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16. Abstract

The ASARCO plant in El Paso Texas is currently in a Custodial Remediation Trust where over $52 million is to be spent on mitigating existing contamination problems over the next 2–3 years. This includes constructing a 3000 ft slurry wall and ground water extraction and treatment facility. On Nov. 13, 2009, the Texas District court issued an order to implement the remediation plan; experts from the TCEQ have reviewed and concurred with the mitigation plan and details were published in the Federal register. As part of the plan all Category I materials will be placed in an on-site containment area and 16 acres of Category II materials will be covered with asphalt materials.

The slag materials available in this facility are very hard, durable aggregates that would make it a good material for inclusion in either hot mix asphalt or concrete materials. Slag has been used very successfully in many applications in Texas. In fact, ASARCO slag was used as a coarse aggregate in the concrete pavement outside the El Paso District office. It is performing very well after over 15 years in service. The main concern is the presence of substantial heavy metals in both the copper and lead slag. Test results to date indicate that both ASARCO slag materials have components that would likely present an increased risk to human health and the environment. Additional testing is proposed in this report. If the Department elects to use the material or construct a roadbed through the ASARCO property, a detailed soil and groundwater management plan (SGMP) will have to be developed and incorporated into the contract. The Department has an existing specification that can be used to develop the SGMP. Similar remediation activities have been successfully undertaken on previous TxDOT projects as well as remediation projects in Tacoma, Washington, and in Omaha, Nebraska. Once the court approved remediation plan is complete, development of the SGMP in accordance with TxDOT's requirements would have to be initiated. It will be necessary to harmonize the work completed under the federal remediation plan with the TxDOT's SGMP requirements, and additional initial costs to TxDOT would be expected to be in excess of $5 million, with long-term monitoring by TxDOT to continue in perpetuity.

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USE OF COPPER AND LEAD SLAG IN HIGHWAY CONSTRUCTION: LITERATURE SEARCH-MATERIALS USE AND CONSTRUCTION CONSIDERATIONS

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CHAPTER 1

INTRODUCTION

Copper and lead slags were produced at the ASARCO facility shown in Figure 1 since the turn of the century.

Figure 1. ASARCO Plant in El Paso. Photo courtesy Special Collections UTEP Library: downloaded from NPR website www.npr.org 2/4/10.

The slags are produced during the recovery and processing of nonferrous metal from natural ores. The slags are molten by-products of high temperature processes that are primarily used to separate the metal and nonmetal constituents contained in the bulk ore. When cooled, the molten slag converts to a rocklike or granular material.

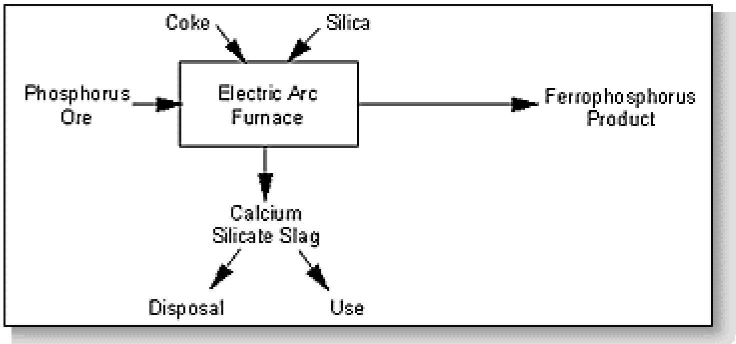

Figure 2. General Process Diagram for Copper and Lead Slag Production.

In the mid-1980s, it was estimated that approximately 3.6 million metric tons (4 million tons) each of copper and phosphorus slag are produced each year in the United States, while the annual production of nickel, lead, and zinc slags is estimated to be in the range of 0.45 to 0.9 million metric tons (0.5 to 1.0 million tons)(*1*).

Most of the molten slag are dumped into a pit and simply allowed to air cool, solidifying under ambient conditions. Granulated slag is produced by using rapid water and air quenching that produces small, uniform particles. The cooling rate has a strong influence on the mineralogy and, consequently, the physical and cementitious properties of the nonferrous slags. Examples of the sizes of the slag particles available at the ASARCO plant are shown in Figure 3.

Figure 3. Examples of the Range of Slag Particle Sizes at El Paso Plant.

Environmental suitability is a major concern in the consideration of using slag as highway construction materials in unbound applications such as granular base and backfill. Similar but lesser concerns exist when considering their use in bound applications such as hot mix asphalt concrete or hydraulic cement concrete layers. Materials from each source must be assessed for heavy metals content and leachability. The chemistry of typical slags is discussed in the next section of this report.

CHAPTER 2
CHEMICAL COMPOSITION OF COPPER AND LEAD SLAG

Table 1 shows the typical elemental compositions of copper and lead slag (*4*).

Table 1. Typical Chemical Compositions of Nonferrous Slag, (%).

Element	Copper Slag	Lead Slag
SiO_2	36.6	35.0
Al_2O_3	8.1	-
Fe_2O_3	-	-
CaO	2.0	22.2
MgO	-	-
FeO	35.3	28.7
K_2O	-	-
F	-	-
MnO	-	-
P_2O_5	-	-
Cu	0.37	-
BaO	-	-
$S0_3$	-	-
Free CaO	-	-
S	0.7	1.1
PbO	-	-

Table 1 shows composition of the major components of typical slag but does not present the heavy elements that can be present in concentrations in the parts per million (ppm) range. These are discussed in the next section.

HEAVY METAL COMPONENTS OF ASARCO SLAG

Elements such as: arsenic (As), lead (Pb), zinc (Zn), beryllium (Be), cadmium (Cd), chromium (Cr), silver (Ag), and selenium (Se) are known to be present in slag, and these can be toxic to plants and animals if they get into the soil and groundwater.

It is the availability and leachability of these heavy metals that will govern the ability to use these materials in highway construction. Availability in this instance refers incidental human ingestion, dermal contact, and inhalation of particulates. The leachability is related to the phase and state of bonding within the slag. Elements partitioned into the silicates and oxides are much less mobile and will not readily leach. In order to properly characterize these phases, researchers must use the following techniques: X-ray diffraction (XRD), scanning electron microscopy (SEM/EDS), and electron microprobe (EPMA) analysis and synthetic precipitation leaching procedures. Apprendix A describes these techniques.

Table 2 summarizes the heavy metal concentration data received from Texas Department of Transportation (TxDOT). The data are from testing of slag samples collected and tested in January 2010. All of the data have been converted to parts per million (ppm) or mg/kg, so a direct comparison of the data can be made.

Table 2. Heavy Metal Concentrations Measured in ASARCO Slag Samples.

EPA Method 6020 Analysis of ASARCO slag in Soil Matrix		
Element	**Copper Slag (ppm)**	**Lead Slag (ppm)**
Antimony	36.20	49.40
Arsenic	265.00	663.00
Barium	1380.00	626.00
Berrylium	1.09	1.62
Cadmium	14.80	59.70
Chromium	9.16	11.30
Copper	5310.00	6370.00
Iron	10100.00	10100.00
Lead	1620.00	1940.00
Selenium	21.40	7.91
Silver	10.70	23.60
Zinc	15600.00	17200.00

Table 3 summarizes the heavy metal leachate concentration data derived from TxDOT slag samples taken and tested in January 2010. All of the data have been converted to ppm or mg/L so a direct comparison of the data can be made. The leachate results were obtained using a synthetic precipitation leaching procedure.

Table 3. Heavy Metal Leachate Concentrations Derived from ASARCO Slag Samples.

Element	**Synthetic Precipitation Leaching Procedure Test Results by EPA Method 6020**	
	Copper Slag (PPM)	Lead Slag (PPM)
Antimony	0.074	0.061
Arsenic	0.050	0.010
Barium	0.193	0.118
Beryllium	0.000	0.000
Cadmium	0.003	0.064
Chromium	0.009	0.000
Copper	0.040	0.031
Iron	0.200	0.150
Lead	0.007	0.053
Zinc	0.033	0.616

In addition, we obtained data from the Texas Commission on Environmental Quality (TCEQ) website concerning groundwater and surface water samples taken from the ASARCO site. Groundwater and surface water are contaminated at the site. Two separate sources have contributed to groundwater contamination at the ASARCO site.

One source of contamination is attributed to two diesel releases from leaking petroleum storage tanks and the other source is from metals released from past plant smelter operations. The diesel and metal contaminate groundwater plumes are co-mingled. The primary Chemicals of Concern (COCs) in the groundwater are arsenic, lead, cadmium, and benzene. The most prevalent COC in the groundwater is arsenic. The groundwater plume is migrating westward toward the Rio Grande. Based on surface water analytical data, the contaminated groundwater appears to have reached the Rio Grande. The latest surface water testing identified arsenic and antimony as the two primary COCs in the surface water.

DEPARTMENT MATERIAL SPECIFICATION 11000 TESTING

TxDOT's Department Material Specification (DMS) 11000 governs the process for evaluating the environmental factors associated with non-hazardous recyclable materials (NRMs) not addressed in other Department specifications. The Department's goal is to use materials with environmental qualities that do not necessitate short-term or long-term management (i.e., worker protection, deed restrictions, tracking, monitoring, or special handling after the project life) in Department specification items.

As described above, TxDOT staff in January 2010 collected and tested unbound samples of copper slag and lead slag materials from the ASARCO site to determine if this material met criteria specified in DMS 11000. The results of these tests are shown in Tables 2 and 3. The test results determined that the unbound copper and lead slag materials have environmental qualities that would likely present an increased risk to human health, the environment, or waters in the state when applied to the land or used in products that are applied to the land. Based on the DMS 11000 testing the unbound slag should only be used in conjunction with short-term and long-term management controls and engineering controls that are designed to reduce the risk to human health, the environment, or waters in the state.

The primary chemicals of concern identified by the DMS 1100 testing were antimony, arsenic, cadmium, copper, lead, and zinc. Specifically the DMS 11000 slag testing determined the following:

- Total concentrations of antimony, arsenic, cadmium, copper, lead, and zinc in the slag each exceeded published risk based residential protective concentration levels for incidental ingestion, dermal contact, and inhalation of particulates.

- Leachate testing of the unbound slag determined that antimony, arsenic, cadmium, and lead each can leach out of the slag at concentrations that exceed known leachate levels from traditional Department aggregate materials.

- Leachate testing of the slag determined that antimony, arsenic, cadmium, and lead each can leach out of the slag at concentrations that exceed published risk based on protective concentration levels for drinking water.

Additional environmental testing is needed to determine if using the slag as a component in cementitious materials or asphaltic binders will reduce or eliminate the risks of incidental ingestion, dermal contact, inhalation of particulates, and leaching of metals.

The presence of heavy metals in the slag materials potentially precludes these materials from being used in unbound applications such as granular base or backfill. In fact, with the magnitude of the contamination it is difficult to justify considering the unbound slag materials for use in any application given the precautions required for worker protection, leachate mitigation, environmental contamination, liability, and associated costs. Each of these will have to be carefully evaluated and managed.

As will be described later in this report, the current remediation plan has classified materials on this site into Category I and Category II materials. Category I materials are those currently classified as problematic. The current plan is to bury these in a designated containment area. The materials with less risk associated with them will be encapsulated and covered with hot mix asphalt. There is potential for using these materials in on-site construction activities.

Critical steps in that determination will be to measure the leachate potential of these materials in a concrete or asphalt matrix. Methods of measuring leachates are discussed in the next section, and the test methods are described in Appendix B.

CHAPTER 3
PHYSICAL ENGINEERING PROPERTIES OF COPPER AND LEAD SLAG

Little physical data are available on lead slag, but air cooled and granulated copper slag have many favorable mechanical properties for use in highway construction. These include excellent soundness characteristics, good abrasion resistance, and hence good skid resistance and good stability due to high internal friction angle. Typical values are shown below.

Table 4. Typical Mechanical Properties of Nonferrous Slag (*3*).

Test	Copper Slag
Los Angeles Abrasion Loss, %	24.1
Sodium Sulfate Soundness Loss, %	0.90
Angle of Internal Friction	40 - 53
Hardness (measured by Moh's scale of mineral hardness)	6 - 7

Details of each material type are available at the following web site

http://www.tfhrc.gov/hnr20/recycle/waste/nfs1.htm.

The information from this site is summarized below.

COPPER SLAG

Shape and Texture: Air-cooled copper slag aggregates are black in color and typically have a glassy appearance. Granulated copper slag aggregates are similar to air-cooled copper slag aggregates but more vesicular.

Gradation: Copper slag can be processed into coarse or fine aggregate. It should be crushed and screened to produce aggregate that satisfies the gradation requirements. Granulated copper slag can be blended with other suitable material as a fine aggregate.

Specific Gravity: As a general rule, the specific gravity will vary with iron content, from a low of 2.8 to as high as 3.8.

Unit Weight: Crushed air-cooled copper slag has a unit weight of 2800 to 3800 kg/m (175 to 237 lb/ft^3) The unit weight is somewhat higher than for conventional aggregates, resulting in increased density asphalt concrete (lower yield). Granulated copper slag is more vesicular and therefore has a lower unit weight than air-cooled slag.

Absorption: Air-cooled copper slag absorption is typically very low (0.1 to 0.5 percent). Granulated copper slag has a higher absorption than air-cooled slag.

Stability Characteristics: The high angularity and friction angle (up to 53°) of copper slag aggregates contribute to excellent stability and load bearing capacity.

Wear Resistance: The superior hardness and abrasion resistance of copper slag aggregates compared with most conventional aggregates contribute to good wear resistance.

Frictional Properties: No specific data were identified.

Adhesion: No specific data were identified, but low absorption values and the glassy nature of copper slag suggest that stripping might be a concern.

Soundness: The excellent soundness exhibited by copper slag aggregate reflects good resistance to freeze-thaw exposure.

LEAD SLAG

Shape and Texture: Lead, lead-zinc, and zinc slags are black to red in color and have glassy, sharp, angular (cubical) particles.

Gradation: No specific data were identified, but processing similar to that of copper slag would be expected.

Unit Weight: The unit weight of granulated lead, lead-zinc, and zinc slags can vary from less than 2500 kg/m to as high as 3600 kg/m (156 to 225 lb/ft^3).

Absorption: No specific data available on lead slag However granulated lead slags tend to be porous, with absorptions up to about 5 percent. This could potentially be a problem.

Stability Characteristics: Although no specific data were identified, it is anticipated that these slags would produce acceptable stability characteristics.

Wear Resistance: Although no specific data were identified, it is anticipated that these slags would produce acceptable wear resistance characteristics.

Frictional Properties: Although no specific data were identified, it is anticipated that these slags would produce acceptable frictional properties.

Adhesion: Although no specific data were identified, it is anticipated that the glassy nature of slag suggests that stripping might be a concern.

Soundness: Although no specific data were identified, it is anticipated that these slags would exhibit adequate soundness properties.

CHAPTER 4

APPLICATIONS OF COPPER AND LEAD SLAG IN HIGHWAY CONSTRUCTION

A literature search found the following points on slag applications:

- Recently this waste product has found use as an additive in Portland cement, as railroad ballast, or an additive for roofing shingles.
- One issue about slag preparation and processing is the toughness of the aggregates. Contractors complain about the wear and tear on all crushing and handling equipment.
- There are many applications of using slag in highway construction including ground granulated blast furnace slag (GGBFS), but this is mostly slag from the production of steel.
- Slag was widely used in HMA asphalt layers in East Texas in the 1960s and 70s from the Alcoa plant in Rockdale. A typical example is shown in the photographs below (Figure 4). The very fine black layer is slag hot mix. This looks to have a gradation similar to TxDOT's current Crack Attenuating Mix (CAM) design, and this is a gritty mix, with good texture and no indication of any moisture damage.

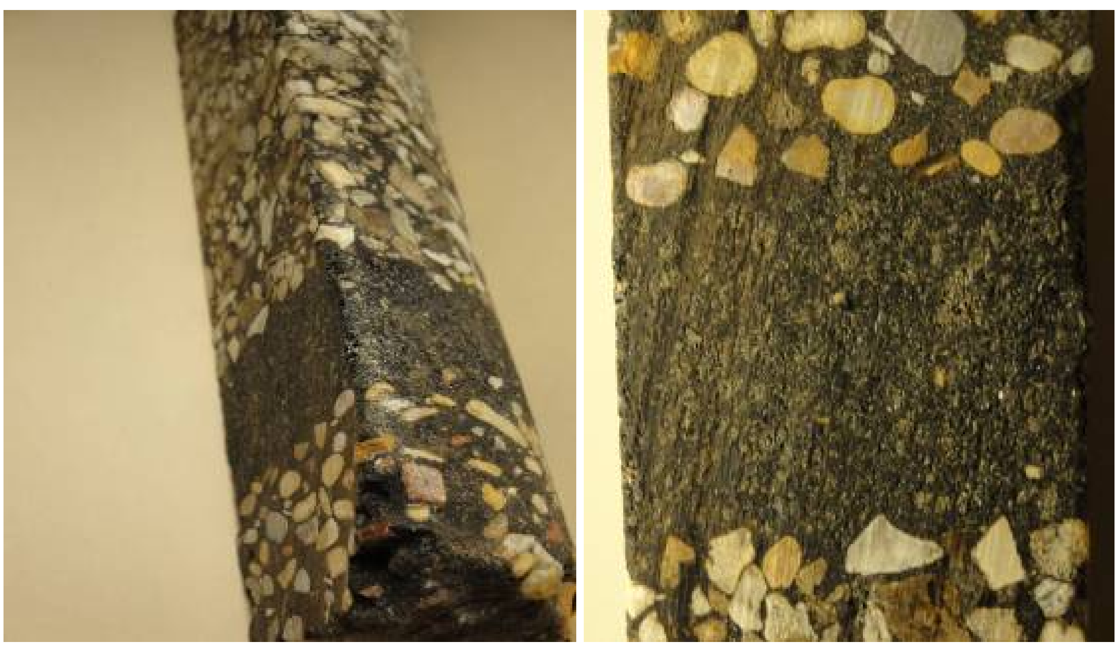

Figure 4. Slag in Old HMA Cores from the Bryan District.

- There is a national slag association that maintains a library of applications of slag and relevant specifications (http://www.nationalslag.org/slagdocs.htm).

However it deals mostly with traditional blast furnace slag and has little information on heavy metal issues.

- The best reference for slag applications in highways including copper and lead slag was developed by the Federal Highway Administration. Much useful information can be found at: http://www.tfhrc.gov/hnr20/recycle/waste/nfs1.htm.

With reference to current and future potential slag applications in Texas, the following paragraphs describe standard specifications for possible inclusion of slag in TxDOT construction and maintenance activities.

Concrete (Item 360)

Copper slag was used as a coarse aggregate (55 percent of coarse aggregate) in a section of Continuously Reinforced Concrete Pavement (CRCP) constructed outside of the District office in El Paso. The max aggregate size was 1.5 inches. After 12 years the pavement scores for this 7 mile section were in the 100s. There are no indications of any durability problems.

Magnesium has been reported to cause significant durability problems in hardened concrete. If this magnesium is present as MgO, then high concentrations in Portland cement will cause rapid volume increases and soundness problems, much the same as accelerated ASR damage. However, if the magnesium is present in sulfate phases, then the sulfate can attack the concrete like typical sulfate attack. At this point we do not know how the magnesium is present in slag samples, but we know it is somewhat soluble because it is present in the water obtained from the site. The phase and concentrations of the magnesium present in the ASARCO samples should be determined if the material is to be used in concrete materials.

Other potential problems with the use of the slag in concrete arise from the concentration of potassium and sodium; analyses of the copper slag show potassium levels ranging from 38 to 757 mg/l and sodium levels ranging from 124 to 1469 mg/l. Again, the researchers would like to stress the importance of knowing how these elements are partitioned in the slag samples so we can better gage the reactivity of these phases and the impact they would have on concrete constructed with this material. For example, if the alkali metals are present primarily in glass phases, then they could be released into the concrete more easily; glass becomes more soluble at high pH than silicate minerals.

In order to properly characterize these phases, the researchers recommend that testing of these materials be conducted using the following techniques: X-ray diffraction, scanning electron microscopy, and electron microprobe analysis. As described in Appendix A the equipment recommended is available at Texas A&M and could be used to identify potential durability problems with using the slag in concrete.

A search of the literature found no reported performance problems using copper slag as either a cement replacement or as an aggregate in concrete. However results from

Thailand (5) using lead slag reported lower compressive strength and substantially higher water absorption.

Hot Mix Asphalt (Item 341)

In a 2009 survey no states reported using copper or lead slag in HMA. However based on the material properties discussed above there does not appear to be any reason why these aggregates would not make durable mixes.

As recommended by the FHWA in http://www.tfhrc.gov/hnr20/recycle/waste/nfs2.htm:

> Conventional asphalt mix design methods (e.g., Hveem, SHRP) are applicable for the design of hot mix asphalt containing slag (particularly air-cooled phosphorus and copper slag) aggregates. No special procedures are required for aggregate gradations. Both coarse and fine slag aggregates can be incorporated in hot mix asphalt, provided that the DOT's physical requirements are satisfied. No special provisions are required for nonferrous slag, and conventional hot mix specifications may be used. Blending with other suitable hot mix asphalt aggregates may be necessary to achieve gradation specifications compliance. Due to the difference in unit weights, mix designs are usually calculated on a volumetric basis.

Flexible Base (Item 247)

The heavy metal contamination problem discussed earlier precludes this material from its use in flexible bases. At this moment we will focus on applications in a bound and coated state (asphalt or concrete).

Chip seals (Item 302)

The El Paso District tried using the ASARCO slag material in a chip seal project in the mid-1980s. This was abandoned soon after starting because of windshield damage. The slag aggregates have such a high specific gravity that they caused numerous driver complaints. The material itself should easily pass the aggregate quality requirements but the weight issue precludes it from use in chip seals.

PROPOSED LABORATORY EVALUATION OF ASARCO MATERIAL

Task 2 of this study calls for a laboratory evaluation of the materials at the ASARCO plant to determine their suitability for use in highway construction. The following steps are potential requirements in conducting that evaluation.

- A detailed review needs to be made of the TCEQ data on the test results and material classification from this site. The current material classified as Category I is scheduled to be buried in a containment cell. Based on the heavy metal concentration that material should not be considered for use in TxDOT projects.

- A large quantity of material is that which TCEQ classified as Category II materials. These should be considered for use in highway application. A survey should be conducted on the amount of this material, gradations, and potential applications. The laboratory staff in the El Paso District would be best to document and classify the existing Category II materials.
- The available Category II material's chemical components need to be identified in accordance with the requirements of DMS 11000.
- In all probability these components will exceed some of the limits of DMS 11000. At that time a decision needs to be made on whether to proceed with lab testing and potential highway construction.
- At that stage TxDOT Environmental Division needs to be consulted to develop a lab testing program that will ensure worker safety and minimize potential future liability to TxDOT.
- At this time it is proposed that only the applications of using this material in hydraulic cement concrete and hot mix asphalt concrete be considered.
- For the use of copper and lead slag in highway applications in concrete the material should be considered as an aggregate. Both materials have substantially less free lime than GGBFS (which is allowed in Item 421 as a partial cement replacement mitigation technique for alkali silica reactivity). Therefore it is uncertain whether this material could be used to replace cement. The following steps are required to evaluate the potential for using both copper and lead slag as an aggregate:
    - Chemical analysis
        - To attempt to determine both the potential for durability problems (ASR type) and leaching problems the amount of potassium, magnesium and sodium needs to be measured in both of the slags. In addition to this whether the mineral is in the oxide or sulfide phase needs to be determined.
    - Item 360 testing
        - As already discussed, copper slag was used as a replacement for 50 percent of the coarse aggregate in concrete placed in the mid-90s in El Paso. Lab testing should include both minimum compressive strength and flexural strength, comparing the virgin concrete with 25, 50, and 75 percent replacement with both copper and lead slag.
    - Water absorption Testing
        - The water absorption of the raw aggregates and concrete cylinders needs to be measured. High water absorption can lead to major workability issues in the field and potentially lead to durability and freeze thaw problems in the hardened concrete.
    - Leachate testing
        - As a final step because of the concern about heavy metal leaching from these products TxDOT should modify and run a leachate test, which simulates worse case scenario. Appendix B of this report describes several leachate tests. They all involve passing de-ionized water through a column of material capturing the

water passing through the materials and measuring the composition of the water. The simple 7 day test is recommended by TCEQ. To simulate the worst case scenario it is recommended that concrete cylinders be made cured for 28 days and then crushed. The crushed material will be tested in the leachate test.

- For the use of copper and lead slag in highway applications in hot mix asphalt the material should be considered as an aggregate. The following steps are required to evaluate the potential for using both copper and lead slag as an aggregate:
    - Item 341 testing
        - Both slags must be tested in accordance to Tables 1, 2, and 6 in Item 341. It is not anticipated that any problems with requirements will be found as the slag is a very tough material. Based on the gradation, consideration should be given to including the slag in a Type D surface mix as either a coarse or a fine aggregate. Both copper and lead slags should be tested separately in the Hamburg Wheel tracking test, the indirect tensile test, and the Boil test. An experimental plan should be developed to consider 25, 50, and 75percent replacement of both coarse and fine aggregates for both slag types.
    - Mix design procedures
        - If the preliminary test results look satisfactory then methodologies need to be developed to account for the high unit weight of the slag in the mix design process. Volumetric design will probably be required.
    - Leachate testing
        - This is identical to the concern discussed above for concrete. To simulate the worst case scenario it is recommended that HMA be crushed as in a full depth rehabilitation operation. The crushed HMA can be blended with 50 percent virgin base materials and tested for leaching. The crushed material will be tested in the leachate test.
- Finished product will need to be tested to determine compliance with DMS 11000.
- Should the decision be made to construct field test sections containing these slag materials, monitor sites will need to be established to collect leachates that either run off the roadway or percolate through the pavement layers. Apprendix C shows such a system using lysimeters.

CHAPTER 5
CURRENT REMEDIATION ACTIVITIES PLANNED FOR THE ASARCO SITE

Volumes of data can be found on the ASARCO case and the proposed remediation plan that will be implemented by the Custodial Remediation Trust. A summary of the proposed plan is presented below:

- demolition of designated facility structures;
- design, contruction and 50-year operation and maintenance of a ground water control system comprised of a 3,000 foot slurry wall, ground water extraction well system, ground water treatment system, 800 foot deep injection well, and monitoring well abandonment;
- capping total area comprising approximately 76 acres with asphalt, including 16 acres of designated Category II material;
- design, construction and placement of designated Category I material within an on-site waste containment cell;
- installation and maintenance of perimeter fencing; and
- TCEQ oversight, general maintenance, repairs, monitoring, and performance reporting on facility remedy in perpetuity.

A review of the proposed plan can be found in two expert reviews. In particular the report by James Shih Hong Sher "Estimation of Costs to Perform Clean up at the ASARCO El Paso Smelter" can be found at the following web site http://www.tceq.state.tx.us/remediation/sites/asarco/asarco. A second report by Mr. B. Costello concluded that the clean up costs were "within a reasonable range." Several major reports are available through this web site providing the results of the years of detailed testing and the efforts to develop the comprehensive mitigation plan.

The $52 million for this clean up has been placed in a custodial account and work is about to start on the clean up itself. Status details and questions and answers about the clean up can be found in the following web site www.recastingasarco.com. The final court mandated order was issued in Nov. 2009, and as of February 2010 this site is canvassing contractors who want to be considered in the bidding process to implement the proposed plan. It is hoped to have the final plan developed this year and implemented in the following two years.

Figure 5. Web Site Developed for the ASARCO Clean Up.

CHAPTER 6
POSSIBLE TXDOT CONSTRUCTION THROUGH THE ASARCO SITE

This clean up process is underway and based on the web site events are moving fast. There is a "Building a Vision" grass roots effort supported by Senator Eliot Shapleigh to consider developmental opportunities for the site.

Based on similar clean ups already completed in Washington and Nebraska, substantial development of the area can be initiated once the clean up is completed. The Qwest Convention Center was constructed on the site of ASARCO's former lead refinery in Omaha, Nebraska. The EPA lauds the cleanup of the former ASARCO Tacoma Smelter site, stating that "ASARCO will also extend an existing path along the waterfront, design and construct the cap to support baseball fields or an amphitheater, and pave the remainder of the site to make way for new buildings. Cleanup and reuse activities have already begun."

It is also possible that TxDOT could build a highway through the site, as construction projects through several other contaminated sites in Texas have been successfully completed. However, these past projects included large scale reuse of contaminated materials as construction materials, which is being consider for the ASARCO site. As part of TxDOT's decision making process to determine whether the ASARCO slag can be incorporated into construction and whether a highway alignment can be successfully constructed on ASARCO property, worker protection, leachate mitigation, environmental contamination, liability, and costs associated with each will have to be carefully evaluated. As an example of potential cost, execution of the Soil Groundwater & Trash Management Plan (SGMP) for the SH 161 Project in Dallas (Landfill) for FY 2009 was approximately $5.5 million. The affected section of the project is still under construction in FY 2010 so additional Soils and Ground Water Management Plan (SGMP) costs will be incurred before the project is completed.

Although not a comprehensive survey of public opinion, results from a January 2010 survey of the University of Texas – El Paso student government do not likely favor using the property as highway right of way. The results of the limited survey can be found at: http://www.recastingthesmelter.com/wp-content/themes/recastingasarco/downloads/UTEP_survey_1-28-2010.pdf.

Should TxDOT wish to incorporate and start construction of a new highway alignment through this site prior to completion of the clean up then there are several risks and challenges associated with this, namely:

- Drilling any type of foundation before ground water extraction system is in place is problematic because extremely high levels of arsenic have been found in the existing ground water. The water table, because of the proximity to the Rio Grande River, is fairly shallow (reported to be 10 to 15 ft). TCEQ reports have also reported that some arsenic contamination has already reached the Rio Grande. Drilling deep foundation holes in this environment could cause other potential problems and make TxDOT liable for subsequent contamination.

- This entire remediation is approved by the U.S. District Court: Southern District of Texas and modification to this plan will presumably need to be approved by the same court.

If the decision is made to proceed with either:

a) construction of a highway through the facility and/or
b) using the materials from the facility as construction materials inside the facility.

Then TxDOT's Environmental Division needs to become heavily involved with establishing the necessary environmental and engineering management plan. The Environmental Division has several documented cases where TxDOT construction has proceeded through sites where contaminated soils are present. In all cases the first step is to develop a Soils and Groundwater Management plan in accordance to the guidelines presented in Environmental Division Specification Item 221 (Appendix D). If the decision is made to process the materials for use as construction materials then a worker safety and environment control plan must also be developed.

CHAPTER 7
RECOMMENDATIONS AND FUTURE WORK NEEDED

There are three main possibilities for TxDOT to participate in the cleanup of the ASARCO site in El Paso:

1. Allow for the use of the slag in highway construction projects away from the ASARCO site.
2. Realign the proposed location of the Border Highway West Extension project to run through the ASARCO site.
3. If running the highway through the ASARCO site, use the slag as part of the highway construction.

The following lists general work activities needed before the above possibilities can be pursued.

<u>Possibility #1</u>

- Rigorous leachate testing would be required on the recommended applications of concrete and hot mix asphaltic concrete, as per TxDOT specification DMS 11000.
- Additional environmental testing would be needed to assess potential future hazards when conducting maintenance, rehabilitation, or reconstruction activities.
- Standard material quality and mixture design testing would need to be performed.
- A tracking mechanism would be needed to developed and implemented to track the location and usage of all material removed from the ASARCO site.
- Potential concrete and hot mix material suppliers would be required to obtain permits for the transportation and storage of all slag removed from the ASARCO site.
- Worker safety precautions would need to be implemented to protect workers at all stages on construction.

<u>Possibility #2</u>

- TxDOT would need to coordinate with the Texas Custodial Trust and their coordination with the public on the plan for development of the site.
- TxDOT would need to coordinate with TCEQ, EPA, and the U.S. District Court: Southern District of Texas, probably delaying the initial clean up schedule.
- TxDOT would need to develop a Soil and Groundwater Management plan, which would include requirements for TxDOT monitoring in perpetuity.
- Standard construction practices (such as drilled shaft/piling construction, embankment and backfill construction, drainage details) would require modification.
- Additional leachate testing would be needed to assess potential future hazards when conducting maintenance, rehabilitation or reconstruction activities.
- Worker safety precautions would need to be implemented to protect workers at all stages on construction.

- As the design for the current alignment, which skirts the ASARCO site, is 90 percent complete, redesigning for a new alignment would require additional engineering expense.

Possibility #3

- All the issues of Possibility #2 would have to be satisfied.
- Standard material quality and mixture design testing would need to be performed.
- For the material to remain on site during construction, portable concrete or hot mix plants would be required as part of the construction contract.

It is a very real possibility that one or more of the above scenarios is possible, given the appropriate allocation of resources, including increased engineering costs for design and testing, legal fees, increased construction bid prices, the cost of the soils and groundwater management program, additional time for design, construction, and coordination with the Trust, the public, TCEQ, and the District Court, and the long-term commitment of resources for tracking and monitoring. Given that recent highway construction costs associated with a TxDOT Soil and Groundwater Management Plan is currently over $5 million it should be expected that implementing one or more of the above scenarios would cost far more than $5 million. Development of a more precise estimate is outside the scope of this phase of the work performed by the authors.

REFERENCES

1 Collins, R. J. and S. K. Ciesielski. Recycling and Use of Waste Materials and Byproducts in Highway Construction, National Cooperative Highway Research Program Synthesis of Highway Practice No. 199, Transportation Research Board, Washington, D.C., 1994.

2 JEGEL. Manitoba Slags, Deposits, Characterization, Modifications, Potential Utilization. Report prepared by John Emery Geotechnical Engineering Limited, Toronto, Ontario, 1986.

3 Hughes, M.L. and T.A. Haliburton, "Use of Zinc Smelter Waste as Highway Construction Material," Highway Research Record No.430, 1973, pp.16-25.

4 OECD Use of Waste materials and by products in Road Construction. Organization of Economic Co-operation and Development, Paris 1977.

5 Penpolcharoen M; "Utilization of Secondary Lead Slag as Construction Material," Cement and Concrete Research, June 2005.

APPENDIX A
ADVANCED TEST EQUIPMENT REQUIRED TO MEASURE CHEMICAL COMPOSITION OF SLAGS

The researchers have access to all equipment necessary to test the slag samples and determine their toxicity. Figure A1 is the Scanning Electron Microscope (SEM) located on the Texas A&M University campus. Figure A2 shows the electron microprobe. Figure A3 shows an image from a meteorite taken with the electron microprobe that can be used to determine how elements are bound in a sample. The X-ray diffractometer is not pictured, but it can tell the crystallinity of the different phases to help determine how immobile the heavy metals are in the slag.

Figure A1. JEOL 6400 Scanning Electron Microscope at Texas A&M University.

Figure A2. Cameca SX50 Electron Microprobe at Texas A&M University.
Taken from http://geoweb.tamu.edu/RResearch/probe/%20Probe_WebPage.html

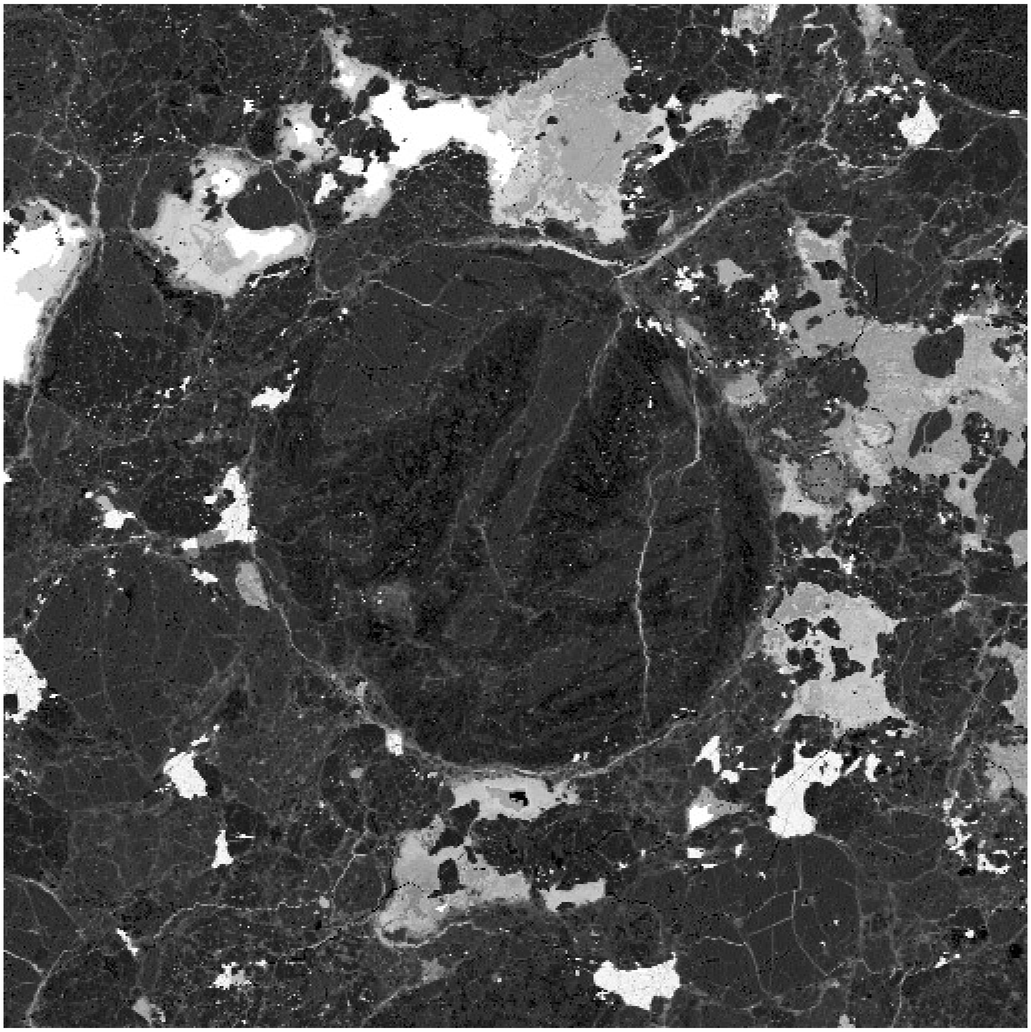

Figure A3. Backscattered Electron Image, Taken with The Electron Microprobe, Showing How Different Elements are Bonded Together in a Meteorite. Image taken from http://geoweb.tamu.edu/Rresearch/probe/%20Probe_WebPage.html

APPENDIX B
RECOMMENDED LABORATORY LEACHATE TESTS

Although slag has beneficial uses there is some concern about its potential human and environmental hazards, since it may contain various levels of metals and other constituents. Several tests (batch and column) have been employed to simulate leaching from these materials in the field. Careful thought and planning must be used when choosing a leachate test because each has its own potential benefits and drawbacks.

Batch tests are usually low cost, easy to operate, carried out over relatively short periods of time (hours to days) and experimental conditions (e.g., pH) are relatively easy to control. However, batch tests sometimes are associated with arbitrary and high liquid: solid ratios (L/S), which is the ratio of extracting liquid to solid waste materials. Often such high L/S ratios will not exist under field conditions. Column tests on the other hand may be closer to field conditions and the material under testing will largely dictate experimental conditions such as pH. Column tests can prove time consuming (tests over days and months), relatively costly and be associated with problems such as channeling of materials along column walls and clogging (Townsend et al., 2003). Below are a few leachate tests that are currently used.

ASTM D3987-06 – Standard Test Method for Shake Extraction of Solid Waste with Water

This is an agitated extraction test which is used to determine the mobility of inorganic constituents from waste material. A representative sample and reagent water (Type IV-ASTM D 1193) with a 20:1 liquid to solid ratio (L/S) is shaken on a rotary agitator for 18±0.25 hours at 30 rpm, to rapidly produce leachate. The aqueous phase is subsequently separated and analyzed using the appropriate procedure and instrumentation. The intent is to produce leachate that is an estimate and not a representative of that which would be formed under field or site-specific conditions. The conditions used in the test (e.g., agitation rate, L/S) may not be suitable for extracting constituents from all forms of waste materials. As a result it is explicitly stated that this method should not be the sole determining factor for engineering design (ASTM, 2006a).

Texas Seven-Day Distilled Water Leachate Test

This method, which is used by the TCEQ, is intended to be used on dry solid waste that does not contain any free liquid. A 250 g (dry weight) representative sample is first placed in a 1500 ml Erlenmeyer flask and 1L of deionized or distilled water is added to it and the material is mechanically stirred for 5 minutes. It is allowed to stand for seven days after which the supernatant is passed through a 0.45 µm filter and further subjected to the appropriate analysis.

ASTM Method D-4874 – Standard Test for Method for Leaching Solid Waste in a Column Apparatus

This method uses a column apparatus (Figure B1) in which reagent water is continuously passed through a representative sample of the waste material in a saturated up-flow mode. The intent is that semi-volatiles and volatiles and the maximum amount of metal species will leach from the solid. The method was written in a manner such that the user can adjust the specific operating conditions to meet particular objectives. The results obtained from this method will depend on the characteristics of the solid waste being tested and the specific operating conditions. As a result the method explicitly states that it cannot be used as the only basis for engineering design of a disposal site (ASTM, 2006b).

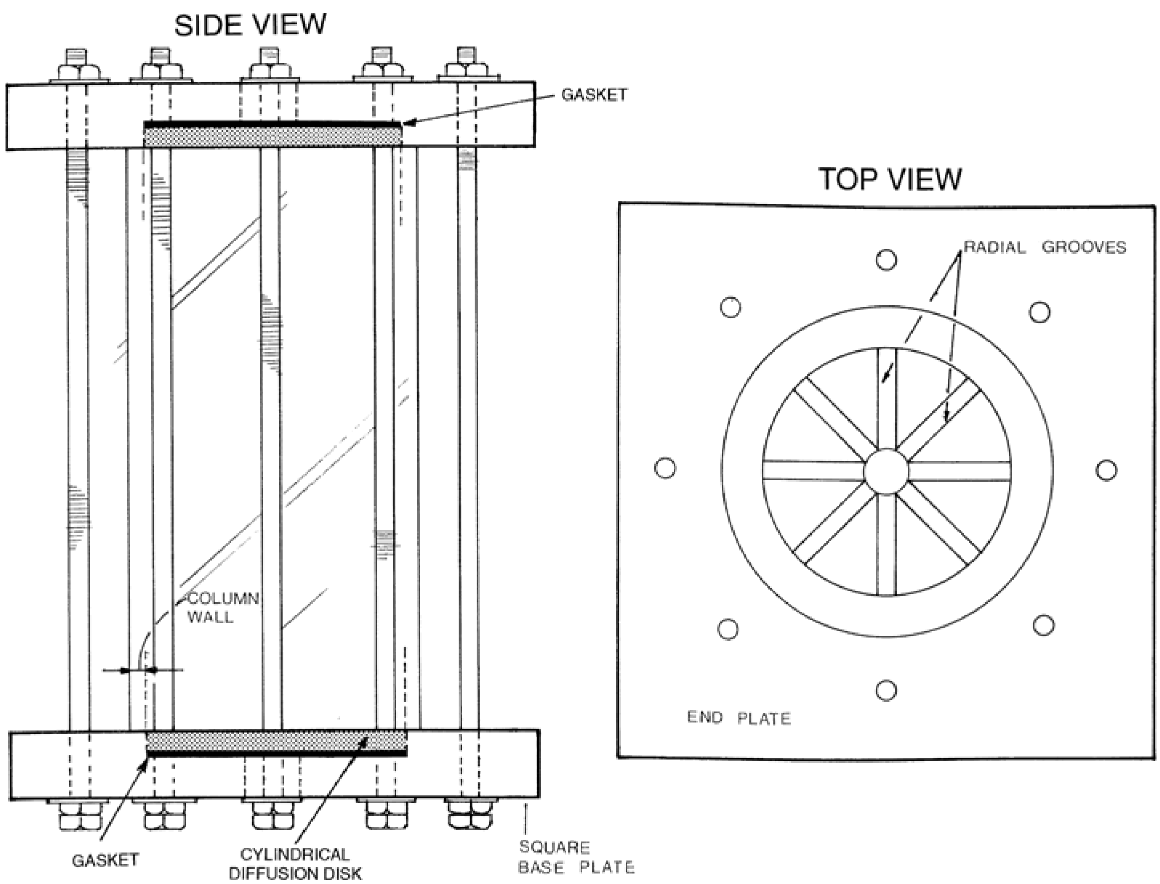

Figure B1. Column Apparatus (Adopted from ASTM D4874-06b).

References

ASTM, 2006. Standard Test Method for Shake Extraction of Solid Waste with Water. ASTM D3987-06a.

ASTM, 2006. Standard Test Method for Leaching Solid Waste in a Column Apparatus. ASTM D4874-06b.

Townsend, T; Jang, Y and Tolaymat, T., 2003. "A Guide to the Use of Leaching Tests in Solid Waste Management Decision Making," Florida Department of Enviromental Protection, March 31, 2003.

Note. The Seven-Day Distilled Leachate Test is cited in 30 TAC§335.503 (relating to Waste Classification and Waste Coding Required); 30 TAC§ 335.505 (relating to Class 1 Waste Determination); 30 TAC§335.507 (relating to Class 3 Waste determination).

APPENDIX C
RECOMMENDED FIELD LEACHATE TESTS WITH LYSIMETER

The lysimeter is a large catchment box typically 12 ft by 12 ft where the moisture entering the pavement and running through the base is captured for analysis in a large collection tanks.

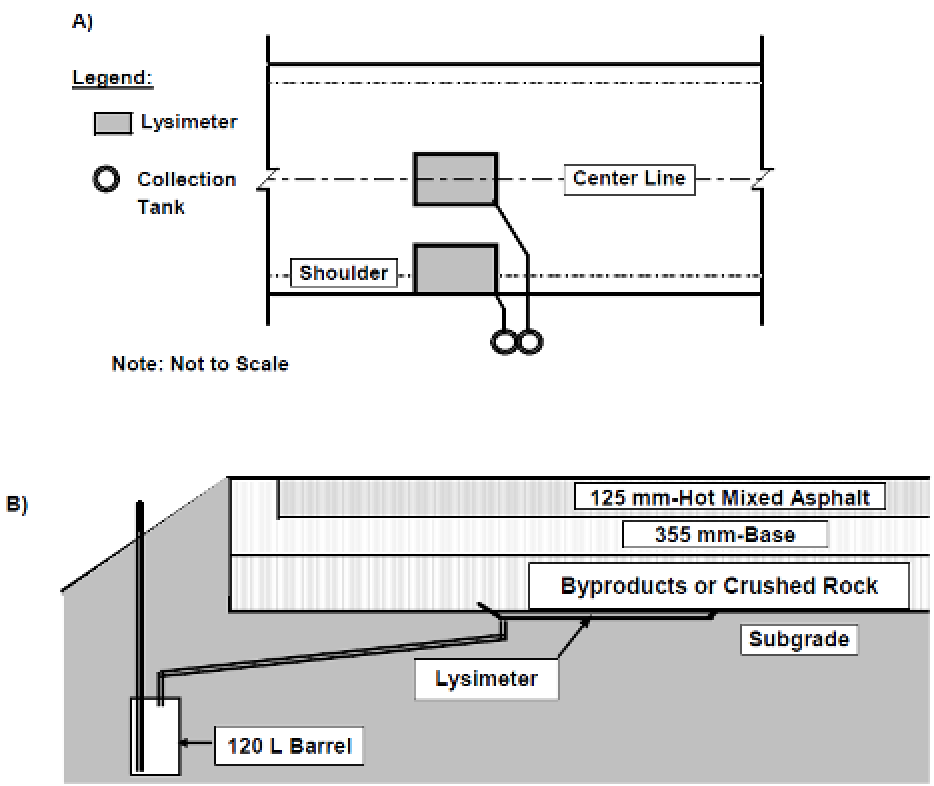

Figure C1. Field Site to Capture Leachates from Experimental Bases.

References

Sauer, J., Benson, C., and Edil, T. "Metal leaching from highway test sections constructed with Industrial Byproducts." Geo Report 5-21, Department of Env Eng, University of Engineering University of Madison Wisconsin, Dec. 2005.

APPENDIX D
ITEM 221 SOIL AND GROUNDWATER MANAGEMENT PLAN(S)

221.1 Description: The procedures required to create a Soil and Groundwater Management Plan (SGMP) for the mitigation of contaminated media related to TxDOT construction activities. If directed by the Statement of Work (SOW), the SGMP will become part of a special specification that will direct construction contractors on how to manage and dispose of contaminated media within a construction zone.

221.2 SGMP Style: The Engineer/Technical Expert shall utilize the following limitations/standards when preparing the SGMP:

- State the Contractor's requirements only once (other than as part of process flow charts) and do not include an executive summary;

- Do not give options (multiple methods) to the contractor in detailing how to manage each contaminated media;

- Prepare the plan as a directive, using imperative voice;

- Always capitalize CONTRACTOR, ENVIRONMENTAL SPECIALIST, or TxDOT when directing them to perform a task; and

- Utilize cost effective procedures and easily purchased products, as applicable.

221.3 Procedures: At a minimum, the Engineer/Technical Expert shall prepare the SGMP to include the following, unless otherwise outlined within the SOW.

221.3.1 SGMP Zone – Indicate the exact location on a depiction of the Project Plan Schematic and within the initial paragraph of the plan where the SGMP starts and ends using the construction project plan station numbers.

221.3.2 Contaminated Media Information – Summarize past studies performed on the subject site detailing:

- The chemicals-of-concern and their concentrations;

- The impacted media (surface soils, surface water, subsurface soils, sediment, groundwater, etc.);

- The known and/or suspected horizontal and vertical extent of the contaminated media; and

- The potential hazards/exposure impacts to construction workers.

221.3.3 Summary of potentially impacted construction improvements – Detail what part of the construction project will potentially be affected by the contaminated media (storm sewers, bridge piers, abutments, etc.)

221.3.4 Soil Management – The Engineer/Technical Expert shall evaluate methods to manage contaminated soils potentially impacting improvements within the SGMP zone. The Engineer/Technical Expert shall take into account costs and ease of construction (the least impact to normal construction methods while still providing effective management of contaminated soils). The SGMP shall include detailed written methodologies on managing the potentially contaminated soils within the SGMP zone. The Engineer/ Technical Expert shall include the rules and regulations that govern the methodologies chosen.

221.3.5 Groundwater Management – The Engineer/Technical Expert shall evaluate methods to manage contaminated groundwater potentially impacting improvements within the SGMP zone. The Engineer shall take into account costs and ease of construction (methods with the least impact to normal construction while still providing effective management of contaminated groundwater). Different techniques for groundwater disposal may be used under this heading, but shall be based on a total gallon limit for the project, or as directed by the SOW. The SGMP shall include detailed written methodologies on managing potentially contaminated groundwater within the SGMP zone. The Engineer shall include the rules and regulations that govern the methodologies chosen.

221.3.6 Construction Materials – The Engineer shall evaluate all construction products proposed to be used within the SGMP zone for the following items listed below. The Engineer shall include a written description of the findings and/or alternatives within the SGMP, upon concurrence by ENV-PPA and the Point-of-Contact (POC) outlined within the SOW. If alternatives to the original design are recommended, then the Engineer shall supply plan details and specifications of the new product to be used to the POC and the ENV-PPA Project Manager.

- The Engineer shall evaluate all of the construction products proposed to be used within the SGMP contamination zone for their compatibility with the contaminated media. If the construction products proposed are not compatible, then the Engineer shall design an alternative product to be used. The alternative product shall be evaluated for cost, reliability/life cycle, ease of installation and use, and accessibility for procurement.

- The Engineer shall evaluate all potential multi-medial migration pathways that may be altered or created by constructing the improvements. This will include all vertical and horizontal pathways. Examples of horizontal pathways may be a graded drain through a groundwater plume or gasses migrating along a pipe chase. Examples of a vertical pathway may be a bridge pier installation through multiple confining layers. If the evaluation indicates a potential pathway issue, the Engineer shall design method(s) to prevent migration of any contamination or potentially contaminated media along or through the construction improvement.

221.3.7 Environmental Specialist – The Engineer/Technical Specialist shall detail the requirements for the Contractor to use an Environmental Specialist to manage the requirements outlined within the SGMP. The Engineer/Technical Expert shall include a bulleted list of duties that the Environmental Specialist will be required to perform including a time schedule to complete the activities. At a minimum, the following items shall be listed within this section as requirements for managing and using the Environmental Specialist.

- The contracted personnel used for the onsite Environmental Specialist shall be billed at a rate no greater than a Field Technician. The contracted rates shall be negotiated between the Contractor and TxDOT prior to work commencing on the project.

- The Environmental Specialist shall have at least two verifiable years performing the work outlined within the SGMP (preferred). The verifiable proof shall be reviewed and accepted by TxDOT prior to the work commencing on the project.

- The Environmental Specialist shall have the 40-hour Hazardous Waste Operation and Emergency Response (HAZWOPR) training.

- The Environmental Specialist shall be employed by a firm or organization that employs a professional(s) who holds a registration in one (1) or more of the following: Professional Engineer by the State of Texas, Registered Environmental Manager/Registered Environmental Professional by the National Registry of Environmental Professionals, Professional Geoscientist by the State of Texas, or a TCEQ-registered Corrective Action Project Manager (if applicable).

221.3.8 Revisions to the SGMP – The Engineer shall include a sub-heading within the SGMP that outlines the requirements to make corrections or updates to the SGMP.

221.3.9 The Engineer/Technical Expert shall include as an Attachment(s) separate process flow charts, one process per sheet, for each potentially contaminated media (soil, groundwater, atmospheric, etc.). Each process flow chart shall graphically depict the method for handling the specific contaminated media from discovery to final disposition (example: the steps and decisions that must be followed to handle contaminated soils).

221.4 Field Documentation and Reporting – The Engineer shall include a section within the SGMP that outlines the field documentation and reporting that is required to be submitted to TxDOT at the close of the project. At a minimum, the following field documentation and reporting should be included in the SGMP:

- SGMP Acceptance – Include an Attachment that provides for written documentation from the Contractor, Sub-Contractor(s), Environmental Specialist, and all personnel working within the SGMP zone to verify that they have read the SGMP and understand the contents. The initial SGMP Acceptance form shall be signed and dated prior to work commencing on the project. The SGMP

Acceptance form is to be re-signed and delivered to TxDOT when changes to the plan or workers are made.

- Field logs and daily activities summaries – The Environmental Specialist shall submit daily activity summaries to the Contractor and TxDOT to verify work performed and time allocation (can be e-mailed). A field log shall be kept for the entire project and submitted to TxDOT at the end of the project by the Contractor.

- A SGMP final report shall be developed by the Environmental Specialist and submitted by the Contractor at the construction project completion. The final report shall contain, at a minimum:

    - Daily field logs;

    - All laboratory results with sample locations;

    - All corrections and revisions to the SGMP;

    - Disposal manifests;

    - Personnel and company responsible for managing the SGMP, including names and certifications; and

    - All other items related to the regulatory handling of the contaminated media, per the SGMP.