, computer software employed, and DST locations of most interest.

URS/Blume Analyses of Double-Shell Tanks

URS/John A. Blume & Associates, Engineers (URS/Blume) conducted several studies of the Hanford Site DSTs. In 1971, URS/Blume performed gravity and seismic load analyses of the 241-AZ DSTs (URS/Blume 1971). Later in 1974, the 241-SY DSTs were analyzed (URS/Blume 1974) for gravity, seismic, and thermal loads. Subsequently, URS/Blume conducted studies of the 241-AW DSTs between 1976 and 1981; for example: (1) analyses of long-term dead, live, and thermal loads and safe-shutdown earthquake ground motions, (2) a detailed evaluation of primary DST knuckles and the concrete DST connections, and (3) investigation of buckling and yielding of the primary DST steel (URS/Blume 1981). These analyses were based upon the following assumptions:

- Each DST was assumed axisymmetric. Nonaxisymmetric loads were modeled with Fourier elements.
- The effects of soil surrounding the DST was also assumed to be axisymmetric.
- The DST-to-DST interaction was not recognized as a primary influence.
- The soil-DST finite element model did not include the secondary liner. This model was used for analyzing gravity loads and earthquake ground motions.
- The wall-to-base-slab joint in the concrete slab was modeled as a sliding type, which permitted free lateral movement of the wall under static loads. For earthquake loading, the same joint was assumed pin-connected, which allowed rotation but prevented sliding of the wall with respect to the base slab.

The load cases listed below were included in these analyses. The substructure approach was used to analyze the critical areas where more-detailed finite element models were required. For example, the secondary steel liner lower knuckle and the primary DST lower knuckle were analyzed using very fine finite element grids.

- Gravity Loads--Gravity loads included the weights of the DSTs, soil, and the liquid waste. Also included were the live loads at the ground surface. The soil-DST model was used for this analysis.

- Hydromechanical Loads--The loads considered under this category were the hydrostatic pressures exerted by the liquid waste, pressure exerted by the vapor above the liquid surface, and the hydrodynamic pressure resulting from impulsive liquid and sloshing during an earthquake.

  The effects of these loads on the concrete DST and the surrounding soil were expected to be minimal and the primary DST was analyzed assuming that the dome and base slab of the concrete DST provided rigid support to the primary DST. An axisymmetric model of the primary DST was constructed and the AXIDYN (URS/Blume 1976) program was used to analyze the responses resulting from these hydromechanical loads. The program accommodates nonaxisymmetric loading.

- Thermal Loads--The temperature of the liquid waste was assumed to be 350 °F. The primary DST base plate and portions of the cylindrical wall in direct contact with the liquid were assumed to be at the same temperature. The thermal structural analysis was performed using this temperature and the owner supplied temperatures of the remainder of the primary DST and those of the concrete DST. The SAP IV (Bathe 1973) computer program was used to perform thermal analyses.

  The thermal-creep analysis, using the SAFE-CRACK computer program, was performed by URS/Blume's consultant firm, the Anatech Research Corporation. The soil overburden load, live load, and internal vapor pressure in the DST were considered as initial mechanical loading acting on the DST. The analysis included the effects of high temperatures on the mechanical properties of concrete, based on the data (Abrams 1979) generated by the Portland Cement Association (PCA) for Hanford concrete mixes. No creep effects, however, were measured in the high-temperature tests reported in Abrams (1979). The creep properties included in the SAFE-CRACK program before 1980 had been extrapolated from lower temperature (200 °F) data. Following the extensive elevated temperature, long duration tests on Hanford concrete performed by the Concrete Testing Laboratories of the PCA in the late 1970s and early 1980s, more representative creep and temperature degraded concrete properties were available and used in the subsequent analyses.

- 0.25g ZPA Earthquake Ground Motion--Both horizontal and vertical ground motions were considered. With the design horizontal free-field ground motions at the surface, the equivalent ground motions at the base of the DST-soil model were generated by the FLUSH (Lysmer 1975) computer program using a deconvolution procedure. Then, the dynamic analysis of the DST-soil model under horizontal seismic loading was performed using the AXIDYN computer program, which also had been used for analyzing the gravity loads. The responses resulting from vertical ground motion were obtained by scaling the gravity load responses by two-thirds of the horizontal acceleration without any dynamic amplification.

For both the primary steel DST and secondary steel liner, the stresses resulting from the above individual load cases were combined and evaluated per the ASME Boiler and Pressure Vessel Code, Section VIII, Division 2 (1974) rules.

The concrete structure was evaluated per the ACI 318 (1971) Code using the temperature- and time-dependent ultimate compressive stress allowables given in Appendix B of the URS/Blume report (URS/Blume 1981).

Kaiser Engineers (Hanford) Analyses of 241-AP Double-Shell Tanks

Kaiser Engineers Hanford (KEH) Co. performed structural analyses of 241-AP DSTs in 1982 (KEH 1982). These DSTs were to be similar but not identical to 241-AW DSTs analyzed by URS/Blume as described above.

Generally, the analysis methodology is identical to that used in URS/Blume Reports. The load cases considered by KEH are also the same. The thermal-creep analysis was again performed by the Anatech Research Corporation using SAFE-CRACK program. The KEH analyses are different from the URS/Blume analyses in the following major aspects:

- The general-purpose ANSYS finite element computer program was used.
- The seismic induced hydrodynamic pressure analysis was performed using the formulas of TID 7024 (Haroun 1981).
- The soil-DST interaction analysis was performed using response spectrum methods.
- To obtain the temperature distribution along the primary and secondary DSTs, the SINDA (Smith 1971) program was used by KEH to perform heat transfer analyses which also included a heat generation rate of 100,000 Btu/min. URS/Blume, on the other hand, was given a temperature distribution by the owner and, therefore, did not have to perform a heat transfer analysis.
- KEH also performed a DST-to-DST interaction analysis using the FLUSH computer program and the SSE free-field time-histories.
- For the evaluation of the concrete DST, KEH used the ACI-349 (1976).

ASA Analysis of Generic Double-Shell Double-Shell Tanks

Additional structural analysis of the DSTs was completed to determine the DSTs' capacity to withstand the most demanding combination of normal loads.

The maximum load combinations for the DSTs will not exceed American Concrete Institute Code allowable limits in the dome, haunch, and upper wall for normal loading. The normal loading includes the soil overburden, uniform and concentrated live loads, and elevated temperatures as limited by the Interim Operational Safety Requirements for standard and aging waste DSTs. The generic accelerated safety analysis DST model was used to evaluate the maximum loading determined from the Phase I load sensitivity study. The results produced by the model compare favorably with the recently completed and approved analytical work that evaluated the increased soil depths and densities on DSTs. Because the analytical model has not been fully verified, the close comparison lends credibility to the accuracy of the results presented in this report.

The evaluation, as requested, concentrated on the structural capacity of the upper portions of the DST secondary concrete structure, which resists the overburden loads. The upper structure as defined by the concrete dome, haunch and wall of the DST demonstrated adequate structural capacity. The greatest structural demand is in the lower wall, as a result of circumferential compression of the lower wall from the lateral soil pressure, and in the footing, caused by the vertical gravity loads from the soil overburden and concentrated loads at the soil surface above the DSTs. The high demand on the DST wall results from the high soil pressures. The soil pressures are assumed to be high because of the uncertainty in soil properties. The high demand on the footing, though not evaluated to code limits, is extremely sensitive to the soil stiffness and was evaluated in this effort with a median soil stiffness. The full range of soil stiffness was not evaluated in this effort. The elastic evaluation of the footing reveals the stresses in the footing are close to the American Concrete Institute Code allowables for shear and bending. The footing capacity is not expected to have a significant influence on the structural stability of the upper structure. However, a footing failure could affect the leak-tight integrity of the primary and secondary steel DSTs.

This supplementary analysis has provided a greater understanding of how the imposed soil loads are resisted by the DSTs. The influence of the loading sequence appears to have a significant effect on the response of the DSTs to the soil and temperature loading. High temperatures alter how DSTs resist the applied loads. Soil properties also have an effect on the ultimate capacity of the DSTs. If operational requirements change in the future, the models used and tools developed to complete this effort can be easily used to evaluate the impact of the changes.

Heatup and Cooldown Analyses

Analyses have been performed to assess waste heatup rates within single-shell tanks (SSTs) and DSTs. A difference in heatup rate exists in magnitude of about 17 °F/day between analyses, which is significant and a cause for discussion.

Analyses that specifically address heatup rates were reviewed and a brief synopsis of each is presented below. The first synopsis is of a SST analysis (Ramble 1982) that documented a higher heatup rate of 20 °F/day. An earlier SST DST farm analysis (RHO 1981b) reported having used a lower heatup rate of

3 °F/day. That analysis was specific to the 241-AX SST DST Farm. The remaining analyses were performed for DST Farms, which used heatup rates of 3 to 3.1 °F/day. Those analyses were specific to the 241-AW DST Farm (RHO 1981b).

Synopsis of Ramble (1983)
Title: *Single-Shell Waste Tank Load Sensitivity Study*

This report is one part of an effort to provide technical bases for the structural integrity of the SSTs. The report documents the effect of backfill soil loads, equipment loads, hydrostatic loads and elevated temperatures on 20- and 75-ft-diameter reinforced concrete waste SSTs. Results from SAFECRACK thermal creep and ultimate soil load analyses are presented for the 75-ft-diameter SSTs that include maximum wall temperatures ranging from 110 to 510 °F, heatup rates form 2.9 to 48.4 °F/day, creep times from 15 to 3,752 days, and varying soil cover depths. On the basis of these results, a heatup/cooldown operating limit of 20 °F/day was proposed.

Synopsis of RHO (1978b)
Title: *Analysis of Underground Waste Storage DSTs 241-AX, at Hanford, Washington*

The investigation scope follows:

"The basic purpose of the present investigation is to determine the combined effects of long-term dead, live, and thermal loads and the safe shutdown earthquake (SSE) ground motions."

In reference to heatup rate, the nonlinear thermal stress and creep analysis was carried out previously by Dr. Rashid. Dr. Rashid used the computer code SAFE-CRACK to perform the nonlinear thermal stress and creep analysis. The heatup rate used in the analysis was 2.85 °F/day.

Synopsis of RHO (1981b)
Title: *A Comprehensive Summary of the Analysis of the 241-AW Underground Waste Storage DSTs, Hanford, Washington*

Four phases of analyses were performed on the 241-AW DSTs:

- Phase I was performed in February 1976 (ARH 1976b).
- Phase II was performed in July 1976 (ARH 1976a).
- Phase III was performed in May 1978 (RHO 1978a).
- Phase IV was performed in July 1981 (RHO 1981b).

A brief summary of the studies conducted in the four phases is given below.

Phase I consisted of a preliminary structural review of the 241-AW DSTs proposed at that time. Although the proposed DSTs were essentially identical to the existing 241-AZ and 241-SY DSTs, the differences in design criteria used for the AW DSTs prevented the results of the analysis of the AZ and SY DSTs from being directly applicable.

Phase II included more detailed analyses of the proposed 241-AW DSTs for long-term, live, and thermal loads. The DSTs were also analyzed for their ability to withstand the safe shutdown earthquake ground motions.

Phase III analyses were of various details of the 241-AW DSTs, particularly the steel DST knuckles and the concrete DST connections. Phase III also included an update of the previous analyses.

Phase IV consists of analyses of the 241-AW DSTs for new design loadings and an investigation of the possibility of buckling and yielding of the steel plate of the primary steel DSTs under negative vapor pressure (vacuum loading).

Of primary concern are the thermal stress and creep evaluations performed by Dr. Rashid. From Phase IV evaluation, he increased the heatup rate to a maximum of 9.5 °F/day maximum. The following conclusions resulted from that evaluation:

> "The heating period was initially specified to be 30 days, which gave minimum and maximum heating rates of 5 °F/day and 9.5 °F/day, respectively. When this heating rate was applied in SAFE-CRACK analysis, the structure under went severe cracking, causing the analysis to become mathematically unstable. Several runs were made to improve the accuracy of the solution, for example by halving the time step, but severe cracking and mathematical instability continued to result. This mathematical instability was attributed to over cracking conditions caused by the rapid heating. It became necessary to change the heating period from 30 days to 90 days. The lengthened time caused the stresses generated by heating to undergo faster relaxation, hence limiting cracking significantly. This new heating rate was then adopted for the structure and the analysis was repeated. The results of analysis discussed in the report are based on 90-day heating period."

Based on a 90-day heating period, the heatup rate would be 1.7 °F/day minimum and 3.1 °F/day maximum. In the earlier analyses, Phases II and III, the heatup rate used by Dr. Rashid was 3 °F/day.

REFERENCES

Abrams, M. S., M. Gillen, and D. H. Campbell, 1979, "Elastic and Strength Properties of Hanford Concrete at Room and Elevated Temperatures," Portland Cement Association prepared for Rockwell International, RHO-C-28, Construction Technology laboratories, Rockwell Hanford Operations, Richland, Washington.

ACI, 1971, Building Code Requirements for Reinforced Concrete, ACI 318, American Concrete Institute, Detroit, Michigan.

ACI, 1976, Code Requirements for Nuclear Safety Related Concrete Structures, ACI-349, American Concrete Institute, Detroit, Michigan.

Anatech Research Corporation, SAFE-CRACK Computer Program.

ARH, 1976a, "Analysis of the Underground Storage Tanks 241-AW at Hanford, Washington," ARH-R-219, URS/John A. Blume and Associates, Engineers, prepared for Vitro Engineering, Richland, Washington.

ARH, 1976b, "Structural Evaluation of Proposed 241-AW Tanks: Phase I - Investigation of Effect of Criteria Changes," ARH-R-218, prepared for Vitro Engineering, Richland, Washington.

ASME, 1974, American Society of Mechanical Engineers Boiler and Pressure Code, Section VIII, Division 2, American Society of Mechanical Engineers, New York, New York.

Bathe, K. J., E. L. Wilson, and F. E. Peterson, 1973, "SAP IV, A Structural Analysis Program for Static and Dynamic Response of Linear Systems," EERC 73-11, College of Engineering, University of California, Berkeley, CA.

Haroun, M. A., and Housner, G. W., "Seismic Design of Liquid Storage Tanks," Journal of Technical Councils, ASCE, Vol. 107, No. 1, 1981, pp. 191-207.

KEH, 1982, "Stress Analysis and Structural Analysis of 241-AP Tank Farm," Project B-340, KEH R-822-81, Kaiser Engineers Hanford Company, prepared for Rockwell Hanford Operations, Richland, Washington.

Lysmer, J., T. Udaka, C. Tsai, and H. Bolton Seed, 1975, "FLUSH - A Computer Program for Approximate 3-D Analysis of Soil-Structure Interaction Problems," EERC 75-30, Earthquake Engineering Center, College of Engineering, University of California, Berkeley, California.

Ramble, 1983, "Single-Shell Waste Tank Load Sensitivity Study," SD-RE-TI-012, Rockwell Hanford Operations, Richland, Washington.

RHO, 1978a, "Additional Analyses of Underground Waste Storage Tanks 241-AW, Hanford Washington, RHO-C-17, URS/John A. Blume and Associates, Engineers, prepared for Vitro Engineering, Richland, Washington.

RHO, 1978b, "Analysis of Underground Waste Storage Tank 241-AX at Hanford, Washington," RHO-R-6, URS/John A. Blume and Associates Engineers, prepared for Vitro Engineering Richland, Washington.

RHO, 1981a, "Effects of Long-Term Exposure to Elevated Temperature on the Mechanical Properties of Hanford Concrete," RHO-C-54, prepared by Portland Cement Association for Rockwell Hanford Operations, Richland, Washington.

RHO, 1981b, "A Comprehensive Summary of the Analysis of the 241-AW Underground Waste Storage Tanks, Hanford, Washington, RHO-C-60, URS/John A. Blume and Associates, Engineers, prepared for Vitro Engineering, Richland, Washington.

Smith, J. P., 1971, "SINDA User's Manual," TRW Systems Group.

URS/Blume, 1971, "Seismic Analysis of Underground Waste Storage Tanks 241-AZ-101 and -102 at Hanford, Washington," JABE-ARHCO-01, San Francisco, California.

URS/Blume, 1974, "Analysis of Underground Waste Storage Tanks 241-SY at Hanford, Washington," ARH-R-172, San Francisco, California.

URS/Blume, 1976, AXIDYN Computer Code, Analysis of Axisymmetric Structural System Subjected to Static Arbitrary Dynamic or Base Acceleration Loading, San Francisco, California.

URS/Blume, 1981, "A Comprehensive Summary of the Analysis of the 241-AW Underground Waste Storage Tanks at Hanford," San Francisco, CA.