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7. Abstract

The objective of this report is to identify single-shell tank waste retrieval technologies to be tested and summarize the waste retrieval work accomplished to date.

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SINGLE-SHELL TANK WASTE RETRIEVAL TECHNOLOGIES

S. A. Krieg
October 11, 1990

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LIST OF TERMS

DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ITU	integrated test unit
QEC	Quadrex Environmental Company
SST	single-shell tank
Westinghouse Hanford	Westinghouse Hanford Company

1.0 SUMMARY

The objective of this report is to identify single-shell tank (SST) waste retrieval technologies to be tested in the scale model tank to achieve *Hanford Federal Facility Agreement and Consent Order* (referred to as Tri-Party Agreement) (Ecology et al. 1989) Milestone M-06-01 and to discuss future program plans for the SST waste retrieval effort.

The Tri-Party Agreement Milestone M-06-01 calls for identification of the technologies to be tested in the scale model tank by October 31, 1990. Milestone M-06-02 calls for initiation of waste retrieval testing in the scale model tank by October 1992. The first step in achieving Milestone M-06-01 was issuance of an engineering study, *Single-Shell Tank Waste Retrieval Study* (Krieg et al. 1990). This study identified alternate technologies for development and testing for retrieval of the three types of waste (liquid, solid, sludge) from the SST. The recommendations from the engineering study are summarized in Table 1.

Westinghouse Hanford Company (Westinghouse Hanford) also contracted an independent consulting firm, Quadrex Environmental Company (QEC), to conduct an industry survey of commercially available systems and equipment that may have applicability to SST waste retrieval. The purpose of using an independent consulting firm for an industry survey was to assure that Westinghouse Hanford did not overlook any promising technologies for waste retrieval. Quadrex identified several systems with potential for waste retrieval. The Quadrex survey, *Hanford Single-Shell Tank Waste Retrieval Methodology Industry Survey* (Quadrex 1990) did not reveal any new or additional systems or concepts, thereby providing added assurance that the applicable systems and equipment were considered in the waste retrieval study (Krieg et al. 1990).

In addition to the two studies discussed above, four feature tests were conducted on equipment to further assess the applicability of those technologies to SST waste retrieval. There were two basic criteria used to determine if a piece of equipment should be feature tested: (1) a significant uncertainty of equipment performance and (2) a need to evaluate for future design modifications.

There are several key technical issues that remain to be solved to expedite the SST waste retrieval effort. Four of the more important technical issues are as follows:

- How much water can be added to the SST during retrieval operation?
- How much development effort is required for a robotic arm control system?
- What amount of the waste can be left in the SST when it is declared "clean?"
- What modifications (penetrations) can be made to the SST?

Table 1. Summary of Equipment Recommended in Single-Shell Tank Waste Retrieval Study.

Equipment	*	Purpose
Robotic arm	P	For delivery and maneuvering of tooling, pumps, and other work devices
Positive displacement pumps	P	For pumping sludge and soft salt cake
Scarifier	P	For breaking up (with air/water jets) and retrieval
Air jets	P	Simplified scarifier for sludge and salt cake retrieval
Water jets	P	Simplified scarifier for sludge and salt cake retrieval
Steam jets	B	Simplified scarifier for sludge and salt cake retrieval
Shear	B	For cutting small pipes, tubing, etc.
Grabber	P	For gripping, grabbing, holding, lifting solid material (pipes, etc.)
Grinder	B	For grinding hard salt cake
Abrasive water jet	P	For cutting steel tubes, pipes, etc.
Abrasive cutoff saw	B	For cutting steel tubes, pipes, etc.
Pulverizer	P	For breaking up hard salt cake
Impact hammer	B	For dislodging salt cake
Clamshell bucket	B	For removing sludge, salt cake, and solid debris from tank
Batch conveyor	P	For conveying cut up risers and solid debris out of the tank
Air conveyance system	P	For conveying liquids, sludges, and solid waste out of the SST

*P = Primary retrieval system
*B = Backup retrieval system
*Note: Test results or detailed evaluations may result in modifications to the classification.

The specific equipment identified for testing to complete Tri-Party Agreement Milestone M-06-01 consists of the primary items from Table 1--the equipment recommended in the waste retrieval study--with one exception: the batch conveyor which is a straightforward mechanical design that does not require development testing.

2.0 INTRODUCTION

High-level radioactive waste has been produced at the Hanford Site since 1944 as a byproduct of processing spent nuclear fuel for the recovery of plutonium, uranium, and neptunium. These wastes have been stored in single-shell underground tanks.

The single-shell waste storage tanks are 75 ft in diameter and have capacities of 0.5 Mgal, 0.75 Mgal, and 1.0 Mgal. In addition to the 75-ft-dia. tanks, there are 20-ft-dia. SSTs with capacities of 55,000 gal. There are a total of 133 75-ft-dia. tanks and 16 20-ft-dia. tanks on the Hanford Site. The tanks are steel-lined, reinforced concrete cylinders buried 7 to 12 ft underground.

Chemical and nuclear wastes were placed in the tanks between 1944 and 1980. The wastes are in the form of liquids, sludges, salt cake, and solid debris. Some sludges are sticky, viscous materials with a consistency similar to peanut butter. A portion of the salt cake is a hard, crystalline material. The actual mechanical properties of the waste vary considerably depending on the liquid content and chemical makeup of the wastes.

Negotiations between the U.S. Department of Energy (DOE), the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) on the ultimate disposal of wastes at the Hanford Site resulted in the signing of the Tri-Party Agreement (Ecology et al. 1989). The Tri-Party Agreement contains 25 major and 136 interim milestones associated with a 30-yr cleanup program at the Hanford Site. Issuance of this document completes Tri-Party Agreement Milestone M-06-01, "Identify Waste Retrieval Technologies to be Tested in Scale-Model Tank," scheduled for completion by October 31, 1990. An associated Tri-Party Agreement Milestone, M-06-00, "Develop Single-Shell Tank Waste Retrieval Technology and Complete Scale-Model Testing," is scheduled for completion by June 1994. At that time the retrieval technology should be developed and sufficient testing completed to confirm the design of the equipment for retrieving waste from the demonstration tank.

Milestone M-07-00, "Initiate Full-Scale Demonstration of Waste Retrieval Technology," is scheduled for October 1997. This milestone will be achieved with the initiation of waste retrieval from a 75-ft-dia. SST that has been termed the "demonstration" tank.

3.0 ENGINEERING STUDIES

3.1 WASTE RETRIEVAL STUDY

One of the primary steps in determining the types of equipment that should be developed or tested for SST waste retrieval was preparation of an engineering study. The study (Krieg et al. 1990) was to recommend for testing or development several alternate technologies for the retrieval of the three types of waste (liquid, sludge, salt cake) from the SSTs. Equipment judged to have more potential for successful retrieval operations will be among the first developed. If this primary equipment performs satisfactorily, the backup equipment may not be developed or tested. The equipment recommended for development and/or testing in the study is summarized in Table 1. The mechanical systems recommended for development in the study are shown on Figure 1. Figure 1 also depicts separate systems for retrieval of sludge and salt cake; however, the sludge and salt cake are expected to be intermixed in many of the SSTs and the majority of the equipment may be used during retrieval of both salt cake and sludge.

A continued investigation of sluicing techniques and resolution of the water addition restrictions was recommended in the waste retrieval study to be carried out in parallel to development of other alternatives.

3.2 QUADREX SURVEY

The QEC survey addresses a variety of possible methods, technologies, and equipment to allow access, inspection, sampling, retrieval, removal, and recovery of the SST-contained debris, tank risers, and internal components and obstructions, and the radioactive and hazardous waste salt cake, sludges, and liquids. The fundamental purpose of contracting for an independent study was to verify that Westinghouse Hanford did not overlook promising technologies or equipment in preparation of the engineering study on SST waste retrieval. Information provided by Westinghouse Hanford was reviewed by QEC, which also identified and surveyed various techniques and options for SST waste retrieval. A brief literature review and an extensive telephone survey of manufacturers and vendors was also conducted by QEC. The results of this survey include a tabulation of manufacturers and vendors and copies of their technical marketing information and capabilities. The systems and equipment tabulated in the survey were not evaluated by QEC for applicability to retrieval operations. The QEC survey (Quadrex 1990) did not reveal new or unexpected systems, equipment, or concepts and all systems and equipment listed in the survey were evaluated in the waste retrieval study (Krieg et al. 1990).

Figure 1. Systems for Waste Retrieval (Sheet 1 of 2).

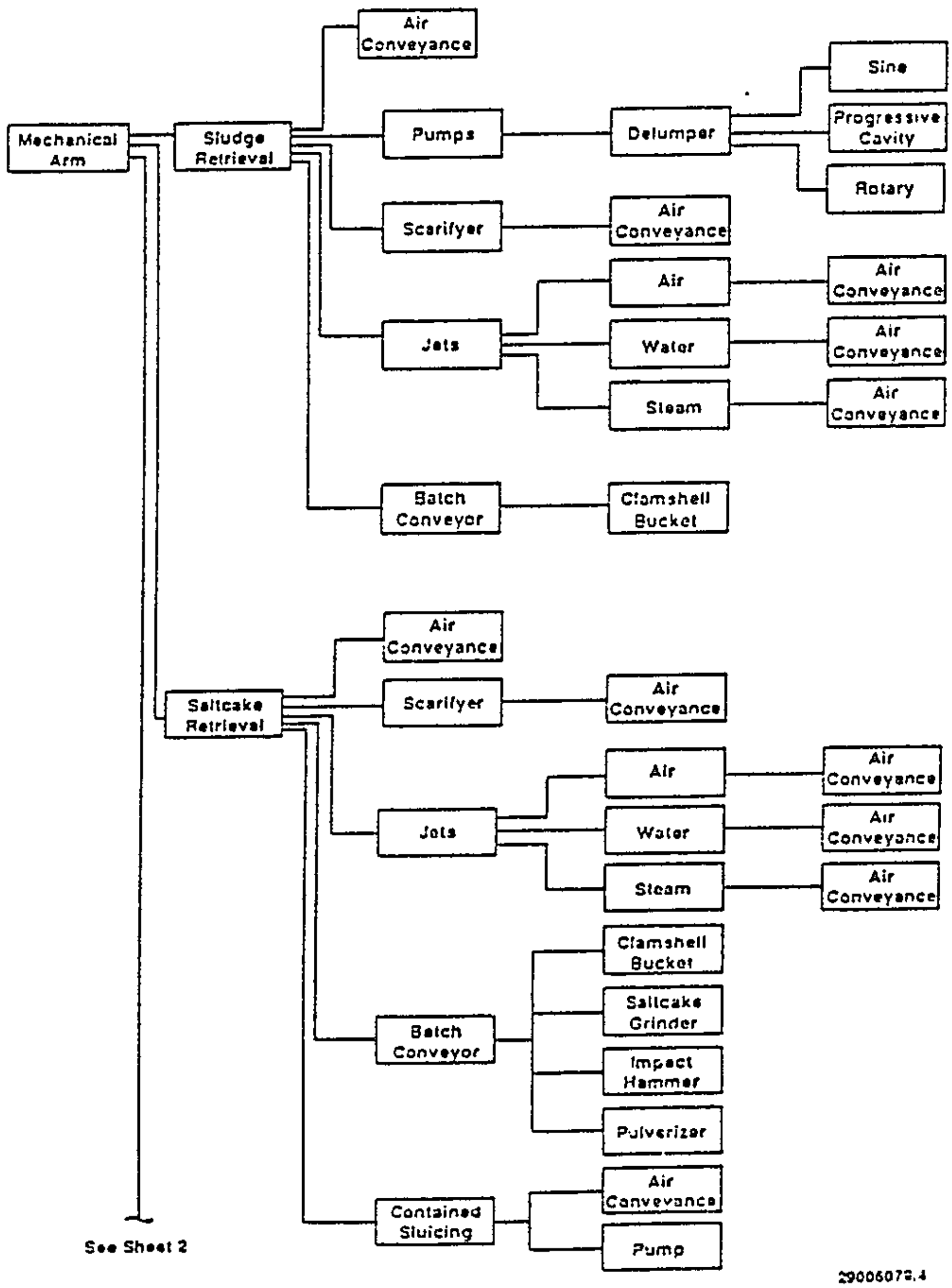
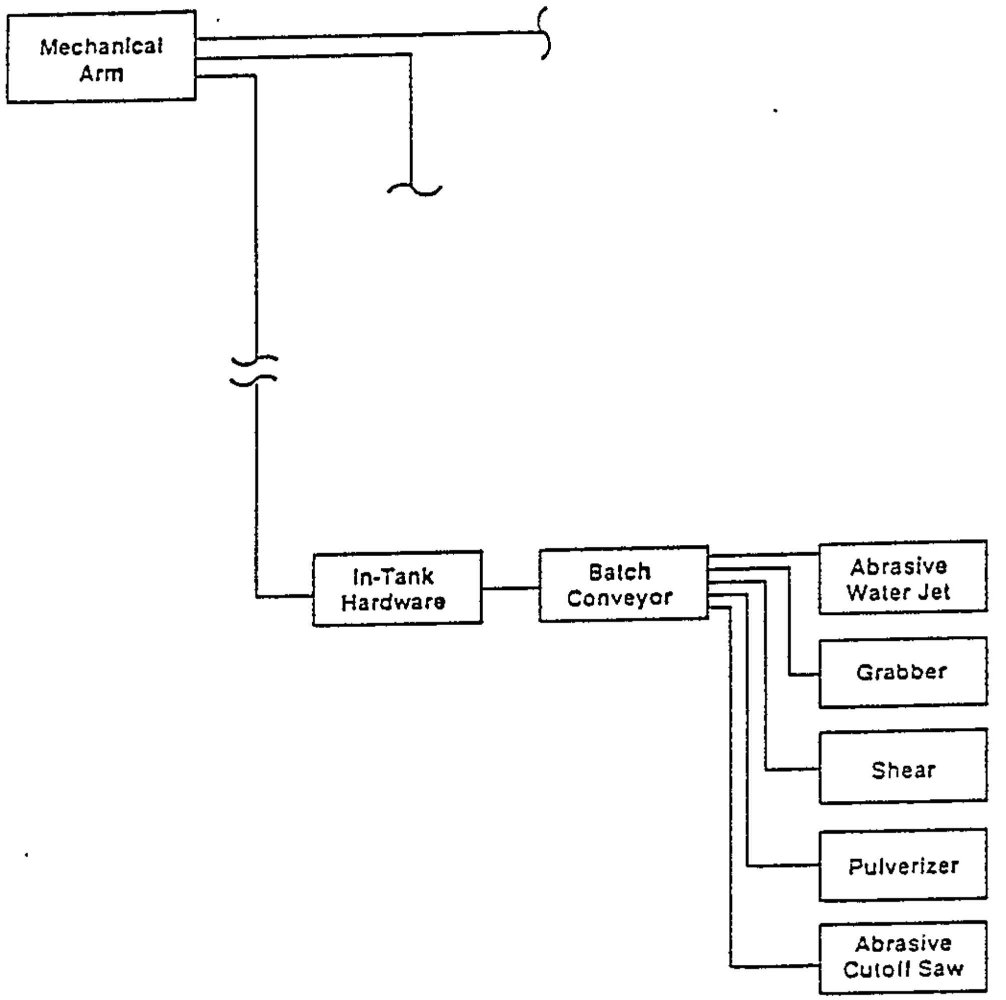


Figure 1. Systems for Waste Retrieval (Sheet 2 of 2).



3.3 RETRIEVAL CONCEPTS ANALYSIS

A number of different systems, concepts, and components have been identified for retrieving the waste from the SST. These have been developed in the waste retrieval study (Krieg et al. 1990), the Quadrex survey (Quadrex 1990), and subsequent brainstorming sessions. Eleven of the mechanical retrieval concepts were evaluated by a Kepner-Tregoe decision analysis. This type of analysis is a systematic approach to selecting the most desirable alternative(s) from a number of acceptable alternatives. The following is a brief description of the six top rated alternatives, all of which were identified in the waste retrieval study (Krieg et al. 1990).

- **Reference Concept**--The reference concept consists of a robotic arm operating through existing or new central 42-in.-dia. openings. Various arm end effectors are employed to cut up risers, pipes, and in-tank hardware, and to retrieve the waste.

- **Multi-Hole Concepts**--The multi-hole concept is similar to the reference concept in that all operations are performed through 42-in.-dia. openings. In this concept either multiple robotic arms are used or a single arm is moved to multiple locations. This allows shorter robotic arms.

- **Contained Sluicing (Pump Out)**--The contained sluicing concept consists of a robotic arm operating through a 42-in.-dia. opening to dislodge and place waste into a sluice module. The waste is mixed with water in the sluice module and the resulting slurry is pumped out of the tank. This concept is similar to the reference concept in that the operations are performed through 42-in.-dia. openings in the top of the tank; however, the sluicing module for preparing the waste for pumping is unique.

- **Contained Sluicing (Air Conveyance)**--This concept is the same as the contained sluicing and pump out approach except an air conveyance system is used instead of a pump to transport the slurried waste out of the tank.

- **Enlarged Penetration Concept**--The enlarged penetration concept consists of a robotic arm operating through a single central penetration in the top of the tank. The penetration will be approximately 12 ft in diameter and all operations will be accomplished through this single opening.

- **Top-Off Concept**--The top-off concept uses a large center penetration, estimated to be about 48 ft in diameter, to deploy equipment for retrieving the waste and performing the necessary in-tank hardware cut-up operations.

4.0 FEATURE TESTING

Preliminary feature testing of various components to determine applicability to SST waste retrieval operations have been conducted. Four equipment items were selected for testing based on both a need to evaluate for design modifications and uncertainty of the equipment performance on simulated wastes. The items tested were (1) an air conveyance system for transporting waste out of the tank, (2) a Sine Pump[1] for pumping waste out of the tank, (3) a needle scaler for dislodging hard waste, and (4) air and water jets to break up the waste. The results of the individual tests are described below.

4.1 AIR CONVEYANCE SYSTEM

Feature tests of a commercially available air conveyance system were conducted during August 1990. The purpose of this test was to determine the applicability of air conveyance as a method for transporting waste dislodged from the SSTs. The performance of the air conveyance system with simulated sludge was mixed. The sludge simulant used for the test was a sticky, viscous material with a consistency similar to automotive grease. This is expected to be the worst-case simulant from the conveyance standpoint. The system had difficulty moving the waste into the feed nozzle. The sludge simulant tended to stick on the hose walls and accumulate in the horizontal hose runs; however, the injection of water into the feed nozzle eliminated the majority of these problems. The air conveyance system appears to be a viable candidate for transporting waste from the SSTs. Water injection and local fluidization of the waste at the feed nozzle will be required for some, or perhaps all, of the varying types of waste. Test results have been documented in the test report, *Feature Test of Air Conveyance System* (Thompson 1990).

4.2 SINE PUMP

Sine Pump feature tests were conducted by Beckwith and Kuffel, Inc., in August 1990. The Sine Pump is a relatively new type of pump used in the food industry. The purpose of the test was to determine the ability of the pump to handle simulated wastes in the fluid form. The simulated wastes varied in viscosity from 40 cP to 1.7M cP. The Sine Pump successfully pumped the simulated wastes but excessive wear was evident with the 40 cP fluid. The wear was on plastic, easily replaceable parts and not on the impeller, shaft, or other parts more difficult to replace. The test indicated that the Sine Pump can pump the high viscosity simulated wastes successfully. The design features and material selection will require development to optimize them for actual sludge retrieval operations. Results of the tests are documented in the test report, *Feature Test of the Sine Pump* (Squires 1990).

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[1]Sine Pump is a trademark of Beckwith and Kuffel, Inc., Seattle Washington.

4.3 PNEUMATIC SCALER

Feature tests of a pneumatic needle scaler were conducted in August 1990. The scaler is a type of pulverizing tool with needles that impact the material and chip it away. The unit tested was a commercially available scaler used for descaling and removing weld slag. The scaler has 19 needles of approximately 0.15 in. dia. and a working area of 0.78 in^2. The scaler was tested on two types of simulated hard cake and succeeded in removing about 0.25 in. of waste per pass. This test demonstrated that the scaler principle is a viable candidate for hard cake break up and final cleaning of the tank surfaces. Larger versions of the scaler are called scabblers and remove several orders of magnitude more material per pass. These are also considered adaptable to hard cake breakup. Test results of the needle scaler are documented in Squires (1990).

4.4 AIR AND WATER JETS

Preliminary testing of air and water jets for use in a scarifier has been completed. The tests were conducted with individual jets acting on simulated hard salt cakes, soft salt cake, and sludge. Air jets were tested at 1, 000 to 1,500 psig and water jets were tested at pressures up to 55,000 psig. The air jets broke up and aerated the soft simulants but had no affect on the hard simulant. The water jets were able to cut to a depth of 1-1/2 in. per pass on hard salt cake simulant but the jet was dissipated in the softer simulants. The jets will be tested in a scarifier where they rotate in a manner similar to a lawn sprinkler. Additional tests to optimize flow rates, jet sizes and other parameters are planned for fiscal year 1991. Preliminary test results are available in *Air/Water Jet Scarifier Feature Test - Interim Test Report* (Leist 1990).

5.0 HYDRAULIC RETRIEVAL (SLUICING)

Sluicing (hydraulic retrieval) was accomplished on some of the SSTs in the 1950's for uranium recovery and in the 1960's to 1970's for strontium and cesium recovery. Sluicing techniques for both campaigns were similar and used one or two nozzles at approximately 350 gal/min of fluid flow per nozzle. Both campaigns were plagued by equipment failures and low waste retrieval rates of about 8 to 10,000 gal/mo. Past sluicing techniques may not be amenable to the tank heel or hard cake although more modern techniques such as pulsed flow, high pressure, close proximity operation, and computer control may overcome these drawbacks. Another major concern with the previous sluicing techniques is that the dilution ratio of water to waste averaged 200 to 1. Many or most of the hard wastes may require that the sluice nozzle be within close proximity to the waste. The logical means to accomplish this is to use the sluice nozzle as an end effector to a mechanical arm.

Sixty-six of the SSTs leak and may not lend themselves to sluicing unless a method can be found to eliminate or adequately contain potential leakage from the tank. This leaves 83 SSTs as candidates for sluicing. How many SSTs will remain non-leakers by the time they are to be retrieved remains unknown. Sluicing may be considered as an alternative to mechanical retrieval or perhaps as a complement to mechanical retrieval.

6.0 CONTROL SYSTEM

An SST waste retrieval system is expected to consist of a robotic arm with remotely replaceable work tools (end effectors) and a control system. The control system design can be divided into roughly three major efforts. These three efforts are described below.

- Robotic Arm--This consists of a mechanical arm with appropriate sensors.
- Simulation--This adds a world model, collision detection, and tie-in to the basic controls. The world model consists of a mathematical model of the tank and its contents. This model makes it possible to add the collision avoidance and simulation graphics.
- Mapping System--This adds sensors and software for mapping the environment and updating the world model. This task also includes force and proximity servo control of the arm.

The work tasks associated with the design and development of a robotic arm control system are depicted in Figure 2. The basic software architecture would be based on the Robot Independent Programming Environment and Robot Independent Programming Language provided by Sandia National Laboratories in Albuquerque, New Mexico. Graphical programming using the Interactive Graphics Robot Instruction Program graphical simulation system, a commercial program marketed by DENEB, will be used.

Computer models of the robotic arm and hydraulic control system will be developed. This simulation system will be general in nature to allow evaluation of other robots, manipulators, and hydraulic control systems.

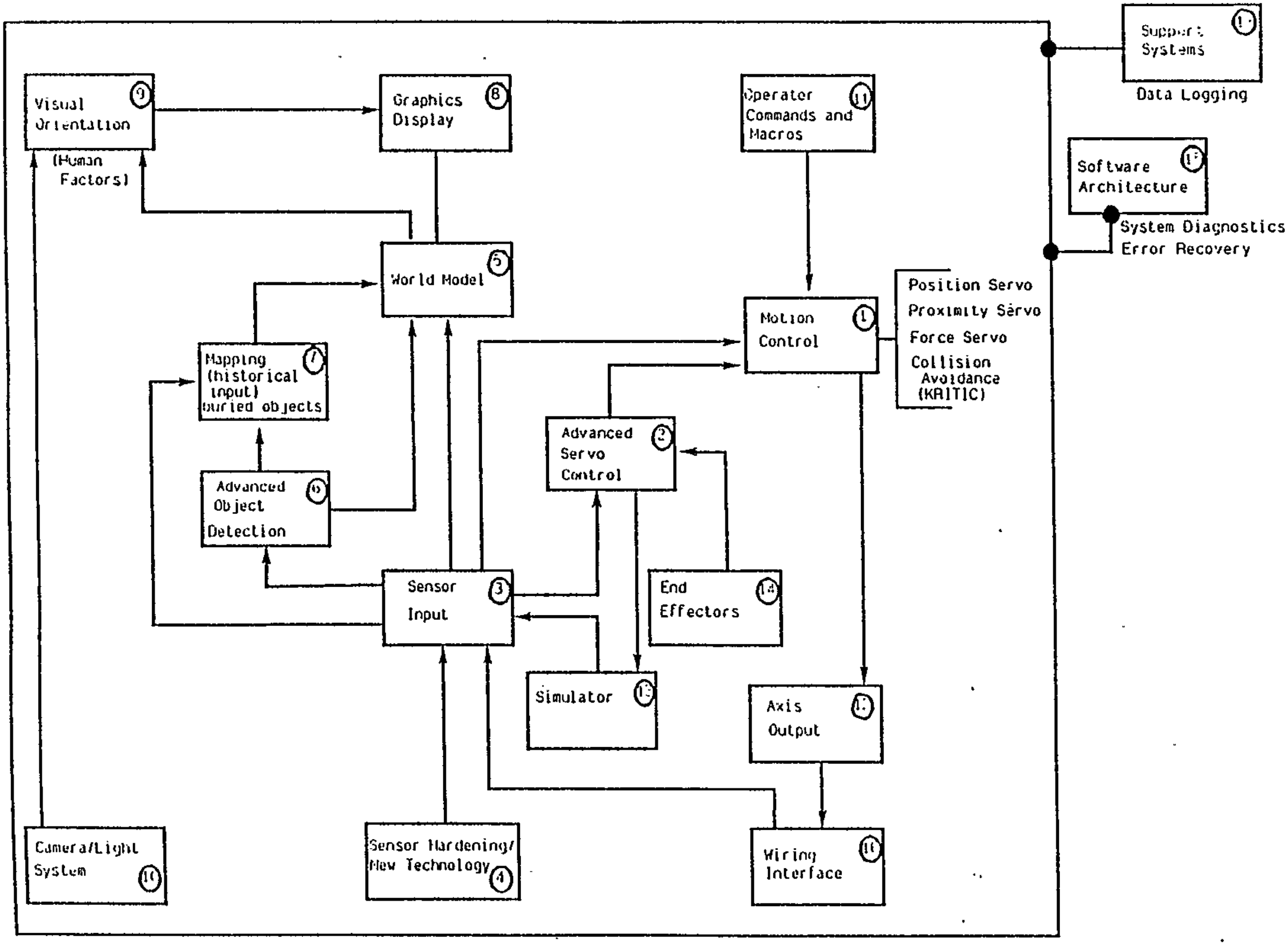

Figure 2. Work Task Block Diagram.

7.0 TECHNICAL ISSUES

There are several key technical issues that remain to be resolved in order to expedite the SST waste retrieval effort. An evaluation of the waste retrieval alternatives is difficult without resolution of the technical issues. Five of the key technical issues are listed below.

- The first issue is water addition to the SST. Water addition restrictions are imposed to limit potential leakage. Limitation on the quantities of water that can be added during retrieval operations will affect the processes that can be used. Moderate amounts of water (<1,000 gal) are needed for controlled scarifying and large amounts of water (>10,000 gal) for sluicing. Westinghouse Hanford is investigating the possibility of using a barrier that may overcome the leakage problems. Typical barriers are ice shields of frozen earth and the injection of materials such as bentonite clay into the area around the outside of the SST. Westinghouse Hanford is also investigating more efficient sluicing techniques that will reduce the 200 to 1 dilution ratio (of water to waste) typical of past sluicing efforts.

- The second technical issue involves development of a control system for the robotic arm and end effectors. The current requirements exceed the state-of-the-art for commercially available control systems. This is a long-term development item that is a key to the success of the retrieval operations and is best addressed in conjunction with one or more of the national laboratories that possess the technical expertise to successfully develop the basis of a workable control system.

- The third issue is the definition of tank cleanup when retrieval operations can be considered complete. The demonstration tank retrieval is considered complete when 95% of the tank inventory is removed. The 95% of tank inventory is too restrictive on tanks with small inventories and there is no technical basis for applying this requirement to all SSTs. The cleanliness criteria for the remaining SSTs will affect the cost and duration of retrieval operations and the type(s) of equipment that can be used for final tank cleanout. Westinghouse Hanford will continue to develop test data and related information that will allow a realistic definition of when an SST is clean.

- Another major technical issue involves the degree of modification to the SST that can be allowed. Larger openings in the top of the tank allow simplification of in-tank equipment but require larger and more extensive confinement systems above the tank. The number, size, and location of new openings that can be made in the top of the tank affect the design of a waste retrieval system. Westinghouse Hanford is now determining what size opening can be made in the top of the SSTs without degrading the structural integrity of the tanks. Costs associated with the enlarged openings are being developed. These data will provide a basis for determining the best tank size opening for performing retrieval operations.

- The reliability and availability of the retrieval equipment is another important technical issue that needs to be defined. The reliability and availability requirements are dependent on both the number of tanks to be retrieved and on the retrieval schedule requirements.

8.0 TECHNOLOGIES TO BE TESTED

Testing the technologies and equipment with potential for SST waste retrieval is required between October 1992 and June 1994 to complete Tri-Party Agreement Milestones M-06-02 and M-06-00, respectively, and to provide the basis for final design of the demonstration tank retrieval equipment. In support of these milestones and the retrieval program in general, the following testing activities are planned.

8.1 FEATURE TESTING

Feature testing will continue on selected components. Components currently identified for feature testing include positive displacement pumps, air jets, water jets, air conveyance system, scabbler, and hydraulic impact units. Additional components will be identified for testing as the retrieval program proceeds.

Feature testing results on tests to date are mixed. Some tools, such as the scaler, look very promising for further development and others, as in the case of air conveyance, were less successful. Testing should be continued to develop engineering and design data and prove technology viability.

8.2 INTEGRATED TEST UNIT

An integrated test unit (ITU) of a mechanical retrieval arm will be developed. Some type of mechanical arm is expected to be applicable for maneuvering equipment in the SST for all retrieval systems under consideration. For the sluicing option the mechanical arm would maneuver the sluice nozzle inside the SST into close proximity of the waste and tank liner. The ITU will consist of a limited reach, commercially available robotic arm mounted on a full reach boom. This test unit will allow development and testing of a control system and arm end effectors. The control system and end effectors would be generic in nature and would apply to all of the retrieval systems under consideration. The development and test data must be available in the required timeframe to be factored into the design of the demonstration tank retrieval equipment.

8.3 TRI-PARTY AGREEMENT MILESTONE

The specific equipment identified for testing to complete Tri-Party Agreement Milestone M-06-01 consists of the primary items from Table 1--the equipment recommended in the waste retrieval study--with one exception: the batch conveyor which is a straightforward mechanical design that does not require development testing. A brief description of the items that will be tested is provided below.

- **Robotic Arm**--The arm system consists of a limited reach, commercially available robotic arm mounted on a full reach boom. This system allows development and testing of a control system as well as means for testing end effectors (see Section 7.2).

- **Scarifier**--The scarifier is one of the arm end effectors that will be tested. The scarifier is used for dislodging, breakup, and retrieval of waste with rotating air or water jets. An air conveyance system is used in conjunction with the scarifier for transporting the waste out of the tank.

- **Grabber**--The grabber is another arm end effector that will be tested. The grabber is used to pick up and move solid objects in the tank. Cut up sections of pipes or risers are considered the primary objects to be handled.

- **Abrasive Water Jet**--The third arm end effector that will be tested is the abrasive water jet cutting head. The abrasive water jet will be used to cut up pipes and other solid debris that requires removal to facilitate waste retrieval.

- **Air Conveyance System**--The air conveyance system will be developed and tested. This system has the ability to transport liquids, solids, and sludges out of the tank to a shipping facility. Development testing of this system should be targeted toward optimizing water injection design features, pick up nozzle design, and overall system specifications.

- **Scabbler**--A pneumatic scabbler will be tested. A scabbler is a large-scale version of the needle scaler and has the potential to both break up hardcake at higher production rates and to clean the last few inches of waste from the tank. The scabbler (and needle scaler) would fall into the category of pulverizer on the list of items in Table 1.

9.0 FUTURE WORK PLANS

Future work plans will be consistent with funding and scope provided by the U.S. Department of Energy.

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