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SLUDGE SOLIDIFICATION PIT 5 INTERIM REMEDIATION PROJECT JOB NO. 1.1.3.1.02

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THE RALPH M. PARSONS COMPANY

STUDY NO. P130011
SLUDGE SOLIDIFICATION

Pit 5 Interim Remediation Project
Job No. 1.1.3.1.02

for
Westinghouse Materials Company of Ohio

March, 1989

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1.0 STUDY OBJECTIVES AND SCOPE

1.1 INTRODUCTION

The Feed Materials Production Center (FMPC) is a uranium metal processing facility occupying a 1,050 - acre site northwest of Cincinnati, Ohio. The FMPC is owned by the U.S. Department of Energy (DOE) and operated under contract by Westinghouse Materials Company of Ohio (WMCO).

Pit 5 is one of the many candidates for remedial action on the FMPC site. The Pit 5 Interim Remediation Project bid was awarded to The Ralph M. Parsons Company (Parsons); Charlotte, North Carolina. Parson's charter is to develop a Design Criteria for the interim remediation of Pit 5. This study covers the solidification of sludge from Pit 5.

1.2 OBJECTIVES

The objective of this study is to select the most feasible solidification method for stabilizing sludge from Pit 5. This study will describe and evaluate sludge solidification methods for the Pit 5 Interim Remediation Project. The ultimate goal is to define a sludge solidification method that will become part of the Design Criteria Report. To this end, the available waste solidification techniques that are currently in use or under development have been examined. A recommended sludge solidification process is developed, and an evaluation has been performed to rate the various processes.

1.3 SCOPE

This Sludge Solidification Study is one in a series of studies being prepared for the Pit 5 Interim Remediation Project. As shown in Figure 1.1, several studies are being prepared in conjunction with the Sludge Solidification Study. After all studies are completed, the Sludge Solidification Study will become part of the system recommended to treat the sludge and convert it into a solid form for final disposal.

An overview of the sludge solidification processes examined in this study are illustrated in Figure 1.2. An initial evaluation was performed to consider the major interactive factors impacting the choice of a process for sludge solidification. It was evident that solidification techniques other than cement or pozzolanic based processes lack the potential for

SOLIDIFICATION WITH ON-SITE DISPOSAL PROCESS SCHEMATIC

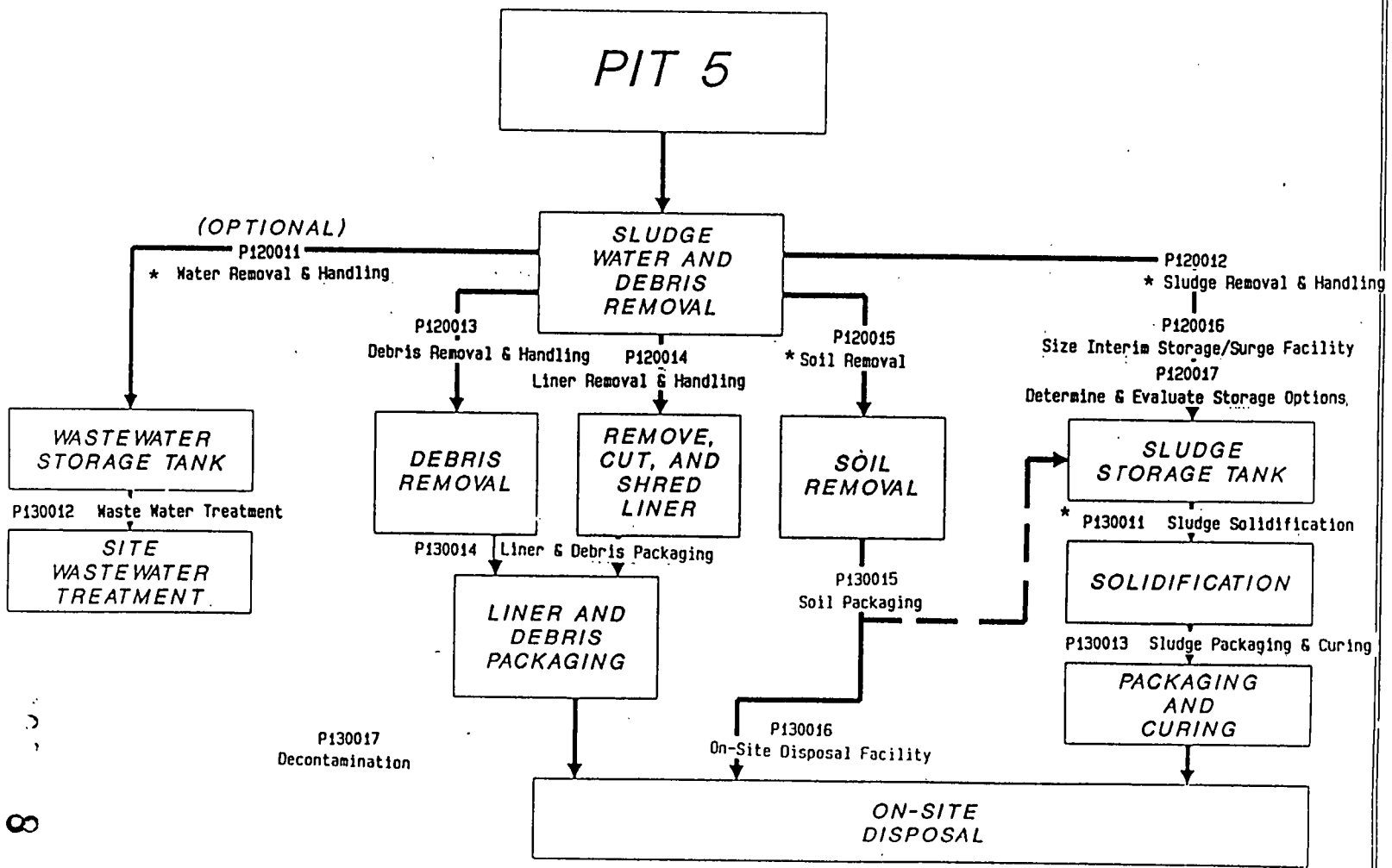
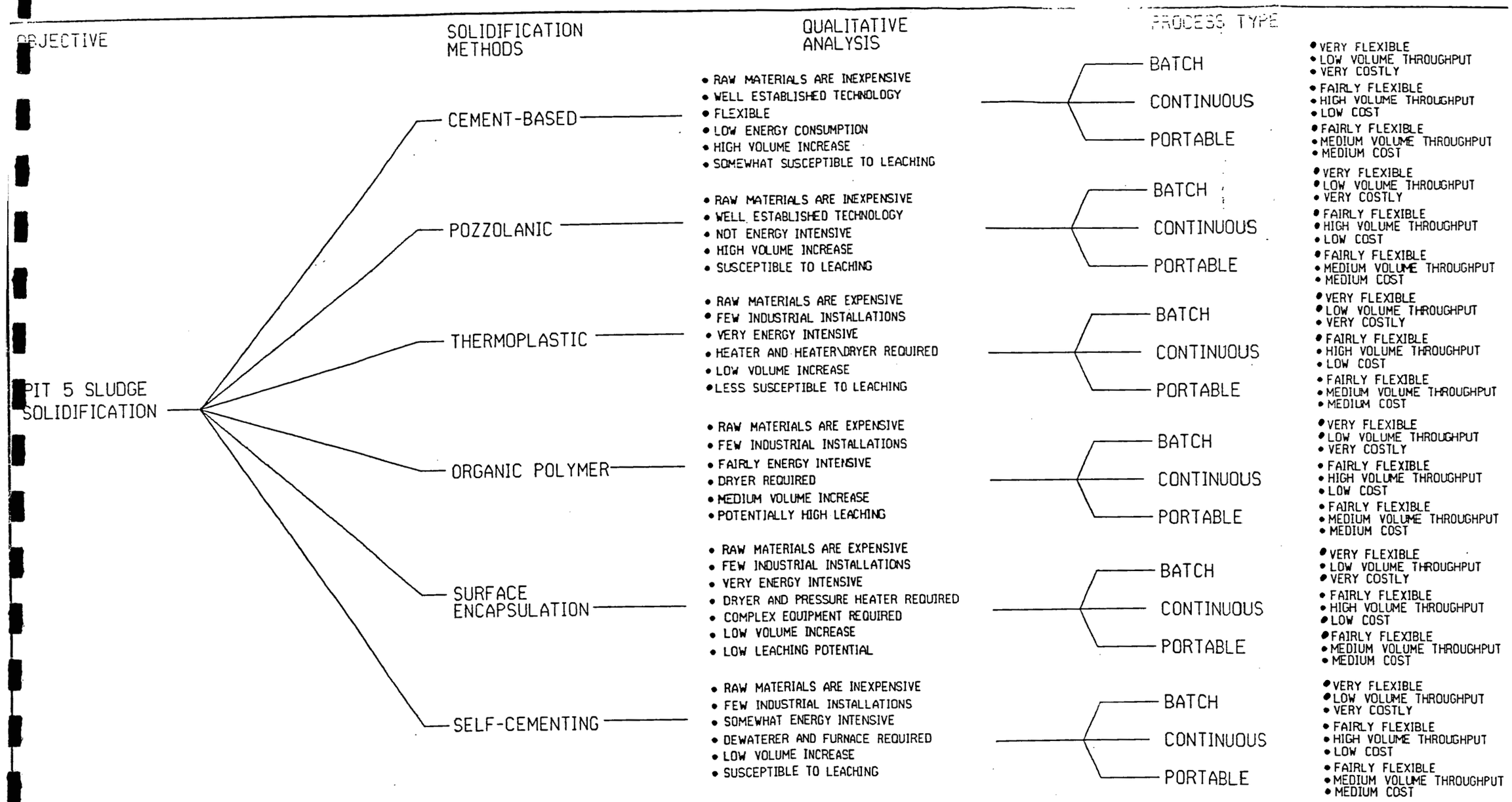


FIGURE 1.1 INTERACTION OF PROJECT STUDIES WITH DESIGN APPROACH

* indicates those studies authorized and funded



MAJOR OPERATIONAL FACTORS

- RELIABILITY
- SIMPLICITY
- ENERGY CONSUMPTION
- PROCESS TYPE
- VOLUME INCREASE
- RAW MATERIALS
- COST
- ENVIRONMENTAL PROTECTION

THIS DRAWING PREPARED BY
THE RALPH M. PARSONS COMPANY
ARCHITECTS - ENGINEERS CHARLOTTE, N. C.

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SOLIDIFICATION STUDY SCREENING PROCESS

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competing with cementation processes since they are inherently more expensive, more complex and more energy intensive.

This study will only consider the solidification of the sludge.

2.0 APPROACH

This study was performed as follows:

1. Literature on various waste solidification processes and available technical data on current industrial waste solidification practices were reviewed.

2. A functional flow diagram for each method of sludge solidification was developed.

3. The relative merits and demerits of each sludge solidification process was evaluated.

4. A recommendation was made for the most feasible Pit 5 sludge solidification process.

3.0 SUMMARY AND CONCLUSIONS

The six solidification methods and three process types (batch, continuous, portable) shown in Figure 1.2 were investigated. The pros and cons of each system are discussed in detail in Section 7.0 and are summarized below. Considerations for the solidification process include: simplicity, energy consumption, volume change, raw materials, and environmental protection. In addition, the available process types were examined for flexibility, throughput capacity, and cost.

Cement-based processes have been used the longest and, with the exception of wastes containing impurities such as borates and sulfates, they work with all kinds of wastes. Their main advantages are that the raw materials are plentiful and inexpensive, and these processes tie up any free water in the waste. Their main disadvantage is that the volume of waste to be disposed of may be greatly increased.

Lime-based pozzolanic processes are similar to cement-based processes, except that sulfates do not cause spalling or cracking of the solidified waste.

Thermoplastic techniques use bitumen, paraffin and polyethylene additives. These techniques have the

advantage of lower leaching rates than cement-based and pozzolanic systems. Also, by disposing of the waste in a dry condition, a much lower volume of waste results. Their principle disadvantages are that more sophisticated equipment is required, and they are much more energy intensive than other systems.

Organic polymer processes encase the waste in a spongy matrix. They have the advantage of having a higher waste-to-reagent ratio than cement based processes. However, since the waste is not bound to the polymer, the potential for waste mobilization (i.e. leaching) is higher.

Surface encapsulation techniques are those in which a waste that has been bonded or pressed together is enclosed in a jacket or coating of inert material. This has the advantage of preventing the waste from coming into contact with water for sometime. Their major disadvantages are that they are relatively expensive and require a large amount of energy.

Waste that is high in calcium sulfate or calcium sulfite can be processed to become self-cementing. When disposing of this type of waste, this process has major advantages over the other methods discussed here. However, this process is energy intensive and little waste falls into this category.

Batch processes mix the waste and reagents in discrete batches. This provides for a great deal of flexibility in dealing with waste variations, but it is very costly, and limits the system throughput.

Continuous processes blend a continuous stream of reagents and waste in an operation at a fixed location. While this results in less flexibility, there are broad limits on system throughput, and it is fairly inexpensive.

Portable processes are small continuous process systems that are mounted on skids or trailers for portability. They are fairly flexible, but due to the size limitations of the trailer or skid, their throughput is limited.

Section 8 compares the relative advantages and disadvantages of each process. Based on this evaluation, a cement-based process employing cement and fly ash has been chosen for the solidification of Pit 5 sludge. Cement is an inexpensive additive which:

1. provides good resistance to leaching,
2. is not energy intensive,
3. uses well established technology, and
4. provides for process flexibility.

In addition, a continuous type treatment scheme has been chosen due to its higher throughput capacity which is necessary to meet the tight-schedule for Pit 5 and its lower cost.

The details of the solidification process selected are described in Sections 9.0 through 9.11. The process flow diagrams shown there will form the basis for the Design Criteria Report to be developed.

All of the details presented in this report are based on the assumptions stated in the various sections. Before actual design begins, several factors must be confirmed. It is assumed that sludge with 30% solids by weight can be pumped; this must be confirmed by a pumping test. Another assumption is the proposed mix formulation; a solidification testing program must be performed to determine the mix formulation and permissible variability of sludge, water content, cement, fly ash, and other additives to achieve the required solidified form.

4.0 BACKGROUND

4.1 PIT CHARACTERIZATION

Pit 5 is a lined waste disposal pit that covers 3.8 acres. It has a maximum depth of 30 feet, and its length and width are approximately 820 and 240 feet, respectively. It contains approximately 102,500 cubic yards of sludge.

The pit was used as a settling and storage basin for low-level radioactive sludge produced in Plant 8. The sludge depth varies between 25 and 30 feet. The water depth varies between 0 and 3 feet with the sludge in the east end of the pit exposed to the air.

Borings indicate that the pit is stratified from surface to bottom. Since the pit was filled from the east end, it is believed that east to west stratification also exists.

The material contained in Pit 5 was originally pumped as a slurry and consequently contains very little solids or debris. There is a decantation tower and access bridge at the southwest end of the pit.

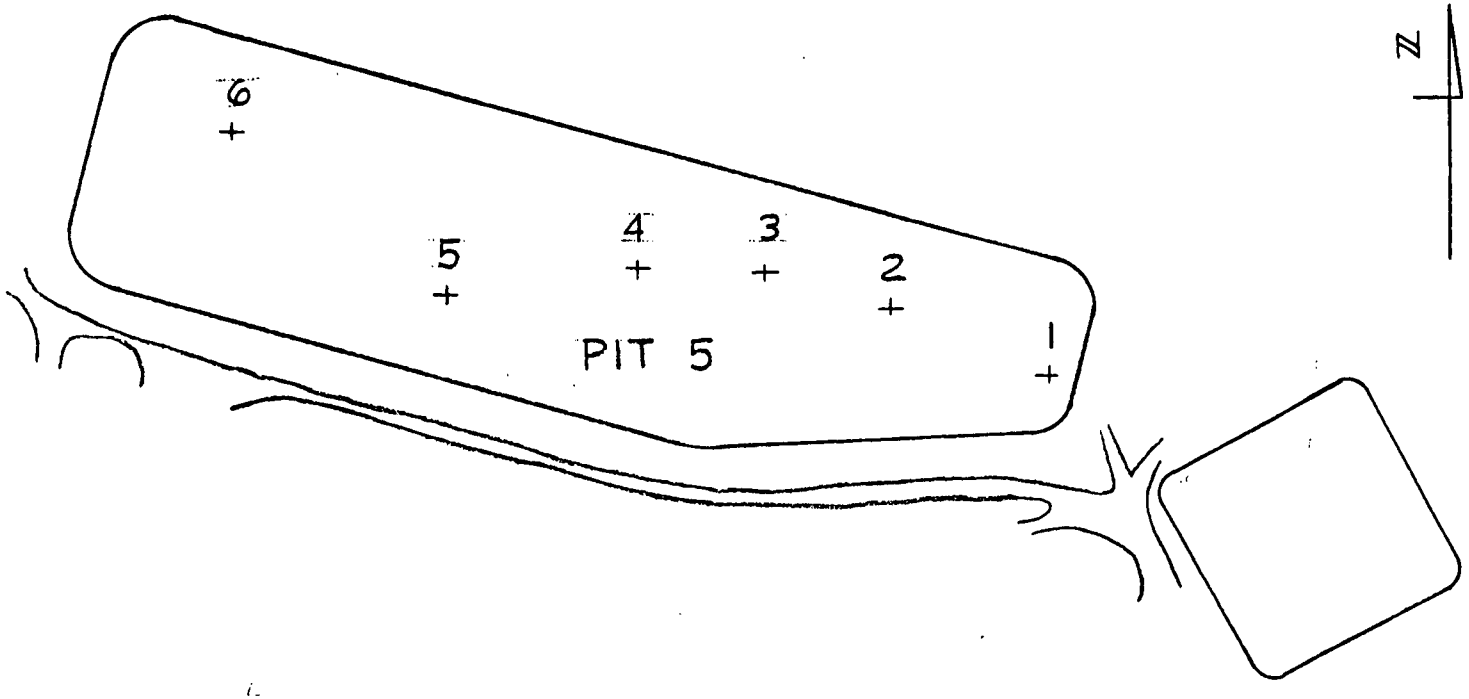
4.2 SLUDGE CHARACTERIZATION

The two major solid constituents of the sludge are magnesium fluoride and an iron-based precipitate. The sludge was pumped from Plant 8 to Pit 5 so both major constituents were pumpable. A pumping test was run in the mid-70's and the iron-based precipitate was still readily pumpable; however, the magnesium fluoride was not readily pumpable. Care was taken to put the material into suspension by mechanical means. Proper velocities were maintained to keep the material in suspension. If a power loss occurred during the pumping operation, it was noted that the magnesium fluoride would fall out of suspension and jam the pumping unit. During the mid-70's pump test, the magnesium fluoride pumped at a notably slower rate than did the iron-based precipitate.

Figure 4.1 shows the sampling point locations used in the Pit 5 characterization by Weston for their report entitled "Geotechnical Evaluation of Material Properties of Waste Pit Materials". The results are listed below.

The volume of sludge is estimated at 102,500 cubic yards. The approximate sludge contents, per IT Corporation, 1988, are as follows:

o	Sludge volume	102,500 cubic yards
o	Sludge solids	75×10^6 lbs.
o	Bulk density of sludge (oven dry)	57.3 lb/ft^3
o	Specific gravity of solids	2.43
o	Entrained sludge water	142×10^6 lbs.
o	Arsenic (As)	139 to 2800 mg/kg
o	Barium (Ba)	15,700 to 36,940 mg/kg
o	Mercury (Hg)	0.39 to 1.8 mg/kg
o	Technetium (Tc-99)	423 to 2990 pCi/g (dry basis)
o	Uranium Total	50,309 kg at 510 ppm (sludge basis)
o	Thorium Total	16,965 kg at 172 ppm (sludge basis)
o	Total radionuclides	4527 to 27,200 pCi/g (dry basis)
o	Organics	900 to 2700 ug/kg
o	EP Toxicity for arsenic, barium, mercury	Below limits



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PIT 5 SAMPLE POINTS		
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5.0 LITERATURE REVIEW AND CURRENT INDUSTRIAL PRACTICE

The waste solidification processes have only been developed recently. This development has been dictated by the urgent need to dispose of hazardous/radioactive wastes so as to be in compliance with regulatory requirements.

Based on a literature review, the following seven major classes of waste stabilization/solidification have been identified:

1. Cement-based processes
2. Pozzolanic processes
3. Thermoplastic techniques
4. Organic polymer techniques
5. Surface encapsulation techniques
6. Self cementing techniques
7. Glassification and production of synthetic materials or ceramics.

These waste solidification techniques are described in Section 7 of this study. The industrial use for a majority of these processes has been rather limited. The techniques that involve relatively complex processes, are energy intensive, or use costly raw materials have not found any large scale industrial application. In fact, there are only a few waste solidification plants either in operation or in the development stage at present, and practically all utilize cement and/or pozzolanic based processes. These facilities are briefly described below.

Savannah River Plant

The Savannah River Plant (SRP), Aiken, South Carolina, has recently completed the construction of a facility (Saltstone Project) at its Z-Area for the solidification of low-level radioactive waste which is in solution form. The decontaminated salt solution is mixed with cement, fly ash (slag and/or hydrated lime may also be used) and a set retarding agent, and the resulting grout is transferred into concrete vaults where it sets into a monolith. The solid waste form, "Saltstone", made with the above-mentioned components has a very low permeability. The proportions in which the various constituents will be mixed are as follows:

Decontaminated Salt Solution	:	40% by weight
Cement	:	12% by weight
Fly Ash	:	48% by weight
Set Retarding Agent (Pozzolith 122-R or equal)	:	Up to 0.5% by weight, if required

This is equal to 15.5 lbs. of cement and fly ash mix per gallon of the decontaminated salt solution. The grout production rate will be approximately 180 gallons per minute.

Apart from the saltstone project in Z-Area, another solidification facility is now in the design and development stage for the Y-Area. The waste treatment process will be based on the use of a mixture of cement and fly ash for solidification of liquid waste. The process and equipment used will be similar to that used for the Saltstone Project in Z-Area.

Oak Ridge Gaseous Diffusion Plant

The treatment facility at the Oak Ridge Gaseous Diffusion Plant (ORGDP), Oak Ridge, Tennessee handles solidification of sludges and high salt containing liquids. As at SRP, this facility also uses cement and fly ash for solidification of the wastes, but the proportion of cement used is comparatively higher. The sludge solidification at ORGDP (as described by Earl W. McDaniel of MMES-ORNL during the meeting at FMPC, Fernald, Ohio on February 17, 1989) has the following aspects:

1) The treatment rate is two hundred 55-gallon drums per 8 hour day (30,000 drums have been prepared).

2) The sludge is removed by backhoe, dumped into a hopper, screened to remove large objects, mixed in 5,000 gallon batches to assure sludge uniformity and mobility and to characterize the sludge. Dry mix is proportioned according to total suspended solids (TSS) of sludge. The components are batched in a conventional batch plant, mixed in a Lilliford high shear mixer (4 to 6 cubic yards mixed in approximately 2 minutes), discharged into concrete trucks that take the mixed sludge to a pouring yard and placed into 55-gallon drums.

3) The sludge is a clay/silt with a consistency of creamy peanut butter having 30 to 35% solids.

4) A 50/50 mixture of Type I cement to Kingston steam plant Class F Fly Ash (Class F fly ash conforming to ASTM C 618) is used.

5) 8 to 10 pounds of the cement/fly ash mixture are used for each gallon of sludge (1 gallon of sludge weighs 12 to 13 pounds).

6) The mix contains 6 to 8% entrained air (using Master Builders additive).

7) Each batch is marked, sampled, and tested for "delisting". If a batch fails the EP Toxicity test for delisting, the batch is returned to the plant for further processing.

It is desirable to keep the water content of sludge as low as possible in order to keep the additives to a minimum, thereby reducing the amount of treated waste to be disposed. A minimum amount of solids for a sludge to be treated should be 18 to 20%. Sludge may have to be thickened to increase the solids content to a desirable 30 to 35%.

The waste needs to be characterized to a level of confidence such that the full range of characteristics has been determined. Constituents of concern for obtaining good cement grout are lead, NaCl, and $NaNO_3$.

Grout Disposal Facility, Hanford Reservation

The grout disposal program at Hanford Reservation, Richland, Washington involves the disposal of phosphate/sulfate waste (PSW) estimated at one million gallons from N Reactor operations and the low-level fraction from double-shell tank (DST) wastes. The first campaign for disposal of PSW in grout form commenced August, 1988, and DST waste disposal is scheduled to start in 1990. Liquid waste will be converted into an environmentally stable solid form by mixing the wastes with Types 1 and 2 portland cement and pozzolanic materials such as Class F fly ash and blast furnace slag. The proportion of cement in the blend is lower than that used at SRP. The selected reference blend ratio is as follows:

Blast Furnace Slag	: 47% by weight
Class F Fly Ash	: 47% by weight
Types 1-2 Portland Cement	: 6% by weight
Mix Ratio	: 9 lbs. solids blend/gallon of waste

Blend formulations will differ for different wastes and is selected on the basis of actual solidification test data for a particular waste. Different types of clays such as Red Indian pottery clay or attapulgite clay may also be used for blend formulations.

The grout slurry will be pumped to disposal vaults for final disposal. High pressure pumps will be used for cleaning the grout pipeline. Grout production rate will vary from 30-70 gallons per minute.

The references used for this study are listed in Section 10.

6.0 SAFETY CRITERIA

The solidification process will be similar to a standard concrete mixing facility and as such will only require standard industrial safety practices. Even though the sludge being solidified is slightly radioactive, there is no need for additional protective features, such as HEPA filters on the facilities ventilation system or double walled piping. Process areas will have secondary containment for tanks and other primary containers. This is due to the very low radioactivity level of the sludge (Weston CIS, 1988).

Since the sludge is processed in a liquid state, any breach of the solidification equipment will not cause a significant amount of material to become airborne. A leak or rupture of a storage tank or a pipe would obviously cause a localized increase in airborne radionuclide concentration, but this would be at low levels and would not lead to a significant release to the environment. Any leaks or spills of the sludge can be easily identified and cleaned up before the situation becomes a hazard to the workers or to the environment.

In order to ensure personnel safety during the solidification operations, all work will be performed in accordance with the site Environmental, Safety and Health (ES&H) Procedures, as well as the FMPC Radiation Control Manual. Among other requirements, these procedures identify the maximum permissible radionuclide concentrations in the air and the types of protective clothing required.

The DOE Orders require radiation exposures to be kept below 1 rem/yr and that exposures be further reduced by maintaining them as low as reasonably achievable

(ALARA). In DOE/EV/1830-T5, (Kathren and Selby, 1980) occupational dose equivalent limits are recommended for various types of operations. This guide recommends a maximum dose rate of 0.125 mrem/hr for continuously occupied work areas, such as the control room.

7.0 SLUDGE SOLIDIFICATION METHODS

There are a number of factors to consider when choosing a solidification/stabilization process. The most important factor is compatibility between the waste and the process chosen. Secondary factors include costs, reliability, simplicity, energy consumption, process type, handling characteristics, and bulking of the resulting product. It is also important to match the process type to the disposal conditions.

7.1 SOLIDIFICATION AGENTS

The EPA (Malone, Jones and Larson, 1980) has identified seven major types of solidification processes. They are:

1. Cement-based processes
2. Pozzolanic processes
3. Thermoplastic techniques
4. Organic polymer techniques
5. Surface encapsulation techniques
6. Self-cementing techniques
7. Glassification and production of synthetic materials or ceramics (vitrification)

Since vitrification is being considered as a separate option (IT Corp., 1988), it will not be included here. The other six options are discussed below.

7.1.1 Cement-Based Processes

Cement-based processes have been used the longest and have successfully solidified a wide range of wastes. These processes require the addition of portland cement to a waste slurry. This causes the suspended solids to become part of the hardening concrete matrix and ties up free water in the process. The resulting mixture hardens to a solid mass over several hours to a few days. Before setting, it can be pumped as needed.

Based on chemical composition and physical properties, portland cements are generally classified into the following five types:

1. Type I

   This type of cement is used in the building trade and constitutes over 90% of the cement manufactured.

2. Type II

   This type is meant for use in the presence of moderate sulfate concentrations in the range of 150-1,500 mg/kg or where the requirements for heat of hydration are moderate.

3. Type III

   This type is characterized by high initial strength and is used where rapid set is required.

4. Type IV

   This type has long set time and low heat of hydration and is usually used for large-mass concrete work.

5. Type V

   This type has low aluminum content and is sulfate resistant. It is used where sulfate concentrations of more than 1,500 mg/kg are involved.

   Types I, II and V have been used for waste solidification.

Figure 7.1 shows a flow diagram for a typical cement-based solidification system. Basically, the waste, the cement and any additives are all combined in a high shear mixer for blending. The free water in the waste is used to hydrate the cement, thus tying it up in the final product. The general reaction that occurs is as follows. Initially, the lime in the cement hydrates and the dissolution of other constituents occurs. This results in a supersaturation of the solution, which leads to the precipitation of metastable hydration products. Within 1/2 to 2 hours, this reaction gradually decreases as gelatinous hydration products coat the cement particles. Eventually, osmotic pressure breaks down this coating and hydration continues, but at a slower rate. At this point, the cement starts to harden, as the colloidal gel of

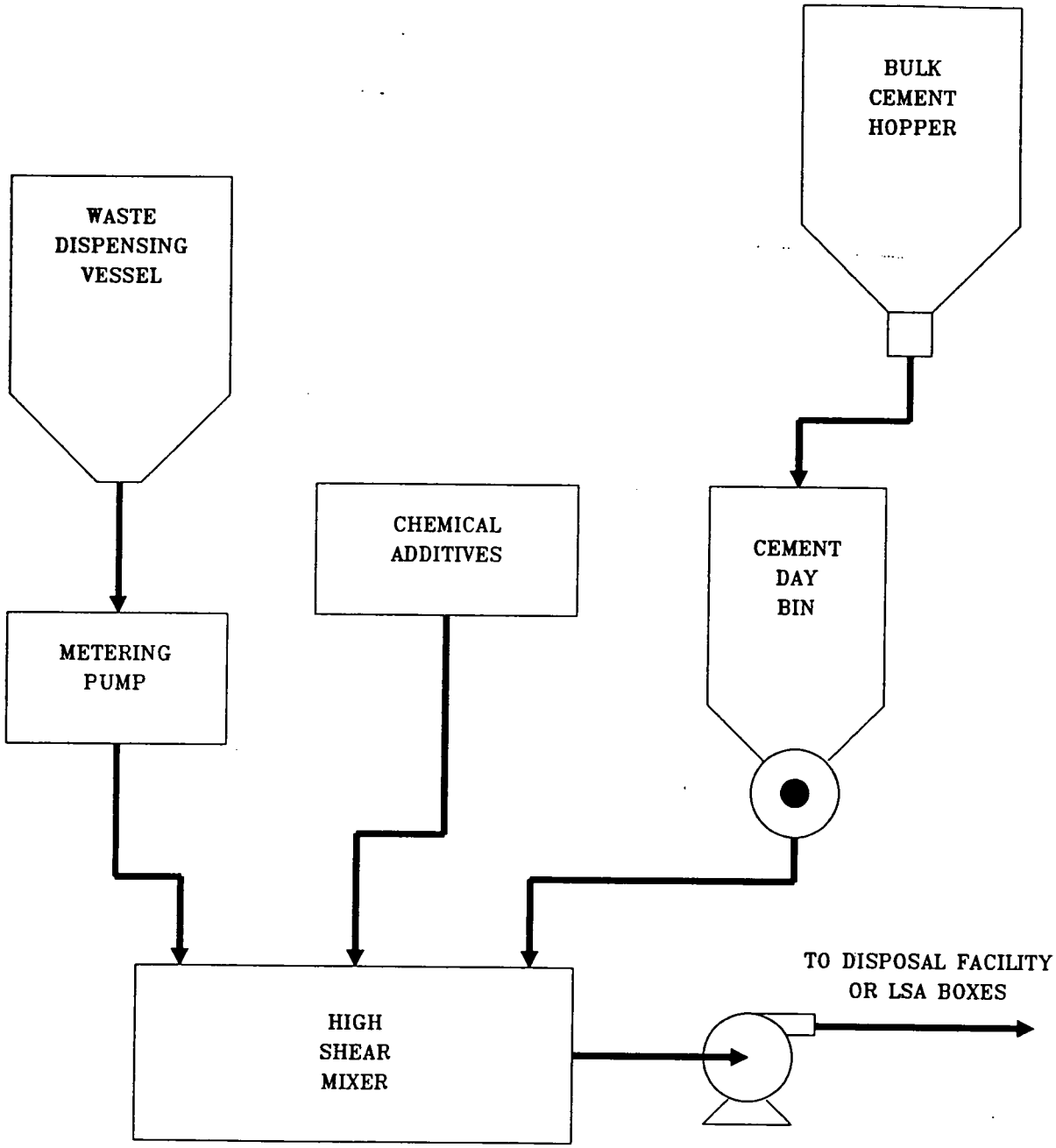

FIGURE 7.1: TYPICAL CEMENT-BASED SOLIDIFICATION SYSTEM FLOW DIAGRAM

SOURCE: CWYNAR,T.C., A.L. NASOL, P.M. PETRON, AND A.J: DIETRICH, 1986.

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metastable hydration products between cement grains begin to crystalize. This forms densely packed fibrils of calcium silicate hydrate. Finally, the fibril network continues to grow and consolidate, which binds together crystalline hydration products, unreacted cement, and the suspended solids initially present in the waste (Neilson and Dole, 1986).

The main advantages of cement-based processes are:

1) The raw materials are plentiful and inexpensive.

2) These processes tie up any free water in the waste.

3) Through the use of different additives such as clay or vermiculite, the properties of the resulting concrete can be tailored to the waste to be disposed.

4) A well established technology is used.

5) Specialized labor is not required.

6) Ease and flexibility of handling is provided.

7) The process is not energy intensive.

8) The process produces a nonbiodegradable, nonflammable, and stable product.

The main disadvantages are:

1) The volume of waste to be disposed of may be greatly increased (by up to twice the original volume for some wastes).

2) The products formed are somewhat susceptible to leaching, especially when in contact with mildly acidic solutions.

3) Impurities such as borates and sulfates adversely affect the ability of the mixture to cure or set.

The use of cement based processes has been extensively documented. They have been used at the Savannah River Plant (Schuler et. al., 1986,) and for low-level waste at the closed reprocessing plant at West Valley, New York (Grant, 1985, and Cwynar, 1986). Similar processes are being used at Hanford and the Oak Ridge Gaseous Diffusion Plant. Concrete-based processes have also been successfully tested for stabilization of PCB

contaminated soils (Buckingham and Peacock, 1987.) In addition, a combination of cement and organic polymer called syncrete has been tested (Cohen and Crouzet, 1986.)

7.1.2 Pozzolanic Processes

Lime-based pozzolanic processes are similar to cement-based processes, except that sulfates do not cause the product to spall or crack and they do not form as strong a solid. They use lime and fine-grained silicaceous (pozzolanic) material which react to form a concrete-like solid. Like cement, water is required for the reaction, so that free water in the waste is bound up in the resulting solid. Fly-ash, cement-kiln dust, or ground blast-furnace slag are the most commonly used pozzolanic materials.

Figure 7.2 illustrates the flow diagram of a typical pozzolanic process. As this figure shows, and as stated above, these processes are very similar to the cement-based processes. The lime, the pozzolanic material, and the waste, as well as any chemical additives, are added to a high shear mixer for blending. This mixture can then be pumped into containers or to a disposal facility.

For the most part, the advantages and disadvantages of these processes are the same as those for the cement-based processes.

Environstone, which is an organic polymer/fly ash mixture, has been tested in Japan and Sweden (Sjoblom, Forsstrom, and Shingleton, 1985), and has been used in Rancho Seco among other sites in this country to solidify low-level radioactive waste (McMahon, 1989.) According to its manufacturer, it has been tested to ensure compliance with 10 CFR 61 requirements for waste stabilization (Rosenstiel, Bodett, and Lange, 1984.) In addition, a mixture of clay, fly ash and hydrated lime was found to successfully solidify an acidic hydrocarbon sludge in a study conducted at Drexel University (Martin, Robinson, and Van Keuren, 1987). An important note is that most of the cement-based processes mentioned in Section 7.1.1 use a blend of cement and pozzolanic materials.

7.1.3 Thermoplastic Techniques

Thermoplastic techniques use bitumen, paraffin and polyethylene additives. In these processes, the waste is dried, heated, and mixed with the heated plastic

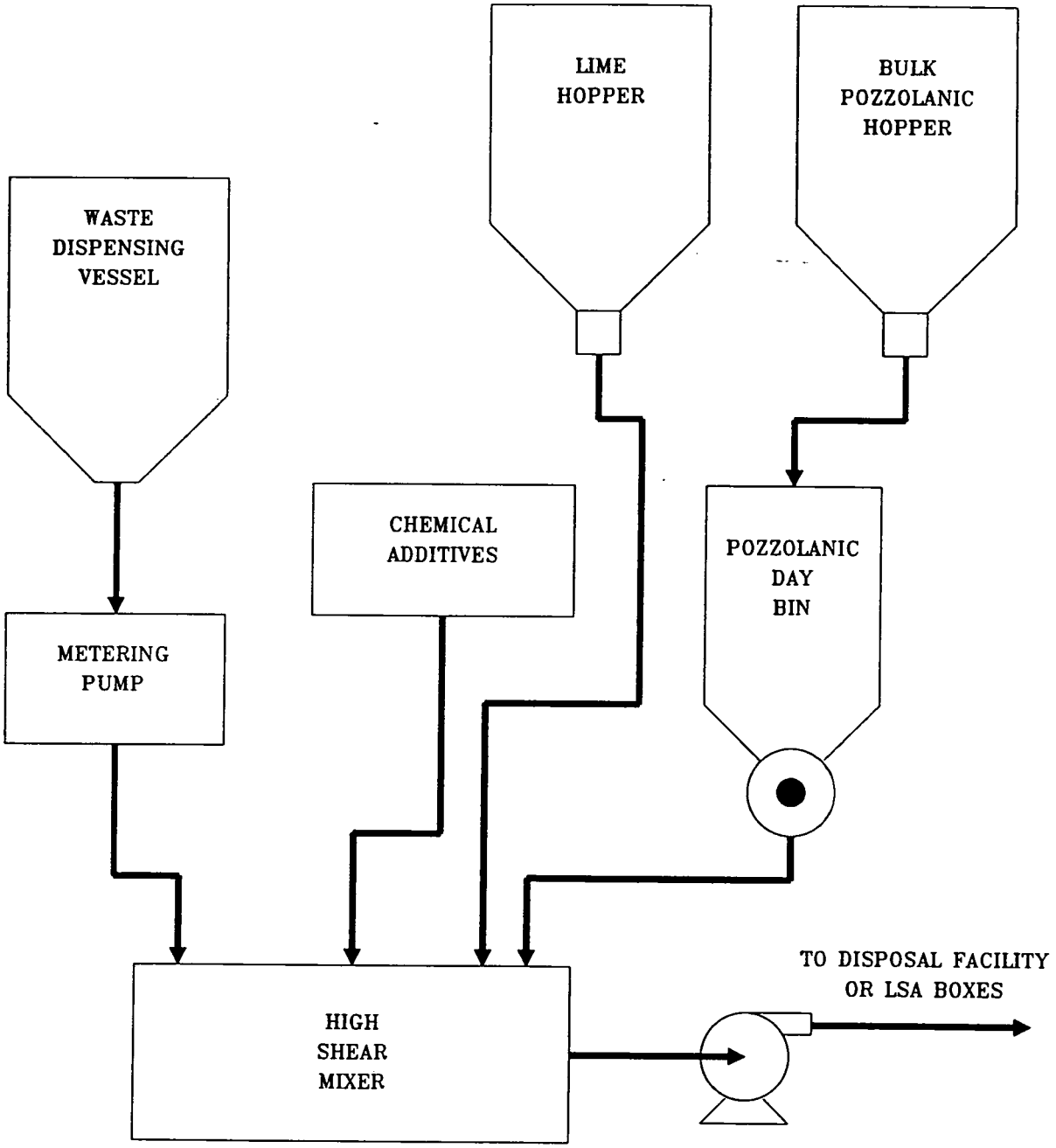

FIGURE 7.2: TYPICAL POZZOLANIC SOLIDIFICATION PROCESS FLOW DIAGRAM

matrix. This mixture is then cooled in a secondary container, such as a LSA box, and transported to the disposal facility (see Figure 7.3). Special equipment is required to heat and mix the components, but it is commercially available. These processes require a high matrix to waste ratio, usually between 1:1 and 2:1. However, since the waste is dried prior to mixing, the total volume to be disposed of is generally less than with a cement-based system.

These thermoplastic techniques have the advantage of:

1) Leaching rates are fairly low.

2) The volumes of solidified waste are usually small since the work is dried prior to mixing with additives.

3) The matrix that forms is resistant to microbial attack and breakdown by aqueous solutions.

4) The waste material can be retrieved from the thermoplastic matrix at a later date, if this is required.

Their principle disadvantages are that:

1) Sophisticated equipment is required.

2) The processes are much more energy intensive than other systems.

3) More costly materials are required.

4) Some mixtures form solids with poor structural integrity at temperatures over 25 degrees Celsius.

5) Thermoplastics can be highly flammable at high temperatures (130 to 230 degrees Celsius) required for processing.

6) There are a wide variety of waste types, such as organic solvents, strong oxidizers, dehydrated salts, and tetraborates of iron and aluminum that are incompatible with this solidification method.

7) May require high efficiency particulate air (HEPA) filters.

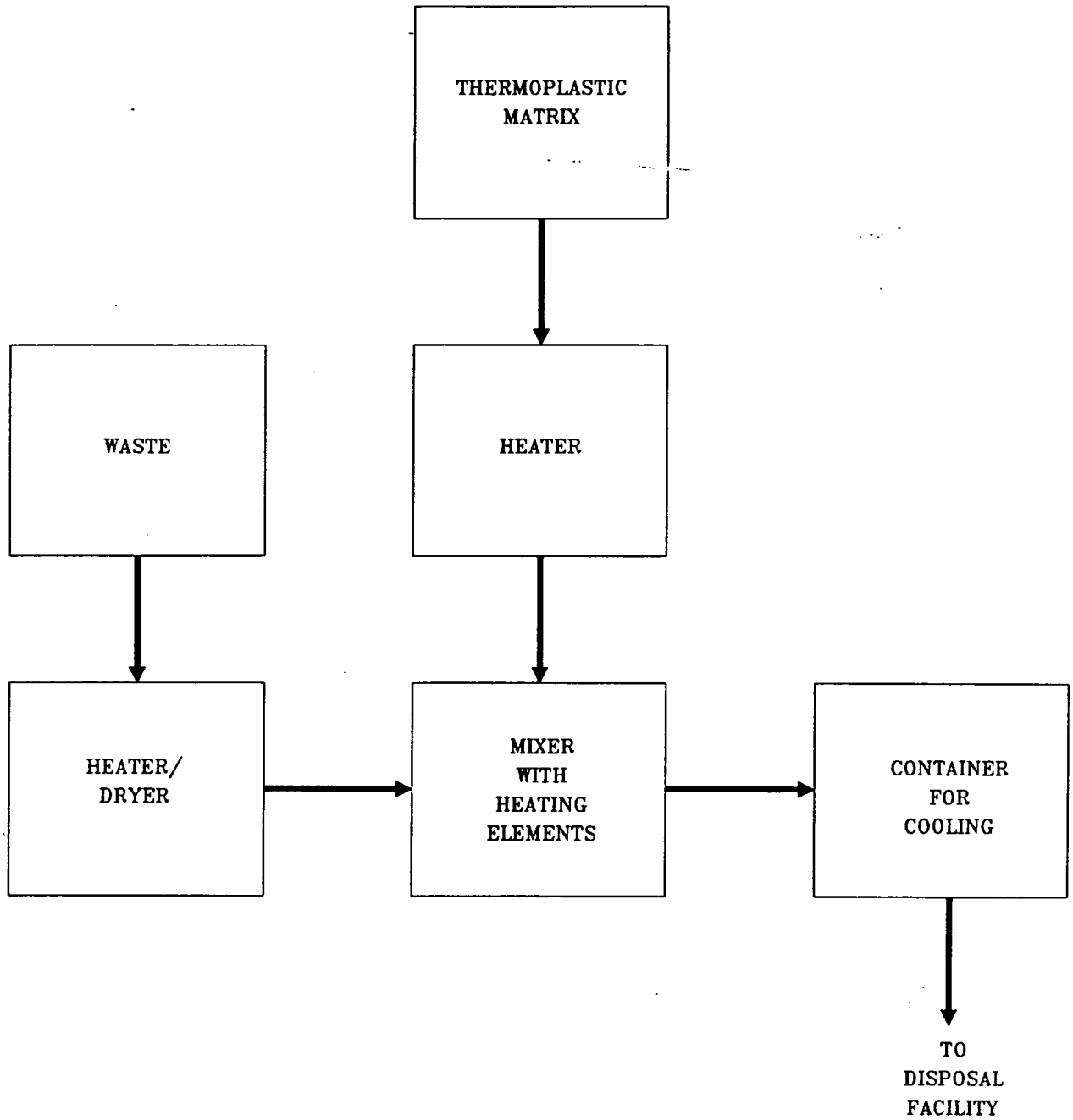

FIGURE 7.3: BLOCK FLOW DIAGRAM FOR TYPICAL THERMOPLASTIC PROCESS

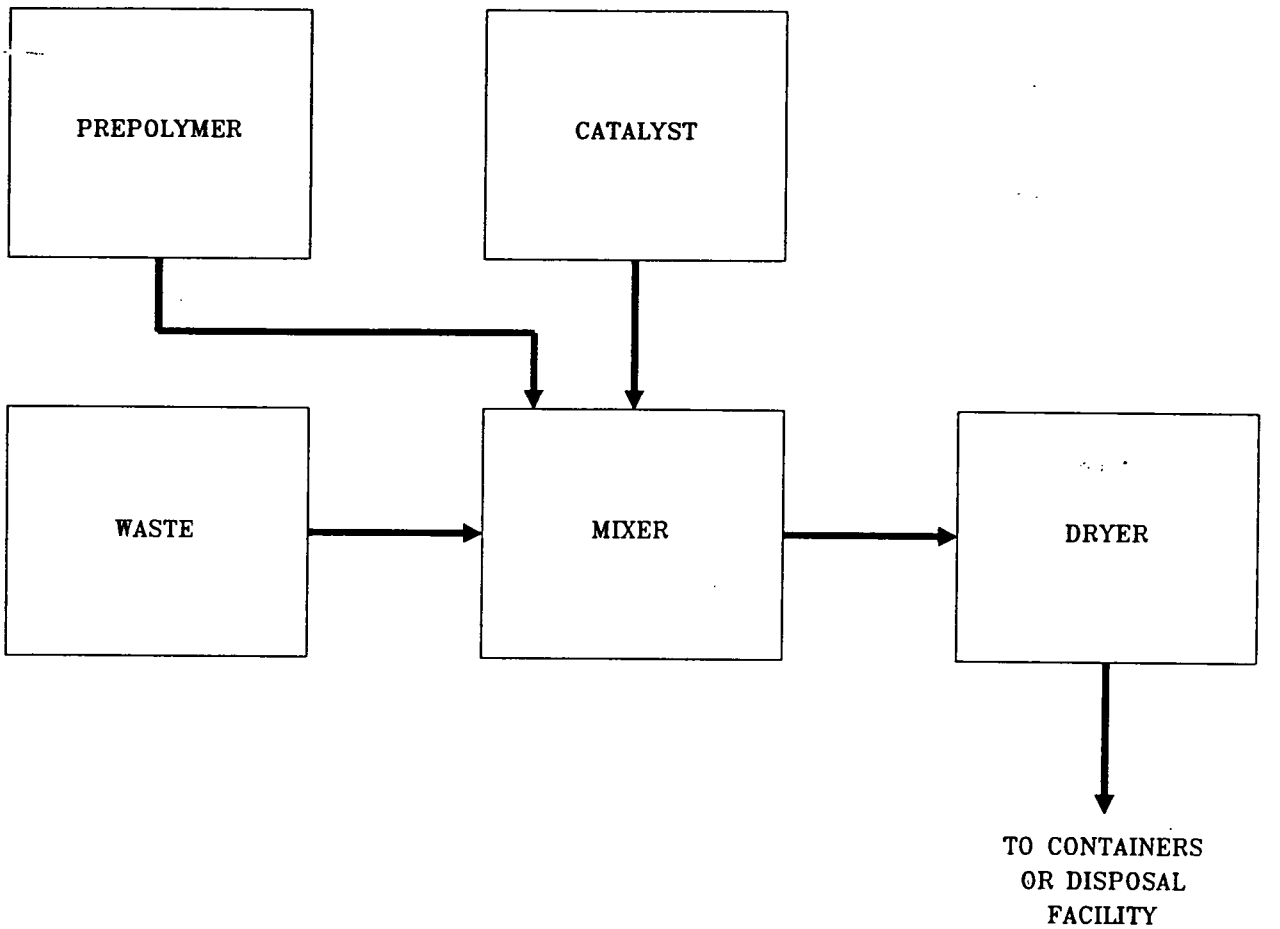

FIGURE 7.4: BLOCK FLOW DIAGRAM
FOR TYPICAL ORGANIC POLYMER PROCESS

7.1.4 Organic Polymer Processes

Organic polymer processes encase the waste in a spongy matrix. In these type of processes, a prepolymer such as vinyl esters or urea-formaldehyde, is mixed with the dewatered waste until it is completely dispersed. Then a catalyst is added, and mixing is continued (see Figure 7.4). After the catalyst has been dispersed throughout the mixture, but before the polymer has formed, the waste is transferred to a storage container, such as a low specific activity (LSA) box.

These organic polymer processes have the following advantages:

1) They have a high waste-to-reagent ratio, typically about 3:1.

2) They produce a material that is not very dense, which reduces transportation costs.

3) They do not require high temperatures to form the final product.

These processes have several disadvantages, which are:

1) The waste is not bound to the polymer, therefore, the potential for waste mobilization (i.e. leaching) is higher than with other systems.

2) Free water is not bound up in the waste and must be removed through dewatering and/or drying.

3) For polymerization to occur, a pH of between 1.0 and 2.0 must be maintained.

4) These wastes can produce highly acidic, highly polluted weep water as they age, the disposal of which can be difficult.

5) May require HEPA filters.

Organic polymers have been tested successfully in Japan (Suzuki, et. al., 1982, and Hayashi, 1982) where their lower bulking factor gives them a significant advantage over other processes.

7.1.5 Surface Encapsulation Techniques

Surface encapsulation techniques are those in which a waste that has been bonded or pressed together is enclosed in a coating of inert material. For these

techniques to work, the waste must be completely dried. This dry waste is then mixed with a setting agent, such as 1,2 polybutadiene-acetone, which also helps bind the coating to the waste. After the mixture has set, it is heated under slight pressure to between 120 and 200 degrees Celsius to fuse the waste into a solid form. This is then covered with a layer of polyethylene (see Figure 7.5). Typically, the admixture would be between 3 and 4 percent of the material to be solidified, and the coating (typically 3-5 mm thick) would add an additional 4 percent by weight.

This technique has the advantages of:

1) Preventing the waste from ever coming into contact with water.

2) Preventing all leaching of the contaminates for as long as the impervious coating remains intact.

Their major disadvantages are:

1) The resins required are relatively expensive.

2) These processes are very energy intensive.

3) These systems require a large expenditure for the required equipment.

4) A skilled labor pool is required to operate the equipment.

5) May require HEPA filters.

7.1.6 Self-Cementing Wastes

Wastes that are high in calcium sulfate or calcium sulfite can be processed to become self-cementing. Typically, after the waste has been dewatered, a small portion is calcined. This produces a partially dehydrated cementitious calcium sulfite or sulfate, which is mixed back into the remaining waste along with other additives such as fly ash (see Figure 7.6).

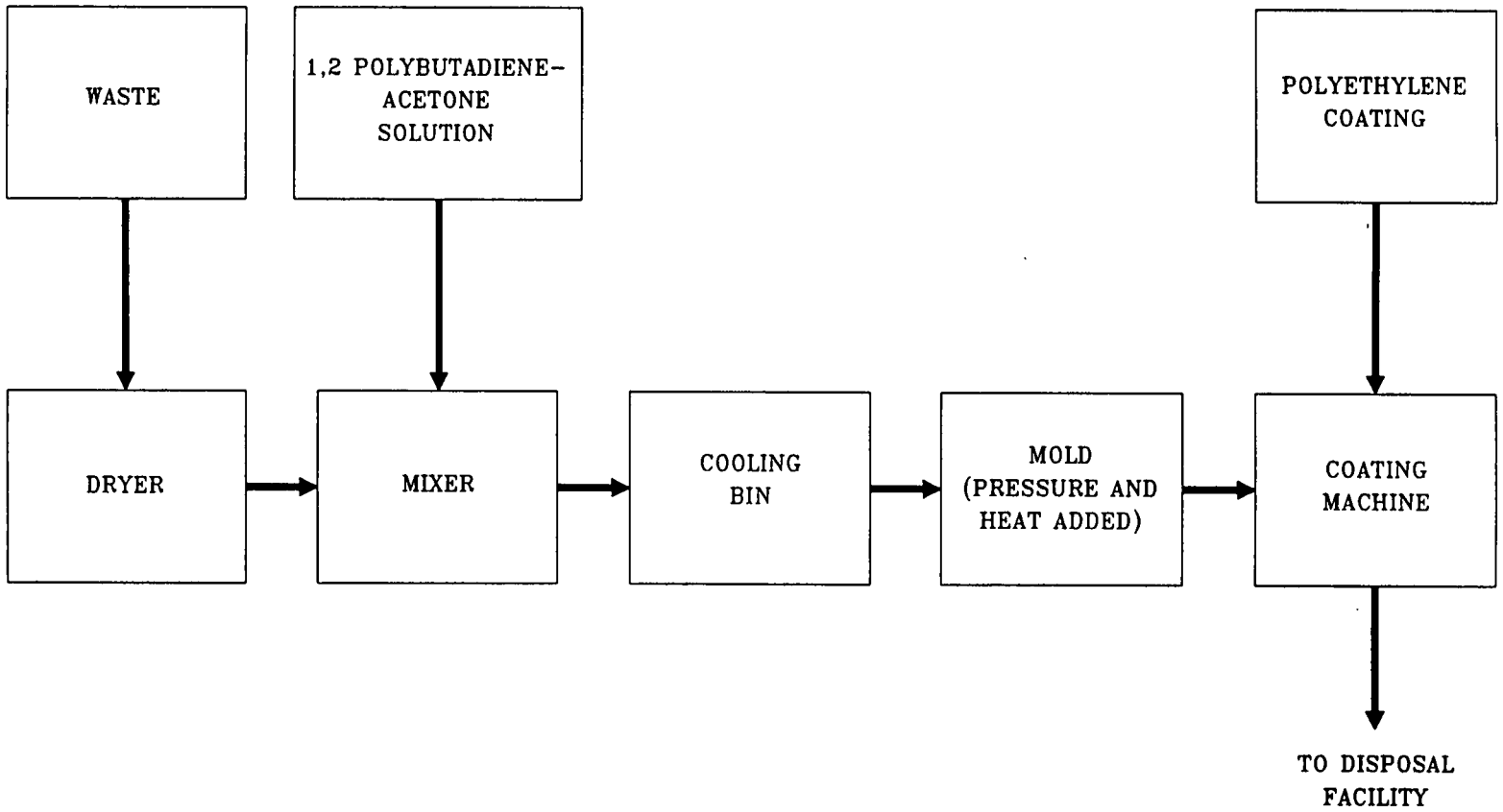

FIGURE 7.5: BLOCK FLOW DIAGRAM
FOR A TYPICAL SURFACE ENCAPSULATION TECHNIQUE

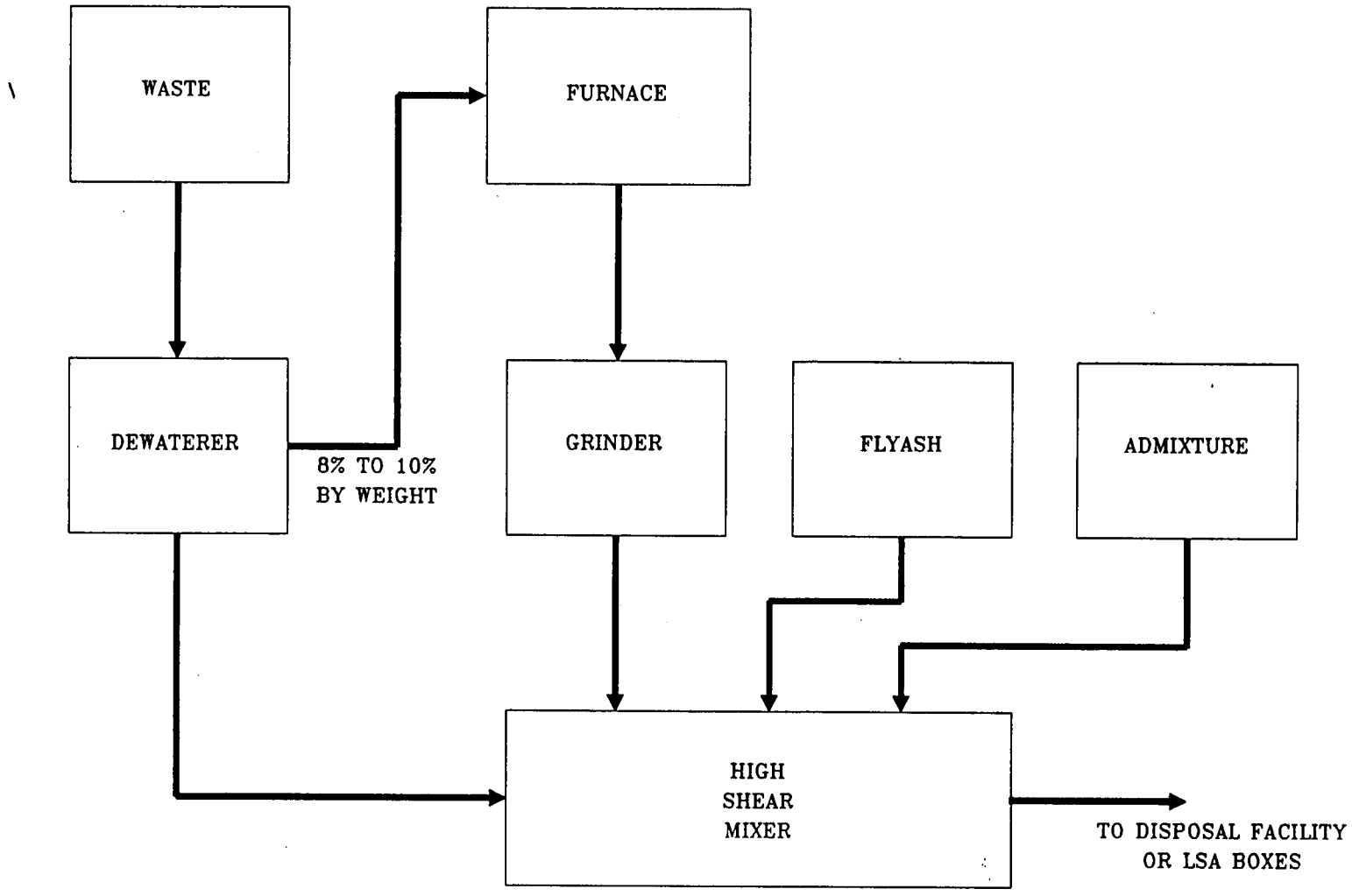

FIGURE 7.6: BLOCK FLOW DIAGRAM
FOR A TYPICAL SELF-CEMENTING PROCESS

When disposing of this type of waste, this self-cementing process has the following advantages:

1) The process produces a nonbiodegradable, nonflammable, and stable product.

2) A completely dry waste is not required, since water is used up in hydration reactions.

3) This method produces a waste form with the same characteristics as cement but the increase in volume is much less than cement-based processes.

Their disadvantages are that:

1) They are fairly energy intensive.

2) Skilled labor is required.

3) Expensive machinery is required.

4) May require HEPA filters.

7.2 MIXING PROCESSES

The EPA (Cullinane, Jones and Malone, 1986) has identified four different mixing processes. They are:

1. Batch processes
2. Continuous processes
3. Portable processes
4. In-situ processes

In-situ processes were not considered since the perception of release problems and the suitability of the current site to act as the final repository for the wastes is questionable.

7.2.1 Batch Processes

In these processes, the reagents and the waste are added to a container, such as a 55-gallon drum or LSA box. Mixing is then performed using either a rotary mixing element, or a system designed to roll or tumble the entire sealed container. This simplifies handling and transportation, and limits worker exposure. However, the cost of the containers limit these processes to small scale operations (Wiles, 1987).

7.2.2 Continuous Processes

In these processes, the reagents and the waste are fed into a specially designed device for mixing. This device could be a helical ribbon mixer, a cone or screw-type mixer, a single or twin screw extruder, a static mixer or a pug mill. This provides a range of capacities of operation and the ability to provide for any needed change in treatment capacity with addition or deletion of parallel processing lines.

7.2.3 Portable Processes

These processes are basically smaller scale continuous processes employing skid or trailer mounted equipment. This increases flexibility since the equipment can be moved from site to site. However, the cost per ton of processed waste is high because of economy of scale. In addition, the need for a compact size limits their throughput.

8.0 EVALUATION OF SLUDGE SOLIDIFICATION METHODS

8.1 TECHNICAL FEASIBILITY

To make a final selection of the solidification process for Pit 5, the different options are compared. The criteria that will be used follows:

1. Cost - least cost.

2. Raw Materials - they should be plentiful, with a reliable supply source, and not introduce complications into the process.

3. Experience - the process to be used should be one with a established track record at other sites, so that one can be confident that it will perform adequately.

4. Energy Usage - the lower the energy needs of the process, the better.

5. Volume Increase - the ideal process is one with little or no increase in volume.

6. Leachability - resistance of the final waste form to the release of undesirable constituents.

7. Complexity - simpler, more reliable systems are preferable to more complex systems.

It is recognized that there is some overlap between these categories and that several others could be added. However, it is felt that these seven give a sufficiently detailed analysis to allow the final judgement to be made. Table 8.1 shows the overall comparison of all six options. A detailed discussion of each option was presented in Section 7. Based on Table 8.1, a cement-based process is the best available method of solidifying Pit 5 sludge.

A full cement-based process would be expensive. All operating or soon to be operating cement-based solidification processes use a combination of cement and pozzolanic materials. Based on experience at Oak Ridge, the Savannah River Plant, and Hanford, indications are that fly ash is a good pozzolanic material to use with the cement-based process. Fly ash reacts with any free calcium hydroxide, which improves the chemical resistance and strength of the final product. Also, fly ash can act as an adsorbent, helping to trap waste material in the concrete matrix (Cullinane, Jones, and Malone, 1986). The proposed process for solidification of Pit 5 wastes is presented in Section 9.

Table 8.1: Comparison of Solidification Alternatives

Process	Cost	Raw Materials	Experience	Energy Use	Volume Increase	Leachability	Complexity	Score
Cement-Based	+1	+1	+1	+1	-1	0	+1	4
Pozzolanic	+1	+1	+1	+1	-1	-1	+1	3
Thermoplastic	-1	-1	0	-1	+1	+1	-1	-2
Organic Polymer	0	-1	0	0	+1	-1	0	-1
Surface Encapsulation	-1	0	-1	-1	+1	+1	-1	-2
Self-Cementing	+1	0	+1	0	+1	0	-1	2

+1 Better or more desirable.
0 Neutral
-1 Worse or less desirable.

8.2 WORKER SAFETY AND HEALTH

As mentioned in Section 6, the ES&H Procedures and the Radiation Control Manual will be the guiding safety documents for the solidification of the Pit 5 sludge. It should be noted that during previous sludge sampling efforts [Characterization Investigation Study - Geotechnical Evaluation of Waste Pit Material Properties and Boring Logs, Weston, 1988] irritating odors were encountered that forced the workers to wear Level B protective clothing.

The solidification of the sludge from Pit 5 is not expected to be a labor intensive effort. In fact, only 4 to 8 employees will be needed to operate and maintain the solidification equipment. The specific number of employees and their responsibilities will depend on the equipment selected.

Data from the sludge sampling tests show dose rates ranging from 0.17 to 2.38 mR/hr for mixed Beta/Gamma fields and from 0.68 to 0.58 mR/hr for Gamma only. The referenced study does not indicate at what distance from the sludge the measurements were made, however, it is implied that the radiation detector was positioned very close to the samples. These measured dose rates are greater than the recommended maximum dose rates of 0.125 mrem/hr for continuously occupied areas. The equipment selection will affect the solidification procedures, the positioning of the workers and the dose rates to which the operators will be exposed. By positioning the control room operators away from the sludge storage tanks their radiation exposures will be in accordance with as low as reasonably achievable (ALARA) philosophy.

All of the solidification methods discussed in Section 7 involve similar safety issues and there are no unique concerns for any one method. The safety of the workers can be ensured with similar procedures for each of the methods.

9.0 DESCRIPTION OF SELECTED SLUDGE SOLIDIFICATION PROCESS (BASED ON CEMENT & FLY ASH)

9.1 GENERAL

This process involves the solidification of Pit 5 sludges with cement, fly ash and certain admixtures to control the setting time of the grout slurry. Certain other cementitious materials such as ground blast furnace slag or some types of clays could also be used as solidification agents, if found suitable. The grout slurry may be pumped to a specially prepared on-site facility for solidification and final disposal. Alternatively, the grout slurry may be packaged into containers (LSA boxes, 55-gallon drums, etc.) for solidification and transported to an on-site facility for final disposal. The solidification of sludge will produce a stable, nonleachable waste form suitable for on-site disposal. The details of the waste disposal facility will be covered under a separate study report.

Figures 9.1, 9.2 and 9.3 illustrate the general process envisioned for Pit 5 sludge solidification.

As illustrated on the attached process flow diagrams (SK-P-001, SK-P-002 and SK-P-003), the sludge is mixed in the pit prior to pumping to increase its homogeneity. This sludge is then pumped to the sludge thickener at about 20 wt. % (20% by weight) solids.

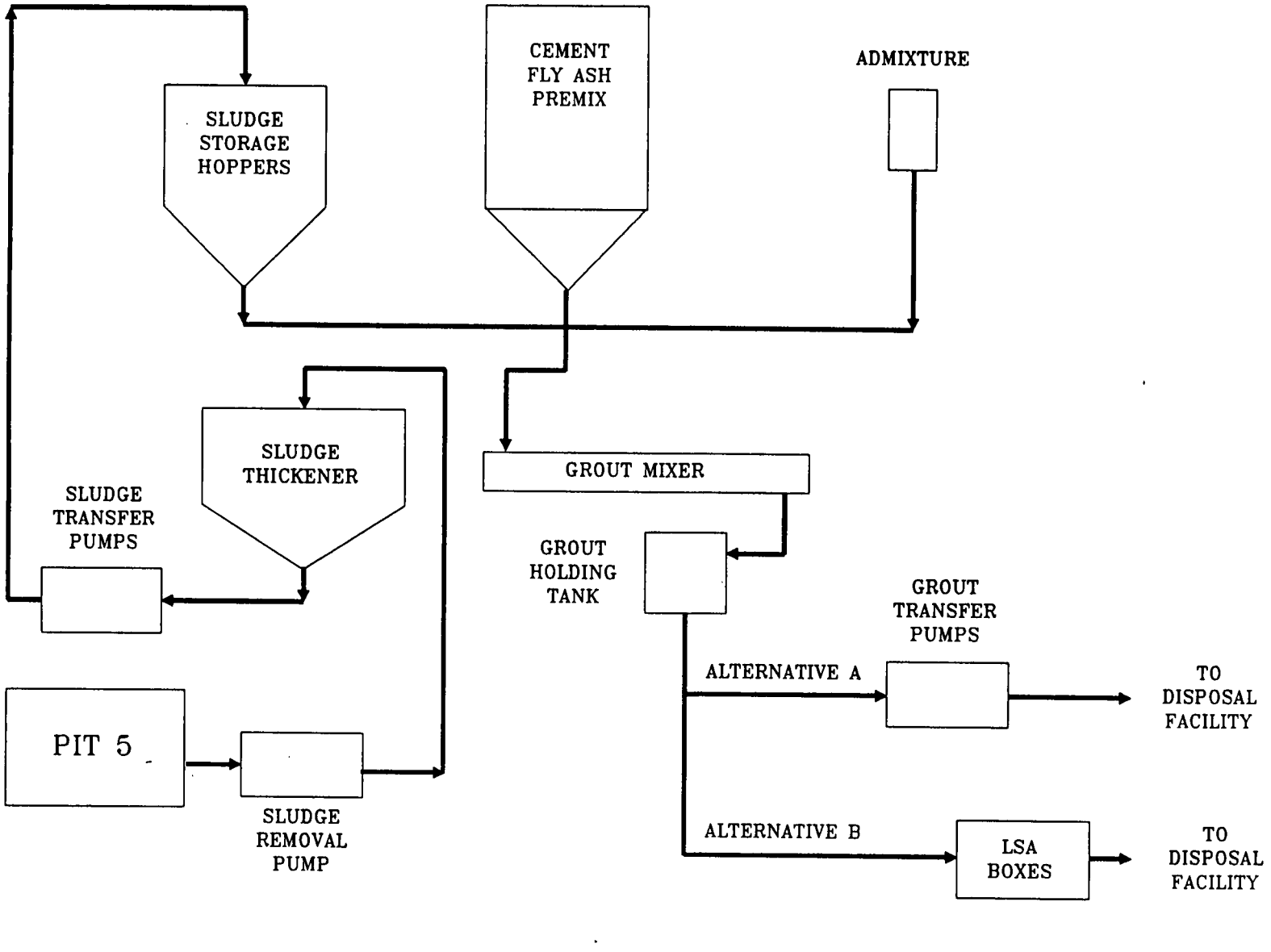

FIGURE 9.1: SLUDGE SOLIDIFICATION BLOCK DIAGRAM

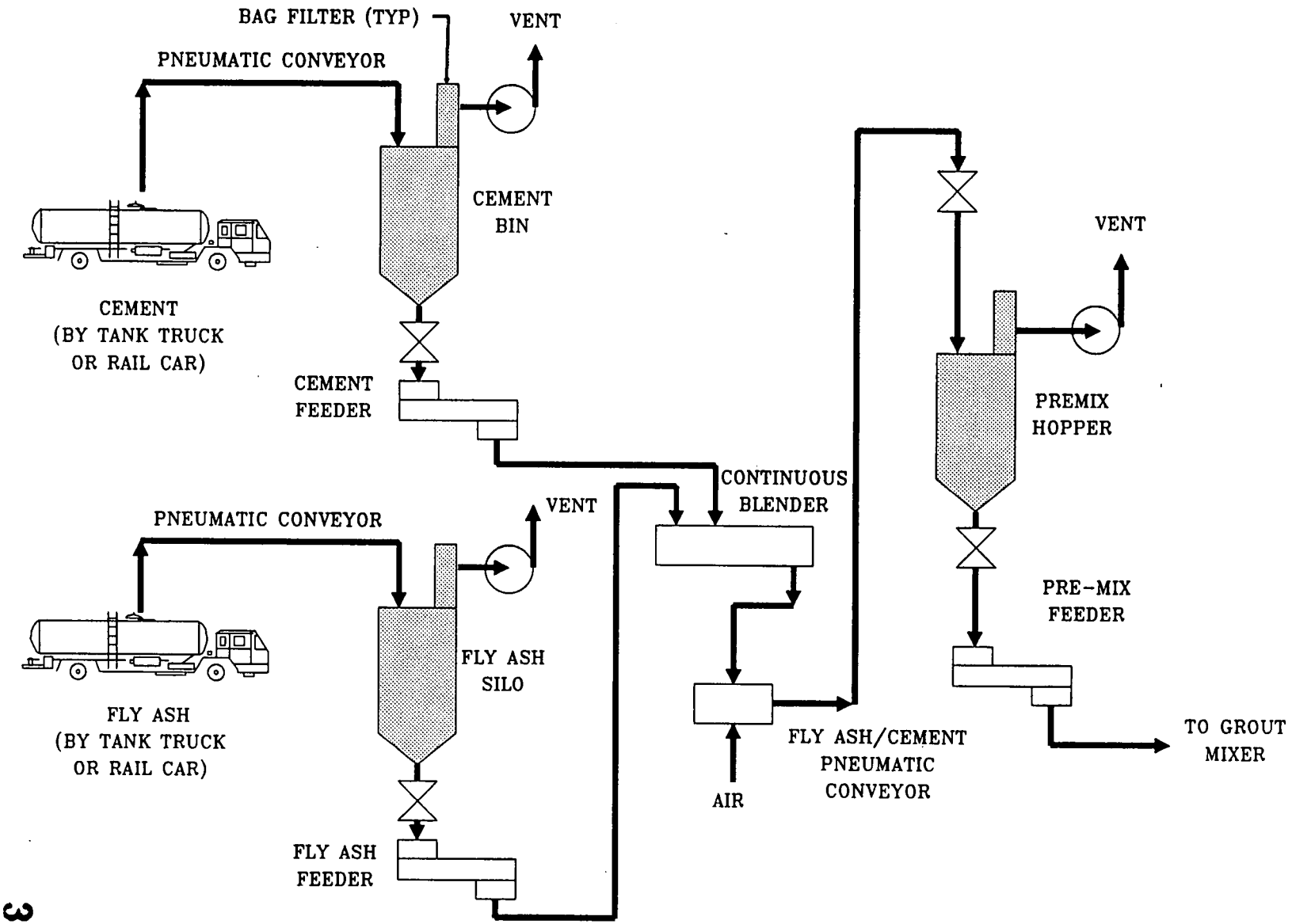

FIGURE 9.2: CEMENT/FLYASH HANDLING FLOW DIAGRAM

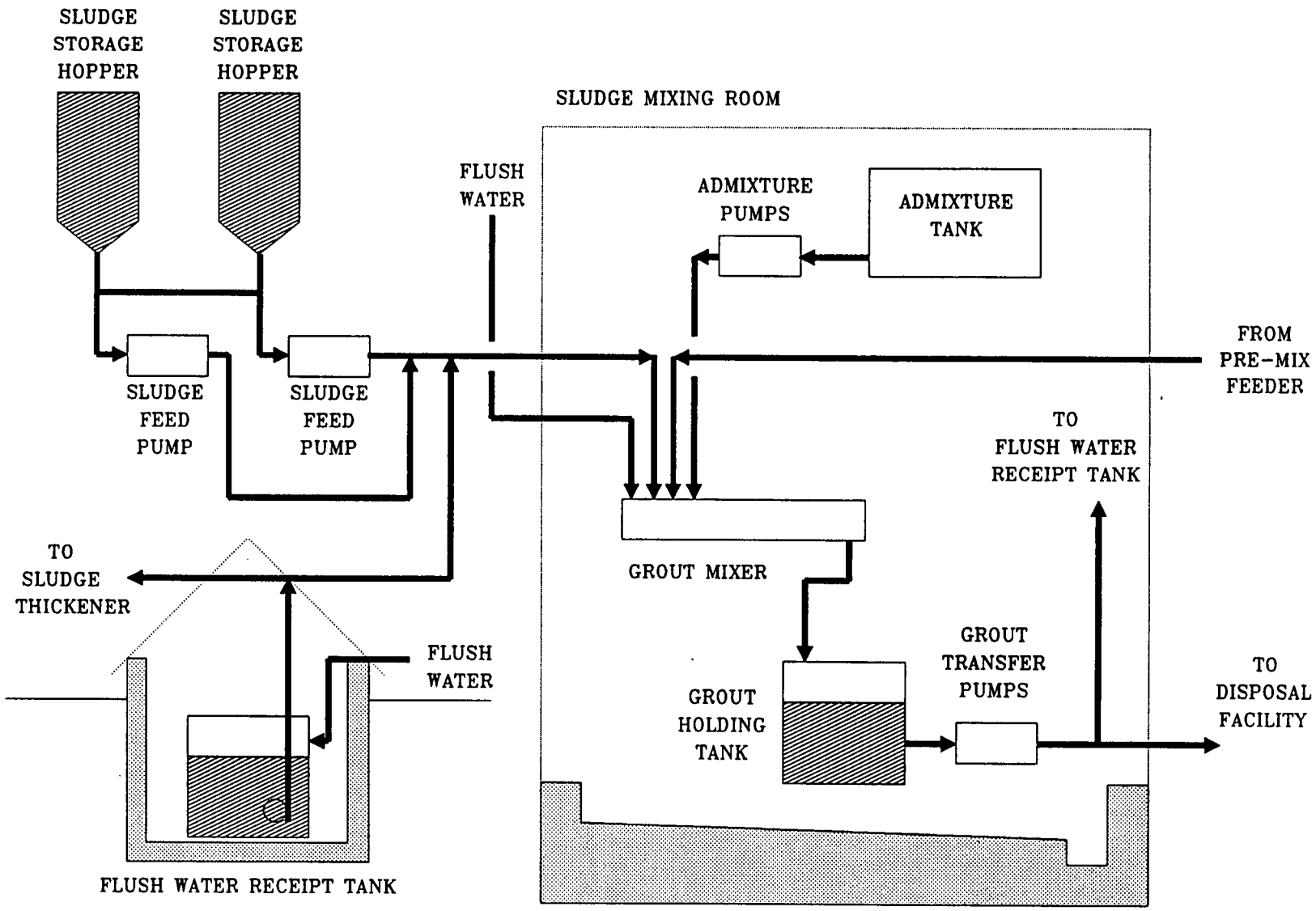

FIGURE 9.3: SLUDGE MIXING FLOW DIAGRAM

The sludge thickener, controlled by a gamma gage, produces sludge with about 30 wt. % solids. The clear water from the thickener overflows to the wet sump. From there, it can be returned to Pit 5 or used to flush the sludge lines.

The thickened sludge is transported via the sludge transfer pumps to the sludge storage hoppers. From there, the sludge feed pumps transfer the sludge to the grout mixer.

Cement and fly ash can be brought into the system by tanker truck or rail car and unloaded into the cement or fly ash bins. Feeders then transfer measured portions of both solidification agents to the fly ash/cement continuous blender. This produces a controlled blend of material that is moved into the premix hopper via the fly ash/cement pneumatic conveyor. The premix feeder then transfers this blend to the grout mixer.

The set retarder is delivered by truck to the admixture tank. From which, the admixture metering pumps add it to the grout mixer.

At the grout mixer, the sludge, cement, fly ash, and admixture are blended to form grout. This grout flows by gravity into the grout holding tank, which serves as a reservoir for the grout transfer pumps. These pumps transfer the grout from the grout holding tank to the disposal facility.

At the end of each day's operations, all of the lines must be flushed to prevent solids from settling out or the grout from hardening in the lines. Booster pumps supply high pressure water for flushing. Process water can also be added to the system at the grout mixer or after the grout transfer pumps. All flush water is returned to the flush water receipt tank (FWRT). This water, if low in solids, can be used instead of process water for flushing the grout mixer, grout holding tank, and grout transfer pump. If high in solids, the water from the FWRT can be returned to the sludge thickener.

9.2 MIX FOR SOLIDIFICATION

The design of a suitable mix formulation should be based upon the results of laboratory/pilot plant treatability studies using Pit 5 sludge. Such tests are required. In the absence of test data on sludge solidification, this study has based its mix formulation on a similar existing project. The Z-Area

Saltstone Project at Savannah River Plant has been selected for this purpose. The mix for the Saltstone Project is as follows:

Decontaminated Salt Solution	- 40% by weight
Cement	- 12% by weight
Fly Ash	- 48% by weight

The above mix contains 40 wt. % liquid and 60 wt. % solids. The same proportion of liquid and solids will be maintained for Pit 5 sludge. No extra water other than that associated with sludge will be used. Pit 5 sludge containing 30% solids by weight will be used in the solidification process. This is based on the assumption that 30 wt. % solids sludge is pumpable. The proportion of cement in the mix will be maintained at 12 wt. % and the combined proportion of fly ash and sludge solids will be 48 wt. %. The water component, 40% by weight, will be provided by the 30 wt. % solids sludge. Based on the above considerations, the following mix has been established for Pit 5:

Components	Product
Water from sludge	- 40% by weight
Solids from sludge (30 wt% solids)	- 17% by weight
Cement	- 12% by weight
Fly Ash (48%-17%)	- 31% by weight
Total	100% by weight

It should be noted that in a 30 wt. % solids sludge (70 parts water: 30 parts of solids), 40 parts of water are associated with about 17 parts of solids. The above formulation is tentative and will probably have to be revised after the actual test results on Pit 5 sludge solidification are available. The possibility of adding some other solidification agents such as blast furnace slag or clay to the mix cannot be ruled out.

9.3 PROCESSING RATE

As per Parsons letter (P-WP-10), 18 months are available for the removal and processing of sludge from Pit 5. For the purpose of this study, it will be assumed that 375 working days (260 available week days per year less 10 days per year for holidays and bad weather) are available for sludge processing. Also, given daily start up and shutdown requirements, it is assumed that 6 hours per day are available for sludge processing. This necessitates a sludge removal rate of 300 gpm at 20% by weight solids. This corresponds to

199,400 pounds of solids per day. After the sludge thickener, the sludge will be thickened to about 30 wt. % solids. This translates to a pumping rate of about 180 gpm into the sludge hoppers. This is the flow rate at which the solidification plant will be designed to operate.

Based on the design mixture of 12% cement to 31% fly ash to 57% sludge (assuming 30% solids), this design flow will require 31 gpm (814 lbs/min) of cement, and 96 gpm (1,681 lbs/min) of fly ash (note, rates are expressed as gallons of final grout per minute for convenience). Therefore, approximately 310 gpm of grout will be produced for disposal. This grout, if pumped into containers, requires a large packaging facility i.e. about 340 drums (55-gallon size) or 39 LSA boxes (64 cubic feet capacity) per hour. These figures give the basis for the design of all of the equipment and pumps in the solidification facility.

It should be noted that this grout production rate is significantly higher than any of the other operating facilities discussed in Section 7.0. Given the temporary nature of this processing facility, lowering this production rate would lower the capital expenditures. It would, however, extend the time to remediate Pit 5. Time requirements for three different sludge pumping rates, and the corresponding grout production rates are shown in Table 9.1. These smaller processing rates would result in savings due to decreased pump sizes, smaller hopper and bin sizes and a smaller mixer.

Table 9.1: Time Schedules for Different Sludge Pumping Rates

Sludge Pumping Rate	Grout Production Rate	Months to Complete
60	100	54
120	205	27
180	310	18

9.4 REQUIREMENTS OF CEMENT AND FLY ASH AND GROUT PRODUCTION

Based on the above mix, the following quantities of different constituents will be required for one ton of grout (see Appendix 1):

Sludge	113 Gallons
Cement	0.12 Tons
Fly Ash	0.31 Tons

The total solids in sludge are estimated at 37,500 tons, which corresponds to 24,683,925 gallons of 30 wt. % solids sludge. Given the time constraint of 18 months, assume 375 working days are available for sludge processing. This leads to a sludge treatment rate of 65,824 gallons per day. Based on above formulation, daily requirements for cement and fly ash will be 70 and 180 tons respectively. Total requirements for cement and fly ash will be 26,250 and 67,500 tons respectively. Total grout production will be approximately 4.6 million cubic feet. See Table 9.2 and Appendix for details.

Table 9.2
Requirements Of Cement And Fly Ash
And Grout Production

Description	Quantity
1. Total sludge solids (sp. gr. 2.43)	37,500 tons 75,000,000 lbs. 494,750 cu. ft.
2. Sludge volume @ 30 wt. % solids	3,299,990 cu. ft. 24,683,925 gal.
3. Time schedule (6 hrs/day effective, 250 days/year)	375 days 2250 hours
4. <u>Design Basis</u> (1 ton of grout) Sludge (30 wt. % solids) Cement Fly Ash	 113 gal. 0.12 tons 0.31 tons
4. <u>Requirements Per Day</u> Sludge Cement Fly Ash	 65,824 gal. 70 tons 180 tons
5. Total cement requirement (sp. gr. 3.15)	26,250 tons 266,790 cu. ft.
6. Total fly ash requirement (sp. gr. 2.1)	67,500 tons 1,033,810 cu. ft.
7. Total volume of grout produced	4,600,590 cu. ft. say 4,600,000 cu. ft.

<u>Note</u>: 1. See Appendix 1 for detailed calculations.
2. Volumes of cement and fly ash represent the actual volumes in grout and are based on specific gravities.

9.5 SLUDGE THICKENING

It is planned that the sludge will be pumped from Pit 5 at about 20 wt. % solids. However, in actual practice, it will be difficult to control the solids content of the sludge; therefore, it is expected that the solids content of the pumped sludge could vary widely. All fluctuations in solids content of the sludge could be controlled by proper operation of the thickener. A nuclear density gage installed at the thickener outlet

will monitor the sludge density and will shut off the sludge transfer pumps if the sludge density falls below a preset limit.

The density control on the thickened sludge is vital as the processing of dilute sludge will result in unduly large quantities of the final solid waste form for disposal. This is due to larger volume of sludge to be handled coupled with increased requirements for cement and fly ash. Apart from increasing the size of the waste disposal facility, it will have an impact on cost. Although a 30 wt. % sludge has been tentatively selected for solidification, attempts have to be made in actual operations to work with sludge, containing more than 30 wt. % solids. However, this requires more data as to the pumping characteristics of sludge and the grout produced. It is likely that grout produced by 35 wt. % or more solids in sludge may present problems in handling or pumping. However, this needs to be determined by actual testing/operations. For the purposes of this study, a 30 wt. % solids sludge will form the basis for design.

The thickener overflow will exit to an aboveground carbon steel sump. Two return water pumps will pump the water back to Pit 5 for preparing the sludge slurry. Normally, one pump will be in operation and the other will be on standby. However, under high level conditions in the sump, the standby pump will be automatically started and both pumps will operate simultaneously. The return water line from the thickener will be designed for the full capacity of both pumps. This contingency has to be provided to take care of any upset conditions when very dilute sludges are pumped to the thickener. These pumps will operate with level controllers.

Sludge transfer pumps and thickener return water pumps will be installed away from the thickener so that exposure to operations and maintenance personnel is kept to the minimum. Table 9.3 gives the thickener input/output data.

Table 9.3
Thickener Input/Output Data

Description	Quantity
1. Total sludge solids (sp. gr. 2.43)	37,500 tons 494,750 cu. ft.
2. Sludge volume @ 30 wt. % solids	3,299,990 cu. ft. 24,683,925 gal.
3. Time schedule (6 hrs/day effective)	375 days 2250 hours
4. Sludge processing/thicker output (30 wt. % solids)	64,824 gal/day 180 GPM approx.
5. Thickener input @ 20 wt. % solids in sludge	290 GPM approx. (say 300 GPM)
6. Water recovered from thickener	110 GPM approx.

9.6 WATER REQUIREMENTS

Water requirements for solidification of Pit 5 sludge will depend upon the solids content of the sludge used for processing. Based on the limited data available on sludge pumpability, it is assumed that 30-35 wt. % solids sludge will be processed.

Pit 5 has 102,500 cubic yards of sludge (2,767,500 ft^3) with a solids content of 37,500 tons (494,750 ft^3 @ 2.43 sp. gr.). Based on this data, the water associated with sludge is 2,272,750 ft^3 (2,767,500 ft^3 -494,750 ft^3). In addition, 750,000 gallons (10,270 ft^3) of surface water is available in Pit 5. All of this will be available for sludge solidification.

It is shown in Table 9.4 that an extra 3,233,000 gallons of water will be required to process the sludge at 30 wt. % solids, whereas processing of sludge at 35 wt. % solid will leave an excess of 1,049,220 gallons of water. If feasible, the best approach would be to process the sludge at more than 30 wt. % solids so that the extra requirements of water and ultimately the project costs are kept to a minimum.

Table 9.4
Water Requirements For
Sludge Solidification

Item	Description	30 wt. % Solids Sludge	35 wt. % Solids Sludge
1.	Total solids in Pit 5 sludge	37,500 tons 75,000,000 lbs. 494,750 ft^3	37,500 tons 75,000,000 lbs. 494,750 ft^3
2.	Volume of sludge (solids+water)	3,299,990 ft^3	2,727,500 ft^3
3.	Water content of sludge (Item 2-1)	2,805,240 ft^3	2,232,750 ft^3
4.	Surface water (750,000 gal.)	100,270 ft^3	100,270 ft^3
5.	Water associated with sludge (see Paragraph 9.6)	2,272,750 ft^3	2,272,750 ft^3
6.	Total water available in Pit 5 (Item 4+5)	2,373,020 ft^3	2,373,020 ft^3
7.	Additional water required for sludge (Item 3-6)	432,220 ft^3 3,233,000 gal.	140,270 ft^3 1,049,220 gal.

9.7 SLUDGE STORAGE

Sludge storage capacity will be provided for (2) days (Total of 16 available hours on one shift per day basis) supply for the solidification facility to take care of inclement weather. Two equal sized carbon steel sludge storage tanks will be provided, each holding 90,000 gallons. In order to maintain fluidity and nearly uniform consistency of the sludge for solidification, these tanks will be equipped with paddle-type, slow speed mixers. During normal operations, one tank will be receiving the sludge from the thickener and the other will be feeding the grout mixer.

Sludge storage tanks will be equipped with level sensing devices to indicate the level of the sludge in each tank. High and low level alarms will be provided.

Flow to each tank will be directed through automatic inlet valves at the option of the operator.

The sludge tanks will be installed outdoors adjacent to the sludge mixing building. Concrete containment will be provided to meet the DOE regulatory requirements. A sump pump will be provided to pump any sludge leaks or spillages back to the thickener.

9.8 CEMENT AND FLY ASH HANDLING AND STORAGE

Cement and fly ash, the two primary sludge solidification agents, will be received by railcars or tank trucks. These will be pneumatically unloaded and stored in bins. Cement storage capacity will be provided for 6 days, the cement bin will have a nominal capacity of 450 tons. Fly ash storage capacity will be provided for 4 days with 2 bins of 360 tons capacity each. All the cement and fly ash bins will be of the same physical size.

All the bins will be provided with bin vent filters. All transfer points with potential for dust emissions will be connected to dust collection system(s).

The mode of transport for cement and fly ash will depend upon the source of supply. Particularly, the source of supply for fly ash should be considered in advance before using any fly ash for solidification testing. In case the supply sources are near, truck transport is likely to be more economical, as the capital expenditure for the railcar unloading system will be eliminated. However, this could be a separate study after the requirements for various raw materials have been established by actual tests. Cement and ash storage bins will be equipped with level instruments for operational control.

Depending upon actual requirements, separate bins for clay and/or blast furnace slag could also be installed. Details of the material handling equipment will be established only after the mix and its constituents have been determined. The conceptual design as shown in the process flow diagram has enough flexibility to meet the requirements of any specific mix.

9.9 SLUDGE AND GROUT PUMPING

Pumping of sludge and grout (slurries) has to take into consideration many aspects such as the slurry density, viscosity, particle size, specific gravity of solids, fluid velocity and pipe wear. The fluid velocity must

provide enough turbulence to keep the solids in suspension. Homogenous slurries provide enough turbulence to keep the solids in suspension at relatively low velocities, less than 6 feet per second. In case of heterogenous slurries, where the solids have a tendency to settle quickly, relatively high velocities above 7 feet per second are necessary. A velocity of 4-7 feet per second is normally practical and economical. Pipe wear becomes a concern at velocities above 8-10 feet per second.

The sludge in Pit 5 is comprised of very fine solids (approximately 80% minus 200 mesh) and for the purpose of this study it is assumed to be pumpable at 30 wt. % solids in sludge. It is quite likely that sludge may be pumpable at 35 wt. % or higher solids. But this needs to be confirmed by further testing.

Slurry pumping is usually handled by rubber-lined centrifugal pumps, positive displacement piston pumps, diaphragm pumps and "advancing cavity" pumps. Submersible centrifugal type pumps were successfully used for pumping Pit 5 sludge during the test in 1976. Piston type positive-displacement pumps are particularly suitable where pumping pressures above 600 psi are required. Such high pressures are not attainable by multiple centrifugal pumps in series. Diaphragm pumps are suitable for low-volume, low-head system and use compressed air as the motive force. Progressive cavity type pumps are very useful for slurries at moderate flows and pressures, and are well suited to very thick slurries such as cement grout. Considering the general characteristics of grout, it is proposed to use Moyno, or equal, progressive cavity type pumps for this service. Sludge at 30 wt. % or more solids can be handled by both the centrifugal or progressive cavity type pumps. However, it is preferred to use progressive cavity type pumps for handling thickener underflow and for feeding the sludge to grout mixer as these pumps can handle easily thick slurries or even pastes with very high viscosities. This is not true for the centrifugal pumps.

After the day's work all lines carrying sludge and grout will be flushed with high pressure water.

9.10 GROUT MIXING

The Pit 5 sludge, cement and fly ash will be mixed in a continuous mixer (Readco Continuous Processor, or equivalent). This mixer is equipped with two parallel shafts of agitators that rotate in the same direction.

The blades of one agitator assembly maintain close clearances with the second assembly as well as with the walls of the barrel. The agitator assemblies move the ingredients forward and backward, assuring a continual mixing and re-mixing within any given section of the mixer. This type of continuous mixer is in operation at Savannah River Plant, Aiken, SC, and at Hanford, Washington for waste solidification and is considered appropriate for Pit 5 sludge solidification as well. The mixer will have enough capacity to process 180 gpm of sludge along with the required quantities of cement and fly ash to produce about 310 gpm of grout. A set retarding agent, if required, will also be metered into the continuous mixer.

The grout slurry will be discharged into a holding tank equipped with a center mounted mixer. The grout transfer pumps will transfer the grout through a pipeline to the disposal facility. Grout pumping will have to be started soon after mixing, as the grout has a tendency to set if allowed to become static.

9.11 FLUSH WATER RECEIPT TANK

The FWRT having a capacity of 5,000 gallons, will receive wastewater from several sources including process area floor drains, the sump pump in the FWRT's secondary containment and flush water from transfer lines flushing.

The flush water pump can transfer flush water to the grout mixer, if needed. Normally, it will return the water in the FWRT to the sludge thickener. In addition, the FWRT is equipped with an agitator to prevent any suspended solids contained in the flush water from settling.

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11.0 APPENDIX

Calculations

Client: WMCO, FERNALD, OHIO — Job No. 4444-39 — Sheet 1 of 2

Subject: PIT 5 - SLUDGE SOLIDIFICATION - DETERMINE MIX — By: K. NAYAR — Date: 2.6.89 — Ckd. — Rev.

1. PROBLEM: Determine the proportion by which sludge cement & fly ash should be mixed for solidification.

2. BASIS OF DESIGN

Since no test data is available on solidification of Pit 5 sludge, the data for SALTSTONE PROJECT at Savanah River Plant will be used as the design basis. The following mix will be used for Saltstone Project at SRP:

Decontaminated salt solution	- 40 % by wt.	
Cement	- 12 % by wt.	60 % by wt. total solids
Fly ash	- 48 % by wt.	
Total	100 %	

For Pit 5 solidification, the following mix may be used:

Water from sludge	- 40 % by wt	
Solids from sludge	- x % (associated with sludge water that constitutes 40 % by wt. of liquid in grout)	
Cement	- 12 % by wt	
Fly ash	- 48 - x % by wt	
Total	100 %	

3. CALCULATIONS

Assume Pit 5 sludge containing 30 % solids by weight is pumpable and will be used in the solidification process.

Solids in sludge - 30 % by wt.
water in sludge - 70 % by wt.

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Amount of solids associated with 40 parts of water in 30 % solids sludge - $\frac{30}{70} \times 40 = 17.1$ parts $\approx$ 17 parts

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 2
Subject PIT 5 - SLUDGE SOLIDIFICATION - By K. NAYAR Date 2.6.89
DETERMINE MIX Ckd. Rev.

Similarly, amount of water associated with 40 parts of water in 35% solids sludge $= \frac{35}{65} \times 40 = 21.54$ parts

say 21 parts

Proposed Mix for Pit 5 sludge Solidification
(Basis: SRP Data on Saltstone Project)

Description	30% Solids in sludge	35% solids in sludge
Water in sludge	40 lbs	40 lbs
Solids in sludge (x lbs)	17 lbs	21 lbs
Cement	12 lbs	12 lbs
Fly ash ($48 - x$)	31 lbs	27 lbs
TOTAL GROUT	100 lbs	100 lbs

4. CONCLUSIONS

1) Based on the assumption that sludge with 30% solids is pumpable, use the mix for 30% solids in sludge for plant design as it will be more conservative as regards the total volume of grout produced.

2) Actual tests should be conducted to determine the optimum mix for Pit 5 sludge solidification.

Client: WMCO, FERNALD OHIO Job No. 4444-39 Sheet 1 of 3
Subject: PIT 5 SLUDGE SOLIDIFICATION - ESTIMATE GROUT VOLUME By: K. NAYAR Date: 2.6.89
Ckd. Rev.

1. PROBLEM : Estimate grout volume

2. BASIS OF DESIGN
- Assume 30 wt % solids in sludge
- Mix based on Z-Area Saltstone Project at SRP : 40 parts liquid to 60 parts cement blend (cement & fly ash)
- MIX (see calculation sheet dated 2.6.89)

Sludge (30 wt % solids)	- 40	lbs water from sludge
	17	lbs solids from sludge
Cement	- 12	lbs
Fly Ash	- 31	lbs
TOTAL	100	lbs of grout

3. CALCULATIONS

ESTIMATE OF SLUDGE, CEMENT AND FLY ASH IN ONE TON OF GROUT

1. Sludge

Sludge contributes water @ 40 lbs per 100 lbs of grout

Water from sludge $= 40 \times \frac{2000}{100} = 800$ lbs

$= \frac{800}{8.34} = 95.9$ Gal ≈ 96 Gal

Solids from sludge @ 17% in grout $= 17 \times \frac{2000}{100} = 340$ lbs

Specific gravity of sludge solids $= 2.43$ (PROJ No. 2754-01-01-32 Geotechnical Evaluation Report by Roy F. Weston, Inc. March, 1988)

Volume of sludge solids $= \frac{340}{2.43 \times 8.34} = 16.78$ Gal ≈ 17 Gal

Total volume of sludge $= 96$ Gal $+ 17$ Gal $= \underline{113 \text{ Gal}}$

Total weight of sludge $= 800$ lbs water $+ 340$ lbs solids $= \underline{1140 \text{ lbs}}$

2. Cement @ 12 % in grout $= 12 \times \frac{2000}{100} = 240$ lbs $= \underline{0.12 \text{ Tons}}$

3. Fly Ash @ 31 % in grout $= 31 \times \frac{2000}{100} = 620$ lbs $= \underline{0.31 \text{ Tons}}$

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 3

Subject PIT 5 - SLUDGE SOLIDIFICATION - ESTIMATE OF GROUT VOLUME By K. NAYAR Date 2.6.89

Ckd. Rev.

SUMMARY

One ton of mixed grout will require:

			wt
Sludge (sp.Gr.=1.21):	113	Gal	1140 lbs
Cement (sp.Gr.=3.15):	0.12	Tons	240 lbs
Fly Ash (sp.Gr.=2.1):	0.31	Tons	620 lbs
		Total	2000

TOTAL VOLUME OF MIXED GROUT

1. Total sludge in Pit 5 = 102,000 CY or 2,754,000 ft^3 or 20,599,920 GAL.

Sludge solids (Table 1-1, Prelim. Rem. Action) = 37,500 tons or 75,000,000 lbs

Pumpable sludge (Assumed) = 30% solids by wt. or 70% by wt. water

Total vol. of sludge solids = $\frac{75000,000}{2.43 \times 8.34 \times 7.48} \approx 494,750\ ft^3$

Total vol. of water in sludge @ 30% solids in sludge (assumed) = $\frac{75,000,000 \times 70}{8.34 \times 7.48 \times 30} = 2,805,240\ ft^3$

Total volume of sludge @ 30% solids by wt. = 3,299,990 ft^3 or 24,683,925 Gal

2. CEMENT

Total cement required @ 0.12 tons per 113 gallons of 30% sludge = $\frac{0.12}{113} \times 24,683,925 = 26,213$ tons

specific gravity of cement = 3.15

volume of cement = $\frac{26,213\ tons \times 2000\ lbs/ton}{3.15 \times 8.34\ lbs/Gal}$

= 1,995,586 Gal

or 266,790 ft^3

3. FLY ASH

Total fly ash required @ 0.31 tons per 113 gallons of 30% sludge = $\frac{0.31}{113} \times 24,683,925$ tons

= 67,717 tons

volume of fly ash @ sp. Gr. 2.1 = $\frac{67,717\ tons \times 2000\ lbs/ton}{2.1 \times 8.34\ lbs/Gal}$

= 7,732,895 Gal = 1,033,810 ft^3

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 3 of 3

Subject PIT 5 SLUDGE SOLIDIFICATION – ESTIMATE OF GROUT VOLUME By K. NAYAR Date 2.6.89

Ckd. Rev.

Total volume of mixed grout = 3,299,990 ft^3 30% sludge
266,790 ft^3 cement
1,033,810 ft^3 fly ash
4,600,590 ft^3

≈ 4,600,000 ft^3

DAILY GROUT PRODUCTION

Time schedule for solidification – 78 weeks or 1½ years
Number of working days/year – 250 days
(allow 10 days/year for inclement weather)
Total number of effective working days – 375 days in 1½ years
Effective working hours per day – 6
Total number of effective working hrs – 250 days/yr × 1.5 × 6
= 2250 Hrs.

Description	TOTAL GROUT		GROUT / DAY		Remarks
	Cubic Feet	Gallons	Cu. Ft	Gallons	
Sludge 30 wt% solids	3,299,990	24,683,925	8800	65,824	≈180 GPM
Cement	266,790	1,995,586	711	5,322	
Fly Ash	1,033,810	7,732,895	2757	20,621	
TOTAL	4,600,600 ≈4,600,000	34,412,406	12,268	91,767	

4. CONCLUSIONS

1. Total volume of grout for disposal will be about 4.6 million cubic feet.
2. Grout mixing plant will have to handle sludge (30% solids) @ 180 GPM approximately.

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 1 of 2 **314**

Subject PIT 5, SLUDGE SOLIDIFICATION - DETERMINE WATER REQUIREMENTS By K. NAYAR Date 2.7.89 Ckd. Rev.

1. PROBLEM: Determine water requirements for sludge solidification

2. BASIS of DESIGN

Total sludge in Pit 5 = 102,500 CY
or 2,767,500 ft^3
or 20,700,900 Gallons

Free water in Pit 5 = 750,000 Gallons or 100,270 ft^3.

sludge solids = 37,500 Tons
or 75,000,000 lbs

sludge solids sp. Gr. = 2.43 (Geotechnical Evaluation Report by Roy F. Weston, Inc. March, 1988)

3. CALCULATIONS

Total volume of sludge solids $= \frac{75,000,000}{2.43 \times 8.34 \times 7.48} = 494,750\ ft^3$

Vol. of water in sludge = 2,767,500 − 494,750 ft^3
= 2,272,750 ft^3

A. Water Requirements @ 30% Solids in Sludge

Total volume of water in sludge @ 30 Wt % solids $= \frac{75,000,000}{8.34 \times 7.48} \times \frac{70}{30} = 2,805,240\ ft^3$

Total water available in Pit5 = Free water + Water in sludge
= 100,270 ft^3 + 2,272,750 ft^3
= 2,373,020 ft^3

Extra water required for making 30 Wt % solids sludge = 2,805,240 ft^3 − 2,373,020 ft^3
= 432,220 ft^3
or 3,233,000 Gal. Approx.

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B. Water Requirements @ 35 % Solids in Sludge

Total vol. of water in sludge @ 35 Wt. % solids $= \frac{75,000,000}{8.34 \times 7.48} \times \frac{65}{35} = 2,232,750\ ft^3$

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 2
Subject PIT 5, SLUDGE SOLIDIFICATION - DETERMINE WATER REQUIREMENTS By K. NAYAR Date 2.7.89
Ckd. Rev.

Total water available in Pit 5 - 2,373,020 ft^3

Extra water available in Pit 5 for processing sludge @ 35 Wt.% solids for solidification - 2,373,020 ft^3 - 2,232,750 ft^3

= 140,270 ft^3

= 1,049,220 Gal.

4. CONCLUSIONS:

- Additional water requirements will be 3,233,000 Gals. for processing sludge containing 30 wt % solids. for solidification.

- Excess water in Pit 5 will be 1,049,200 Gals approximately for processing sludge containing 35 wt. % solids for solidification.

Client: WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 1 of 1

Subject: SLUDGE SOLIDIFICATION - DETERMINE DAILY REQUIREMENTS OF RAW MATERIALS By: K. NAYAR Date: 2.17.89 Ckd. Rev.

1. PROBLEM: Determine daily requirements of raw materials

2. BASIS OF DESIGN

One ton of mixed grout will require:

Sludge (sp. Gr. = 1.21)	=	113 Gal	1140 lbs
Cement (sp. Gr. = 3.15)	=	0.12 Tons	240 lbs
Fly Ash (sp. Gr. = 2.1)	=	0.31 Tons	620 lbs
		Total	2000 lbs

3. CALCULTIONS

Time schedule for sludge solidification : 18 months or $1\frac{1}{2}$ yrs.

Total effective operating hours @ 6 Hrs/day and 250 days/year : $(6 \times 250) \times 1.5$ = 2250 Hrs. or 375 days

Total vol. of sludge solids @ 30 Wt% solids and 2.43 sludge solids specific gravity $= \frac{37{,}500 \text{ tons} \times 2000}{8.34 \times 2.43 \times 7.48} \approx 494{,}750 \text{ ft}^3$

Water associated with sludge @ 30 Wt% solids $= \frac{37{,}500 \text{ tons} \times 2000}{8.34 \times 7.48} \times \frac{70}{30} = 2{,}805{,}240 \text{ ft}^3$

Total vol. of sludge @ 30% solids $= 494{,}750 \text{ ft}^3 + 2{,}805{,}240 \text{ ft}^3 = 3{,}299{,}990 \text{ ft}^3$

$= 3{,}299{,}990 \times 7.48 = 24{,}683{,}925$ Gal.

Sludge to be treated per day $= 24{,}683{,}925 \text{ Gal} \div 375 \text{ days} = 65{,}824$ Gal/day

Cement required per day : $\frac{0.12}{113} \times 65{,}824 \text{ Gal} = 69.9$ tons ≈ 70 tons $= 140{,}000$ lbs

Fly ash required per day : $\frac{0.31}{113} \times 65{,}824 = 180.6$ tons ≈ 180 tons $\approx 360{,}000$ lbs

4. SUMMARY

Material		Qty/Day	Bulk Vol./Day
Sludge	(Density: 75.5 lbs/ft³)	≈ 65,824 Gal	8800 ft³ or 65,824 Gal.
Cement	(Bulk Density: 94 lbs/ft³)	140,000 lbs (70 tons)	1489 ft³ or 11,138 Gal.
Fly Ash	(Bulk Density: 75 lbs/ft³)	360,000 lbs (180 tons)	4800 ft³ or 35,904 Gal.

Client WMCO Job No. 4444-39 Sheet 1 of 2
Subject SLUDGE SOLIDIFICATION : SIZE STORAGE HOPPERS / BINS By K. NAJAR Date 2.17.89
Ckd. Rev.

1. PROBLEM

Size storage hoppers / bins.

2. BASIS OF DESIGN

a) Requirements of Raw Materials / Day

Sludge (Density : 75.5 lbs/ft³) - 65,824 Gal
Cement (Bulk Density : 94 lbs/ft³) - 11,138 Gal (70 Tons)
Fly Ash (Bulk Density : 75 lbs/ft³) - 35,904 Gal (180 Tons)

b) Storage Capacity for Raw Materials

Effective working hours per day - 6 Hrs.
Sludge - 16 Hrs requirements
Cement - 6 days requirements
Fly Ash - 4 days requirements

3. CALCULATIONS

Sludge

Sludge storage capacity required for 16 hrs. @ 65,824 Gal / day of 6 hrs - $65,824 \times \frac{16}{6} = 175,531$ Gal $\approx 180,000$ Gal

Provide two tanks of 90,000 Gallons each.
Tank size (3384 Gal capacity per ft Ht.) - 24' Dia x 28' H
(Free board 1.4 ft. Approx.)

Cement

Cement storage capacity required @ 11,138 Gal / day (70 tons/day) - $11,138 \times 6 = 66,828$ Gal $\approx 70,000$ Gal
or 9358 ft³
or $\frac{9358 \times 94}{2000} = 439.8$ tons ≈ 440 tons nominal

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Provide a cement storage bin of 70,000 gallons (440 tons nominal) storage capacity.

Client: WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 2
Subject: SLUDGE SOLIDIFICATION: SIZE STORAGE HOPPERS / BINS By: K. NAYAR Date: 2.17.89
Ckd. Rev.

Fly Ash

Fly ash storage capacity required @ 35,904 Gal/day = 35,904 x 4 = 143,616 Gal

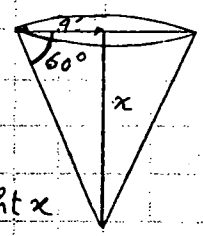
≈ 144,000 Gal

180 tons/day x 4 days = 720 tons

Provide two (2) storage bins for fly ash storage of 72,000 Gal. each (360 tons nominal) storage capacity

72,000 Gallon Hopper

1. Vol. of 60° cone hopper (bottom)



Tank diameter (Assumed) = 18'
Angle of cone = 60°
volume / ft height of 18' dia. tank = 1904 Gal.
Volume of cone = $\frac{\pi D^2}{4} \times \frac{1}{3} \times$ cone height x

$x/9 = \tan 60$
$x = 1.732 \times 9.0$
$= 15.6$ ft

$= \frac{3.142 \times 18 \times 18}{4} \times \frac{1}{3} \times 15.6 = 1323.4\ ft^3$

$= 1323.4 \times 7.48 \approx 9900$ Gal

2. Vol of cone @ 35° angle of repose (top heap)

$x/9 = \tan 35$
$x = 0.7 \times 9 = 6.3$ ft

$= \frac{3.142 \times 18 \times 18}{4} \times \frac{1}{3} \times 6.3 = 534.5\ ft^3$

$= 534.5 \times 7.48 \approx 4000$ Gal

straight side height, 18' dia. tank excluding 6.3' of conical heap $= \frac{72{,}000 - (9900 + 4000)}{1904} = 30.5$ ft

straight side height $= 30.5' + 6.3' = 36.8' \approx 38'$

Hopper size = 18' Dia. x 38' SSH, 60° angle of cone

4. CONCLUSION

select following hoppers / bins each of size 18' Dia. x 38' SSH, 60° cone:

Description	Qty	Capacity Each	Total Storage, No. of Days Approx.
Sludge hopper	2	90,000 Gal	2.7 (16 working Hrs)
Cement bin	1	450 tons	6
Fly ash bin	2	360 tons	4

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 2
Subject SLUDGE SOLIDIFICATION - SIZE PREMIX FEED TANK By K. NAYAR Date 2.20.89
Ckd. Rev.

1. PROBLEM

Determine size of premix feed tank.

2. BASIS OF DESIGN

Capacity of premix feed tank : 1 hour storage of premixed cement and fly ash

3. CALCULATIONS

Cement required / day (6 Hrs. operation): 70 tons
or 11.67 tons/Hr

Fly ash required / day (6 Hrs. operation): 180 tons
or 30 tons/Hr

Bulk volume of cement required per hour @ 94 lbs / ft³ : $\frac{11.67 \times 2000}{94}$ ft³
= 248.3 ft³
= 248.3 × 7.48 Gal
= 1857 Gal

Bulk volume of fly ash required per hour @ 75 lbs / ft³ : $\frac{30 \times 2000}{75}$ ft³
= 800 ft³
= 800 × 7.48 Gal
= 5984 Gal

Bulk volume of cement + fly ash required per hour : 1857 + 5984 Gal.
= 7841 Gal
≈ 8000 Gal

or 11.67 tons cement
30 tons fly ash
41.67 ≈ 42 tons cement + fly ash

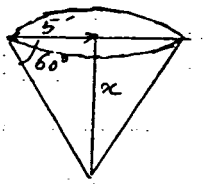
Client: WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 2
Subject: SLUDGE SOLIDIFICATION - SIZE PREMIX FEED TANK By: K. NAYAR Date: 2.20.89
Ckd. Rev.

select a conical bottom tank, 10' Dia & 60° angle of cone.

volume per foot height of 10' Dia tank : 587.5 Gal

1. Volume of conic hopper (bottom)

Tank diameter = 10'
Angle of cone = 60°



Volume of cone $= \frac{\pi D^2}{4} \times \frac{1}{3}$ cone height x

$= \frac{3.142 \times 10 \times 10}{4} \times \frac{1}{3} \times 8.66 = 226.75\ ft^3$

$\frac{x}{5} = \tan 60$

$x = 1.732 \times 5$
$= 8.66'$

$= 226.75 \times 7.48 = 1696$ Gal

2. Volume of conic heap @ 35° angle of repose

$\frac{x}{5} = \tan 35$

$x = 0.7 \times 5$
$= 3.5$ ft

$= \frac{3.142 \times 10 \times 10}{4} \times \frac{1}{3} \times 3.5 = 91.64\ ft^3$

$= 91.64 \times 7.48 = 685$

Straight side height (SSH) for 10' Dia tank excluding 3.5' height of conic heap $= \frac{8000-(1696+685)}{587.5}$

$= 9.6$ ft

Straight side height $= 9.6' + 3.5' = 13.1' \approx 14'$

4. CONCLUSION

select a premix feed tank, size 10' Dia. x 14' SSH, with a conical bottom (60° angle of cone).

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 1 of 3
Subject SLUDGE SOLIDIFICATION - SIZE SLUDGE THICKENER By K NAYAR Date 2.21.89
Ckd. Rev.

1. PROBLEM : Determine size of sludge thickener

2. BASIS OF DESIGN

sludge pumping rate @ 20% solids in sludge : 300 GPM

solids in influent sludge : 20 % by wt.

solids in thickener underflow : 30 % by wt.

sludge solids specific gravity : 2.43

sludge solidification capacity @ 30% solids in sludge : 65,824 Gal/day of 6 Hrs (360 min)
182.8 GPM ≈ 180 GPM

3. CALCULATIONS

sludge: 20% solids by wt.

100 lbs of 20% solids sludge contains : 80 lbs of H_2O
or $80 \div 8.34 = 9.60$ Gal

100 lbs of 20% solids sludge contains : 20 lbs of solids

or $\frac{20}{8.34 \times 2.43} = 0.987$ Gal
≈ 1.0 Gal

Volume of 100 lbs of 20% solids sludge : $9.6 + 1.0 = \underline{10.6 \text{ Gal}}$

sludge: 30% solids by wt.

100 lbs of 30% solids sludge contains : 70 lbs of water
or $70 \div 8.34 = 8.39$ Gal
≈ 8.4 Gal.

100 lbs of 30% solids sludge contains : 30 lbs of solids

or $\frac{30}{8.34 \times 2.43} = 1.48$ Gal
≈ 1.5 Gal

volume of 100 lbs of 30% solids sludge : $8.4 + 1.5 = \underline{9.9 \text{ Gal}}$

Client WMCO, FERNALD, OHIO Job No. 4444-39 Sheet 2 of 3
Subject SLUDGE SOLIDIFICATION : SIZE SLUDGE THICKENER By K. NAYAR Date 2.21.89
Ckd. Rev.

volume of thickener underflow @ 30% solids in sludge for 6 Hrs : 182.8 × 60 × 6 ≈ 65,800 Gallons

solids in 30% solids sludge-volume of 65,800 gallons (9.9 Gal contain 30 lbs solids in 30% solids sludge) $\frac{30}{9.9} \times 65{,}800$ lbs

= 199,394 lbs

volume of 20% solids sludge required to produce 65,800 Gals of 30% solids sludge containg 199,394 lbs of solids (@20 lbs solids in 10.6 Gal of 20% solids sludge) = $\frac{10.6}{20} \times 199{,}394$ Gal

= 105,679 Gal/6 Hrs

Influent Sludge Pump Capacity

At 6 hrs effective pumping time = $\frac{105{,}679}{60 \times 6}$ = 293.6 GPM ≈ 300 GPM

@ 7 hrs effective pumping time = $\frac{105{,}679}{60 \times 7}$ = 251.6 GPM ≈ 250 GPM

Water Removed from Sludge

volume of influent sludge @ 20% solids = 105,679 Gal
volume of thickener underflow @ 30% solids = 65,800 Gal
water removed = 39,879 Gal

Water removal rate @ 6 Hrs effective operating time = $\frac{39{,}879}{60 \times 6}$ = 110.8 GPM ≈ 110 GPM

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Subject By K. NAYAR Date 2-21-89
Ckd. Rev.

Liquid Loading on Thickener

Volume of influent 20% solids sludge - 105,679 Gal/6 Hrs
or 17,613 Gal/Hr

Surface area required @ 600 GPD/ft² or 25 GPH/ft² - $\frac{17,613}{25}$ = 704 ft²
≈ 700 ft²

Solids Loading on Thickener

Quantity of solids in influent sludge - 199,394 lbs/6 Hrs
or 33,232 lbs/Hr
or 16.62 tons/Hr

Since no experimental data on thickening characteristics of the Pit 5 sludge is available, it may be necessary to size the thickener with liquid loading. Use a safety factor of 1.5.

Surface area of the thickener - 700 ft² x 1.5
or 1050 ft²

Thickener diameter : $\frac{\pi D^2}{4} = 1050 \text{ ft}^2$

$D^2 = \frac{1050 \times 4}{3.142} = 1337$

$D = 36.6$ ft
≈ 36 ft

Use a thickener with 10 feet side wall height.

4. CONCLUSION

Select a 36 feet diameter thickener with a 10 feet side wall height.