INL/EXT-12-27877

Silo Storage Preconceptual Design

Stephanie L. Austad
Patrick W. Bragassa
Kevin M. Croft
David S. Ferguson
Scott C. Gladson
Annette L. Schafer
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The INL is a U.S. Department of Energy National Laboratory
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Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Silo Storage Preconceptual Design

1. INTRODUCTION

1.1 Background

The National Nuclear Security Administration (NNSA) has a need to develop and field a low-cost option for the long-term storage of a variety of radiological material. The storage option's primary requirement is to provide both environmental and physical protection of the materials. Design criteria for this effort require a low initial cost and minimum maintenance over a 50-year design life. In 1999, Argonne National Laboratory-West was tasked with developing a dry silo storage option for the BN-350 Spent Fuel in Aktau Kazakhstan. Argon's design consisted of a carbon steel cylinder approximately 16 ft long, 18 in. outside diameter and 0.375 in. wall thickness. The carbon steel silo was protected from corrosion by a duplex coating system consisting of zinc and epoxy. Although the study indicated that the duplex coating design would provide a design life well in excess of the required 50 years, the review board was concerned because of the novelty of the design and the lack of historical use. In 2012, NNSA tasked Idaho National Laboratory (INL) with reinvestigating the silo storage concept and development of alternative corrosion protection strategies. The 2012 study, "Silo Storage Concepts, Cathodic Protection Options Study" (INL/EST-12-26627), concludes that the option which best fits the design criterion is a passive cathodic protection scheme, consisting of a carbon steel tube coated with zinc or a zinc-aluminum alloy encapsulated in either concrete or a cement grout. The hot dipped zinc coating option was considered most efficient, but the flame-sprayed option could be used if a thicker zinc coating was determined to be necessary.

1.2 Scope

This document takes the option recommended in INL/EXT-12-26627 and prepares a "generic" preconceptual design and cost estimate for silo storage independent of exact location. The design must provide both environmental and physical protection of the materials; have a low initial cost; and minimum maintenance over a 50-year design life. Design considerations for retrievability and security vulnerability are also required. This design does not include any infrastructure design such as fencing, grading, roads, etc.

1.3 Assumptions

1.3.1 Waste Form Assumptions

- The waste consists primarily of activated metals, radioisotope thermoelectric generator (RTG, RITEG), miscellaneous contaminated debris, miscellaneous sealed sources, and smoke detectors.
- The waste to be stored at the storage facility will include the pre-processed fuel elements and the post-processed waste. Post-processed fuel element waste will not contain sodium, liquids, or non-radionuclide hazardous materials (i.e., carbon based waste including cleaning solvents, PCBs, etc.). Post-processed waste will be primarily activated metals.
- Radioisotope thermoelectric generator (RTG, RITEG) obtained their power from radioactive decay. In such a device, the heat released by the decay of a suitable radioactive material is converted into electricity by the Seebeck effect using an array of thermocouples. These will contain primarily activated metals with a smaller mass-fraction of miscellaneous contaminated organic parts (see Figure 1).

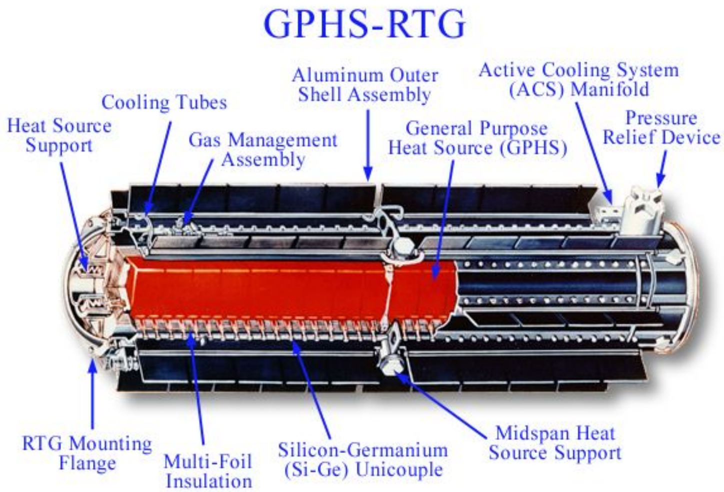

Figure 1. A graphic of the makeup of an RTG.

- Smoke detectors (see Figure 2) contain radionuclides such as Pu-239, Ra-226 and Am-241. The radioactive materials were initially sealed inside a single envelope (metal foil) or deposited on a ceramic support and vitrified. Therefore, they will contain the Pu-239 decay chain (Pu-239->Pu240->Am-241), and therefore will contain all of the daughter products.

Figure 2. Typical smoke detector.

- Waste contained or associated with the cooling canals will be remote-handled waste and will include a combination of fuel elements, activated metals, and resins. Resins will be a combination of anion and cation exchange resins. These will degrade radiolytically if exposed to high radiation fields associated with the activated metals.
- Sealed sources will be assumed to have been (or can be) removed from the non-radiologically contaminated equipment. It is assumed that the older sealed sources will contain Ra-226, Cs-137, Co-60, Am-241 and their respective decay chains. Newer sealed sources will contain more Co-60. Removal of the source from the carrier equipment will reduce the size of the material allowing it to be placed in smaller close-packed containers.

1.3.2 Waste Storage Assumptions

- Waste will be characterized to the extent practicable. For the purposes of interim storage, at a minimum, C-14, I-129, H-3, Ni-63, U-238, Co-60, Cs-134, Cs-137, Nb-94, Ni-63, Sr-90, and Am-241 inventories will be estimated. Total gamma emissions per container and per gram will be provided.
- Waste will be in storage for 50-years. It is assumed that this waste is not being deposited for permanent disposal. Therefore the waste must be retrievable without excessive worker exposure.
- Waste retrieval will be subject to non-proliferation constraints requiring it to be removed only with special equipment (i.e., lifting lugs, sealed storage, etc.).
- Waste will be contained in steel liners (containerized) prior to shipment to the waste disposal facility. Waste requiring extra shielding during transport and handling will all be contained in a single type of storage container.
- Waste arriving at the storage facility will not contain free liquids; will have been carefully drained. However, it is assumed that pre-drying of the waste has not been performed.
- Waste arriving at the facility does not contain biodegradable, radiolytically degradable, or thermally degradable materials that produce explosive gasses. If the waste will produce explosive gasses, the inner steel liner will be vented to the atmosphere prior to retrieval.
- Worker exposure limits will be enforced at the facility during waste disposal, waste retrieval, and waste storage. Exposure limits will be similar to those enforced through 10 CFR 835 (Occupational Radiation Protection) and 10 CFR 20.
- Criticality concerns will be addressed by the waste container packaging and will not be a consideration for the silo storage design effort.

2. SILO CONTAINER OPTIONS AND AFFECT ON LINERS

The potential material that will be stored in the silos is in many different shapes, sizes, forms, and packaging. It is assumed the material will be repackaged into cylindrical containers or drums. The size and quantities of these containers drives the shape, size and quantities of the storage silos. An evaluation of the types and sizes of containers is required to determine the potential impacts on the silo design. For the purposes of a conceptual level design, a baseline maximum size of a container will be established.

The basic criteria for this preliminary level of the silo design with regards to the containers that will be used are assumed to be as follows:

- Availability: The containers should be reasonably available in the region where the silos will be constructed, either commercially or easily fabricated.
- Approved for Usage: The container should be acceptable for use for storage of radioactive material, with respect to the specified life span of the project.
- Size: The size of the containers should allow efficient storage capability, without excessively driving the costs of silo construction.
- Lifting and Handling: Storage containers should allow for easy lifting and handling, during transport both to and from the site and during loading and retrieval operations. The inside diameter of the silo should allow for retrieval of each container. Assume that the minimum diameter of the liner is based on the maximum diameter of the container plus 3-inches on each side (6-inches overall).

Four sizes of containers will be evaluated to account for the various materials to be stored consisting of an oversized Silo/Vault 200 liter, 120 liter and a smaller canister size container.

2.1 Russian 200 Liter Steel Drum

The Russian 200 Liter steel storage drum is a commonly used container in the region where the silos will likely be constructed. These types of drums are available as uncoated carbon steel, stainless steel, painted or galvanized finish. This drum is approximately equal to the ANSI MH2 55 gallon drum. Some of the advantages of this drum are summarized below.

2.1.1 Advantages

- Availability: This type of drum is currently used predominately in this region for the storage of radioactive material.
- Use: This drum has been approved for use for this type of storage.
- Size: The larger size of drum will allow the storage of more material in any one container, or will facilitate oversized or odd shaped items much easier than smaller drums. Large enough to be used as an over pack for an existing container.
- Handling: Since this container is used in the region, lifting and handling fixtures, over packs, or other handling equipment should be readily available.
- Costs: This drum is commercially available.

2.1.2 Disadvantages

- Larger silos are required for storage, increasing initial construction costs.
- Retrieval of damaged or corroded drums may be difficult.

2.1.3 Silo Construction Impacts

The 200 liter drum has an outside diameter of 585 mm which would require a minimum inside pipe diameter of 737 mm (29 in) for an assumed clearance of 76.2 mm (3-inches) around the diameter of the drum for rigging attachments. The smallest available nominal pipe size is a 750 mm pipe which has a 762 mm OD and available with a 9.53 mm (0.375-in) wall thickness or 7.92 mm (0.312-inch). Assuming 12-inches of concrete used as backfill around the liner, a minimum excavated hole of 1371.6 mm (4.5-ft) diameter is required as shown in Table 1 and Figure 3.

The use of the 200 L drum is standard for storage of radioactive material in this region, but as shown in Figure 3, requires a 30-inch diameter pipe and large diameter hole to be excavated for each silo (4.5-ft with 12-inches of concrete cover).

2.2 Russian 120 Liter Drum

The Russian 120 liter drum is equivalent to the US ANSI MH-2 30 gallon container. The diameter of the drum is 530 mm (20.86-in) and with a rigging allowance of 76.2 mm on all sides, 152.4 mm overall (6-inches) the minimum required liner diameter is 682.4 mm (26.86-in).

The smallest available nominal pipe size is a 750 mm pipe which has a 762 mm OD and available with a 9.53 mm (0.375-in) wall thickness or 7.92 mm (0.312-inch). Assuming 12-inches of concrete used as backfill around the liner, a minimum excavated hole of 1371.6 mm (4.5-ft) diameter is required as shown in Figure 4 and Table 2.

As shown in the comparisons between these two containers, the overall size of the silo and components does not vary. Whether a 200 or 120 Liter drum size is used the construction and fabrication costs and methods are relatively the same.

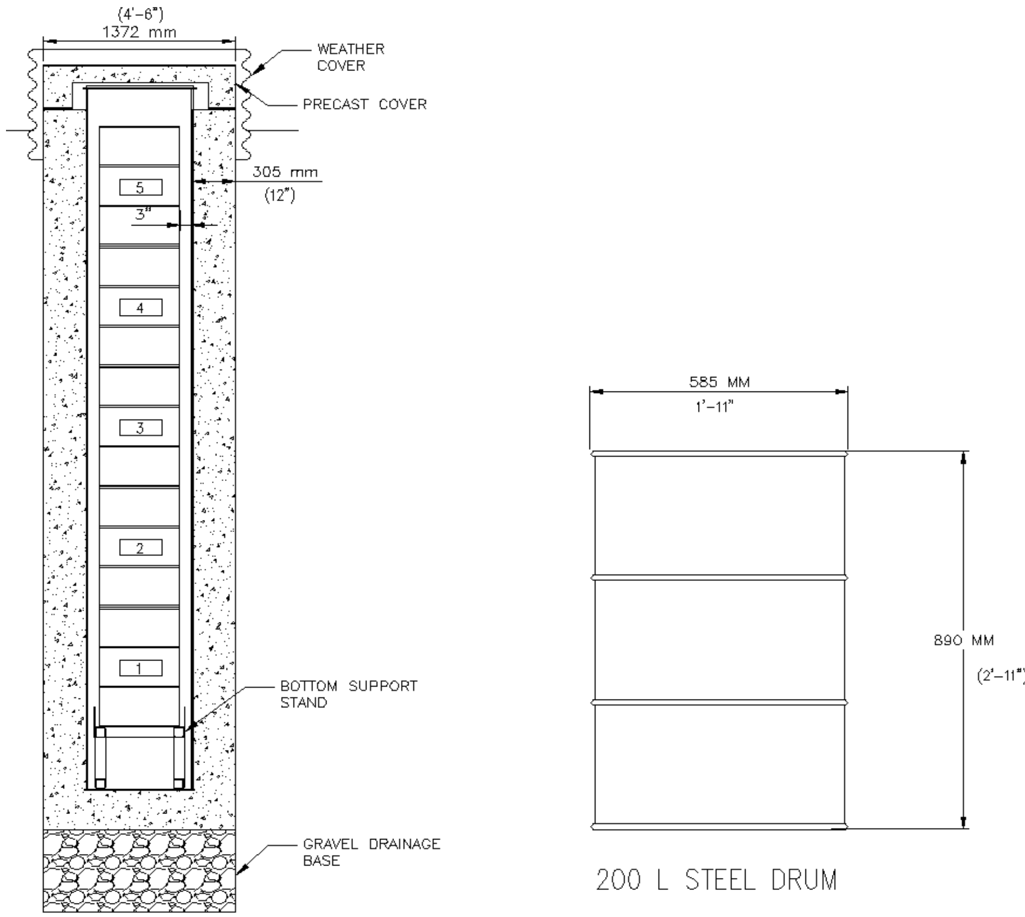

Figure 3. Typical silo construction for 200-L drums.

Table 1. Silo quantities for 200-L drum.

200 L Drum	Metric	US
Nominal Pipe Size	750 mm x 9.53 mm	30-inc sch 40 (.375)
Excavation Diameter	1371.6 mm	4.5 ft
Wt Steel	858.3 kg	1888 lbs
Volume Concrete	4.98 m^3	176 ft^3

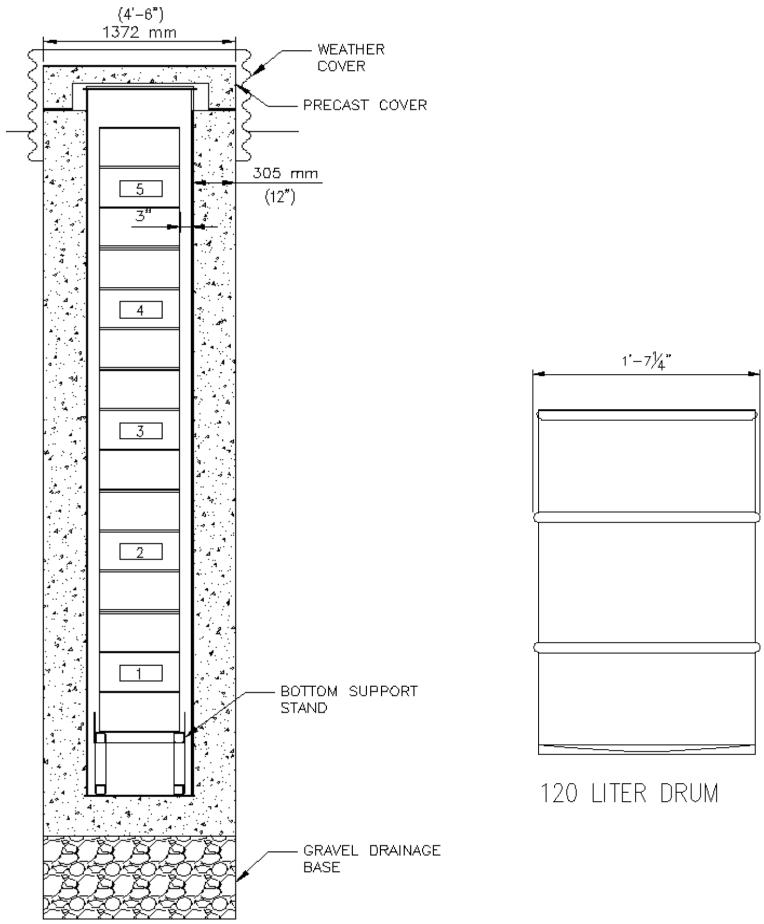

Figure 4. Typical silo construction for 120-L drum.

Table 2. Silo quantities for 120-L drum.

30 Gallon Drum	Metric	US
Nominal Pipe Size	750 mm x 9.53 mm	30-inc sch 40 (.375)
Excavation Diameter	1371.6 mm	4.5 ft
Wt Steel	858.3 kg	1888 lbs
Volume Concrete	4.98 m^3	176 ft^3

2.3 Small Diameter Canister Liner

It may be required to store smaller diameter canisters (paint cans) at some locations depending on the material at that particular site. For evaluation purposes, assume a 305 mm (12-inch) OD container is used for the smaller silos. This would require a liner diameter of 457.2 mm (18-inch). The minimum pipe size available would be a 450 mm x 9.53 mm (18-inch x.375-inch).

The overall silo construction would be a 1066 mm diameter (42-in) with concrete backfill of 305 mm (12-inch) around the perimeter. The size of the silo and type of container would be adjusted to fit the needs of the specific site and material to be stored, but the assumed 305 mm container is a good representative size for many applications. The overall construction is identical to the drum storage silos, only sized for the smaller containers as shown in Figure 5 and Table 3.

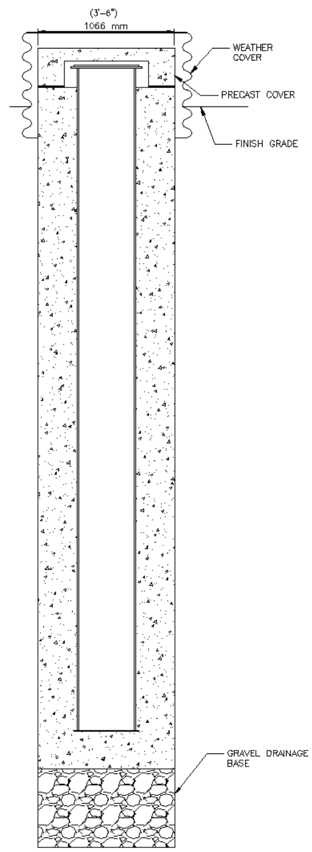

Figure 5. Small container storage silo construction.

Table 3. Silo quantities for small storage.

305 mm (12-in) Container	Metric	US
Nominal Pipe Size	450 mm x 9.53 mm	18-inc (.375)
Excavation Diameter	1066 mm	3.5 ft
Wt Steel	512 kg	1129 lbs
Volume Concrete	3.56 m^3	125.6 ft^3

2.4 Oversized Silos/Vaults

The need for oversized storage silos or vaults is required for most of the storage sites to handle the large bulky items that may be located at the facility. The size of the oversized vaults is site specific but could accommodate any object using plate steel welded to form a box type vault. The items that are to be stored within the vaults can be placed directly in or pre-packaged in a secondary container.

A precast lid may be placed over the vault for security, weather protection, and shielding and sealed for moisture intrusion prevention. A weather cover may be placed around each vault to reduce the exposure to moisture as with the container storage silos as shown in Figure 6.

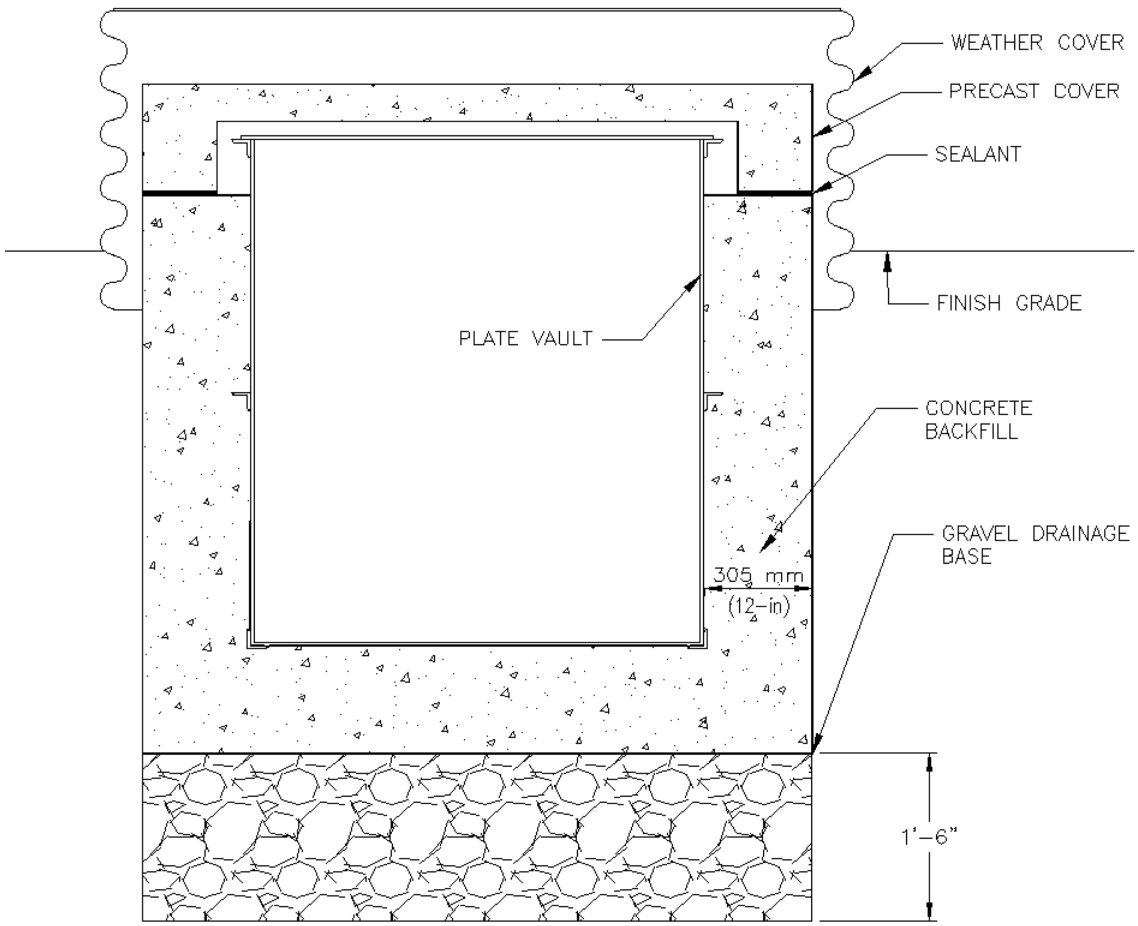

Figure 6. Typical oversized vault construction.

3. MOISTURE PROTECTION IN SILO DESIGN

The silo design shall protect the canisters stored within from corrosion and deterioration for the 50-year design life. The primary source of the corrosion will be in the form of moisture which can originate from external or internal sources. Minimizing the moisture found within the silo liners must be considered in the design of the storage system.

3.1 Internal Moisture Design Provisions

Internal silo moisture may come from the materials within the individual containers, humidity, loading operations or other sources. Studies performed at the INL have shown that the control of internal moisture is a serious condition that must be controlled. To reduce the corrosion of the containers within the silos, a means to remove the moisture or mitigate its affect must be included in the design. In addition to internal sources of moisture, the build-up of gases from the individual containers may be present, which, may not contribute to corrosion, but can pose a potential risk to the silos and retrieval operation.

The following subsections discuss the physical methods that are available to mitigate the effects of moisture and gases within the silos.

3.1.1 Positive Over Pressure

The application of a small internal pressure in the silo tube would help prevent the intrusion of external moisture. This pressure could be applied via a small tube and valve included in the silo tube construction. The addition of a second tube that reached the bottom of the silo could allow the removal of any moisture accumulation in the bottom of the silo. This approach also allows monitoring the health of the silo and in determining the internal atmospheric conditions inside the silo prior to opening.

3.1.2 Liner Drain

The storage silos can be designed with a drainage system that will allow any moisture in the liner to be drained out the bottom of the silo and dispersed in the base material. A granular base material will allow drainage from the silo and prevent intrusion from exterior sources. The top portion of the liner can be vented to prevent any potential gas build up by direct holes or filtered openings and allow natural ventilation. A support stand can be installed in the bottom of the silo to elevate the bottom container off the floor of the silo and out of any potential build up of water. This type of design would require the site groundwater level below the silo base and protection from flooding, weather and surface groundwater intrusion to minimize the moisture levels. The granular base material will be designed to provide drainage over the lifetime of the project without blocking from fines and shall prevent intrusion of moisture by capillary action of the material.

3.1.3 Welded Closure Plate

The silo liner can be sealed through welding the top plate. This type of closure system can be effective at reducing the amount of moisture from entering the silo, but does present issues when the material needs to be removed from the silo. Additionally, it will be more difficult to maintain quality control on the field welds and the area around the weld will have to be treated separately for corrosion protection.

3.1.4 Bolted Closure Plate

The silo liner top plate can also be attached through a bolted flange. The advantage of this system is that it is easier to reopen the silo to remove the material and it does not require field welding the plate. The main disadvantage is that the seals may fail during the 50 year design life and have to be replaced.

3.1.5 Bottom Support Stand

A means shall be provided that will position the containers within a silo above and away from any water that may collect within the liner. A stand can be designed to support the combined weight of all containers that can be stored within a silo. This Bottom Support Stand, shown in Figure 7, will be designed to position the stack of containers above the level of any water that may collect. The stand material shall be compatible with the liner and container materials. The support stand can also be used as a means of retrieval of the containers by lifting the entire stack of containers.

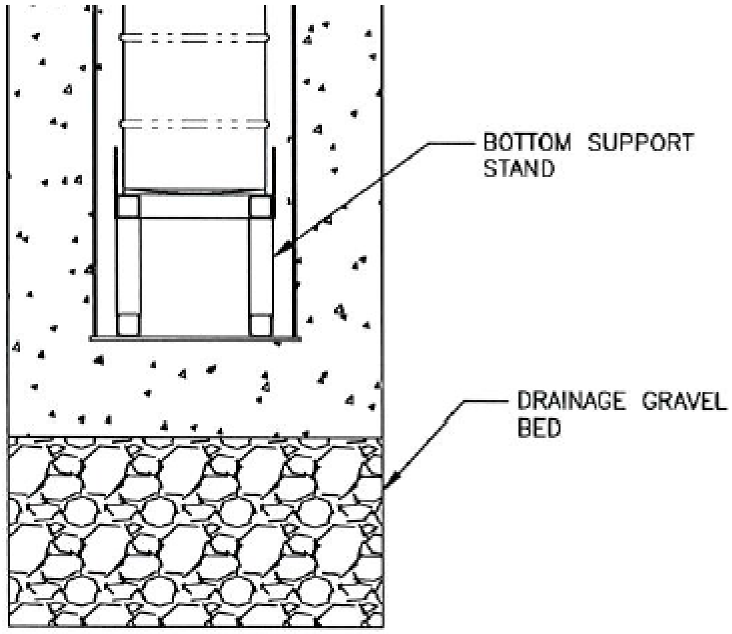

Figure 7. Bottom support stand.

3.2 Exterior Moisture Design Provisions

3.2.1 Concrete Backfill Durability

The concrete backfill will protect the liner from moisture below grade. The concrete mix will be specifically designed to resist corrosion and to protect the steel by reducing the concrete permeability, using sulfate resisting cement, a more durable compressive strength, and a conservative thickness of concrete, all of which resists or at least slows the intrusion of moisture.

The storage silo liners will be constructed vertically in the ground by excavating an oversized hole or shaft in the soil, placing the liner pipe and backfilling with a protective concrete barrier in the remainder of the hole. Concrete will be used as backfill due to its protective properties for corrosion prevent, security, and ease of backfilling. The durability of the concrete barrier must be such that the carbon steel liner pipe will not corrode

The durability of the concrete with respect to the overall silo design can be expressed best as providing the appropriate cementitious material for sulfate resistance, air entrainment for freeze-thaw resistance, protection from dry shrinkage and thermal cracking and proper protection from expansive cracking related to alkali silica reactions. Typically, the ACI 318 building code relies upon a specified compressive strength of the concrete, maximum water-cement ratio, minimum cement content and air entrainment to provide these features of durability, without necessarily addressing or ensuring the composition of the mix is optimized to resist the relevant exposure conditions required to meet the goals of the silo design. With respect to the design of the storage silos, the goal of the concrete backfill is not so much a structural need, but a protective barrier to minimize the corrosion of the silo liner and prolong its usable life through the required 50 year lifespan.

The major degradation processes that will most likely attack and affect the underground concrete barrier in the silo design are discussed in the following subsections.

3.2.1.1 Sulfate attack. Sulfate attack in concrete results from naturally occurring sulfate salts such as sodium, potassium, calcium, and magnesium found in ground water and soils reacting with the alumina bearing compounds in cementitious materials forming expansive reaction products and a breakdown of the hydrated Portland cement material properties. The result of the expansive reaction can be spalling and cracking and a reduction in strength due to the diminished cement properties, which in turn reduces the concrete's ability to resist cracking, all of which can lead to the intrusion of moisture to the silo liner material.

3.2.1.2 Steel corrosion. Because of its high alkalinity, concrete creates a passive layer around the steel and prevents corrosion. Corrosion of the internal steel liner can be caused by transport of chloride ions to the surface of the steel and react to reduce the alkalinity. Carbonization of the concrete due to carbon dioxide ingress will also reduce the ph at the steel surface and allow the introduction of the corrosion process.

3.2.1.3 Alkali silica reaction. Most aggregates react to some degree with alkalis in the cement. Usually the reactions are beneficial such as increasing the bond between the aggregate and hydrated cement. The Alkali ions present in the cement material can cause a reaction with the silica mineral forms present in certain aggregate sources in the presence of moisture. This reaction forms an expansive alkali silicate gel that absorbs water and causes concrete to crack. In most cases ASR cracking can be categorized as cosmetic, surface type cracking, but concrete used in a barrier role, the addition of surface cracking can lead to an increase in moisture into the concrete matrix.

3.2.1.4 Leaching. Leaching occurs by high level of ground water which can dissolve soluble materials in concrete and gradually result in its degradation. Leaching can increase the porosity of the concrete, by continued dissolution of material, and thereby increase the transport properties of the concrete leading to the degradation processes previously mentioned.

3.2.1.5 Carbonization. Carbonization occurs when concrete is exposed to carbon dioxide, a reaction producing carbonates takes place that can result in a decrease in the ph of the cement material, shrinkage of the concrete and subsequent cracking and deterioration. Since the concrete will be buried and protected by soil, carbonization from groundwater will be the primary concern. Carbon dioxide can be present in the soil from rainwater and other naturally occurring sources within the soil.

3.2.1.6 Cracks. Cracks occurring in the concrete material in the silo design could be either structural type cracks or intrinsic type cracks caused by internal stresses of the concrete. Structural cracking of the concrete should not be a credible risk due to the fact the concrete will not be loaded externally under normal conditions, other than earth pressures and possibly silo loading operations. Intrinsic cracking may occur as a result of plastic shrinkage, plastic settlement, thermal cracking, and dry shrinkage cracking.

3.2.2 Preventative Design Methods

3.2.2.1 Sulfate attack. Sulfate attacks the concrete material directly and can crack and weaken the concrete to allow moisture to reach the silo liners. Protecting against sulfate attack requires using the appropriate cementitious materials and reducing the ingress of sulfates in the concrete. ACI 318 Table 4.3.1 classifies different levels of sulfate exposure based on the concentration of sulfate ions in the soil or water anticipated to be in contact with the concrete on a scale from S0 through S3. The code requires corresponding levels of maximum water-cement ratio, minimum compressive strengths and cement types as a means to resist sulfate (see Table 4).

Table 4. ACI exposure category and ACI exposure requirements.

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

Category	Severity	Class	Condition	
F Freezing and thawing	Not applicable	F0	Concrete not exposed to freezing-and-thawing cycles	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and occasional exposure to moisture	
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture	
	Very severe	F3	Concrete exposed to freezing-and-thawing and in continuous contact with moisture and exposed to deicing chemicals	
S Sulfate			Water-soluble sulfate (SO_4) in soil, percent by weight	Dissolved sulfate (SO_4) in water, ppm
	Not applicable	S0	$SO_4 < 0.10$	$SO_4 < 150$
	Moderate	S1	$0.10 \le SO_4 < 0.20$	$150 \le SO_4 < 1500$ Seawater
	Severe	S2	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10{,}000$
	Very severe	S3	$SO_4 > 2.00$	$SO_4 > 10{,}000$
P Requiring low permeability	Not applicable	P0	In contact with water where low permeability is not required	
	Required	P1	In contact with water where low permeability is required.	
C Corrosion protection of reinforcement	Not applicable	C0	Concrete dry or protected from moisture	
	Moderate	C1	Concrete exposed to moisture but not to external sources of chlorides	
	Severe	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. w/cm*	Min. f'_c, psi	Additional minimum requirements			
			Air content			Limits on cementitious materials
F0	N/A	2500	N/A			N/A
F1	0.45	4500	Table 4.4.1			N/A
F2	0.45	4500	Table 4.4.1			N/A
F3	0.45	4500	Table 4.4.1			Table 4.4.2
			Cementitious materials†—types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	2500	No Type restriction	No Type restriction	No Type restriction	No restriction
S1	0.50	4000	II‡	IP(MS), IS (<70) (MS)	MS	No restriction
S2	0.45	4500	V§	IP (HS) IS (<70) (HS)	HS	Not permitted
S3	0.45	4500	V + pozzolan or slag‖	IP (HS) + pozzolan or slag‖ or IS (<70) (HS) + pozzolan or slag‖	HS + pozzolan or slag‖	Not permitted
P0	N/A	2500	None			
P1	0.50	4000	None			
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement#		Related provisions	
			Reinforced concrete	Prestressed concrete		
C0	N/A	2500	1.00	0.06	None	
C1	N/A	2500	0.30	0.06	None	
C2	0.40	5000	0.15	0.06	7.7.6, 18.16**	

Portland cements that conform to ASTM Type II and V are used for moderate and severe sulfate conditions, respectively. Type II cements has a maximum limit of 8% on the tricalcium aluminate, C_3A, while Type V cements limit the phase to 5%. A Portland cement might optionally be tested for sulfate resistance in accordance with ASTM C 452. Most fly ashes (primarily Class F), slag and silica fume provide resistance against sulfate resistance. These supplementary cementitious materials and blended cements are good options for sulfate resistance. Since the silos may be constructed in any type of soil condition, Type V cement should be used with a pozzolan and a maximum water-cement ratio of 0.45 and minimum compressive strength of 4500 psi for sulfate resistance.

3.2.2.2 Steel corrosion protection. As previously stated, steel embedded in concrete is protected from corrosion by the high ph of the concrete keeping the steel in a non-active corrosive state. Intrusion of chlorides into the concrete through contact with chloride-contaminated soil, water or marine atmosphere, however, may lead to corrosion of the steel by lowering the ph. The goal of corrosion protection is to prevent or slow the chlorides from getting to the steel surface. Methods used to prevent this corrosion are achieved by both physical and chemical means.

- Physical Methods:
  - Additional thickness of clear cover between the moisture source and the steel increases the time it takes for chlorides to reach the steel.
  - Barriers such as membranes and surface coatings.

- Chemical Methods:
    - Concrete mixes used to mitigate chlorides are based on the diffusion rate of chlorides. Dense concrete mixes that are less permeable slow the diffusion of chlorides through concrete. Therefore, the time for chlorides in the soil or water to reach the steel is increased.
    - The use of mineral admixtures (such as fly ash, silica fume, metakaolin, etc.), reduced water content, and increased cementitious material content (water/cement ratio) result in high-density, durable concrete that decreases the permeability of the concrete.
    - Corrosion inhibitors used as an admixture neutralize the chlorides as well as using non-chloride admixtures. Use of Non-liner: Non corrosive material used as a liner such as stainless, aluminum, or galvanized steel would certainly reduce, slow or eliminate the corrosion of the liners.
- ACI 318 Table 4.2.1 (Table 4 above) defines the corrosion categories as follows:
    - C0 - Not Applicable: Dry concrete or protected from moisture.
    - C1 – Moderate: Concrete exposed to moisture but not to external sources of chlorides.
    - C2 – Severe: Concrete exposed to moisture and external chloride sources.

Since the silos may be constructed at locations with a variety of environmental conditions, it is prudent to assume a Severe Class category (C2). Table 4.3.1 of ACI 318 specifies the requirements for corrosion prevention by limiting the water-cement ratio to 0.4, a minimum compressive strength of 5,000 psi and a maximum water-soluble chloride ion content of 0.015 percent by weight of cement. Cementitious material to be used in the concrete shall be a combination of Type V or II Portland cement and supplementary cementitious material such as fly ash or natural pozzolan.

Lowering the water-cement ratio to 0.4 and thorough consolidation of the concrete and a resistant cement material and additives when combined with a conservative cover thickness over the steel will provide the best resistance to corrosion of the steel liner from chlorides. This is especially true when the uncertainty of concrete quality is considered with exposure uncertainties. A 12-inch thick cover of concrete will be assumed to provide the best chance of preventing moisture from reaching the steel. Due to the depth of silos, a 12-inch thick cover will be easier to place and consolidate and assure complete coverage.

3.2.2.3 Alkali silica reaction protection. Alkali Silica Reaction and the subsequent expansion of the concrete occur when the following is present:

- Concrete has moisture present
- Concrete contains aggregates with siliceous constituents that are alkali silica reactive
- A source of sufficient alkalis (sodium or potassium) is available

Strategies to prevent ASR expansion usually focus on controlling on one or more of the following:

- Control the available moisture
- Control the amount of reactive siliceous material in aggregates or concrete
- Lowering the ph of the concrete pore fluid to decrease the solubility of the silica in the pore fluid.

The prevention of ASR is a difficult task to accomplish to any degree of certainty without the use of field sampling of aggregates and concrete materials. This is expensive and may not be readily available in areas where the silos will be constructed. Since the affect of ASR attack on concrete is usually at or near the surface of the concrete and not full depth penetrating, a more reasonable approach is to lower the permeability of the concrete by lowering the water-cement ratio and lowering the amount of high alkali content cement through the use of pozzolans, silica fume or ground slag.

Pozzolans (fly ash) and slag effectively replace portions of the cement which is the chief source of alkalis. Fly Ash: fly ash is a finely divided residue byproduct of the combustion of powdered coal, classified as Class C or F by ASTM C618. Class F fly ash is generally more effective in mitigating the effects of ASR. Typical proportions of fly ash vary from 15 to 30 % of the cementitious material.

Blast Furnace Slag: Ground granulated blast furnace slag is a finely ground glassy siliceous material formed as a by-product of iron manufacturing. The alkalis encapsulated in slag are released much slower than those in Portland cement (but higher than fly ash) making it an inexpensive substitute in the correct proportions. Effective amounts of slag required to reduce ASR expansion varies from 25-50% by mass of cementitious material.

Silica Fume: Silica fume is a very fine powder containing 85 to 99% amorphous silica by mass and is a by-product of the silicon and ferro-silicon metal industry. Silica fume actively removes alkalis from the pore solution and thereby reduces the ph. Replacing at least 10% of high-alkali cement with silica fume has been effective in most cases. Higher percentages may cause other problems in concrete (cracking).

3.2.2.4 Cracks. Plastic shrinkage and settlement occurs during construction while the concrete is still in its "plastic" stage and usually results from poor construction practices. Thermal cracks can result from poor control of construction materials and curing and protection practices. Since the silo design concrete would be cast directly into an excavated hole, the majority of the concrete will be relatively stable with respect to thermal control. The interface temperatures between the concrete and the silo liner and soil boundary will need to be monitored and controlled during construction to avoid a potential temperature differential.

3.2.2.5 Carbonization. Carbonization of concrete can be mitigated by reducing the amount of water that can enter the concrete. This can be achieved as mentioned previously by reducing the permeability of the concrete by the mix design or providing barriers between the soil and the concrete. In the case of the silo backfill, a barrier cannot be economically used; therefore the concrete mix design must be used. This can most be effected by lowering the water-cement ratio.

3.2.3 Summary

The silo design will be used as a standard design for construction at several different locations with varying soil and environmental conditions, material and construction quality variances, it is recommended that the design of the concrete backfill be based on conservative prescriptive design requirements and construction controls that improve the final product's durability and meet the goals of the storage silos 50 year life span. Based on the criteria presented in this study, the durability of the concrete and silo liner can be improved by specifying the appropriate mix design and performance parameters. The design features determined to increase the durability of the concrete with respect to each of the degradation processes identified can be summarized as follows:

- Reduce the permeability of the concrete by lowering the water-cement ratio to 0.4
- Specifying a minimum compressive strength of concrete of at least 4500 psi
- Use of a sulfate resistant Portland cement (Type V)
- Use of Fly Ash and silica fume for lowering the water-cement ratios and resistance to negative material reactions
- Provide a conservative concrete cover over the liner pipe. A 12-inch thick cover of concrete will assure adequate protection.
- Use a corrosion resistance liner material such as galvanized steel

- Use specific construction limits and controls to improve quality and reduce the risks of cracking, temperature shrinkage, and better consolidation.

3.2.4 Liner Material

The selection of the liner material shall prevent moisture from entering the storage area. This is accomplished through corrosion resistant materials or coatings as well as thickness of material and corrosion prevention methods. The material selected as part of this conceptual level design for the liner is a galvanized carbon steel which is economical and commercially available.

3.2.5 Liner Closure

There are many methods of closing and securing the liner from seal welding the lid shut, using a bolted flange connection, and combinations of the two. The type of closure method may depend on the level of security required by the site, the length of time the material is expected to be stored, or the environment where it will be stored.

3.2.5.1 Bolted flange connection. A bolted flange connection would be similar to the blank pipe flange and would be secured by bolting the flange plate to the flange. A gasket would be needed to seal the interface. The advantage of this type of connection would be the ease of installation and removal but also is less secure and could be subject to failure of the gasket and possible moisture intrusion through the connection. The connection may have to be inspected periodically to determine if any leaks have occurred.

3.2.5.2 Welded connection. A continuously welded top plate would provide a more permanent solution by sealing the joint around the perimeter of the plate. This requires more field work to accomplish, but if properly performed provides a more secure, sealed connection. The performance of the connection to resist moisture would be dependent upon the quality of the welding, materials and exposure, but once installed, would require little further maintenance other than protection from the environment.

The best method of closing the silos from a security perspective is to provide a welded top plate. This provides a more secured closure and better assurance that moisture will not penetrate the connection. This assumes that there are no restrictions from welding at the site, or with the materials stored in the silos. This type of top plate closure can be used for either the sealed liner or the open-vented liner system.

The final method of closing the top plate will be completed with the detailed design; however for conceptual purposes, several options are identified in Figure 8.

The top closure plate can be welded by using a shop welded top flange to provide a consistent bearing surface and a simple fillet weld to seal the plate (A). This type of connection allows for field adjustment of the top plate since more surface area is available and more flexibility for a proper fit up. The top plate can also be welded by a butt type weld between the liner and plate ends (B) which would require joint preparation of the connection and much closer tolerance for the plate fabrication or finally the top plate could be oversized and a fillet type weld used to seal the joint (C). Since the weld in this joint is under the plate, moisture does not settle on the weld material and is drained away. However, this is a more difficult weld to perform and inspect.

The most economical type of connection would be the oversized top plate and fillet weld since this requires the least amount of preparation and joint welding (C).

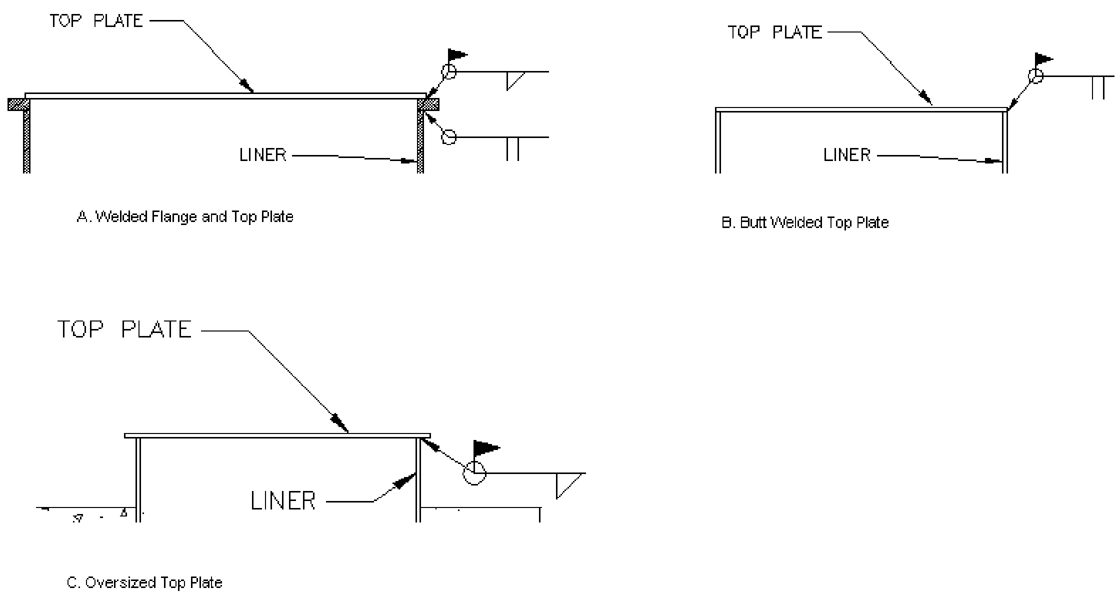

Figure 8. Top plate welded connections.

Regardless of the option used to close the silo, a method to protect the top of the silo must be provided to reduce the chances for corrosion and moisture attack and to provide a level of security to the silo liner. The top of the silo will be at grade and exposed for future retrieval and monitoring.

3.2.6 Cover Options

The cover options for the silo assembly can be provided in a graded approach depending on the desired level of protection, either from weather element and/or security requirements. The options discussed in the following subsections are presented for consideration.

3.2.6.1 Precast security cover. A precast concrete cover, as shown in Figure 9, can be used to provide a degree of weather protection, shielding, security and surface damage protection. Precast concrete can be easily formed to any shape or size and can be fabricated with cast-in lift points. Coatings and sealers can be used to help weatherproof the concrete. This type of cover can also provide a measure of security, since a means of lifting would be required or demolition prior to exposing the liner top.

A precast cover would also protect the silo from damage from vehicles such as transports, snow removal equipment, construction equipment or other surface machinery over the lifetime of the silo. The joint between the precast and silo concrete must be sealed to prevent moisture from snow and rain from infiltrating to the liner. This joint sealant will be exposed to UV deterioration and wear and may require periodic maintenance for long term storage.

If the liner is vented at the top, either through open or filtered holes, the vents could be extended through the precast and grouted in place which would have to be disconnected prior to removing the cover. Steel covers could also be constructed which would be lighter to handle, but not as robust for a security deterrent.

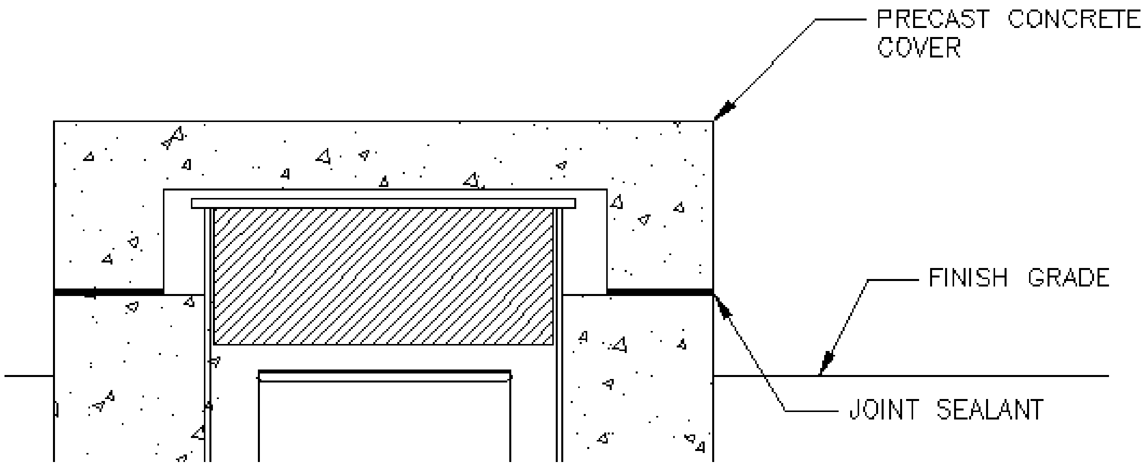

Figure 9. Typical precast concrete cover.

Precast concrete covers provide a very durable element for security and vehicular protection but still need to be sealed at the joints and coated to resist weathering themselves.

3.2.6.2 Weather cover. A weather cover, as shown in Figures 10 and 11, can be constructed to protect the silo top from exposure and reduce the chances of moisture from attacking the liner material. Weather covers such as this are used frequently for this reason and are an inexpensive means of providing weather protection. The weather cover can be constructed of galvanized corrugated metal pipe, or HDPE corrugated pipe for corrosion resistance. Corrugated pipe of either material is commercially available in a range of large diameters and proven history of use in most environments. Hinged covers plates can be added with locks for additionally security.

The weather covers can be sized to accommodate and protect any monitoring equipment, vent piping or ports used with the silos. Weather covers do not provide the same security protection as precast concrete, but will significantly reduce the amount of moisture that can reach the silo liners. Depending on the level of protection desired, a weather cover alone may be sufficient in lieu of a precast or steel cover or in addition to a precast concrete type security cover.

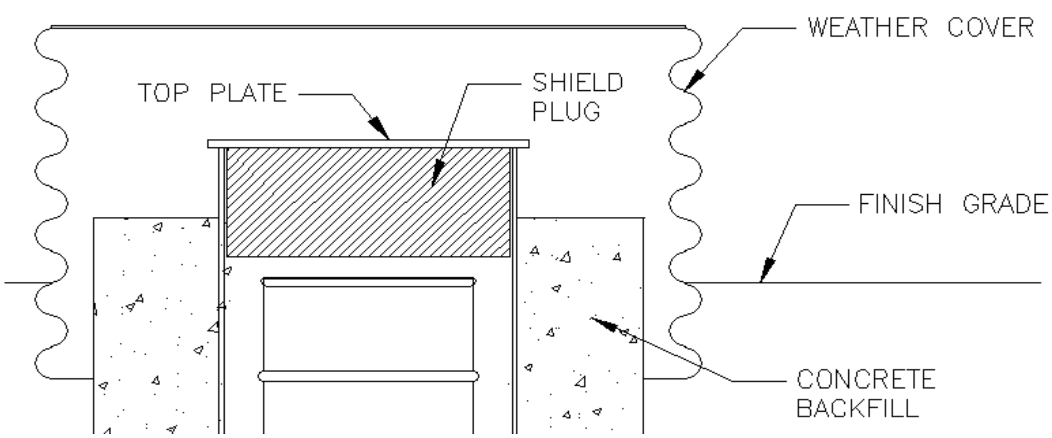

Figure 10. Typical weather cover.

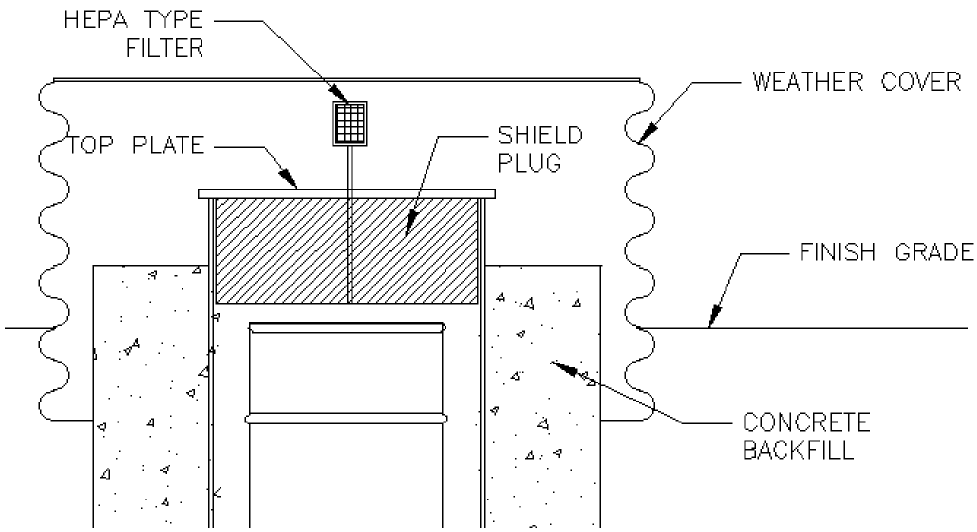

Figure 11. Typical weather cover with vent and filter.

3.2.6.3 Combination cover. The best option for protecting the silo above grade features may be a combination of the two options previously discussed. The level of protection necessary is dependent on site specific requirements such as weather exposure, risk to the material stored, storage life and level of maintenance expected or desired and cost. This type of design, as shown in Figure 12, could be used on some or all of the silos at a specific site based on the specific aforementioned criteria.

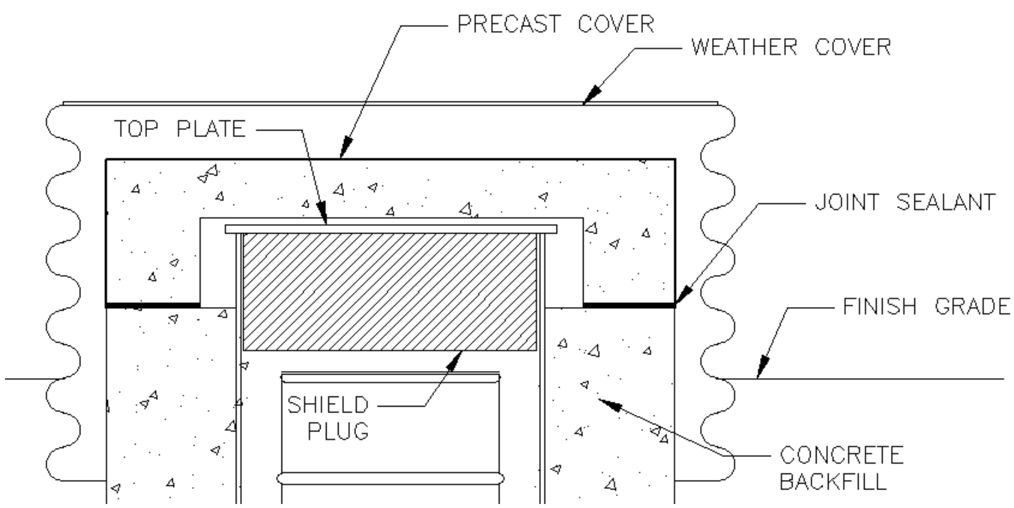

Figure 12. Combination cover.

3.2.7 Moisture Protection Recommendation Summary

The recommended silo design is based on relying on durability of the silo components to resist corrosion and protect the contents for the 50 year design life. Since the specific details of the site location, soil conditions, size and quantities of the waste material and security and protection goals of the materials are not known at this time, only general conceptual level design recommendations are provided.

3.2.7.1 Liner material. The liner material shall be a minimum 9.53 mm (3/8-inch) thick galvanized carbon steel pipe or plate. This material will provide the most economical moisture resistance liner for the design life. The dimensions of the pipe or plates are dependent on the specific storage container used, retrieval method and quantities to be stored.

3.2.7.2 Concrete backfill. The concrete backfill shall be a minimum of 305 mm (12-inch) thick with a minimum compressive strength of 4500 psi. The concrete mix shall use sulfate-resistant Type V Portland cement, a water-cement ratio of 0.4, and fly-ash and silica fume admixtures to provide the best resistance to moisture and chemical attacks.

3.2.7.3 Liner closure. The method used for closing the silo liners will be by seal welding the top plate to provide a secure cap to the liner. The extent of sealing the liner shall be based on the specific security requirements of the material stored within. A bolted flange may be an option for a specific application where security of the material would allow it. The use of positive pressure could be used to reduce moisture intrusion and provide for silo integrity monitoring.

3.2.7.4 Interior support stand. A support stand shall be used within the silo to elevate the bottom container out of any potential build–up of moisture. This stand shall be constructed of a similar material as the liner and containers to prevent galvanic corrosion. This stand can also serve as a secondary method of retrieval of the containers if they become damaged.

3.2.7.5 Cover design. The silo cover design can be modular in general and modified as a graded approach to meet the specific silo storage requirements such as security and level of moisture protection and monitoring. The final cover options to be applied with a graded approach are discussed in the following sections.

3.2.7.6 Liner cap. This cover would simply be the liner closure top plate with a seal weld to the liner pipe. This would be the most basic cover and applicable to installations where moisture will not be a design consideration due to expected time of storage, environmental limits, or the resistance of material stored within. This design would assume the galvanized top plate provides adequate security and weather protection for the material stored.

3.2.7.7 Precast concrete cover. The precast concrete cover would be used where more security or protection is required. This cover is used in addition to the liner cap plate. This cover could be the final cap, or used in conjunction with a weather cover.

3.2.7.8 Weather cover. The weather cover option could be used with only the liner cap or with the precast cover options, depending on the security and/or shielding requirements.

The weather cover design presented in this study provides an in-expensive means to protect the top of the silo and house any monitoring, venting or filtering equipment.

The silo designs are summarized in Figure 13.

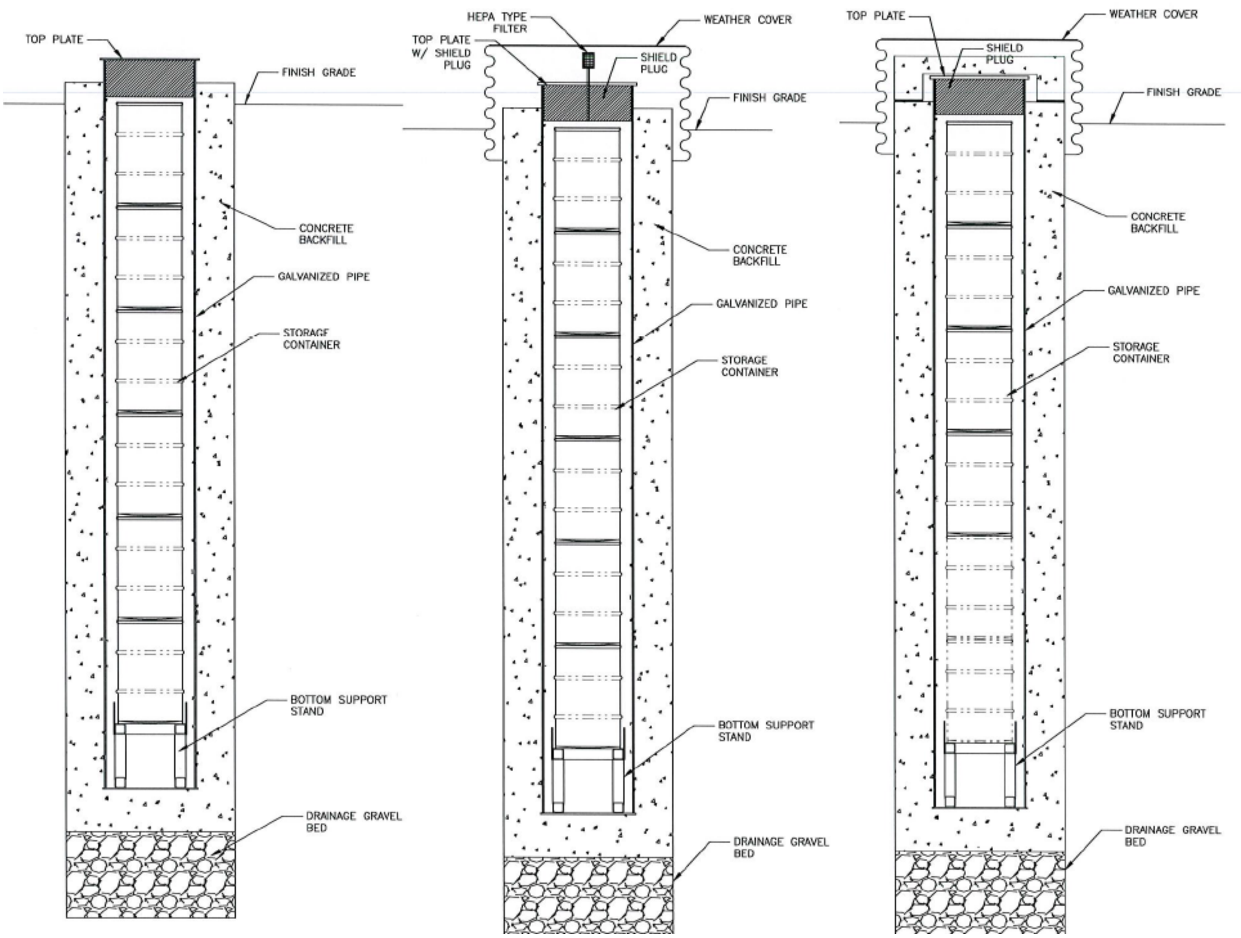

Figure 13. Base design, weather protections, and security protection.

4. SILO LOADING AND RETRIEVAL OPTIONS

Regardless of the material used for the silo units, the methods used to load and retrieve materials stored within, must be developed sufficiently enough to assure the operations can be performed with the final design concept.

Vertically loaded storage silos, or vaults pose a problem in that remote handling and manipulating is required to attach or remove rigging during the loading or retrieval operation. Specifically, retrieval of individual containers can be difficult if the rigging is inaccessible. Containers that have been stored for a period of time may be of questionable condition from corrosion or handling damage and may not be able to be retrieved in the same method that was used to load the container. Permanently attached rigging may be damaged, corroded or inaccessible for retrievable. Depending on the location of the storage facility, the equipment available for both loading and retrieval of the materials may be limited. The design of the storage silo should be flexible enough to allow for redundant methods to be used for loading and unloading.

4.1 Equipment Assumptions

The equipment used for lifting and handling of the storage containers are usually construction grade mobile cranes with traditional rigging hardware such as slings, shackles, hooks and spreader bars. Some storage silos utilize special rigging fixtures that operate remotely, or utilize mechanical engagement devices. A standardized silo design to be used at multiple locations, should limit the complexity of the lifting fixture or mechanism.

4.2 Loading of Silos

The loading of vertical storage silos is much easier than the retrieval process, due mainly to the fact that the condition of the containers is typically new or at a minimum verifiable. Vertical storage silos or vaults are usually loaded by a variety of means and methods such as bottom loading shipping casks, open-air transfers using cranes, or other specialized machinery depending on the site and availability of equipment.

4.2.1 Open Air Transfers

Open Air Transfers are used on relatively low level radioactive materials where shielding is not required or controlled otherwise. Rigging or a lift fixture is attached to the container and to a mobile crane or other means and the container is lifted and inserted into the storage silo. The rigging is either remotely disconnected or sometimes left attached to the individual container. This type of transfer is the most flexible and simplistic and can accommodate higher radiation levels by the use of temporary shielding or more remote operation.

4.2.2 Shielded Transfer

Shielded transfers are sometimes used for containers with higher levels of radiation. This type of transfer uses a shielded collar or port around the storage silo opening to shield workers for the radiation source while the container is being lowered into the silo and rigging is being disconnected. The design of a storage silo must allow sufficient room for the shielded port, or be capable of supporting the weight of the shielding. As with the open-air transfer, the rigging is usually remotely disconnected or left on the individual container.

4.2.3 Transfer Casks

Transfer casks are used on higher level radioactive material containers where shielding is desired through the transfer operations. The casks are unloaded through the bottom by sliding a door open and lowering the container into the storage silo by a mechanism inside the cask. These types of transfer systems are significantly more complicated and require a more substantial bearing capacity to work on.

4.3 Retrieval of Stored Containers

Retrieval of stored containers from within a vertical silo or vault is typically achieved in a procedure opposite of the loading sequence. This however becomes complicated when the containers have become damaged either from corrosion, internal rupture, or previous handling damage. Lifting a damaged container such as a drum can be risky if the integrity of the container cannot be guaranteed. The use of existing rigging previously attached is frequently used, but the rigging is often damaged by corrosion, radiation breakdown or damaged from loading. The remote attachment of rigging to containers within a vault or silo can be difficult on complicated fixtures. The design of the storage silo should provide adequate room for the attachment of rigging, or modifications to the rigging for retrieval purposes. During a recent retrieval project, at the INL, permanently attached wire rope slings on canisters stored in steel silos had to be replaced prior to retrieval due to corrosion, which delayed the project and added significant cost and the potential for worker exposure.

4.3.1 Hoisting and Rigging Equipment

Since the assumption of this portion of the design is that Russian 200 liter drums will be used as the storage container, the rigging to be used to load and retrieve the containers must be compatible with drum handling. Drums are handled in a variety of ways in commercial industry using below-the-hook lift fixtures and forklift mounted drum lifters, choke slings, baskets, magnets and special designed lifters. Examples are shown in Figure 14.

Figure 14. Commercial-grade drum below the hook lifting fixtures.

The top-mounted friction type fixtures are commonly used but require a silo diameter much larger than the drum for operation (since they pivot). These types of fixtures do not positively attach and can drop a load if hung up. These fixtures also rely on the integrity of the drum for grip and to support the material within. The bottom supported lift fixture provides a safer means of lifting, since the container is not stressed in tension. Damaged containers should be lifted in this manner if the integrity cannot be assured. An electrical magnet fixture lifts from the top such as the friction clamp, but without the additional side clearance requirements. The condition of the container would have an effect on the performance of the magnet and as with the friction type clamp; a damaged drum may not be capable of supporting its own weight if lifted from the top.

A custom designed and fabricated fixture may be used based on the expected condition of the containers. This type of fixture may be a basket type of frame that supports the containers from the bottom, resists corrosion and has a convenient method of attaching rigging remotely. This type of fixture would be required on all of the drums to be functional. As an alternate to this basket type of fixture, a platform could be developed to be placed on the bottom of each silo that is capable of supporting the lifted load of all containers in the silo. This would be placed at the time the bottom drum is loaded and could be used to retrieve the entire stack if needed. Rigging would have to be left in place on the platform, but could be oversized and galvanized for protection.

Another option for rigging and handling would be to fabricate containers with permanently attached lift points on the lid for easier access. Figure 15 below shows a container fabricated from 20-inch OD, schedule 5 pipe. The size is similar to the 30 gallon barrels, and would provide a reliable means of lifting and handling, specifically for retrieval of containers. Containers such as this will have a higher initial cost to fabricate than drums, but would provide easier handling and a greater assurance of retrievability.

Whether drums are used or a fabricated type of container, the method of loading and unloading the silos is best handled by a top rigged assembly. If it can be reasonably expected to have little damage or corrosion at the time of retrieval, then a top supporting method of lifting is easily the most cost effective means. For the purposes of this conceptual level design, it is assumed that a method of top loading rigging will be used for loading and retrieval of the containers.

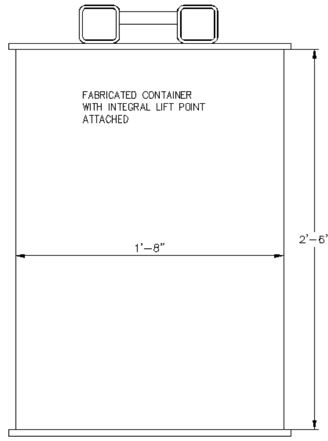

Figure 15. Fabricated container with integral lift point.

4.3.2 Rigging Impact on Silo Diameter

The inside diameter of the silo should allow for retrieval of each container. To provide some flexibility in the retrieval method, the inside diameter of the liner shall be oversized a minimum of 3-inches around the entire perimeter of the container to allow a method of remote attachment to be used. The design of the bottom support stand can incorporate rigging attachments or at least provisions to utilize the stand to lift the stack of containers if damage has occurred. This at least provides of means for retrieving the containers in the future.

5. SILO CONSTRUCTION OPTIONS

It is assumed that normal construction practices are sufficient for the construction of the silo modules. Specialty tools, equipment, and labor are kept to a minimum for economy and adaptability to the specific site based on available work forces.

5.1 Site Work

5.1.1 Site Preparation

The site preparation shall consist of site grading and leveling for the preparation of the storage area, roadwork and construction of staging and lay down areas. Site preparation design is not within the scope of this study and will be performed by others at a later date.

5.1.2 Excavation

Excavation for silo construction, as shown in Figure 16, would be performed using common construction earth augers which can successfully excavate a vertical shaft in any even inch increment up to 10-feet or greater and almost any depth as needed.

The earth augers can usually removed most of the soil and material from the shaft, but residue material will be left at the bottom of the excavation that may need to be addressed if significantly uneven. Depending on the type of soils in the construction area, the hole should be stable but installation of the silos should follow the excavation fairly shortly. Non-cohesive type soils such as sand, loams, silts and certain gravels may be somewhat unstable and may require immediate installation.

Figure 16. Typical earth auger equipment and completed auger excavation.

Due to the close proximity of adjacent silos, excavation of a silo hole may undermine the adjacent hole(s). Therefore for construction sequence planning it should be assumed that silo liners and backfill material will be installed directly after holes are drilled, or locations staggered to prevent collapse of excavations and allow the work to be performed in combined batches. Excavation of silo holes should not be performed adjacent to installed silos until the backfill material has sufficiently cured to prevent stress cracks in the cementitious backfill. Figure 17 shows a typical silo field layout.

Figure 17. Typical storage silo layout.

5.1.3 Installation

The excavation hole shall be over excavated to allow for the installation of a granular base material to provide a bearing surface and to allow a drainage bed for the silo liners. The granular base should be approximately 2-4-ft thick.

The silo pipes can be rigged from the top, lifted and set using a mobile crane. A brace can be designed that is attached to the pipe at ground level to hold the pipe in position while the backfill grout/concrete is placed. This would allow alignment and leveling of the pipe while the material is placed. There are various methods to accomplish this, but a simple brace such as this would allow the backfill to be placed in a continuous uninterrupted operation. To assure the concrete bottom of the silo is consolidated and free of voids, the base can be placed first, and then the silo steel pipe set and the backfill then continued without a cold joint between the base and walls of the backfill. It is desirable to avoid a cold joint in the cementitious backfill to reduce the pathways for moisture to migrate to the silo liner.

A precast base could be used and the steel pipe could be attached prior to setting in the hole, but this would require the excavation base to be level and would create a cold joint at the interface between the precast and backfill material. The silo liner could also be placed prior to the concrete base and the entire mass placed monolithically using a tremie chute or other means.

5.1.4 Backfill

The purpose of the concrete backfill is to protect the silo liner from moisture and corrosion, provide security and shielding as well as a convenient method of backfilling the excavation. The concrete backfill will need to be placed using a tremie chute to avoid separating the aggregate from the mix and to assure proper consolidation. The 305 mm (12-inches) thickness of the backfill is based on corrosion protection of the silo liner for long term durability.

6. MONITORING

Monitoring of the storage silos is intended to determine the condition of the silos and materials stored in the silos. In this case, monitoring is used to identify whether corrosion of the liners and/or a change in the radiological condition of the materials contained within them, has occurred. As previously stated, a study performed at INL in 2012, "Silo Storage Concepts, Cathodic Protection Options Study" (INL-12-26627), recommended that a passive cathodic protection scheme be applied to these silos. The passive cathodic scheme would consist of the carbon steel liner being zinc or zinc-aluminum coated, followed with the coated liner being externally encapsulated in concrete or cement grout. This section considers both the corrosion monitoring aspects of the design and monitoring of the radiological materials contained within the silos, regardless of silo size or geometry.

6.1 Corrosion

Corrosion monitoring of underground silos has been performed for many years, using multiple methods. Determination of the final approach will be performed in the final design of the system. Options under consideration for monitoring of corrosion in these silos are discussed in the following subsections.

6.1.1 Passive Monitoring

This option suggests that the material protection provided for the encapsulated liners and the design of the silos is deemed sufficient to justify adopting a "no corrosion monitoring" posture. Once in place, the silo would not be monitored for corrosion during the 50 year storage life of the silo.

Actual knowledge regarding corrosion processes, during the storage period, is not known with this choice. If the system is ignored for the period of storage, the resulting condition of the silo will be unknown until time of retrieval.

6.1.2 Positive Gas Pressure

Monitoring of the silo liner integrity by sealing the silo and applying a small internal pressure to its interior (~34.5 KPa; ~5 psig) is a viable and often used process; then performing periodic monitoring for pressure loss, as evidenced by viewing a location protected pressure gauge at the silo.

At a nominal 34.5 KPa (~5 psig) gas pressurization level, pressure swings due to temperature variation would not be significant; as estimated at ±6.9 KPa (± 1 psig). Perfect sealing of these silos may not be possible, yet initial monitoring of the pressure loss (when the silo is new) would indicate a nominal schedule for recharging, via something as simple as an silo installed type of Schrader air pressurization valve. The evidence of corrosion penetration of the silo would be that the frequency of silo pressurization would increase beyond the normal maintenance frequency. This evaluation process will be developed further during the final design of the systems.

6.1.3 Moisture Level Monitoring

Maintaining a relatively dry environment inside the liner space of the silos is important in preventing corrosion of the liner. The presence of moisture inside silo liners may be reflective of one or more of the following conditions:

- Containerized materials that are vented to the liner and were not dried when put into the storage containers
- Undried containerized materials inside a sealed container that has been breached or has corroded with internal moisture leaking into the liner space
- Vented silo liners and stored contents that reflect the moisture content (humidity level) of the local atmosphere
- Ingress of moisture through the liner as a result of corrosion through the liner.

With the exception of the last condition, each item noted above represents a situation that can be base lined and tracked, from an original moisture content standpoint. With the proposed design, there is no significant source for addition of moisture to the system. The last condition, because of the passive cathodic precautions that are planned for the system and the other moisture minimization/barrier design alternatives previously discussed, is not considered credible in this application.

Moisture monitoring techniques and equipment are commercially available. Monitoring for moisture level inside the silo liners may be performed randomly, routinely, or continuously. A routine approach would provide for monitoring of the moisture on a scheduled basis. To support this, a probe could be installed that would be a permanent part of the silo. Then, a hand held monitor could be attached and readings taken according to a pre-determined schedule. A probe and hand held could be used similar to that shown in Figure 18. Further development of this concept is needed during final design.

Figure 18. Typical hand-held moisture monitor.

6.1.4 Ultrasonic Wall Thickness Monitoring Equipment

A method commonly employed for determination of the progress of corrosion in a system is wall thickness measurement. Wall thickness measurement determination using ultrasonic technology is applied by the use of equipment that is mounted against strategic locations of the outside of the silo liner as shown in Figure 19.[a] The ultrasonic equipment is designed to measure wall thickness and send the information to a data logging system. Changes in the wall thickness, due to corrosion, are logged in a database that would be interpreted by qualified analytical personnel. The sensing unit must remain operational for the 50-year life of the storage system. Additional study is required to justify its use for this duration.

[a] Information from Rohrback Cosasco Systems, Inc.

Figure 19. Example of ultrasonic wall thickness measurement equipment.

6.1.5 Sacrificial Probe Sensors

Another method for indirectly determining corrosion characteristics of the local geology is the use of commercially available “sacrificial” corrosion probes. In general a sacrificial probe has sensing elements made of the metal or alloy for which corrosion data is required. The probe bodies may be of the same alloy, but thicker, or of a higher, less corrosive alloy. The probe is placed in locations that are in close proximity to the item of concern; in this case the silo liners. As the corrosion process proceeds and the sacrificial materials are depleted, results are logged in a data base for interpretation by qualified personnel. The sacrificial system is representative to the installed liners and, based upon their proximity, should indicate similar corrosion of the silo. Corrosion of the sacrificial materials should provide information of liner degradation in sufficient time to respond to the situation. As with the ultrasonic wall thickness sensor, the 50-year silo life is a concern for this electronic device. Additional study is needed to justify its use for this duration. A typical system would appear as shown in Figure 20. Figure 21 shows a typical installation of the sacrificial system.

Figure 20. Example of commercial system for sacrificial monitoring of liner corrosion.

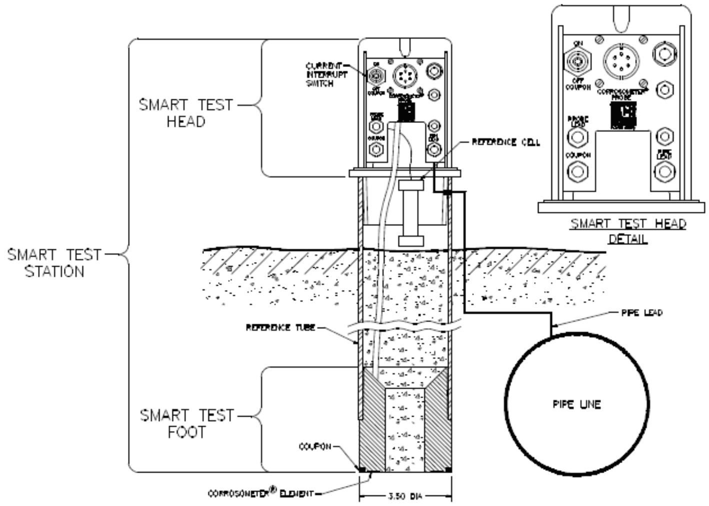

Figure 21. Example of sacrificial equipment installation.

6.1.6 Potential (Voltage) Measuring Half-Cell

Potential measurement technology between the silo liner and the soil is commercially available and widely used for corrosion measurement of items buried in soil. Discussed here are two types.

Copper/copper sulfate half-cells are typically favored for potential measurements of systems buried in soils. Figure 22 illustrates the principle of construction of a copper/copper sulfate reference electrode (CCSRE) used for soil application.

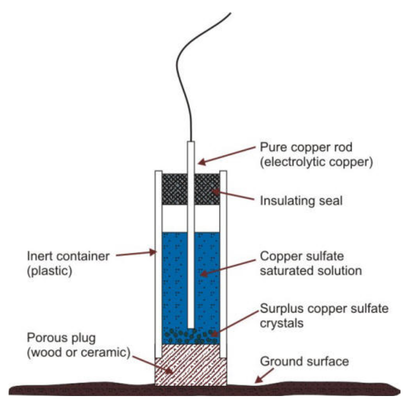

Figure 22. Schematic of a copper/copper sulfate reference electrode.

Figure 23 shows a picture of a commercial CCSRE ready for field work. What is often referred to as a pipe-to-soil potential is actually the potential measured between the pipe and the reference electrode used to make the measurement. The soil itself has no standard value of potential against which the potential of a pipe can be measured independently.

Figure 23. Example of CCSRE half-cell.

The half cell potential of a CCSRE is dependent only upon the electrochemical equilibrium established between Cu and its ions in solution.[b] The CCSRE has a published design life of 20 years, which means that the units would require multiple replacements during the lifetime of the silo field.

The other type, a more long-lived technology is available using silver and chloride materials. It is silver/silver-chloride half-cell technology[c], also available commercially. The schematic of Figure 22 is also representative of this, except that the materials used are different. This type of unit has an advertised life of 60 years, which exceeds the design life of the silo storage area. A Silver/Silver-Choride half cell is shown in Figure 24.

Figure 24. Example of a silver/silver-chloride half-cell.

A commercially available electronic data reading/logging system is required with either of these technologies. Additional study and investigation of this technology, as a potential candidate in this application, will be performed during final design.

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[b] Information obtained from internet: Corrosion-Doctors.org/Corrosion-Thermodynamics/Reference-Half-Cells-Copper.htm

[c] Information obtained from M. C. Miller Co., www.mcmiller.com

6.1.7 Silo Interior Visual Monitoring

Visual monitoring of a portion of the silo interior is a potentially viable option. Should the silo vented option be selected, the system could incorporate designed hardware and processes to insert and lower a camera into the silo. The camera could be lowered down to the lowest level of the liner and be oriented to look at the wall and inspect for corrosion. This option has radiological control implications both from a radiation and contamination standpoint. The potential implementation of this concept requires additional study and design in order to justify its viability for this application.

6.1.8 Corrosion Monitoring Recommendations

Knowing the condition of the silo structure is important from a future material retrieval and environmental stewardship standpoint. Therefore, a non-monitoring approach is not considered a viable option. Each of the other options discussed may be implemented individually, in multiples, or collectively. For the baseline situation of this design effort, it is recommended that the simplest, most economical option would be to monitor the integrity of the liner using pressure. Should the option be chosen to vent the silo through an HEPA filter, then monitoring the wall thickness of the liner would be the most definitive option for determining the integrity of the liner.

6.2 Security Monitoring

Security monitoring of the underground silos requires the ability to verify that the radiological materials contained in the silos are as originally placed and have not been compromised, tampered with, or removed. Options for performing this surveillance are as discussed in the following subsections.

6.2.1 Local Radiation Air Monitor

Radiation monitoring of the area surrounding the storage silos is necessary to provide for the security of the contents. Continuous monitoring of the area is needed to alarm if unauthorized tampering of silo contents takes place. The equipment necessary to do this is commercially and readily available. An example of the equipment that might be employed in this situation is as shown inFigure 25.[d] This or similar units would be strategically placed around the storage site, providing coverage for all of the storage silos. The system can provide for local and/or remote alarm functionality. Design, selection, and location(s) of a final system will be performed in final design of this system.

6.2.2 Constant Air Monitor

Constant air monitoring (CAM), i.e. sensing for leakage of radioactive materials from the silo(s), is needed in order to prevent contamination of the environment, flora, and/or fauna. A typical CAM is shown in Figure 26. It provides for continuous air monitoring for alpha and beta particulates and has local and remote alarm functionality. Multiple units may be employed to accommodate the size of the silo field. Final determination of the type, quantity, and placement for this equipment will be addressed during final design of the system.

[d] Information obtained from Canberra Industries.

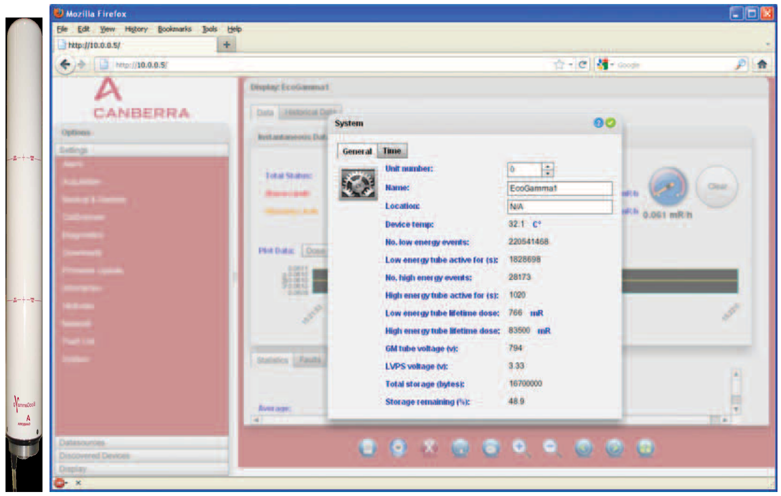

Figure 25. Example of RAM system used for security of silos.

Figure 26. Typical constant air monitor (CAM).

6.2.3 Video Surveillance

Video surveillance of the silo storage area will be performed to enhance the safeguards and security of the materials stored in the silos. Video surveillance equipment is commercially available as complete systems. A typical system is as shown in Figure 27.[e] The video surveillance system will provide for visual area monitoring of the silo field. Images may be recorded on pc-cards, hard disk, or flash drives for archival and other record keeping purposes and programmed for capturing the images at pre-selected intervals. The type, number, and placement of the system(s) will be determined during final design efforts.

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[e] Information obtained from Canberra Industries

Figure 27. Typical video surveillance system.

7. SILO CORROSION LIFE ESTIMATE

7.1 Introduction and Background

7.1.1 Life Objective

As has been stated elsewhere the objective is to have the silo intact during its fifty (50) year rated life. Pitting or localized corrosion is considered the primary way that the silo will be penetrated.

7.1.2 Corrosion Processes

There are three different corrosion processes going on simultaneously around the storage silo: external soil corrosion attacking the silo sides and bottom, external atmospheric corrosion attacking the silo top, and internal atmospheric corrosion attacking the silo inside surfaces. The internal corrosion is occurring simultaneously with the external corrosion. The total life of the liner system is the shortest of these combined attacks. These processes and directions are discussed below. Not included in this estimate is the corrosion on the inner container and the corrosion or degradation internal to that container attacking the stored material. These are outside the scope of this study.

7.1.3 Protection layers

While the steel silo is the fundamental protection layer, the outer concrete shell and the galvanized zinc/aluminum coating protect the steel silo. Therefore, these layers are included in the estimate and play a critical role in the total life estimate. The number and characteristic of the layers is determined by which corrosion direction that is being estimated. Each layer and direction has a different corrosion rate.

Before external soil based corrosion can start the corrosive electrolyte (water) has to penetrate the concrete shell and reach the next layer, the galvanizing. The galvanizing then starts to corrode. After corrosion of the galvanizing layer progresses to the point where there is a sufficiently large area, the exposed steel starts to corrode. For estimating purposes, the time to penetration of the steel is considered the end of life for the silo. No credit is taken for the inner surface galvanizing for external based corrosion.

External atmospheric based corrosion starts to attack the galvanized steel immediately but is a much slower process than the soil corrosion. Again the corrosion of the galvanizing is considered separately from the underlying steel. After corrosion of the galvanizing layer progresses to the point where there is a sufficiently large area the exposed steel starts to corrode. For estimating purposes, the time to penetration of the steel is considered the end of life for the silo. No credit is taken for the inner surface galvanizing.

Internal atmospheric based corrosion starts to attack the galvanized steel immediately but is a much slower process than the soil or external atmospheric corrosion. Again the corrosion of the galvanizing is considered separately from the underlying steel. After corrosion of the galvanizing layer progresses to the point where there is a sufficiently large area the exposed steel starts to corrode. For estimating purposes, the time to penetration of the steel is considered the end of life for the silo. No credit is taken for the outer surface galvanizing.

7.1.4 Elevated Temperature

Most corrosion studies are based on room or ambient temperatures. Corrosion rates exponentially increase with increase in local temperature. The estimate uses an Arrhenius predictions based on a doubling of the rate for ever rise of 30°C scaled to start at 20°C. Reaching a maximum around approximately 60°C then exponentially falls back to a low level as the water in the area is evaporated.

7.1.5 Assumptions

- Quality control of the galvanized coating and the concrete/mortar are key to the success of the silo corrosion protection idea presented here. The quality of the thickness and completeness of the coating are both important.
- It is assumed that the concrete/mortar placement techniques and craft skill result in a void and large crack free concrete liner.
- Limiting the salinity of the water and the chloride concentration of the initial concrete mixture, including admixtures, is also important. It is assumed that the initial concrete chloride concentration will be less than 0.1% (or 1,000 ppm) which is a common upper limit for potable water.
- It is assumed that the bounding conditions described in section 7.1.7 below have been generally followed.
- It is assumed that the minimum thicknesses of the galvanizing (one nominal size step thinner) and steel silo (-12.5%) are within normal industry standards and the concrete minimum thickness is at the nominal value stated in section 2 above minus 100 mm (4 inches).
- It is assumed that the initial decay heat loading of the silo contents is packaged such that an individual silo's average temperature is less than 35°C over the fifty year life.
- It is assumed that any free liquid water, soil, or organic debris are removed from the interior of the silo and that the walls and bottom are visibly dry and clean prior to the contents being placed and the silo being closed. Care needs to be taken to prevent organic debris from falling into the silo during content placement or closure.
- It is assumed that the atmosphere within the silo doesn't become more corrosive during the storage life time and that the amount of water or moisture coming off from the contents isn't significant to the point of changing the corrosion environment.

7.1.6 Conservative Factors

There are a number of factors that makes the estimate conservative yet generally applicable to a wide range of installation locations.

It has been reported in a number of sources that the galvanizing limits the pitting factor of the underling steel. No reduction in the pitting factor of the bare steel has been taken. If limited to general corrosion the steel life is approximately 20 times longer. That is to say that the pitting acceleration factor used in the estimate is 20.9.

It has been reported in a number of sources that there is an exponential decline in corrosion rate with time. This implies that the corrosion rate in the last year of storage life will be less than the first year. This estimate assumes constant corrosion rates.

The thicknesses of the various components have been assumed to be all at their minimum tolerance levels.

The corrosion rates used in the estimate are all at the upper ends of their respective ranges.

The estimate includes a minimum remaining thickness of the steel silo of 25 mils or 0.64 mm (0.025 inches). This remaining thickness allows for a thin barrier to prevent contamination from reaching the environment.

7.1.7 Bounding Conditions

Table 5 shows the bounding conditions in which this life estimate is considered acceptable. Installation of these silo systems outside of these bounds is certainly possible but site specific local soil, water table, or other factors must be determined and a specific corrosion protection design or other considerations must be made before use. Please note that these characteristics are not mutually exclusive and may represent different ways to express similar or related properties.

Table 5. Bounding conditions.

Characteristic	Acceptable Range
Soil Resistivity	Greater than 1,000 Ω·cm (10 Ω·m)
Soil pH	6 to 8.5
Total Dissolved Salts	Less than 1,000 ppm
Soil Conductivity	Less than 1 dS/m (1,000 μS/cm)
Redox Electrode Potential	Less than 100 mV (<0.1 volt)
Sulfate	Less than 2,000 ppm
Soil Gypsum	Less than 1% by weight
Acid Producing or Sulfate Reducing Bacteria (SRB)	None known in the area or no history of microbial caused corrosion
Airborne Chloride Concentration	Less than 40 mdd (averaged over the 50 year life)
Airborne Sulfur Dioxide	Less than 0.5 ppm (averaged over the 50 year life)
Salt Water (Brackish, Mine Tailings, Industrial or Oil Field Waste Water)	Greater than 1km away if down wind or greater than 300 m if upwind from site
Sewage, Farm Waste, Industrial Waste Water Storage Ponds, Vaults, or Pipe Lines	Greater than 300 m away and outside the runoff path (preferably at least 10 m above highest runoff path elevation)
Roadways with Deicing Salts Used	Greater than 10 m away from 2 lane roads and greater than 50 m away from 4 or more lane roads and outside road side drainage ditches
Geothermal Areas, Hot Springs, Mineral Springs,	Greater than 300 m away

Characteristic	Acceptable Range
or areas with Hydrogen Sulfide Gas	
Mine Waste or Overburden Piles, Heaps, Tailings, Coal Field Drainage Areas or Piles, Industrial Slag Piles, or other areas with runoff water with a pH outside the range of 6 to 8.5	Greater than 300 m away and outside the runoff path (preferably at least 10 m above highest runoff path elevation)
Poorly Drained, Water Saturated, Mucky, or Boggy wet lands with greater 30% Organic materials in the soil	Greater than 100 m away
Areas of free flowing water, Rivers, Streams, Creeks, Springs, or Washes (Both continuous or intermittent)	Greater than 100 m away and outside the runoff path (preferably at least 10 m above highest runoff path elevation)
River Deltas or Historic Channels	Greater than 300 m away
Permafrost Areas	Greater than 300 m away
Soil Water Table	At least 300 mm above highest recorded elevation
Floodplain	Outside 50 year
Electrified Rail Lines, Cathodic Protection Systems, Overhead Power Lines	At least 50 m away
Used to Store Material with a Significant Thermal Decay Heat	Packaged to limit silo temperature to less than 35°C average temperature over the storage life.

7.2 Calculation Sections

The concrete/mortar shell is first and foremost a barrier to prevent water from initiating soil corrosion on the underlying layer. There are two threats to this layer, carbonization and associated weakening of the concrete, or chloride diffusion toward the underlying layer. These are shown in “Concrete Shell Life part 1 and part 2”, see Appendix C.

Carbonization is the process where carbon dioxide in the soil reacts with the concrete to physically weaken the concrete, allowing cracking, and chemical lowers the pH of the matrix toward neutral (~7). The corrosion rate of steel is affected by the pH of the electrolyte (water), for a pH of greater than 10.5 the corrosion rate of steel decreases significantly. Note that the carbonization coefficient is affected by the silo temperature. The carbonization end-of-life for the concrete is the period until the carbonization process reaches the minimum depth of the concrete. It is assumed that corrosion of the galvanization layer starts at that time.

Chloride Diffusion is the process where chloride in the soil penetrates the concrete to corrode the galvanized layer. The CTL, Chloride Threshold Level, is the percentage of chloride in the electrolyte where corrosion of the galvanizing starts. The chloride diffusion end-of-life for the concrete is the period until the diffusion process reaches the minimum depth of the concrete.

After the concrete shell is exhausted, corrosion of the galvanized layer starts from the soil side. The corrosion rate of the galvanization, adjusted for the silo temperature (35°C) of 2.3 is 30.6 μpy. The critical benefit of the galvanizing is to reduce pitting of the underlying steel.

After the galvanized layer is penetrated, the underlying steel starts to corrode from the soil side. The corrosion rate for the estimate is 36 μpy, the elevated temperature effect is 1.7, and the pitting acceleration factor is 20.9. Once the steel is penetrated then the life of the silo is over, no credit is taken for the inner galvanizing layer.

From the interior of the silo toward the outside the first corrosion barrier is the inner galvanized layer. The effective corrosion rate of the atmospheric corrosion is 1.8 μpy. This is composed of three parts, the base rate of 3 μpy, the elevated temperature adjustment of 2.3, and a sheltering factor of 3.8. The sheltering factor is a reduction in the corrosion caused by protection for large temperature variations, more uniform humidity, limited industrial pollution, and protection from rain fall.

After the inner galvanized layer is penetrated, the underlying steel starts to corrode from the atmospheric or internal side. The effective corrosion rate of the atmospheric corrosion is 160 μpy, including temperature effects. Once the steel is penetrated then the life on the silo is over, no credit is taken for the outer galvanizing layer.

With multiple corrosion processes operating simultaneously the life of silo is a combination of the corrosion from the inside of the silo and from the outside soil. These occur at different rates through the different layers. The estimate uses an iterative technique to find the resultant net silo life.

A separate corrosion path is from the external atmosphere (air) attacking the galvanized steel silo at the upper exposed top of the silo. There are again the two layers to account for, the galvanized layer and the underlying steel. After the inner galvanized layer is penetrated then the underlying steel starts to corrode from the external atmospheric side. The effective corrosion rate of the atmospheric corrosion is 127 μpy including temperature effects.

With multiple corrosion processes operating simultaneously the life of silo is combination of the corrosion from the inside of the silo and from the outside from the air at the top. Again these occur at different rates through the different layers. The estimate uses an iterative technique to find the resultant net silo life.

The final estimated silo life from all the corrosion processes is the shorter of the life from the soil portion or the atmospheric topside portion. The final estimated silo life is 83 years, which is greater than the required 50 year life. Therefore the design will meet the design requirement.

7.3 Parameter Sensitivity Estimate

The final estimated silo life is considered conservative when applied within the boundary conditions discussed above. It is expected that the actual life of the silo will be longer. There are numerous parameters estimated and safety factors within the estimated life calculation. Table 6, Parameter Sensitivity Estimate, shows the range of those parameters to bring the overall silo to a fifty (50) year life. Each parameter is adjusted to give the 50 year life while all the other parameters are maintained at their base values. The values for steel thickness, zinc/aluminum galvanizing thickness, and concrete cover thickness are the recommended design values when applied within the conditions of Table 5, therefore the 50 year life sensitivity values should not be used for cost savings.

Table 6. Parameter sensitivity estimate.

Estimate Section	Parameter	Base Value	Value for 50 Yr Life
Various	Silo Temperature	35°C	55°C (25°C gives 100 yr)
Concrete Shell Estimate Part 1 & Part 2	Concrete Thickness (Indirect by Auger Hole diameter & tolerance and Silo diameter & tolerance)	8.1 inches	Approx 2.5 inches
Concrete Shell Estimate Part 1 & Part 2	$Safety\_factor_{concrete}$ (Carbonation Rate & Chloride Diffusion Rate)	1	3.1
Concrete Shell Estimate Part 2	Water/Cement Ratio	0.40	Approx 0.60
Concrete Shell Estimate Part 2	Soil % Chlorides	0.1% (1,000ppm)	1.5% (15,000ppm)
Zinc Coating Life	Nominal Thickness	75µm (3 mil)	Approx 35 µm
Steel Thickness	Nominal Thickness	0.375 in (STD Sch)	Approx 0.13 in
Steel External Soil Corrosion	Steel Soil Corrosion Rate	36.1 µpy	Not Limiting (Other combination of factors control life)
Steel Internal Corrosion	Zinc Interior Atmospheric Rate	3 µpy	40 µpy
Steel Internal Corrosion	Steel Interior Atmospheric Rate	160 µpy	550 µpy
Combined External Atmospheric Liner	Zinc Atmospheric Rate	3 µpy	35 µpy
Combined External Atmospheric Liner	Steel Atmospheric Corrosion Rate	127 µpy	Not Limiting (Other combination of factors control life)

8. RECOMMENDATIONS

8.1 General

The recommended design of this report is modular in general terms and is based upon the assumption that a variety of design configurations will be used based on the specific details of each proposed site, such as environmental, soil, weather conditions, as well as the specific goals and requirements for the material being stored, such as security, shielding, condition, monitoring and length of storage. All of these factors affect the silo design and associated costs to construct and maintain, and it is assumed that these could vary significantly at each location.

The basic design recommended by this study uses a galvanized steel liner of a minimum of 9.53 mm (3/8-inch) steel encased in 305 mm (12-inch) thick site-cast concrete (min 4500 psi) with a shielded, welded lid and a minimum of a galvanized steel weather cover. The pre-cast concrete security cover and types and amount of monitoring can be applied as required by the site specific needs. The use of bottom support stands provides a means to assure containers are raised above any moisture within the silo and allow for retrieval of containers. Positive pressure could be used to reduce moisture intrusion and provide for silo integrity monitoring. The basic design is shown in Figure 28.

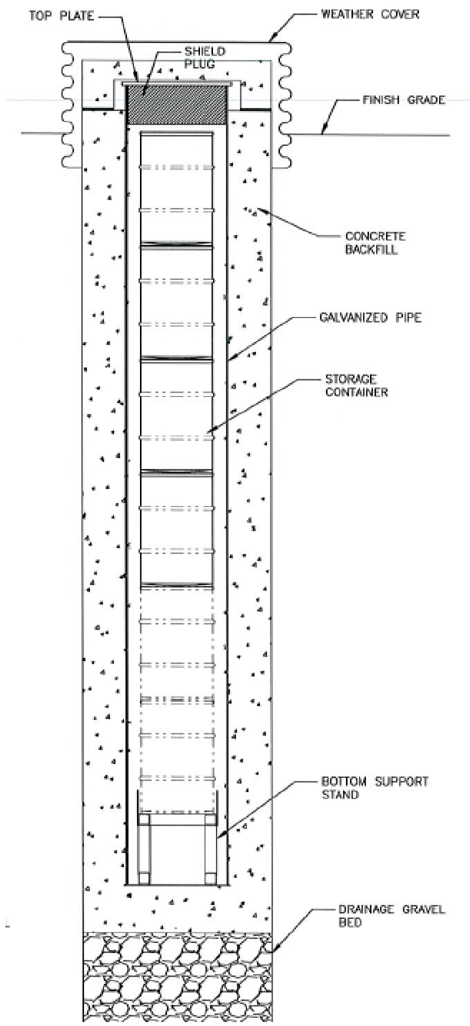


Figure 28. Basic silo design configuration.

9. COST SUMMARY

9.1 Itemized Costs

The costs for each type of silo have been itemized with monitoring listed as optional costs. Costs include fabrication and installation of silos in arrays of 100 or more for an economy of scale. Costs identified below are per silo for each of the different sizes for a relative comparison of the vault options, based on the summary recommendation presented in Section 8.0. No site infrastructure or utility costs are included in these costs. Monitoring costs should be added to total costs based on option used. A 35% Management Reserve (MR) is assumed for the total costs. See Appendix A for a complete description of the estimate basis and assumptions.

Table 7. Silo Itemized Costs (Per Silo)

Container		Cost
200 Liter	**(750 mm Diameter)**	
	Fabrication	$10,686
	Installation	$8,269
	Shield Lid*	$3,221
	Precast Cover*	$1,008
	Weather Cover*	$ 779
	Subtotal	$23,963
	MR 35%	$8,387
	Total	**$32,350**
Small Container	**(305 mm Diameter)**	
	Fabrication	$6,070
	Installation	$6,422
	Shield Lid*	$ 3,221
	Precast Cover*	$ 1,008
	Weather Cover*	$ 779
	Subtotal	$17,500
	MR 35%	$6,125
	Total	**$23,625**
Oversized Vault	(1.8 m x 1.8 m x 2.4 m)	
	Fabrication	$19,548
	Installation	$ 10,572
	Precast Cover*	$ 2,406
	Weather Cover*	$ 3,159
	Subtotal	$35,685
	MR 35%	$12,490
	Total	**$48,175**

* Optional

Table 8. Sampling of monitoring options cost (costs added based upon technology choice).

Rad Air Monitoring (RAM)	$26K/8 Units (based on 300 ft x 300 ft area)
Rad Area Monitoring (CAM)	$136K/4 Units (based on 300 ft x 300 ft area)
Humidity Monitoring (In Silo)	$92K/200 Units
Corrosion Monitoring - Ultrasonic	$24,135/Unit
Corrosion Monitoring - Sacrificial Anode	$12K/Unit
Video Area Monitoring	$25K/Unit

Appendix A
Cost Estimate

INTEROFFICE MEMORANDUM

Idaho National Laboratory INL

Date: September 24, 2012

To: S. L Austad, Engineer

From: S. N. Wasley and A. W. Miller, Cost Estimators

Subject: In Ground Silo Storage

Per your request, Cost Estimating has prepared a cost estimate comparison study for the above-mentioned subject. Per your direction, the product of this study identifies the comparative costs for silo storage tubes considering differing sizes. The estimate identifies a cost per each per silo design, the economy of scale represented in this estimate is based on fabrication and installation of 100 each.

The work included in this study is representative of a Class 5 level in accordance with the Association for Advancement of Cost Engineering (AACE) International classification system and includes an allowance for management reserve consistent with Battelle Energy Alliance, LLC (BEA) Cost Estimating practices. Consistent with your direction, the study is limited to the cost of fabricating and installation of the silo tubes identifying various sizes and monitoring options. The cost associated with each is identified on the attached project summary. It should be noted that the BEA standard estimating format employed for this study sums the individual costs to totals for sizes and monitoring options and total cost, yet neither has relevancy to the study nor do these totals represent a total project cost (TPC) or a total estimated cost (TEC). The costs to be considered for comparative purposes are limited to the summary level for a particular size and monitoring option.

Please note the following:

A. This cost estimate is a comparative cost for subcontract fabrication and installation services; therefore, no determination has been defined as to direct or indirect funding. General and Administrative (G&A) costs have not been included in this estimate due to the nature of this estimate.
B. This cost estimate has been evaluated in the AACEI classification matrix as a Class 5 estimate (*ref. Department of Energy (DOE) G. 430.1-1X, Appendix J*). The primary characteristic used in this guideline to define the classification category is the degree of project definition at this time. The intent of this classification is to assist in the interpretation of the quality and value of the information available to prepare this cost estimate and the expected accuracy levels that can be produced. Per AACEI, a Class 5 indicates the lowest amount of project information quality and value with a graded approach to a Class 1, which indicates the highest amount of project information quality and value.
C. A formal review of this cost estimate was held with the project team and the cost estimators. This review allowed the project team to discuss, in detail, the perceived scope, basis of

estimates, assumptions, project risks, and the resources that make up this cost estimate. Comments from this review have been incorporated into this estimate to reflect a project team consensus of this document.

D. Due to the nature of this estimate for offsite fabrication and installation , the 9 block evaluation is not applicable.

Refer to the cost estimating summary, and detail sheets with the cost breakdowns. Also included for your use are the cost estimate recapitulation sheets describing the basis and assumptions used in development of this estimate.

This estimate, the work, and the work breakdown structure are based on the information perceived by this estimator as to the scope of work to be completed. Any changes to the methodology used to prepare this estimate could have a significant effect on the cost estimate and/or schedule and should be reviewed by me. If you have any questions or comments, do not hesitate to contact me at 526-6835 or e-mail Scott.Wasley@inl.gov or A. W. miller at 526-1827 or e-mail Andrew.Miller@inl.gov.

Attachments

cc: Estimate File MA49-A

Uniform File Code: 8309
Disposition Authority: A16-1.5-b
Retention Schedule: Cut off at the end of each fiscal year. Destroy 10 years after cutoff.

NOTE: Original disposition authority, retention schedule, and Uniform Filing Code applied by the sender may not be appropriate for all recipients. Make adjustments as needed.

Summary Report

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Project Number: *MA49-A*

ESTIMATE ELEMENT	Estimate Subtotal	Escalation	Management Reserve	TOTAL
		0.00%	*35.00%*	
Total Estimated Cost (TEC)	**$751,915**	**$0**	**$263,170**	**$1,015,085**
		0.00%	*35.00%*	
Total Cost	**$751,915**	**$0**	**$263,170**	**$1,015,085**
Rounded Total Cost (Rounded to the nearest $ 1000)				**$1,015,000**

	Remarks
Type of Estimate: Class-5	
Estimator: A. W. Miller / S. N. Wasley	
Checked By:	
Approved By:	

415.31 *Rev. 04* *08-01-2012*	*Battelle Energy Alliance, LLC*

FORMAL COST ESTIMATE SUPPORT DATA RECAPITULATION

Project Title:	In Ground Silo Storage
Estimator:	A. W. Miller / S. N. Wasley
Date:	September 13, 2012
Estimate Type:	Class 5
File:	MA49-A
Approved By:	Page 1 of 7

I. **PURPOSE:** *Brief description from the requester of the intent of how the estimate is to be used, i.e., for engineering study, comparative analysis, request for funding, proposal, etc.*

The purpose of this estimate is to identify costs between silo storage sizes, oversized vaults, monitoring, and weather enclosure capping requirements. It is expected that this estimate will be considered and used by the project team in the path forward decision making process for this project.

II. **SCOPE OF WORK:** *Brief statement of the project's objective. Thorough overview and description of the proposed project. Identify work to be accomplished, as well as any specific work to be excluded.*

A. **Objective:**

The objective of this work is to fabricate/construct and install in ground storage silo to store radiological waste for a period of 50 years. The in ground silos will be constructed of a concrete encased galvanized steel pipe with precast concrete lids and corrugated weather enclosures to protect the silos from the elements. These silos will accommodate 200 liter, 120 liter, and a small diameter inner waste container. Also included in the estimate is an oversized waste storage vault which will be approximately 1.8m x 1.8m x 2.4m with a galvanized steel structure encased in 304mm of precast concrete with a precast concrete lid and a corrugated weather enclosure. The estimate provides cost options for lids, weather enclosure covers, and monitoring.

B. **Included:**

The scope of work required to achieve this objective includes the following:

1. Procurement and shipping of raw materials to the fabricator.
2. Cost of fabrication unique to each silo size and configuration.
3. Costs to hot dip galvanize all steel materials, including the shipping costs to and from the galvanizer.
4. Earth auger to excavate vertical shafts approximately 1.2m to 1.5m diameter x 6.1m depth.
5. Install gravel drainage and concrete base.
6. Installation of the silo/vaults into the vertical hole.
7. Concrete cement placement around the perimeter of steel liner.
8. Concrete forming around the top of the silo.
9. Temporary placement of the precast lids and weather caps for future waste loading of the silos.

10. Allowance for a simple drain fitting within the silo/vault.
11. Allowance for visual weld testing of the silo base end cap/plate.
12. Allowance for leak testing of the silo tube.
13. Allowance for miscellaneous documentation and test reports.
14. Option allowance for general area radiation monitoring.
15. Option allowance for contamination air monitoring.
16. Option allowance for corrosion monitoring, two options.
17. Option allowance for humidity monitoring.
18. Option Allowance for area video monitoring

C. **Excluded:**

This scope of work specifically excludes the following:

1. Project management, project administration, or supervision.
2. Development of the engineering and design documents.
3. Any environmental certification/documentation required for silo storage.
4. Site improvements e.g., roads, fences, site work, electrical power, and infrastructure.
5. All monitoring systems do not include any electrical conduit/wire or controls to operate these systems.
6. Epoxy coatings will not be required for sealing of concrete materials.
7. Loading of waste into the silos/vaults and closure of the silo/vaults. This activity will be performed by others at a later date.
8. Installation of the final shield plug.
9. Operations of the waste site facility.
10. Purchase of new waste canisters.
11. Waste canister retrieval tooling devices.
12. Concrete reinforcing materials.

III. **ESTIMATE METHODOLOGY:** *Overall methodology and rationale of how the estimate was developed, i.e., parametric, forced detail, bottom up, etc. Total dollars/hours and rough order of magnitude (ROM) allocations of the methodologies used to develop the cost estimate.*

This document will be used to help evaluate the desired waste storage configurations for future planning of the silo/vault storage. A "forced detail" method was used in the development of this estimate, due to the uniqueness of the scope of work and lack of a parametric model to support the proposed scope of work. This method provides for a greater degree of detail to review than would be provided utilizing parametric modeling. The activities and resources were developed by the cost estimator and discussion with environmental engineering that provided the level of detail documented in the estimate.

Estimate Methodology	ROM Percentage (%)
Project Team	50
Recorded Actuals	0
Parametric	0
Vendor Information	40
Other (e.g., RS Means)	10
TOTAL	100

IV. **BASIS OF THE ESTIMATE:** *Overall explanation of sources for resource quantities, pricing, and schedules.*

A. **Classification Basis**: *The source for the determination of the classification of the estimate or sections of the estimate when a rolling wave planning process is utilized. Source documents include Association for the Advancement of Cost Engineering (AACE) Recommended Practices (RP) and are driven by the Primary and Secondary Characteristics available at the time the estimate is completed.*

Determination of the estimate classification has been accomplished using Battelle Energy Alliance, LLC (BEA) Cost Estimate Classification Worksheet to determine the primary characteristic determination level and criteria established and provided by *Association of the Advancement of Cost Engineering (AACE) Recommended Practices (RP)* to determine the secondary characteristic determination level.

Resulting from this evaluation process, it has been determined that the available documentation is suitable of supporting a Class 5 estimate in accordance with primary characteristic determination and a Class 5 estimate in accordance with the secondary characteristic determination data.

B. **Quantification Basis:** *The source for the measureable quantities in the estimate that can be used in support of earned value management. Source documents may include drawings, design reports, engineers' notes, and other documentation upon which the estimate is originated.*

The requester provided a draft pre-conceptual design document identifying the different silo/vault storage configurations that were used to establish the activities and quantities for this estimate.

C. **Planning Basis:** *The source for the execution and strategies of the work that can be used to support the project execution plan, identification of long-lead items, acquisition strategy, schedules, market conditions, and other documentation upon which the estimate is originated.*

1. Per the requester and recommendation of the estimator:
   a. These silo tubes would be fabricated within a 321km radius of the future waste facility by a fabrication subcontractor regularly engaged in work of this type. This fabrication work scope would be competitively bid.
   b. This work will be performed during standard working hours and no premium time will be required for off-shift or weekend work.
   c. Work will be able to progress consecutively and will not require delays between work segments.
   d. The cost estimate does not consider or address funding or labor resource restrictions. Sufficient funding and labor resources will be available in a manner allowing optimum usage of that funding and resources as estimated.
   e. The estimate reflects current day cost; therefore, no escalation has been applied.
   f. Radiation monitoring would consist of a general area monitoring system that would support approximately 200 silos.
2. Subcontractor labor and markup rates are based on this estimator's judgment. These rates have been adjusted to reflect the estimated anticipated market conditions.
3. Concrete material will be obtained from a batch plant within the local area of the new waste storage facility.
4. Concrete would be a cast in place monolithic pour 304mm thick including wall and bottom.
5. The concrete silos will be not be reinforced and no epoxy paint coatings inside or out.
6. The concrete vault will be a monolithic pour approximately 304mm thick including wall and bottom. This precast concrete vault will be reinforced with steel bar on 304mm centers and no epoxy paint coatings inside or out.

D. **Cost Basis:** *The source for the costing on the estimate that can be used in support of earned value management, funding profiles, and schedule of values. Sources may include published costing references, judgment, actual costs, preliminary quotes and/or other documentation upon which the estimate is originated.*

1. Cost reflected within this estimate is based on performing work in the United States of America (USA).
2. Cost shown in the estimate reflects a cost per silo/vault. These unit costs are based on an economy of scale of 100 each or greater of each configuration.
3. Majority of the piping and plate material costs were obtained from suppliers regularly engaged with materials of this type.
4. Fabrication labor units were developed from standard published industry references. These units were then factored based on estimator judgment considering material quantities and requirements of silo/vault being fabricated and installed.
5. Estimate is based on current day cost. No escalation has been applied.

6. Material tax is based on an anticipated rate of 6% rate.
7. Earth auger activities are based on preliminary vendor cost information.
8. Piping materials are based on preliminary vendor information.
9. Galvanizing hot dip process is based on preliminary vendor information.
10. Unit concrete cost identified in the estimate includes concrete materials, forms (at top), concrete pumping equipment, and manpower.

V. **ESTIMATE QUALITY ASSURANCE:** *A listing of all estimate reviews that have taken place and the actions taken from those reviews.*

A. A review of the cost estimate with the project team and the cost estimators was held. This review allowed for the team to review and comment, in detail, on the perceived scope, basis of estimate, assumptions, project risks, and the resources that make up this cost estimate. Comments from this review have been incorporated into this estimate to reflect a project team consensus of this document.

B. An internal organizational check has been performed on this estimate with the purpose of checking the methodology approach used, discussing the document with the estimator, and ensuring the document has been reviewed and discussed with the requester, reflects a team consensus, has adequately documented the basis, assumptions, and risks to the project, and has mitigated those risks.

VI. **ASSUMPTIONS:** *Condition statements accepted or supposed true without proof of demonstration; statements adding clarification to scope. An assumption has a direct impact on total estimated cost.*

A. Concrete material will be cast in place utilizing a semi-monolithic pour concept.

B. Fabrication would be performed by a fabrication subcontractor in the proposed waste facility vicinity.

C. Weld testing of the silo tube end cap/plate would not require radiograph x-ray testing.

D. Galvanized material would require the purchase of standard carbon steel piping. This pipe would require sending the prefabricated silo/vault to a galvanizing plant for dipping.

E. The top welded cap/plate weld would require some type of cold galvanizing process once the top plate/cap weld was completed.

F. Vault steel plate cutting will utilizing water jet equipment to achieve the desired weld bevel.

G. After fabrication the silo/vaults will be located and stored at the future waste facility staged for installation.

H. No concrete form work will be required below grade level; the auger hole will serve as the concrete form.

I. The proposed waste facility area soil composition will support the desired earth auguring activities.

J. During the earth auguring activities solid rock will not be encountered.

K. Shield plug and final cap closure will be installed by others, once the waste container has been loaded.

L. Precast concrete cover and weather cover will be installed to prevent intrusion of foreign matter.

M. Fabrication and installation subcontractors, including equipment, are available within a reasonable distance of the proposed waste facility.

VII. MANAGEMENT RESERVE (MR) GUIDELINE IMPLEMENTATION:

Management Reserve Methodologies: *Explanation of methodology used in determining overall management reserve. Identify any specific drivers or items of concern and any inherent risks typical with this type of environment. Inflationary and deflationary impacts are addressed in this section.*

No formal risk review was performed for this estimate. A blanket management reserve allowance of 35% was applied to this cost estimate. This allowance was concurred with by the cost estimators and the requester as generally reflective of the risks and assumptions stated in this document, and as appropriate for the purpose of this cost estimate.

A. **Threats:** *Uncertain events that are potentially negative or reduce the probability that the desired outcome will happen.*

1. No detailed information or design exists for this work scope. The estimated costs were based on the cost estimator's perceived idea as to the needs and requirements and work scope that will be required. Further investigation into the needs, requirements, and materials selection may increase the costs due to requirements or needs not identified in the scope of this estimate.
2. This project is heavily dependent on carbon steel and concrete products. Competition for these commodities in today's environment due to global expansion uncertainty and project shortages affect the basic concepts of the supply and demand theories, thus increasing costs.
3. Preciseness in the forced detail take-offs leaves little room if crews are unable to meet the estimated production rates. Factors could include fabrication techniques, testing requirements, material availabilities, resource impacts, and/or availability.
4. Location of the proposed waste facility area would not support earth auguring activities due to loose granular soils or solid rock.
5. Availability of fabrication and installation subcontractors e.g., earth augur equipment, concrete pumping equipment, galvanize dipping, etc.

B. **Opportunities:** *Uncertain events that could improve the results or improve the probability that the desired outcome will happen.*

1. Solicit request for quotations to multiple fabricators regularly engaged with fabrication of this type, which could result in a more competitive bids.
2. Optimization of the design and utilizing industry standard materials could reduce material and fabrication costs.

3. Facility could be fabricated and constructed in an area sustaining lower than industry standard labor rates.

C. **Accepted Risks**: *Activities with a greater than 50% and less than 100% probability of occurrence has been accepted as part of this scope of work.*

None

D. **Excluded Risks**: *Risks that have been identified and have a probability of occurrence but are specifically excluded from this estimate.*

None

Note: Management reserve does not increase the overall accuracy of the estimate; it does, however, reduce the level of risk associated with the estimate. Management reserve is intended to cover the inadequacies in the complete project scope definition, estimating methods, and estimating data. Management reserve specifically excludes changes in project scope, unexpected work stoppages, (e.g., strikes, disasters, and earthquakes) and excessive and/or unexpected inflation or currency fluctuations. This estimate does not contain any contingencies and has not been evaluated to include any contingencies and has not been evaluated to include any of the risks that pertain to Department of Energy.

VIII. **OTHER COMMENTS/CONCERNS SPECIFIC TO THE ESTIMATE**:

None

Project Summary Report

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Level	Group	Description	Estimate Subtotal	Escalation	Management Reserve MR	MR %	TOTAL
1.0		Silo - 200 Liter	$18,955	$0	$6,634	35.00%	$25,590
1.1		.... 200 Liter - Fabrication	$10,686	$0	$3,740	35.00%	$14,426
1.2		.... 200 Liter - Installation	$8,269	$0	$2,894	35.00%	$11,164
2.0		Silo - 120 Liter	$16,760	$0	$5,866	35.00%	$22,626
2.1		.... 120 Liter - Fabrication	$9,427	$0	$3,299	35.00%	$12,726
2.2		.... 120 Liter - Installation	$7,334	$0	$2,567	35.00%	$9,900
3.0		Silo - Small Diameter	$12,492	$0	$4,372	35.00%	$16,865
3.1		.... Small Dia - Fabrication	$6,070	$0	$2,125	35.00%	$8,195
3.2		.... Small Dia - Installation	$6,422	$0	$2,248	35.00%	$8,670
4.0		Silo - Oversized Vault	$30,119	$0	$10,542	35.00%	$40,661
4.1		.... Oversized Vault - Fabrication	$19,548	$0	$6,842	35.00%	$26,389
4.2		.... Oversized Vault - Installation	$10,572	$0	$3,700	35.00%	$14,272
5.0		Silo Lid (Shield Plug)	$6,443	$0	$2,255	35.00%	$8,698
5.1		.... Silo Lid - Welded W/HEPA	$2,899	$0	$1,015	35.00%	$3,914
5.2		.... Silo Lid - Bolted W/out HEPA	$3,544	$0	$1,240	35.00%	$4,784
6.0		Silo/Vault Covers	$7,352	$0	$2,573	35.00%	$9,925
6.1		.... Silo Covers (One Size)	$1,787	$0	$625	35.00%	$2,412
6.1.1		.... Silo Precast Concrete Cover	$1,008	$0	$353	35.00%	$1,361
6.1.2		.... Silo Corrigated Weather Cover	$779	$0	$273	35.00%	$1,052
6.2		.... Vault Cover Corrigated w/Precast Cover	$5,565	$0	$1,948	35.00%	$7,513
6.2.1		.... Vault Precast Concrete Cover	$2,406	$0	$842	35.00%	$3,247
6.2.2		.... Vault Corrigated Weather Cover	$3,159	$0	$1,106	35.00%	$4,265
7.0		Monitoring Options	$659,793	$0	$230,928	35.00%	$890,721
7.1		.... Rad Air Monitoring - CAM (per 200 Silos)	$220,750	$0	$77,263	35.00%	$298,013

Project Summary Report

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Level	Group	Description	Estimate Subtotal	Escalation	Management Reserve MR	MR %	TOTAL
7.2		. . . . Radiation Area Monitoring - RAM (per 200 Silos)	$76,618	$0	$26,816	35.00%	$103,435
7.3		. . . . Humidity Monitoring (per 200 Silos)	$68,554	$0	$23,994	35.00%	$92,548
7.4		. . . . Corrosion Monitoring - Ultrasonic (PER EACH SILO)	$17,878	$0	$6,257	35.00%	$24,135
7.5		. . . . Corrosion Monitoring - Sacrificial Anode (per 200 Silos)	$190,436	$0	$66,653	35.00%	$257,088
7.6		. . . . Video Area Monitoring (per 200 Silos)	$85,557	$0	$29,945	35.00%	$115,502
Total		**MA49-A In Ground Silo Storage**	**$751,915**	**$0**	**$263,170**	**35.00%**	**$1,015,085**

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
1.1 200 Liter - Fabrication												
		FAB	*U.C. per LF*				*0*	*0*	*120*	*0*	*0*	*120*
	Purchase Pipe 30" x .375 Wall, Carbon Steel		20.00	LF	0		$0	$0	$2,400	$0	$0	$2,400
Memo:	Based on vendor pricing.											
		FAB	*U.C. per LBS*				*0*	*0*	*0.75*	*0*	*0*	*0.75*
	Purchase 3/8" Bottom Plate		184.00	LBS	0		$0	$0	$138	$0	$0	$138
Memo:	Based on vendor pricing.											
		FAB	*U.C. per EA*				*0*	*0*	*500*	*0*	*0*	*500*
	Purchase 30" Class B Flange		1.00	EA	0		$0	$0	$500	$0	$0	$500
Memo:	Based on estimator judgment.											
		FAB	*U.C. per EA*		*4*	*$50.00*	*200*	*0*	*0*	*0*	*0*	*200*
	Cut Pipe to Length		1.00	EA	4	FAB	$200	$0	$0	$0	$0	$200
		FAB	*U.C. per EA*		*2.5*	*$50.00*	*125*	*0*	*0*	*0*	*0*	*125*
	Weld in Bottom Plate		1.00	EA	3	FAB	$125	$0	$0	$0	$0	$125
		FAB	*U.C. per EA*		*5*	*$50.00*	*250*	*0*	*0*	*0*	*0*	*250*
	Weld on Top Flange or Bevel for Future Welding		1.00	EA	5	FAB	$250	$0	$0	$0	$0	$250
		FAB	*U.C. per Allow*		*2*	*$50.00*	*100*	*0*	*75*	*0*	*0*	*175*
	Weld Fittings for Monitoring Devices & Drain		1.00	Allow	2	FAB	$100	$0	$75	$0	$0	$175
		FAB	*U.C. per EA*		*5*	*$50.00*	*250*	*0*	*250*	*0*	*0*	*500*
	Fabricate Bottom Spacer		1.00	EA	5	FAB	$250	$0	$250	$0	$0	$500
		FAB	*U.C. per Allow*		*2*	*$50.00*	*100*	*0*	*50*	*0*	*0*	*150*
	Allowance for Lifting Eyes, etc.		1.00	Allow	2	FAB	$100	$0	$50	$0	$0	$150
		FAB	*U.C. per SF*		*0.032*	*$50.00*	*1.6*	*0*	*0.74*	*0*	*0*	*2.34*
	Surface Prep prior to Galvanizing		314.00	SF	10	FAB	$502	$0	$232	$0	$0	$735
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.044*	*0*	*0.044*
	Ship pipe to be Galvanizer (200 Mile Raduis)		3,000.00	LBS	0		$0	$0	$0	$132	$0	$132
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.435*	*0*	*0.435*
	Galvanizing Process		3,000.00	LBS	0		$0	$0	$0	$1,305	$0	$1,305

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*

Estimate Number: *MA49-A*

Client: *S. L. Austad*

Prepared By: *A. W. Miller / S. N. Wasley*

Estimate Type: *Class-5*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
1.1 200 Liter - Fabrication												
	FAB	*U.C. per LBS*					*0*	*0*	*0*	*0.044*	*0*	*0.044*
Ship to Job Site Stagging Area (200 Mile Raduis)			3,000.00	LBS	0		$0	$0	$0	$132	$0	$132
	FAB	*U.C. per Allow*			*4*	*$50.00*	*200*	*0*	*0*	*0*	*0*	*200*
Allowance for Shop Inspection, Quality Control, & Misc Testing			1.00	Allow	4	FAB	$200	$0	$0	$0	$0	$200
	FAB	*U.C. per EA*			*2*	*$50.00*	*100*	*0*	*10*	*0*	*0*	*110*
Documentation and Test Reports			1.00	EA	2	FAB	$100	$0	$10	$0	$0	$110
Subtotal							$1,827	$0	$3,655	$1,569	$0	$7,052
Sales Tax							$0	$0	$219	$0	$0	$219
Markups		46.97%					$858	$0	$1,820	$737	$0	$3,415
Subtotal Estimate												**$10,686**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$940	$0	$1,993	$807	$0	$3,740
---Total 1.1 200 Liter - Fabrication					37		**$3,626**	**$0**	**$7,688**	**$3,113**	**$0**	**$14,426**
1.2 200 Liter - Installation												
	DRILL	*U.C. per LF*					*0*	*0*	*0*	*150*	*0*	*150*
Auger Hole 5' Dia (Operator & Equipment)			20.00	LF	0		$0	$0	$0	$3,000	$0	$3,000
Memo: Based on vendor price information.												
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*35*	*0*	*35*
Place Gravel			1.40	Cyds	0		$0	$0	$0	$49	$0	$49
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
Place Concrete			8.00	Cyds	0		$0	$0	$0	$2,400	$0	$2,400
Memo: Concrete unit cost accounts for minimal forms, concrete, pumping, and labor to place.												
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
Concrete for Over Bore @ 10%			0.80	Cyds	0		$0	$0	$0	$240	$0	$240
	CONC	*U.C. per EA*			*6*	*$40.00*	*240*	*0*	*0*	*0*	*0*	*240*
Set Silo in Place			1.00	EA	6	SILO	$240	$0	$0	$0	$0	$240

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
1.2 200 Liter - Installation												
		CONC	*U.C. per Hrs*		*1*	*$40.00*	*40*	*125*	*0*	*0*	*0*	*165*
	Crane Usage		2.00	Hrs	2	SILO	$80	$250	$0	$0	$0	$330
		CONC	*U.C. per Allow*		*0.33*	*$40.00*	*13.2*	*60*	*0*	*0*	*0*	*73.2*
	Silo Transport Truck to Job Site		1.00	Allow	0	SILO	$13	$60	$0	$0	$0	$73
		CONC	*U.C. per Allow*		*2*	*$40.00*	*80*	*0*	*50*	*0*	*0*	*130*
	Anchor Silo Prior to Concrete Pour		1.00	Allow	2	SILO	$80	$0	$50	$0	$0	$130
		CONC	*U.C. per EA*		*0.5*	*$40.00*	*20*	*0*	*0*	*0*	*0*	*20*
	Lower in Bottom Spacer		1.00	EA	1	SILO	$20	$0	$0	$0	$0	$20
		CONC	*U.C. per EA*		*1*	*$40.00*	*40*	*35*	*0*	*0*	*0*	*75*
	Install the Precast Cover		1.00	EA	1	SILO	$40	$35	$0	$0	$0	$75
		CONC	*U.C. per EA*		*0.5*	*$40.00*	*20*	*0*	*0*	*0*	*0*	*20*
	Install the Weather Cover		1.00	EA	1	SILO	$20	$0	$0	$0	$0	$20
	Subtotal						$493	$345	$50	$5,689	$0	$6,577
	Sales Tax						$0	$0	$3	$0	$0	$3
	Markups		25.67%				$191	$134	$21	$1,343	$0	$1,689
	Subtotal Estimate											**$8,269**
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$240	$168	$26	$2,461	$0	$2,894
---Total 1.2 200 Liter - Installation					**12**		**$924**	**$646**	**$99**	**$9,494**	**$0**	**$11,164**
2.1 120 Liter - Fabrication												
		FAB	*U.C. per LF*				*0*	*0*	*115*	*0*	*0*	*115*
	Purchase Pipe 26" x .375 Wall, Carbon Steel		20.00	LF	0		$0	$0	$2,300	$0	$0	$2,300
Memo:	Based on vendor pricing.											
		FAB	*U.C. per LBS*				*0*	*0*	*0.75*	*0*	*0*	*0.75*
	Purchase 3/8" Bottom Plate		147.00	LBS	0		$0	$0	$110	$0	$0	$110
Memo:	Based on vendor pricing.											

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
2.1 120 Liter - Fabrication													
	Purchase 26" Class B Flange Memo: Based on vendor pricing.	FAB	U.C. per EA	1.00	EA	0		0 $0	0 $0	320 $320	0 $0	0 $0	320 $320
	Cut Pipe to Length	FAB	U.C. per EA	1.00	EA	3.5 4	$50.00 FAB	175 $175	0 $0	0 $0	0 $0	0 $0	175 $175
	Weld in Bottom Plate	FAB	U.C. per EA	1.00	EA	2.25 2	$50.00 FAB	112.5 $113	0 $0	0 $0	0 $0	0 $0	112.5 $113
	Weld on Top Flange or Bevel for Future Welding	FAB	U.C. per EA	1.00	EA	4.2 4	$50.00 FAB	210 $210	0 $0	0 $0	0 $0	0 $0	210 $210
	Weld Fittings for Monitoring Devices & Drain	FAB	U.C. per Allow	1.00	Allow	2 2	$50.00 FAB	100 $100	0 $0	75 $75	0 $0	0 $0	175 $175
	Fabricate Bottom Spacer	FAB	U.C. per EA	1.00	EA	4 4	$50.00 FAB	200 $200	0 $0	200 $200	0 $0	0 $0	400 $400
	Allowance for Lifting Eyes, etc.	FAB	U.C. per Allow	1.00	Allow	2 2	$50.00 FAB	100 $100	0 $0	50 $50	0 $0	0 $0	150 $150
	Surface Prep prior to Galvanizing	FAB	U.C. per SF	272.00	SF	0.032 9	$50.00 FAB	1.6 $435	0 $0	0.74 $201	0 $0	0 $0	2.34 $636
	Ship pipe to be Galvanizer	FAB	U.C. per LBS	2,522.00	LBS	0		0 $0	0 $0	0 $0	0.044 $111	0 $0	0.044 $111
	Galvanizing Process	FAB	U.C. per LBS	2,522.00	LBS	0		0 $0	0 $0	0 $0	0.435 $1,097	0 $0	0.435 $1,097
	Ship to Job Site Stagging Area	FAB	U.C. per LBS	2,522.00	LBS	0		0 $0	0 $0	0 $0	0.044 $111	0 $0	0.044 $111
	Allowance for Shop Inspection & Quality Control	FAB	U.C. per Allow	1.00	Allow	4 4	$50.00 FAB	200 $200	0 $0	0 $0	0 $0	0 $0	200 $200

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
2.1 120 Liter - Fabrication												
FAB		*U.C. per EA*			*2*	*$50.00*	*100*	*0*	*10*	*0*	*0*	*110*
	Documentation and Test Reports		1.00	EA	2	FAB	$100	$0	$10	$0	$0	$110
	Subtotal						$1,633	$0	$3,267	$1,319	$0	$6,218
	Sales Tax						$0	$0	$196	$0	$0	$196
	Markups	46.97%					$767	$0	$1,626	$619	$0	$3,013
	Subtotal Estimate											**$9,427**
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$840	$0	$1,781	$678	$0	$3,299
---Total 2.1 120 Liter - Fabrication					33		**$3,239**	**$0**	**$6,870**	**$2,617**	**$0**	**$12,726**
2.2 120 Liter - Installation												
DRILL		*U.C. per LF*					*0*	*0*	*0*	*125*	*0*	*125*
	Auger Hole 4' Dia (Operator & Equipment)		20.00	LF	0		$0	$0	$0	$2,500	$0	$2,500
CONC		*U.C. per Cyds*					*0*	*0*	*0*	*35*	*0*	*35*
	Place Gravel		1.00	Cyds	0		$0	$0	$0	$35	$0	$35
CONC		*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
	Place Concrete		7.20	Cyds	0		$0	$0	$0	$2,160	$0	$2,160
Memo:	Concrete unit cost accounts for minimal forms, concrete, pumping, and labor to place.											
CONC		*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
	Concrete for Over Bore @ 10%		0.72	Cyds	0		$0	$0	$0	$216	$0	$216
CONC		*U.C. per EA*			*6*	*$40.00*	*240*	*0*	*0*	*0*	*0*	*240*
	Set Silo in Place		1.00	EA	6	SILO	$240	$0	$0	$0	$0	$240
CONC		*U.C. per Hrs*			*1*	*$40.00*	*40*	*125*	*0*	*0*	*0*	*165*
	Crane Usage		2.00	Hrs	2	SILO	$80	$250	$0	$0	$0	$330
CONC		*U.C. per Allow*			*0.33*	*$40.00*	*13.2*	*60*	*0*	*0*	*0*	*73.2*
	Silo Transport Truck to Job Site		1.00	Allow	0	SILO	$13	$60	$0	$0	$0	$73

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
2.2 120 Liter - Installation												
CONC		*U.C. per Allow*			*2*	*$40.00*	*80*	*0*	*50*	*0*	*0*	*130*
Anchor Silo Prior to Concrete Pour			1.00	Allow	2	SILO	$80	$0	$50	$0	$0	$130
CONC		*U.C. per EA*			*0.5*	*$40.00*	*20*	*0*	*0*	*0*	*0*	*20*
Lower in Bottom Spacer			1.00	EA	1	SILO	$20	$0	$0	$0	$0	$20
CONC		*U.C. per EA*			*1*	*$40.00*	*40*	*35*	*0*	*0*	*0*	*75*
Install the Precast Cover			1.00	EA	1	SILO	$40	$35	$0	$0	$0	$75
CONC		*U.C. per EA*			*0.5*	*$40.00*	*20*	*0*	*0*	*0*	*0*	*20*
Install the Weather Cover			1.00	EA	1	SILO	$20	$0	$0	$0	$0	$20
Subtotal							$493	$345	$50	$4,911	$0	$5,799
Sales Tax							$0	$0	$3	$0	$0	$3
Markups		26.39%					$191	$134	$21	$1,186	$0	$1,531
Subtotal Estimate												**$7,334**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$240	$168	$26	$2,134	$0	$2,567
---Total 2.2 120 Liter - Installation					**12**		**$924**	**$646**	**$99**	**$8,230**	**$0**	**$9,900**
3.1 Small Dia - Fabrication												
FAB		*U.C. per LF*					*0*	*0*	*56*	*0*	*0*	*56*
Purchase Pipe 18" x .375 Wall, Carbon Steel			20.00	LF	0		$0	$0	$1,120	$0	$0	$1,120
Memo: Based on vendor pricing.												
FAB		*U.C. per LBS*					*0*	*0*	*0.75*	*0*	*0*	*0.75*
Purchase 3/8" Bottom Plate			42.00	LBS	0		$0	$0	$32	$0	$0	$32
Memo: Based on vendor pricing.												
FAB		*U.C. per EA*					*0*	*0*	*250*	*0*	*0*	*250*
Purchase 18" Class B Flange			1.00	EA	0		$0	$0	$250	$0	$0	$250
Memo: Based on vendor pricing.												
FAB		*U.C. per EA*			*2.5*	*$50.00*	*125*	*0*	*0*	*0*	*0*	*125*
Cut Pipe to Length			1.00	EA	3	FAB	$125	$0	$0	$0	$0	$125

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
3.1 Small Dia - Fabrication												
		FAB	*U.C. per EA*		*1.8*	*$50.00*	*90*	*0*	*0*	*0*	*0*	*90*
	Weld in Bottom Plate		1.00	EA	2	FAB	$90	$0	$0	$0	$0	$90
		FAB	*U.C. per EA*		*2.8*	*$50.00*	*140*	*0*	*0*	*0*	*0*	*140*
	Weld on Top Flange or Bevel for Future Welding		1.00	EA	3	FAB	$140	$0	$0	$0	$0	$140
		FAB	*U.C. per Allow*		*2*	*$50.00*	*100*	*0*	*75*	*0*	*0*	*175*
	Weld Fittings for Monitoring Devices & Drain		1.00	Allow	2	FAB	$100	$0	$75	$0	$0	$175
		FAB	*U.C. per Allow*		*2*	*$50.00*	*100*	*0*	*50*	*0*	*0*	*150*
	Allowance for Lifting Eyes, etc.		1.00	Allow	2	FAB	$100	$0	$50	$0	$0	$150
		FAB	*U.C. per EA*		*3*	*$50.00*	*150*	*0*	*175*	*0*	*0*	*325*
	Fabricate Bottom Spacer		1.00	EA	3	FAB	$150	$0	$175	$0	$0	$325
		FAB	*U.C. per SF*		*0.032*	*$50.00*	*1.6*	*0*	*0.74*	*0*	*0*	*2.34*
	Surface Prep prior to Galvanizing		188.00	SF	6	FAB	$301	$0	$139	$0	$0	$440
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.044*	*0*	*0.044*
	Ship pipe to be Galvanizer		1,650.00	LBS	0		$0	$0	$0	$73	$0	$73
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.435*	*0*	*0.435*
	Galvanizing Process		1,650.00	LBS	0		$0	$0	$0	$718	$0	$718
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.044*	*0*	*0.044*
	Ship to Job Site Stagging Area		1,650.00	LBS	0		$0	$0	$0	$73	$0	$73
		FAB	*U.C. per Allow*		*4*	*$50.00*	*200*	*0*	*0*	*0*	*0*	*200*
	Allowance for Shop Inspection & Quality Control		1.00	Allow	4	FAB	$200	$0	$0	$0	$0	$200

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
3.1 Small Dia - Fabrication											
FAB	*U.C. per EA*			*2*	*$50.00*	*100*	*0*	*10*	*0*	*0*	*110*
Documentation and Test Reports		1.00	EA	2	FAB	$100	$0	$10	$0	$0	$110
Subtotal						$1,306	$0	$1,851	$863	$0	$4,019
Sales Tax						$0	$0	$111	$0	$0	$111
Markups	46.97%					$613	$0	$921	$405	$0	$1,940
Subtotal Estimate											**$6,070**
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$672	$0	$1,009	$444	$0	$2,125
---Total 3.1 Small Dia - Fabrication				**26**		**$2,591**	**$0**	**$3,892**	**$1,712**	**$0**	**$8,195**
3.2 Small Dia - Installation											
DRILL	*U.C. per LF*					*0*	*0*	*0*	*125*	*0*	*125*
Auger Hole 4' Dia (Operator & Equipment)		20.00	LF	0		$0	$0	$0	$2,500	$0	$2,500
CONC	*U.C. per Cyds*					*0*	*0*	*0*	*35*	*0*	*35*
Place Gravel		0.75	Cyds	0		$0	$0	$0	$26	$0	$26
CONC	*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
Place Concrete		5.60	Cyds	0		$0	$0	$0	$1,680	$0	$1,680
Memo: Concrete unit cost accounts for minimal forms, concrete, pumping, and labor to place.											
CONC	*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
Concrete for Over Bore @ 10%		0.56	Cyds	0		$0	$0	$0	$168	$0	$168
CONC	*U.C. per EA*			*4*	*$40.00*	*160*	*0*	*0*	*0*	*0*	*160*
Set Silo in Place		1.00	EA	4	SILO	$160	$0	$0	$0	$0	$160
CONC	*U.C. per Hrs*			*1*	*$40.00*	*40*	*125*	*0*	*0*	*0*	*165*
Crane Usage		2.00	Hrs	2	SILO	$80	$250	$0	$0	$0	$330
CONC	*U.C. per Allow*			*0.33*	*$40.00*	*13.2*	*60*	*0*	*0*	*0*	*73.2*
Silo Transport Truck to Job Site		1.00	Allow	0	SILO	$13	$60	$0	$0	$0	$73

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
3.2 Small Dia - Installation												
		CONC	*U.C. per Allow*		*1.5*	*$40.00*	*60*	*0*	*35*	*0*	*0*	*95*
	Anchor Silo Prior to Concrete Pour		1.00	Allow	2	SILO	$60	$0	$35	$0	$0	$95
		CONC	*U.C. per EA*		*0.5*	*$40.00*	*20*	*0*	*0*	*0*	*0*	*20*
	Lower in Bottom Spacer		1.00	EA	1	SILO	$20	$0	$0	$0	$0	$20
		CONC	*U.C. per EA*		*1*	*$40.00*	*40*	*35*	*0*	*0*	*0*	*75*
	Install the Precast Cover		1.00	EA	1	SILO	$40	$35	$0	$0	$0	$75
		CONC	*U.C. per EA*		*0.4*	*$40.00*	*16*	*0*	*0*	*0*	*0*	*16*
	Install the Weather Cover		1.00	EA	0	SILO	$16	$0	$0	$0	$0	$16
	Subtotal						$389	$345	$35	$4,374	$0	$5,143
	Sales Tax						$0	$0	$2	$0	$0	$2
	Markups		24.81%				$151	$134	$14	$977	$0	$1,277
	Subtotal Estimate											**$6,422**
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$189	$168	$18	$1,873	$0	$2,248
---Total 3.2 Small Dia - Installation					**10**		**$729**	**$646**	**$70**	**$7,225**	**$0**	**$8,670**
4.1 Oversized Vault - Fabrication												
		FAB	*U.C. per*				*0*	*0*	*0.01*	*0*	*0*	*0.01*
	Steel Fabrication		1.00		0		$0	$0	$0	$0	$0	$0
		FAB	*U.C. per LBS*				*0*	*0*	*0.75*	*0*	*0*	*0.75*
	Purchase 3/8" thick, Carbon Steel w/lid material		4,780.00	LBS	0		$0	$0	$3,585	$0	$0	$3,585
Memo:	Based on vendor pricing.											
		FAB	*U.C. per LF*				*0*	*0*	*6.5*	*0*	*0*	*6.5*
	3" x 3" x 3/8" Angle Carbon Steel		88.00	LF	0		$0	$0	$572	$0	$0	$572
Memo:	Based on vendor pricing.											
		FAB	*U.C. per SF*		*0.015*	*$50.00*	*0.75*	*0*	*0*	*0*	*0*	*0.75*
	Water Jet Cut 3/8" Vault Panels		312.00	SF	5	FAB	$234	$0	$0	$0	$0	$234

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
4.1 Oversized Vault - Fabrication												
FAB	Assemble Panels and Tack Weld	*U.C. per SF*	312.00	SF	*0.051* 16	*$50.00* FAB	*2.565* $800	*0* $0	*0* $0	*0* $0	*0* $0	*2.565* $800
FAB	Weld Vault Panels Together	*U.C. per LF*	120.00	LF	*0.267* 32	*$50.00* FAB	*13.35* $1,602	*0* $0	*0* $0	*0* $0	*0* $0	*13.35* $1,602
FAB	Weld Fittings for Monitoring Devices & Drain	*U.C. per Allow*	1.00	Allow	*2* 2	*$50.00* FAB	*100* $100	*0* $0	*75* $75	*0* $0	*0* $0	*175* $175
FAB	Fabricate Bottom Spacer	*U.C. per EA*	1.00	EA	*8* 8	*$50.00* FAB	*400* $400	*0* $0	*400* $400	*0* $0	*0* $0	*800* $800
FAB	Allowance for Lifting Eyes, etc.	*U.C. per Allow*	1.00	Allow	*3* 3	*$50.00* FAB	*150* $150	*0* $0	*75* $75	*0* $0	*0* $0	*225* $225
FAB	Surface Prep prior to Galvanizing	*U.C. per SF*	624.00	SF	*0.032* 20	*$50.00* FAB	*1.6* $998	*0* $0	*0.74* $462	*0* $0	*0* $0	*2.34* $1,460
FAB	Ship Vault to be Galvanizer (200 Mile Raduis)	*U.C. per LBS*	5,500.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.044* $242	*0* $0	*0.044* $242
FAB	Galvanizing Process	*U.C. per LBS*	5,500.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.435* $2,393	*0* $0	*0.435* $2,393
FAB	Ship Vault back to Job Site for Installation	*U.C. per LBS*	5,500.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.044* $242	*0* $0	*0.044* $242
FAB	Allowance for Shop Inspection, Quality Control, & Misc Testing	*U.C. per Allow*	1.00	Allow	*10* 10	*$50.00* FAB	*500* $500	*0* $0	*0* $0	*0* $0	*0* $0	*500* $500

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
4.1 Oversized Vault - Fabrication												
	FAB	*U.C. per EA*			*3*	*$50.00*	*150*	*0*	*10*	*0*	*0*	*160*
Documentation and Test Reports			1.00	EA	3	FAB	$150	$0	$10	$0	$0	$160
Subtotal							$4,935	$0	$5,179	$2,877	$0	$12,990
Sales Tax							$0	$0	$311	$0	$0	$311
Markups		46.97%					$2,318	$0	$2,578	$1,351	$0	$6,247
Subtotal Estimate												**$19,548**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$2,538	$0	$2,824	$1,480	$0	$6,842
---Total 4.1 Oversized Vault - Fabrication					99		**$9,791**	**$0**	**$10,891**	**$5,707**	**$0**	**$26,389**
4.2 Oversized Vault - Installation												
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*6.75*	*0*	*6.75*
Excavate Vault Hole (Operator & Equipment)			27.00	Cyds	0		$0	$0	$0	$182	$0	$182
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*8.75*	*0*	*8.75*
Backfill & Compact			10.00	Cyds	0		$0	$0	$0	$88	$0	$88
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*10.5*	*0*	*10.5*
Haul Overburden Away			15.00	Cyds	0		$0	$0	$0	$158	$0	$158
	CONC	*U.C. per Cyds*					*0*	*0*	*0*	*35*	*0*	*35*
Place Gravel			5.00	Cyds	0		$0	$0	$0	$175	$0	$175
	CONC	*U.C. per EA*			*6*	*$40.00*	*240*	*0*	*0*	*0*	*0*	*240*
Set Vault in Place			1.00	EA	6	SILO	$240	$0	$0	$0	$0	$240
	CONC	*U.C. per Hrs*			*1*	*$40.00*	*40*	*125*	*0*	*0*	*0*	*165*
Crane Usage			3.00	Hrs	3	SILO	$120	$375	$0	$0	$0	$495
	CONC	*U.C. per SF*			*0.02*	*$50.00*	*1*	*0*	*0.2*	*0*	*0*	*1.2*
Construct Concrete Form for Vault (Top Edge Only)			128.00	SF	3	FAB	$128	$0	$26	$0	$0	$154

Code	Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
4.2 Oversized Vault - Installation													
		CONC	*U.C. per EA*			*3*	*$50.00*	*150*	*0*	*0*	*0*	*0*	*150*
	Place and suspend Vault Excavated Hole			1.00	EA	3	FAB	$150	$0	$0	$0	$0	$150
		CONC	*U.C. per Cyds*					*0*	*0*	*0*	*300*	*0*	*300*
	Pour Concrete into Forms, includes, concrete, and labor			19.00	Cyds	0		$0	$0	$0	$5,700	$0	$5,700
Memo:	Addition concrete has been included to account for the over angle of repose needed during the excavation activities. It was assumed that the top 5 feet would require this repose, an addition of 8 cyds of concrete was added for this repose area. Concrete unit cost accounts for minimal forms, concrete, pumping, and labor to place.												
		CONC	*U.C. per Allow*			*0.6*	*$40.00*	*24*	*60*	*0*	*0*	*0*	*84*
	Vault Transport Truck to Job Site			1.00	Allow	1	SILO	$24	$60	$0	$0	$0	$84
		CONC	*U.C. per EA*			*2*	*$40.00*	*80*	*35*	*0*	*0*	*0*	*115*
	Install the Precast Cover			1.00	EA	2	SILO	$80	$35	$0	$0	$0	$115
		CONC	*U.C. per EA*			*1*	*$40.00*	*40*	*35*	*0*	*0*	*0*	*75*
	Install the Weather Cover			1.00	EA	1	SILO	$40	$35	$0	$0	$0	$75
Subtotal								$782	$505	$26	$6,302	$0	$7,615
Sales Tax								$0	$0	$2	$0	$0	$2
Markups			38.80%					$303	$196	$11	$2,445	$0	$2,955
Subtotal Estimate													**$10,572**
Escalation								$0	$0	$0	$0	$0	$0
Management Reserve								$380	$245	$13	$3,062	$0	$3,700
---Total 4.2 Oversized Vault - Installation						**18**		**$1,465**	**$946**	**$51**	**$11,809**	**$0**	**$14,272**
5.1 Silo Lid - Welded W/HEPA													
		FAB	*U.C. per LBS*			*0.01*	*$50.00*	*0.5*	*0*	*0.75*	*0*	*0*	*1.25*
	Fabricate 3/8" thk top plate 36" Dia			200.00	LBS	2	FAB	$100	$0	$150	$0	$0	$250
		FAB	*U.C. per LBS*			*0.012*	*$50.00*	*0.6*	*0*	*0.75*	*0*	*0*	*1.35*
	Fabricate 3/8" thick Carbon Steel Shield Plug Encasement 30" Dia			320.00	LBS	4	FAB	$192	$0	$240	$0	$0	$432

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
5.1 Silo Lid - Welded W/HEPA												
		FAB	*U.C. per EA*		*0.5*	*$50.00*	*25*	*0*	*60*	*0*	*0*	*85*
	Pour Encasement with Concrete (.2 Cyds)		1.00	EA	1	FAB	$25	$0	$60	$0	$0	$85
		FAB	*U.C. per LF*		*0.267*	*$50.00*	*13.35*	*0*	*0*	*0*	*0*	*13.35*
	Weld on Top Plate to Encasement Body		8.00	LF	2	FAB	$107	$0	$0	$0	$0	$107
		FAB	*U.C. per LF*		*0.267*	*$50.00*	*13.35*	*0*	*0*	*0*	*0*	*13.35*
	Weld on Bottom Plate to Encasement Body		8.00	LF	2	FAB	$107	$0	$0	$0	$0	$107
		FAB	*U.C. per Allow*		*2*	*$50.00*	*100*	*0*	*60*	*0*	*0*	*160*
	Ventilation Port Allowance for HEPA Filter		1.00	Allow	2	FAB	$100	$0	$60	$0	$0	$160
		FAB	*U.C. per EA*		*1*	*$50.00*	*50*	*0*	*150*	*0*	*0*	*200*
	Small HEPA Filter Cartridge w/Filter Element		1.00	EA	1	FAB	$50	$0	$150	$0	$0	$200
		FAB	*U.C. per Allow*		*1.5*	*$50.00*	*75*	*0*	*30*	*0*	*0*	*105*
	Allowance for Lifting Eyes, etc.		1.00	Allow	2	FAB	$75	$0	$30	$0	$0	$105
		FAB	*U.C. per SF*		*0.032*	*$50.00*	*1.6*	*0*	*0.74*	*0*	*0*	*2.34*
	Surface Prep prior to Galvanizing		38.00	SF	1	FAB	$61	$0	$28	$0	$0	$89
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.044*	*0*	*0.044*
	Ship pipe to be Galvanizer (200 Mile Radius)		520.00	LBS	0		$0	$0	$0	$23	$0	$23
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.435*	*0*	*0.435*
	Galvanizing Process		520.00	LBS	0		$0	$0	$0	$226	$0	$226
		FAB	*U.C. per LBS*				*0*	*0*	*0*	*0.044*	*0*	*0.044*
	Ship to Job Site Stagging Area (200 Mile Raduis)		520.00	LBS	0		$0	$0	$0	$23	$0	$23
		FAB	*U.C. per Allow*		*1.5*	*$50.00*	*75*	*0*	*0*	*0*	*0*	*75*
	Allowance for Shop Inspection, Quality Control, & Misc Testing		1.00	Allow	2	FAB	$75	$0	$0	$0	$0	$75

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
5.1 Silo Lid - Welded W/HEPA												
	FAB	*U.C. per EA*			*0.75*	*$50.00*	*37.5*	*0*	*10*	*0*	*0*	*47.5*
Documentation and Test Reports			1.00	EA	1	FAB	$38	$0	$10	$0	$0	$48
Subtotal							$929	$0	$728	$272	$0	$1,929
Sales Tax							$0	$0	$44	$0	$0	$44
Markups		46.97%					$436	$0	$362	$128	$0	$926
Subtotal Estimate												**$2,899**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$478	$0	$397	$140	$0	$1,015
---Total 5.1 Silo Lid - Welded W/HEPA					**19**		**$1,843**	**$0**	**$1,531**	**$540**	**$0**	**$3,914**

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
5.2 Silo Lid - Bolted W/out HEPA												
	FAB	*U.C. per EA*					*0*	*0*	*720*	*0*	*0*	*720*
Purchase 30" Class B Blind Flange (7/8" Thick)			1.00	EA	0		$0	$0	$720	$0	$0	$720
	FAB	*U.C. per EA*					*0*	*0*	*250*	*0*	*0*	*250*
30" Bolt & Gasket Set, Class B			1.00	EA	0		$0	$0	$250	$0	$0	$250
	FAB	*U.C. per LBS*			*0.012*	*$50.00*	*0.6*	*0*	*0.75*	*0*	*0*	*1.35*
Fabricate 3/8" thick Carbon Steel Shield Plug Encasement 30" Dia			320.00	LBS	4	FAB	$192	$0	$240	$0	$0	$432
	FAB	*U.C. per EA*			*0.5*	*$50.00*	*25*	*0*	*60*	*0*	*0*	*85*
Pour Encasement with Concrete (.2 Cyds)			1.00	EA	1	FAB	$25	$0	$60	$0	$0	$85
	FAB	*U.C. per LF*			*0.267*	*$50.00*	*13.35*	*0*	*0*	*0*	*0*	*13.35*
Weld on Top Plate to Encasement Body			8.00	LF	2	FAB	$107	$0	$0	$0	$0	$107
	FAB	*U.C. per LF*			*0.267*	*$50.00*	*13.35*	*0*	*0*	*0*	*0*	*13.35*
Weld on Bottom Plate to Encasement Body			8.00	LF	2	FAB	$107	$0	$0	$0	$0	$107
	FAB	*U.C. per Allow*			*1.5*	*$50.00*	*75*	*0*	*30*	*0*	*0*	*105*
Allowance for Lifting Eyes, etc.			1.00	Allow	2	FAB	$75	$0	$30	$0	$0	$105

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
5.2 Silo Lid - Bolted W/out HEPA												
Surface Prep prior to Galvanizing	FAB	*U.C. per SF*	38.00	SF	*0.032* 1	*$50.00* FAB	*1.6* $61	*0* $0	*0.74* $28	*0* $0	*0* $0	*2.34* $89
Ship pipe to be Galvanizer (200 Mile Raduis)	FAB	*U.C. per LBS*	600.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.044* $26	*0* $0	*0.044* $26
Galvanizing Process	FAB	*U.C. per LBS*	600.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.435* $261	*0* $0	*0.435* $261
Ship to Job Site Stagging Area (200 Mile Raduis)	FAB	*U.C. per LBS*	600.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.044* $26	*0* $0	*0.044* $26
Allowance for Shop Inspection, Quality Control, & Misc Testing	FAB	*U.C. per Allow*	1.00	Allow	*1.5* 2	*$50.00* FAB	*75* $75	*0* $0	*0* $0	*0* $0	*0* $0	*75* $75
Documentation and Test Reports	FAB	*U.C. per EA*	1.00	EA	*0.75* 1	*$50.00* FAB	*37.5* $38	*0* $0	*10* $10	*0* $0	*0* $0	*47.5* $48
Subtotal							$679	$0	$1,338	$314	$0	$2,331
Sales Tax							$0	$0	$80	$0	$0	$80
Markups		46.97%					$319	$0	$666	$147	$0	$1,132
Subtotal Estimate												**$3,544**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$349	$0	$730	$161	$0	$1,240
---Total 5.2 Silo Lid - Bolted W/out HEPA					**14**		**$1,347**	**$0**	**$2,814**	**$623**	**$0**	**$4,784**
6.1.1 Silo Precast Concrete Cover												
Construct Concrete Form for 30" Silo	CONC	*U.C. per SF*	53.00	SF	*0.02* 1	*$50.00* FAB	*1* $53	*0* $0	*0.3* $16	*0* $0	*0* $0	*1.3* $69
Pour Concrete into Forms, includes rebar, concrete, and labor	CONC	*U.C. per Cyds*	1.60	Cyds	0		*0* $0	*0* $0	*0* $0	*400* $640	*0* $0	*400* $640

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
6.1.1 Silo Precast Concrete Cover											
FAB Ship Precast Vault to Job Site Stagging Area	*U.C. per LBS*	350.00	LBS	0		*0* $0	*0* $0	*0* $0	*0.044* $15	*0* $0	*0.044* $15
Subtotal						$53	$0	$16	$655	$0	$724
Sales Tax						$0	$0	$1	$0	$0	$1
Markups	38.98%					$21	$0	$7	$256	$0	$283
Subtotal Estimate											**$1,008**
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$26	$0	$8	$319	$0	$353
---Total 6.1.1 Silo Precast Concrete Cover				**1**		**$99**	**$0**	**$32**	**$1,230**	**$0**	**$1,361**
6.1.2 Silo Corrigated Weather Cover											
FAB Corrigated Galvanized Carbon Steel 60" Dia	*U.C. per SF*	80.00	SF	*0.045* 4		*0* $0	*0* $0	*4.31* $345	*0* $0	*0* $0	*4.31* $345
FAB Corrigated Galvanized Carbon Steel Top Weather Cover	*U.C. per SF*	20.00	SF	*0.045* 1		*0* $0	*0* $0	*3.1* $62	*0* $0	*0* $0	*3.1* $62
FAB Weld Corrigated Galvanized Carbon Steel Top to Bottom Pipe Weather Cover	*U.C. per LF*	16.00	LF	*0.18* 3		*0* $0	*0* $0	*3.1* $50	*0* $0	*0* $0	*3.1* $50

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
6.1.2 Silo Corrigated Weather Cover											
FAB	*U.C. per Allow*			*0.5*	*$50.00*	*25*	*0*	*20*	*0*	*0*	*45*
Lifting Eye Allowance		1.00	Allow	1	FAB	$25	$0	$20	$0	$0	$45
Subtotal						$25	$0	$476	$0	$0	$501
Sales Tax						$0	$0	$29	$0	$0	$29
Markups	46.97%					$12	$0	$237	$0	$0	$249
Subtotal Estimate											$779
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$13	$0	$260	$0	$0	$273
---Total 6.1.2 Silo Corrigated Weather Cover				**8**		**$50**	**$0**	**$1,002**	**$0**	**$0**	**$1,052**
6.2.1 Vault Precast Concrete Cover											
FAB	*U.C. per*					*0*	*0*	*0.01*	*0*	*0*	*0.01*
Precast Concrete Encasement		1.00		0		$0	$0	$0	$0	$0	$0
CONC	*U.C. per SF*			*0.02*	*$50.00*	*1*	*0*	*0.2*	*0*	*0*	*1.2*
Construct Concrete Form for Vault		128.00	SF	3	FAB	$128	$0	$26	$0	$0	$154
CONC	*U.C. per Cyds*					*0*	*0*	*0*	*400*	*0*	*400*
Pour Concrete into Forms, includes rebar, concrete, and labor		3.40	Cyds	0		$0	$0	$0	$1,360	$0	$1,360
FAB	*U.C. per LBS*					*0*	*0*	*0*	*0.044*	*0*	*0.044*
Ship Precast Vault to Job Site Stagging Area		1,200.00	LBS	0		$0	$0	$0	$53	$0	$53

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
6.2.1 Vault Precast Concrete Cover											
FAB	*U.C. per Allow*			*2*	*$50.00*	*100*	*0*	*50*	*0*	*0*	*150*
Allowance for Lifting Eyes, etc.		1.00	Allow	2	FAB	$100	$0	$50	$0	$0	$150
Subtotal						$228	$0	$76	$1,413	$0	$1,716
Sales Tax						$0	$0	$5	$0	$0	$5
Markups	39.78%					$97	$0	$35	$553	$0	$685
Subtotal Estimate											**$2,406**
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$114	$0	$40	$688	$0	$842
---Total 6.2.1 Vault Precast Concrete Cover				**5**		**$438**	**$0**	**$156**	**$2,653**	**$0**	**$3,247**
6.2.2 Vault Corrigated Weather Cover											
FAB	*U.C. per SF*			*0.045*	*$50.00*	*2.25*	*0*	*4.31*	*0*	*0*	*6.56*
Corrigated Galvanized Carbon Steel 8' x 8' x 5' High		176.00	SF	8	FAB	$396	$0	$759	$0	$0	$1,155
FAB	*U.C. per SF*			*0.045*	*$50.00*	*2.25*	*0*	*3.1*	*0*	*0*	*5.35*
Corrigated Galvanized Carbon Steel Top Weather Cover		70.00	SF	3	FAB	$158	$0	$217	$0	$0	$375
FAB	*U.C. per LF*			*0.18*	*$50.00*	*9*	*0*	*3.1*	*0*	*0*	*12.1*
Weld Corrigated Galvanized Carbon Steel Top to Bottom Pipe Weather Cover		42.00	LF	8	FAB	$378	$0	$130	$0	$0	$508

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
6.2.2 Vault Corrigated Weather Cover												
	FAB	*U.C. per Allow*			*0.5*	*$50.00*	*25*	*0*	*20*	*0*	*0*	*45*
Lifting Eye Allowance			1.00	Allow	1	FAB	$25	$0	$20	$0	$0	$45
Subtotal							$957	$0	$1,126	$0	$0	$2,082
Sales Tax							$0	$0	$68	$0	$0	$68
Markups		46.97%					$449	$0	$560	$0	$0	$1,010
Subtotal Estimate												**$3,159**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$492	$0	$614	$0	$0	$1,106
---Total 6.2.2 Vault Corrigated Weather Cover					**19**		**$1,898**	**$0**	**$2,368**	**$0**	**$0**	**$4,265**

7.1 Rad Air Monitoring - CAM (per 200 Silos)

Memo: *Cost allowance is based on a 300 ft x 300 ft square area (200 Silos) using 4 air monitors along the perimeter. This system would monitor for air contamination. Note, the estimate does not include any allowances for electrical power or controls to operate these monitors. The monitoring equipment cost allowance was provided by the project team.*

Code Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
	CONC	*U.C. per EA*			*40*	*$40.00*	*1600*	*0*	*35000*	*0*	*0*	*36600*
Radioactive Comtamination Air Monitoring Equipment, Allowance			4.00	EA	160	SILO	$6,400	$0	$140,000	$0	$0	$146,400
	CONC	*U.C. per EA*					*0*	*0*	*1000*	*0*	*0*	*1000*
Devise Mounting Allowance			4.00	EA	0		$0	$0	$4,000	$0	$0	$4,000
Subtotal							$6,400	$0	$144,000	$0	$0	$150,400
Sales Tax							$0	$0	$8,640	$0	$0	$8,640
Markups		38.80%					$2,483	$0	$59,227	$0	$0	$61,710
Subtotal Estimate												**$220,750**
Escalation							$0	$0	$0	$0	$0	$0
Management Reserve							$3,109	$0	$74,153	$0	$0	$77,263
---Total 7.1 Rad Air Monitoring - CAM (per 200 Silos)					**160**		**$11,992**	**$0**	**$286,020**	**$0**	**$0**	**$298,013**

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*

Estimate Number: *MA49-A*

Client: *S. L. Austad*

Prepared By: *A. W. Miller / S. N. Wasley*

Estimate Type: *Class-5*

Code	Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
7.2 Radiation Area Monitoring - RAM (per 200 Silos)													

Memo: *Cost allowance is based on a 300 ft x 300 ft square area (200 silos) using 8 rad monitors along the perimeter. This system would monitor radiation field levels. Note, the estimate does not include any allowances for electrical power or controls to operate these monitors. The monitoring equipment cost allowance was provided by the project team.*

Code	Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
		CONC	*U.C. per EA*			*40*	*$40.00*	*1600*	*0*	*4000*	*0*	*0*	*5600*
	Radioactive Monitoring Equipment, Allowance			8.00	EA	320	SILO	$12,800	$0	$32,000	$0	$0	$44,800
		CONC	*U.C. per EA*					*0*	*0*	*1000*	*0*	*0*	*1000*
	Devise Mounting Allowance			8.00	EA	0		$0	$0	$8,000	$0	$0	$8,000
	Subtotal							$12,800	$0	$40,000	$0	$0	$52,800
	Sales Tax							$0	$0	$2,400	$0	$0	$2,400
	Markups		38.80%					$4,967	$0	$16,452	$0	$0	$21,418
	Subtotal Estimate												$76,618
	Escalation							$0	$0	$0	$0	$0	$0
	Management Reserve							$6,218	$0	$20,598	$0	$0	$26,816
---Total 7.2 Radiation Area Monitoring - RAM (per 200 Silos)						**320**		**$23,985**	**$0**	**$79,450**	**$0**	**$0**	**$103,435**

7.3 Humidity Monitoring (per 200 Silos)

Memo: *Cost allowance is based on one humidity sensor unit per silo and 10 hand held units to support 200 silos. Note, the estimate does not include any allowances for electrical power or controls to operate these monitors. The monitoring equipment cost allowance was provided by the project team.*

Code	Description	Contractor		Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
		CONC	*U.C. per EA*					*0*	*0*	*2150*	*0*	*0*	*2150*
	Humidity Hand Held Monitoring Devise			10.00	EA	0		$0	$0	$21,500	$0	$0	$21,500

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
7.3 Humidity Monitoring (per 200 Silos)											
Memo: Cost allowance is based on one humidity sensor unit per silo and 10 hand held units to support 200 silos. Note, the estimate does not include any allowances for electrical power or controls to operate these monitors. The monitoring equipment cost allowance was provided by the project team.											
CONC	*U.C. per EA*			*2*	*$40.00*	*80*	*0*	*50*	*0*	*0*	*130*
Humidity Sensor Lead Wire, one per Silo		200.00	EA	400	SILO	$16,000	$0	$10,000	$0	$0	$26,000
Subtotal						$16,000	$0	$31,500	$0	$0	$47,500
Sales Tax						$0	$0	$1,890	$0	$0	$1,890
Markups	38.80%					$6,208	$0	$12,956	$0	$0	$19,164
Subtotal Estimate											**$68,554**
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$7,773	$0	$16,221	$0	$0	$23,994
---Total 7.3 Humidity Monitoring (per 200 Silos)				**400**		**$29,981**	**$0**	**$62,567**	**$0**	**$0**	**$92,548**
7.4 Corrosion Monitoring - Ultrasonic (PER EACH SILO)											
Memo: Cost allowance is based on one ultrasonic corrosion unit per silo. This unit would monitor corrosion levels. Note, the estimate does not include any allowances for electrical power or controls to operate these monitors. The monitoring equipment cost allowance was provided by the project team.											
CONC	*U.C. per Ea*			*4*	*$40.00*	*160*	*0*	*12000*	*0*	*0*	*12160*
Ultrasonic Corrosion Monitoring, Allowance		1.00	Ea	4	SILO	$160	$0	$12,000	$0	$0	$12,160
Subtotal						$160	$0	$12,000	$0	$0	$12,160
Sales Tax						$0	$0	$720	$0	$0	$720
Markups	38.80%					$62	$0	$4,936	$0	$0	$4,998
Subtotal Estimate											**$17,878**
Escalation						$0	$0	$0	$0	$0	$0
Management Reserve						$78	$0	$6,179	$0	$0	$6,257
---Total 7.4 Corrosion Monitoring - Ultrasonic (PER EACH SILO)				**4**		**$300**	**$0**	**$23,835**	**$0**	**$0**	**$24,135**

DETAIL ITEM REPORT

Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
7.5 Corrosion Monitoring - Sacrificial Anode (per 200 Silos)												
Memo:	*Cost allowance is based on 10 anodes per 200 silos. These anodes would be placed throughout the 200 silo area. Note, the estimate does not include any allowances for electrical power or controls to operate this system. The anode corrosion equipment cost allowance was provided by the project team.*											
	CONC	*U.C. per EA*			*25*	*$40.00*	*1000*	*0*	*12000*	*0*	*0*	*13000*
	Sacrificial Anode Units (10 Units per 200 Silos)		10.00	EA	250	SILO	$10,000	$0	$120,000	$0	$0	$130,000
	Subtotal						$10,000	$0	$120,000	$0	$0	$130,000
	Sales Tax						$0	$0	$7,200	$0	$0	$7,200
	Markups	38.80%					$3,880	$0	$49,356	$0	$0	$53,236
	Subtotal Estimate											**$190,436**
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$4,858	$0	$61,794	$0	$0	$66,653
---Total	**7.5 Corrosion Monitoring - Sacrificial Anode (per 200 Silos)**				**250**		**$18,738**	**$0**	**$238,350**	**$0**	**$0**	**$257,088**
7.6 Video Area Monitoring (per 200 Silos)												
Memo:	*Cost allowance is based on two video units per 200 silos. Note, the estimate does not include any allowances for electrical power or controls to operate these video systems. The monitoring equipment cost allowance was provided by the project team.*											
	CONC	*U.C. per EA*			*40*	*$40.00*	*1600*	*0*	*25000*	*0*	*0*	*26600*
	Area Video Monitoring System (2 each per 200 Silos)		2.00	EA	80	SILO	$3,200	$0	$50,000	$0	$0	$53,200
	CONC	*U.C. per EA*			*15*	*$40.00*	*600*	*0*	*2000*	*0*	*0*	*2600*
	Video Mounting/Stand Allowance		2.00	EA	30	SILO	$1,200	$0	$4,000	$0	$0	$5,200
	Subtotal						$4,400	$0	$54,000	$0	$0	$58,400
	Sales Tax						$0	$0	$3,240	$0	$0	$3,240
	Markups	38.80%					$1,707	$0	$22,210	$0	$0	$23,917
	Subtotal Estimate											**$85,557**
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$2,138	$0	$27,808	$0	$0	$29,945
---Total	**7.6 Video Area Monitoring (per 200 Silos)**				**110**		**$8,245**	**$0**	**$107,258**	**$0**	**$0**	**$115,502**

DETAIL ITEM REPORT

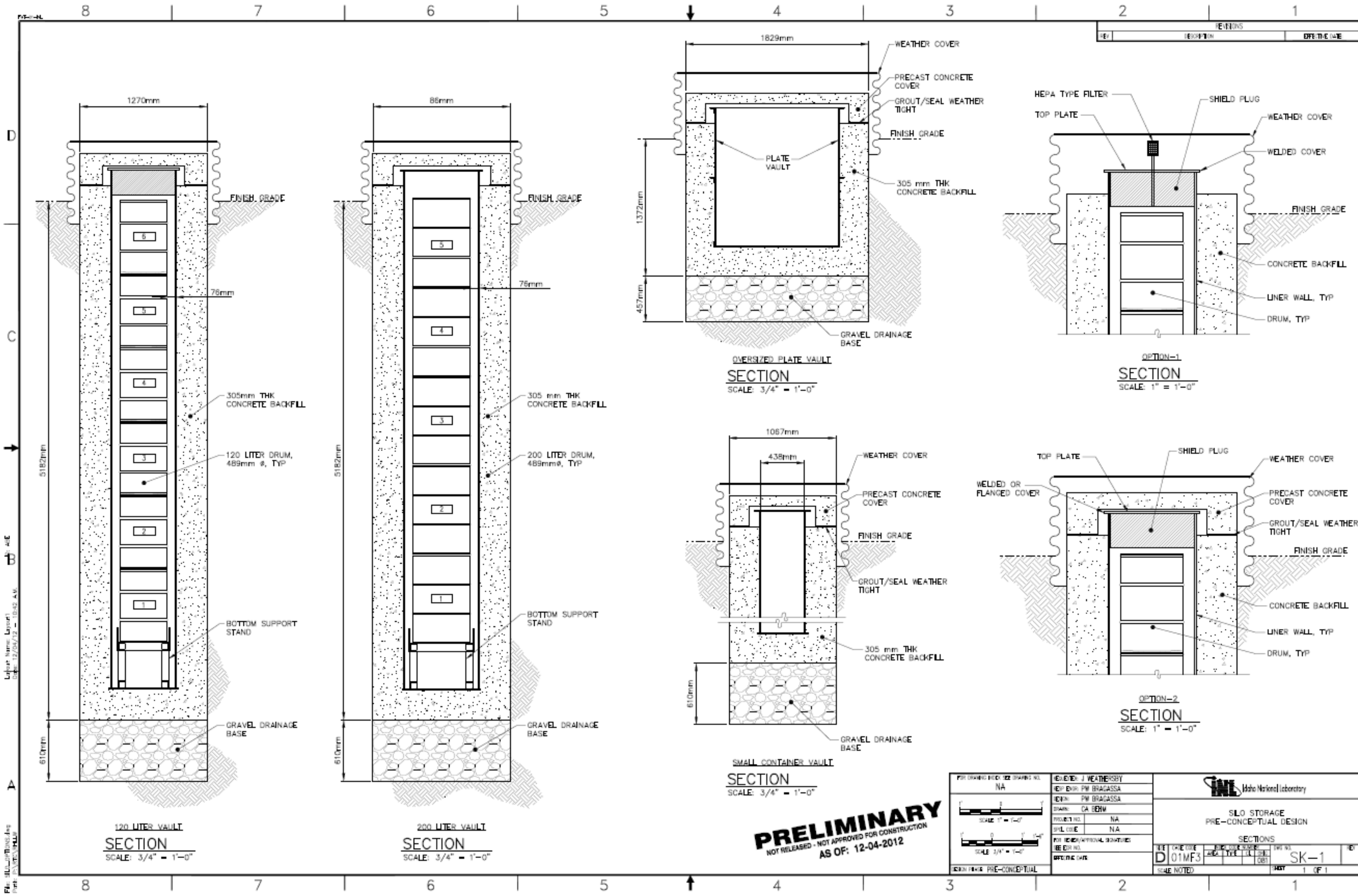
Project Name: *In Ground Silo Storage*

Project Location: *Unknown*
Estimate Number: *MA49-A*

Client: *S. L. Austad*
Prepared By: *A. W. Miller / S. N. Wasley*
Estimate Type: *Class-5*

Code	Description	Contractor	Qty	UOM	Hrs	Resource	Labor	Equipment	Material	Subcontractor	Other	TOTAL
	Subtotal **MA49-A In Ground Silo Storage**						$64,488	$1,540	$419,372	$30,558	$0	$515,958
	Sales Tax						$0	$0	$25,162	$0	$0	$25,162
	Markups						$26,034	$598	$174,016	$10,147	$0	$210,795
	Subtotal Estimate											$751,915
	Escalation						$0	$0	$0	$0	$0	$0
	Management Reserve						$31,683	$748	$216,492	$14,247	$0	$263,170
	Total MA49-A In Ground Silo Storage				1,555		$122,206	$2,886	$835,042	$54,952	$0	**$1,015,085**

Appendix B
Drawing


1270mm
FINISH GRADE
76mm
305mm THK CONCRETE BACKFILL
120 LITER DRUM, 489mm ø, TYP
BOTTOM SUPPORT STAND
GRAVEL DRAINAGE BASE
5182mm
610mm
120 LITER VAULT
SECTION
SCALE: 3/4" = 1'-0"
FINISH GRADE
76mm
305 mm THK CONCRETE BACKFILL
200 LITER DRUM, 489mmø, TYP
BOTTOM SUPPORT STAND
GRAVEL DRAINAGE BASE
200 LITER VAULT
SECTION
SCALE: 3/4" = 1'-0"
1829mm
WEATHER COVER
PRECAST CONCRETE COVER
GROUT/SEAL WEATHER TIGHT
FINISH GRADE
PLATE VAULT
305 mm THK CONCRETE BACKFILL
1372mm
457mm
GRAVEL DRAINAGE BASE
OVERSIZED PLATE VAULT
SECTION
SCALE: 3/4" = 1'-0"
HEPA TYPE FILTER
TOP PLATE
SHIELD PLUG
WEATHER COVER
WELDED COVER
FINISH GRADE
CONCRETE BACKFILL
LINER WALL, TYP
DRUM, TYP
OPTION-1
SECTION
SCALE: 1" = 1'-0"
1067mm
438mm
WEATHER COVER
PRECAST CONCRETE COVER
FINISH GRADE
GROUT/SEAL WEATHER TIGHT
305 mm THK CONCRETE BACKFILL
610mm
GRAVEL DRAINAGE BASE
SMALL CONTAINER VAULT
SECTION
SCALE: 3/4" = 1'-0"
TOP PLATE
SHIELD PLUG
WEATHER COVER
WELDED OR FLANGED COVER
PRECAST CONCRETE COVER
GROUT/SEAL WEATHER TIGHT
FINISH GRADE
CONCRETE BACKFILL
LINER WALL, TYP
DRUM, TYP
OPTION-2
SECTION
SCALE: 1" = 1'-0"
PRELIMINARY
NOT RELEASED - NOT APPROVED FOR CONSTRUCTION
AS OF: 12-04-2012
REVISIONS
Idaho National Laboratory
SILO STORAGE
PRE-CONCEPTUAL DESIGN
SECTIONS
SK-1
01MF3
PRE-CONCEPTUAL

Appendix C
Corrosion Calculations

Storage Liner Deterministic Method Model for Steel Liner Life

DSFerguson 11/26/2012

$temp := 35$ °C -- Liner Average Temp (Deg C over 50 years) for Hottest Loading (Model overly conservative at temps over 60°C)

Concrete Shell Life Estimate part 1 - Carbonation Diffusion

$dia_{hole\_nom} := 1370 \cdot mm$ $\quad liner_{OD\_nom} := 30 \cdot in$ $\quad liner_{tol} := 12.5\%$ $\quad hole_{ID\_tol} := 100 \cdot mm$

$dia_{hole\_nom} = 53.9 \cdot in$

$$liner_{OD\_max} := liner_{OD\_nom} \cdot (1 + liner_{tol}) \qquad thickness_{concrete} := \frac{dia_{hole\_nom} - liner_{OD\_max} - hole_{ID\_tol}}{2}$$

$48 \cdot in = 1219 \cdot mm$ $\qquad thickness_{concrete} = 8.1 \cdot in$ $\qquad thickness_{concrete} = 206.4 \cdot mm$

$depth_{carbonation} := thickness_{concrete}$ Assumed the concrete will react enough to allow the electrolyte to attack the zinc layer at the carbonation depth.

$RH := 50\%$ 50% relative humidity is worst case (C_c is lower either side of 50%) --- the following C_c function below doesn't address RH above 50% (fails)

$$C_c := \left[0.001478 \cdot \left(\frac{RH}{\%}\right)^2 + 0.144 \cdot \frac{RH}{\%} + 0.0351 \cdot temp - 1.9853\right] \cdot \frac{mm}{\sqrt{yr}}$$

C_c is Carbonation Coefficient see note [1] $\qquad C_c = 10.1 \cdot \frac{mm}{\sqrt{yr}}$

$safety\_factor_{concrete} := 1$ $\qquad \frac{1}{safety\_factor_{concrete}} = 100 \cdot \%$

$$C_c \cdot safety\_factor_{concrete} = 10.1 \cdot \frac{mm}{\sqrt{yr}} \qquad life_{carb} := \left(\frac{depth_{carbonation}}{C_c \cdot safety\_factor_{concrete}}\right)^2 \qquad life_{carb} = 414.4 \cdot yr$$

$$\left(C_c \cdot safety\_factor_{concrete}\right)^2 = 102.8 \cdot \frac{mm^2}{yr} \qquad \left(C_c \cdot safety\_factor_{concrete}\right)^2 = 3.3 \times 10^{-12} \cdot \frac{m^2}{sec}$$

Carbonation Coefficient combined with safety factor -- See NIST NISTIR #5690 paragraph 2.2.2, see Note [2]

Concrete Shell Life Estimate part 2 - Chloride Diffusion

$wcr := 0.40$ Water/Cement Ratio

$Cl_{soil} := 0.1\%$ $\quad Cl_{soil} = 1000 \cdot ppm$ % Chlorides in Soil

^ Typical Total Dissolved Salts (TDS) for soil is 0.04% to 0.5%, Seawater salinity is 3.1% to 3.8%, typ drinking water 20-1000 ppm, Caspian Sea 1%-1.3%

$$D_{cl} := 1.445 \cdot 10^{-10} \cdot \frac{cm^2}{s} \cdot e^{13.8 \cdot wcr} = 113.8 \cdot \frac{mm^2}{yr}$$

Diffusion Rate of Chlorides, see [4] Eq 19

$safety\_factor_{concrete} = 1$

from above

$life_{guess} := life_{carb}$

$CTL := 0.06\%$

Chloride Threshold Level, the % chloride that starts corrosion -- See ACI-357 & Elsevier Corrosion Science #49 (2007) 4113-4133, "Chloride Threshold Level for Corrosion of Steel in Concrete" by Ki Yong Ann

$$\text{Given} \quad CTL = Cl_{soil} \cdot safety\_factor_{concrete} \cdot erfc\left(\frac{thickness_{concrete}}{2 \cdot \sqrt{D_{cl} \cdot life_{guess}}}\right)$$

Chloride Coefficient Thru Concrete -- See Note [3]
erfc is the built-in 'complementary error function'

$life_{cl} := Find(life_{guess}) = 680.3 \cdot yr$ <-- Solve for life

$$\rho_{h2o} := 1 \cdot \frac{kg}{l}$$

$$Cl_{soil} \cdot \rho_{h2o} = 1 \cdot \frac{gm}{l}$$

$life_{concrete} := if(life_{carb} < life_{cl}, life_{carb}, life_{cl})$ <------ Shorter life --------> $life_{concrete} = 414.4 \cdot yr$

--- Continue next page ---

Zinc Coating Life Estimate External

$nom_{zinc} := 75\cdot\mu m = 2.953\cdot mil$

ASTM-A123-12 Grade 75 is 3.0 mils

6. Coating Properties

6.1 *Coating Thickness*—The average thickness of coating for all specimens tested shall conform to the requirements of Table 1 for the categories and thicknesses of the material being galvanized. Minimum average thickness of coating for any individual specimen is one coating grade less than that required in Table 1. Where products consisting of various material thicknesses or categories are galvanized, the coating thickness grades for each thickness range and material category of material shall be as shown in Table 1. In the case of orders in

A123/A123M – 12

TABLE 1 Minimum Average Coating Thickness Grade by Material Category

Material Category	All Specimens Tested Steel Thickness Range (Measured), in. (mm)				
	<1/16 (<1.6)	1/16 to <1/8 (1.6 to <3.2)	1/8 to 3/16 (3.2 to 4.8)	>3/16 to <1/4 (>4.8 to <6.4)	≥1/4 (≥6.4)
Structural Shapes and Plate	45	65	75	85	100
Strip and Bar	45	65	75	85	100
Pipe and Tubing	45	45	75	75	75
Wire	35	50	60	65	80
Reinforcing Bar					100

TABLE 2 Coating Thickness Grade[A]

Coating Grade	mils	oz/ft²	µm	g/m²
35	1.4	0.8	35	245
45	1.8	1.0	45	320
50	2.0	1.2	50	355
55	2.2	1.3	55	390
60	2.4	1.4	60	425
65	2.6	1.5	65	460
75	3.0	1.7	75	530
80	3.1	1.9	80	565
85	3.3	2.0	85	600
100	3.9	2.3	100	705

[A] The values in micrometres (µm) are based on the Coating Grade. The other values are based on conversions using the following formulas: mils = µm × 0.03937; oz/ft² = µm × 0.00327; g/m² = µm × 7.067.

$$thick_{zinc\_min} := \text{if}\left(nom_{zinc} = 100\cdot\mu m, nom_{zinc} - 15\cdot\mu m, \text{if}\left(nom_{zinc} = 75\cdot\mu m, nom_{zinc} - 10\cdot\mu m, nom_{zinc} - 5\cdot\mu m\right)\right)$$

$thick_{zinc\_min} = 65\cdot\mu m$ $\quad thick_{zinc\_min} = 2.56\cdot mil$

Note: Change min thickness (below) by looking at one level thinner in Table 2

$$eter\_zinc(x) := 271\cdot 10^{5}\cdot e^{\frac{-9970.9\cdot\frac{cal}{mole}}{R_{gas}\cdot(x+273.15)}}$$

Function for estimation of the elevated temperature effects based on Arrhenious prediction, a doubling of corrosion rate for ever 30 Deg C rise. From "Corrosion Handbook", by H.H. Uhlig, 6th printing 1958, pg. 128. The function is scaled to have a base temperature of 20 Deg C "eter" of 1 and an "eter" of 7.8 at 60°C.

$eter_{zinc} := eter\_zinc(temp) = 2.298$ "eter" is Elevated Temperature Effects Ratio

$paf_{zinc} := 1$ at 1, Pitting is not a factor "paf" is Pitting Acceleration Factor, maximum pitting rate divided by general corrosion rate.

$corr_{zinc\_soil} := 13.3\cdot\mu py$ Note: 30 µpy is for galvanized steel, if "Aluzink" (aluminum zinc alloy) is used then the rate drops to 13.3

Corrosion rate data from "Corrosion of Steel and Metal-Coated Steel in Swedish Soils - Effects of Soil Parameters", Figure 6 for Zinc Coating", pg. 46, by G.Camitz & T-R. G. Vinka, in "Effects of Soils Characteristics on Corrosion", ed. by V. Chaker & J.D. Palmer, ASTM STP-1013

$safety\_factor_{zinc} := 1$

$$life_{zinc\_soil} := \frac{thick_{zinc\_min}}{corr_{zinc\_soil}\cdot eter_{zinc}\cdot paf_{zinc}\cdot safety\_factor_{zinc}}$$

$life_{zinc\_soil} = 2.13\cdot yr$

$corr_{zinc\_soil}\cdot eter_{zinc}\cdot paf_{zinc}\cdot safety\_factor_{zinc} = 30.6\cdot\mu py$

--- Continue next page ---

Steel Liner Life Estimate Part 1 - External Corrosion --

$nominal_{steel} := .375 \cdot in$ $tol_{steel} := 12.5\%$ $thick_{steel\_min} := nominal_{steel} \cdot (1 - tol_{steel})$ $thick_{steel\_min} = 8.33 \cdot mm$ $thick_{steel\_min} = 0.328 \cdot in$

$nominal_{steel} = 9.525 \cdot mm$

12.5% Manuf. Tolerance on Thickness of Steel - assume worst case at thinner thickness, per ASTM A106 .

$ph_{adjustment} := 100\%$

Corrosion rate correction factor of 37% (the corrosion rate is 37% of the rate at pH=7) is for high (>12) pH concrete. This could be 12% if pH is >13. Assuming 5 to 9 pH is 100%. This is from Fig. #3 "Effect of pH on corrosion of steel in aerated water.", Pg. 536 of Uhlig's Corrosion Handbook, ed. by R.Winston Revie

$corr_{low} := 7 \cdot \mu py$ $corr_{ave} := 20.82 \cdot \mu py$ $corr_{high} := 36.1 \cdot \mu py$

$corr_{steel} := corr_{high} \cdot ph_{adjustment}$ Assume the highest case corrosion rate, --> $corr_{steel} = 36.1 \cdot \mu py$ $corr_{steel} = 1.421 \cdot \frac{mil}{yr}$

Corrosion rate data from "Corrosion of Steel and Metal-Coated Steel in Swedish Soils - Effects of Soil Parameters", Figure 3 for 'Carbon Steel' flat bars above the water table ("A"), pg. 43, by G.Camitz & T-R. G. Vinka, in "Effects of Soils Characteristics on Corrosion", ed. by V. Chaker & J.D. Palmer, ASTM STP-1013

$$eter\_steel(x) := 5.9056 \cdot 10^{4} \cdot e^{\frac{-6400 \cdot \frac{cal}{mole}}{R_{gas} \cdot (x+273.15)}}$$

Functions for estimation of the elevated temperature effects based on Arrhenius prediction, a doubling of corrosion rate for ever 30 Deg C rise. From "Corrosion Handbook", by H.H. Uhlig, 6th printing 1958, pg. 128 & interpolation from Fig 2, pg 129 at 7 pH for iron in water w/ 5 mL of oxygen per liter. The functions are scaled to have a base temperature of 20 Deg C.

$eter_{steel} := eter\_steel(temp)$ $eter_{steel} = 1.71$

$paf_{steel} := \frac{439 \cdot \mu py}{21 \cdot \mu py}$ $paf_{steel} = 20.9$ Pitting Acceleration Factor for Steel

Pitting factor data (439 µpy pitting rate & 21 µpy general corrosion rate) from "Corrosion of Steel and Metal-Coated Steel in Swedish Soils - Effects of Soil Parameters", Figure 5 for 'Carbon Steel' panels above the water table ("B") in sand backfill in muddy clay, pg. 45, by G.Camitz & T-R. G. Vinka, in "Effects of Soils Characteristics on Corrosion", ed. by V. Chaker & J.D. Palmer, ASTM STP-1013

This is conservative as the zinc will reduce the pitting. "Zinc promotes a more uniform corrosion by preventing the formulation of pits during the highly aggressive initial stages of burial" - "Corrosion Resistance of Zinc and Zinc Alloys" by Frank B. Porter, pg 354, cht 4. --- Most likely the paf will be no more than 5 (@5 the steel life will be ~27 years).

$paf_{steel} \cdot corr_{steel} \cdot eter_{steel} = 1288 \cdot \mu py$ <--- Net Effective Steel Corrosion Rate ---> $paf_{steel} \cdot corr_{steel} \cdot eter_{steel} = 50.7 \cdot \frac{mil}{yr}$

$corr_{steel\_external} := paf_{steel} \cdot corr_{steel} \cdot eter_{steel}$

$life_{steel} := \frac{thick_{steel\_min}}{corr_{steel\_external}}$ <-- Steel Lifetime ---> $life_{steel} = 6.5 \cdot yr$ With a Pitting Factor of 2.7, then steel lifetime ~ 50 years

--- Continue next page ---

Steel Liner Life Estimate Part 1 - Internal Corrosion --

$thick_{zinc\_min} = 65 \cdot \mu m$

from above

$eter_{zinc} = 2.30$

from above

$sheltered\_factor_{zinc} := 3.8$

ASM Metals Handbook - Chapter 13B - Corrosion Performance of Zinc, see [5] for "rural" areas- sheltering improves corrosion rate.

$corr_{zinc\_interior} := 3 \cdot \frac{\mu m}{yr}$

From Uhlig 2011 Chp 62 pg 881--- For a rural setting the range is .2 to 3 and for marine it is 0.5 to 8. It is assumed that environment inside the silo isn't changing and will be backfilled with clean dry argon or nitrogen during the closure process.

In an indoor atmosphere, the corrosion rate of zinc is very low, typically <0.1 μm/year. Generally, a visible tarnish film forms slowly, starting at spots where dust particles have fallen on the surface. Over a period of time, such films grow

$$life_{zinc\_internal} := \frac{thick_{zinc\_min} \cdot sheltered\_factor_{zinc}}{corr_{zinc\_interior} \cdot eter_{zinc}} \qquad life_{zinc\_internal} = 35.8 \cdot yr$$

Assumes that one only layer of zinc counts

Credit is given for only one layer of zinc as failure of the silo is considered when the steel silo is penetrated.

$RH_{inside} := 100\%$

A RH of 100% is conservative. It is assumed that environment inside the silo isn't changing and will be backfilled with clean dry argon or nitrogen during the closure process.

$\rho_{steel} = 7.84 \cdot \frac{gm}{cm^3}$

$\rho_{steel} = 489 \cdot \frac{lbm}{ft^3}$

$$corr_{steel\_internal} := \left(0.484 \cdot temp + 0.701 \cdot \frac{RH_{inside}}{\%} - 52.67\right) \cdot \frac{mdd}{\rho_{steel}}$$

From Uhlig's Corrosion Handbook, 3ed, 2011, Eq (43.1) Chapter 43 "Carbon Steel Atmospheric Corrosion", pg 580 -- Assumed that no chlorides or sulfur dioxides and no rain inside the silo. This function fails at RH's of less than 51% (it gives zero corrosion at 51% and negative corrosion for RH less than 51%).

$corr_{steel\_internal} = 6.3 \cdot mpy$

$corr_{steel\_internal} = 160.1 \cdot \mu py$

$corr_{steel\_internal} = 0.16 \cdot \frac{mm}{yr}$

$corr_{steel\_internal} \cdot \rho_{steel} = 34.4 \cdot mdd$

$thick_{steel\_min} = 8.334 \cdot mm$

from above

$$life_{steel\_internal} := \frac{thick_{steel\_min}}{corr_{steel\_internal}} \qquad life_{steel\_internal} = 52.1 \cdot yr$$

$$life_{silo\_internal} := life_{zinc\_internal} + life_{steel\_internal} \qquad life_{silo\_internal} = 87.9 \cdot yr$$

Internal corrosion only
see below for combined

--- Continue next page ---

Combined Life of Soil-Liner System --

$f_{soil}(t) :=$
"Start from the soil side"
"Test for time within the concrete and zinc"
$depth_{steel\_consumed} \leftarrow 0 \cdot in \text{ if } t \le (life_{concrete} + life_{zinc\_soil})$
otherwise
  "Corrosion within steel -- depth=time*corr_rate"
  $depth_{steel\_consumed} \leftarrow [t - (life_{concrete} + life_{zinc\_soil})] \cdot (corr_{steel\_external})$
"Return the depth of steel consumed."
$depth_{steel\_consumed} \leftarrow thick_{steel\_min} \text{ if } depth_{steel\_consumed} > thick_{steel\_min}$
$depth_{steel\_consumed}$

Function to calc the thickness of steel consumed as a function of exposure time for external (soil) corrosion.

$f_{internal}(t) :=$
"Start from the inside"
"Test for time within the zinc"
$depth_{steel\_consumed} \leftarrow 0 \cdot in \text{ if } t \le life_{zinc\_internal}$
otherwise
  "Corrosion within steel -- depth=time*corr_rate"
  $depth_{steel\_consumed} \leftarrow (t - life_{zinc\_internal}) \cdot (corr_{steel\_internal})$
"Return the depth of steel consumed."
$depth_{steel\_consumed} \leftarrow thick_{steel\_min} \text{ if } depth_{steel\_consumed} > thick_{steel\_min}$
$depth_{steel\_consumed}$

Function to calc the thickness of steel consumed as a function of exposure time for internal (atmospheric) corrosion.

$life_{concrete} = 414.4 \cdot yr$

$life_{zinc\_internal} = 35.8 \cdot yr$

$life_{guess} := if(life_{concrete} < life_{zinc\_internal}, life_{concrete} \cdot 110\%, life_{zinc\_internal}) = 36 \cdot yr$

find a good starting estimate for solver block

$thick\_resultant_{min} := .025 \cdot in$ <-- Minimum steel to remain at end of life. Sheet Metal Gauge 12 = 0.1046 inches.

The defined life of the system is when the corrosion from both sides is equal to the thickness of the steel silo minus the required minimum thickness. -- This is a dual rate problem, with different rates from two directions.

Given $f_{soil}(life_{guess}) + f_{internal}(life_{guess}) = thick_{steel\_min} - thick\_resultant_{min}$ <-- Solve Block Constraint

$life_{soil\_interior} := Find(life_{guess}) = 83.9 \cdot yr$ <-- Iteratively Solve for life

$f_{soil}(life_{soil\_interior}) = 0.000 \cdot in$ $f_{internal}(life_{soil\_interior}) = 0.303 \cdot in$ $f_{soil}(life_{soil\_interior}) + f_{internal}(life_{soil\_interior}) = 0.303 \cdot in$

Thickness of steel consumed.

Available thickness --> $thick_{steel\_min} = 0.328 \cdot in$

$thick_{steel\_min} - thick\_resultant_{min} = 0.303\,in$

$life_{soil\_interior} = 83.9 \cdot yr$ Life of System from both internal and external soil corrosion

--- Continue next page ---

Combined Life of External Air-Liner System --

$corr_{zinc\_atmospheric} := 3 \cdot \frac{\mu m}{yr}$

$safety\_factor_{air} := 1$

$sheltered\_factor_{zinc} = 3.8$

From Uhlig 2011 Chp 62 pg 881--- For a rural setting the range is .2 to 3 and for marine it is 0.5 to 8.

ASM Metals Handbook - Chapter 13B - Corrosion Performance of Zinc, see [5] for "rural" areas- sheltering improves corrosion rate. -- From above.

$life_{zinc\_atmos} := \frac{thick_{zinc\_min} \cdot sheltered\_factor_{zinc}}{corr_{zinc\_atmospheric} \cdot safety\_factor_{air}}$ $life_{zinc\_atmos} = 82.3 \cdot yr$

Assumes that one only layer of zinc counts & no temperature effects

$thick_{zinc\_min} = 65 \cdot \mu m$ Credit is given for only one layer of zinc as failure of the silo is considered when the steel silo is penetrated.

from above

$SO2_{\_air} := 0.50 \cdot ppm$ Sulfur Dioxide Air Concentration based on US-EPA National Ambient Air Quality Standard - Available at www.epa.gov/air/criteria.html

$Cl_{air} := 40 \cdot mdd$ Chloride Levels in Air Deposition Rate based on approx 300 m from shore, see fig. 8 under note [6]

$temp_{air} := 20$ °C -- Liner Average Outside Air Temp (Deg C over 50 years)

$RH_{outside} := 90\%$ RH 50 yr (average).

$$corr_{steel\_atmos} := \left(0.484 \cdot temp_{air} + 0.701 \cdot \frac{RH_{outside}}{\%} + 0.075 \cdot \frac{Cl_{air}}{mdd} + 8.202 \cdot \frac{SO2_{\_air}}{ppm} - 52.67\right) \cdot \frac{mdd}{\rho_{steel}} \cdot safety\_factor_{air}$$

From Uhlig's Corrosion Handbook, 3ed, 2011, Eq (43.1) Chapter 43 "Carbon Steel Atmospheric Corrosion", pg 580. This function fails at RH's of less than 51% (it gives zero corrosion at 51% and negative corrosion for RH less than 51%). NOTE: Eq (43.1) appears to have an typogrpahical error in the units for chloride and sulfur dioxide.

$corr_{steel\_atmos} = 4.99 \cdot mpy$

$corr_{steel\_atmos} = 126.7 \cdot \mu py$

$corr_{steel\_atmos} = 0.127 \cdot \frac{mm}{yr}$

$thick_{steel\_min} = 8.334 \cdot mm$

$corr_{steel\_atmos} \cdot \rho_{steel} = 27.2 \cdot mdd$

from above

$life_{steel\_air} := \frac{thick_{steel\_min}}{corr_{steel\_atmos}}$ $life_{steel\_air} = 65.8 \cdot yr$

Function to calc the thickness of steel consumed as a function of exposure time for external (atmospheric) corrosion.

```
f_atmos(t) := | "Start from the air side"
              | "Test for time within the zinc"
              | depth_steel_consumed ← 0·in  if t ≤ life_zinc_atmos
              | otherwise
              |   | "Corrosion within steel -- depth=time*corr_rate"
              |   | depth_steel_consumed ← (t − life_zinc_atmos)·(corr_steel_atmos)
              | "Return the depth of steel consumed."
              | depth_steel_consumed ← thick_steel_min  if depth_steel_consumed > thick_steel_min
              | depth_steel_consumed
```

$thick\_resultant_{min} = 0.025 \cdot in$ <-- Minimum steel to remain at end of life. Sheet Metal Gauge 12 = 0.1046 inches.

from above

$life_{guess} := life_{zinc\_atmos} \cdot (1 + 10\%) = 91 \cdot yr$ <--find a good starting estimate for solver block

The defined life of the system is when the corrosion from both sides is equal to the thickness of the steel silo minus the required minimum thickness. -- This is a dual rate problem, with different rates from two directions.

Given $f_{atmos}(life_{guess}) + f_{internal}(life_{guess}) = thick_{steel\_min} - thick\_resultant_{min}$ <-- Solve Block Constraint

$life_{atmos\_interior} := Find(life_{guess}) = 83.2 \cdot yr$ <-- Iteratively Solve for life

$f_{atmos}(life_{atmos\_interior}) = 0.004 \cdot in$ $f_{internal}(life_{atmos\_interior}) = 0.299 \cdot in$ $f_{atmos}(life_{atmos\_interior}) + f_{internal}(life_{atmos\_interior}) = 0.303 \cdot in$

Thickness of steel consumed.

Available thickness --> $thick_{steel\_min} = 0.328 \cdot in$

$life_{atmos\_interior} = 83.2 \cdot yr$

--- Continue next page ---

$life_{soil\_interior} = 83.9 \cdot yr$ <-- from above --> $life_{atmos\_interior} = 83.2 \cdot yr$

$life_{worst\_case} := if\left(life_{atmos\_interior} < life_{soil\_interior}, life_{atmos\_interior}, life_{soil\_interior}\right)$ <------ Shorter life ---------> $life_{worst\_case} = 83.2 \cdot yr$

$$Life_{worst\_case} := trunc\left(\frac{life_{worst\_case}}{yr}\right) \cdot yr$$

Truncate the answer to the lower full year.

$\boxed{Life_{worst\_case} = 83 \cdot yr}$

The Worst Case Life of the system from internal and either atmospheric or soils based corrosion.

NOTES:

[1] Carbonation Coefficient vs RH & Temp Function from "Influence of Local Climatic Conditions on the Carbonation Rate of Concrete" by H. Mihashi, from CRC Book "Creep, Shrinkage and Durability Mechanics of Concrete and Concrete Structures" - Tanabe et al. 2009, page 938, Eq (4), ISBN 978-0-415-48508-1

[2] Carbonation Coefficient from "Long-Term Performance of Engineered Concrete Barriers" by J.R. Clifton, et al., NIST NISTIR 5690 July 1995, page 4, paragraph 2.2.2 available at http://fire.nist.gov/bfrlpubs/build96/PDF/b96076.pdf

[3] Chloride Coefficient Thru Concrete --See Eq 3, "The influence of Chloride Binding on the Chloride Induced Corrosion Risk in Reinforced Concrete" by G.K. Glass, Corrosion Science 42 (2000) pg 329-344

[4] "Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal" by J.C.Walton, NUREG/CR--5542 T191 000576 -- Available at: http://www.osti.gov/bridge/servlets/purl/6548946/6548946.pdf

[5] - ASM Metals Handbook - Chpt 13B - Corrosion Performance of Zinc,

[6] From Article "Study on Cover Depth for Prestressed Concrete Bridges in Airborne-Chloride Environments" PCI Journal, March-April 2006, Pages 42-53

Conversion Units ==

$ipy = \frac{in}{yr}$ $mil = .001 \cdot in$ $mpy = \frac{mil}{yr}$ $\mu m = 10^{-6} \cdot m$ $\mu py = \frac{\mu m}{yr}$ $1 \cdot mpy = 25.4 \cdot \mu py$ $R_{gas} = 1.9872 \cdot \frac{cal}{mole}$

$ppm = \frac{1}{1000000}$ $ppb = \frac{1}{1000000000}$ $mdd = 1 \cdot \frac{mg}{(0.1 \cdot m)^2 \cdot day}$ <-- milligram/decimeter/day