CHAPTER TWO

GLASS STRUCTURE AND ITS RELATIONSHIP TO VITRIFICATION

Vitrification is attractive as a waste treatment process primarily because of the properties of glass. These properties give vitrification its high-quality product and flexibility in inorganic incorporation. Because an understanding of the properties of glass is fundamental to understanding the advantages of vitrification as a waste treatment process, this chapter offers a brief overview of glass structure and discusses how this structure relates to the durability of vitrified glass containing hazardous waste. This chapter is summarized mainly from McLellan and Shand (1984). Sections 2.3.3 and 2.3.4 are summarized from Wicks (1985, 1986). Because this chapter deals with the incorporation of inorganic contaminants into the glass structure, organic contaminants will not be addressed here.

2.1 Glass Structure

Glass is a rigid, noncrystalline material of relatively low porosity, often composed primarily of silica, alumina, and oxides of alkali and alkaline earth elements. While phosphate, sulfide, and oxynitride glasses are also important glass types, most glasses used in waste immobilization are silicate glasses. Therefore, this handbook limits its review to silicate glasses.

Thermally-formed glasses are produced by fusing or melting crystalline materials and/or amorphous materials (e.g., previously formed glasses) at elevated temperatures to produce liquids. These liquids are subsequently cooled to a rigid condition without crystallization. Most thermally-formed waste glasses, however, also have a crystalline phase. For example, while the ISV product is substantially glassy, it is actually a mixture of glass and microcrystalline phases. Glass composition is largely inorganic, with silica (SiO_2) being the most common constituent. From an engineering standpoint, what distinguishes glass from crystalline substances is the lack of a definite melting point temperature. When glass is heated, it will gradually deform and, at high enough temperatures, form a viscous liquid.

Silicate glasses are not composed of discrete molecules, but are three-dimensional networks. The basic structural unit of the silicate network is the silicon-oxygen tetrahedron in which a silicon atom is bonded to four oxygen atoms (Figure 2-1). The silica tetrahedra are linked at the corners, where each shares one oxygen atom with another tetrahedron (Figure 2-2). Some, or all four, of the oxygen atoms from the tetrahedron can be shared with other tetrahedra to form a three-dimensional network. What prevents these tetrahedra from forming a crystalline network is that the extended 3-dimensional network is irregular and the Si-O-Si bonds random (McLellan and Shand, 1984).

The shared oxygen atoms are called bridging oxygens. In pure silica glass, the ratio of silicon to oxygen is ideally 1:2 and all oxygen atoms are bridging. Some atoms, such as sodium, are ionically bonded to oxygen when present in

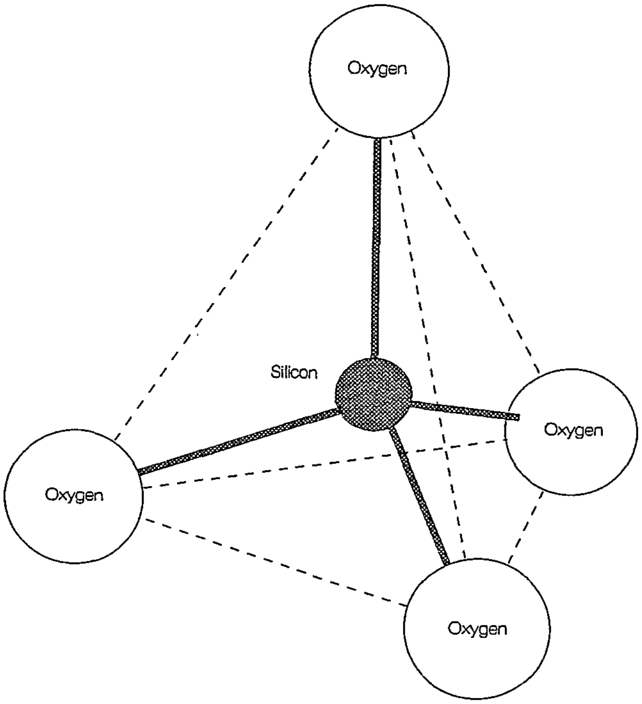

Figure 2-1. Silicon-Oxygen Tetrahedron (McLellan and Shand, 1984)

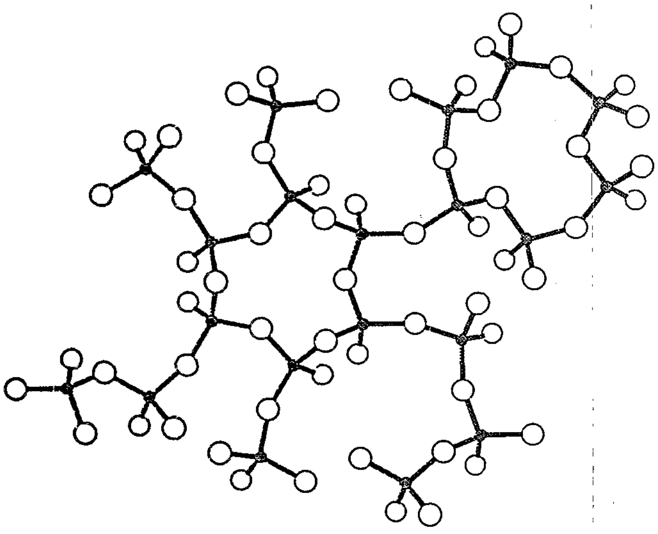

Figure 2-2. Example Silicate Glass Network Structure (McLellan and Shand, 1984)

glass and thus interrupt tetrahedra linking and the continuity of the network. An oxygen atom ionically bonded to another atom is called nonbridging.

Appreciable amounts of most inorganic oxides can be incorporated into silicate glasses. Elements that can replace silicon are called network formers. By replacing silicon in the glass network, some inorganic species (such as some metals found in the middle portion of the periodic table) can be incorporated into a glass. Most monovalent and divalent cations (such as sodium, calcium, and some other metals and metalloids grouped near either side of the periodic table) do not enter the network, but form ionic bonds with nonbridging oxygen atoms, and are termed network modifiers. The effect of variation in the network integrity and the constituents of the glass are manifested in changes in glass properties such as softening point temperature and chemical durability (i.e., leachability and solubility) (McLellan and Shand, 1984).

The role of elements in the glass may vary with conditions. For example, aluminum may be a network former or a modifier depending on the ratio of aluminum to alkali and alkaline earth ions and is thus called an intermediate. The role of iron depends on redox state or oxygen availability in the molten material. For example, Fe (III) is a network former (McLellan and Shand, 1984).

Because of the network structure of glasses, it does not help to express their composition as chemical formulae. The most common way of describing glass is to list relative amounts of oxides derived from the raw materials used in a glass formulation, even though these oxides do not exist, per se, in the glass network.

Many types of glass can be formed depending on the raw materials used. The glass industry prepares special formulations to obtain glasses with properties desirable for various uses. Important considerations for the treatment of hazardous wastes include processing characteristics, such as melt viscosity and redox conditions, and product characteristics, such as durability.

Vitreous silica, the simplest glass, can be prepared by heating silica (SiO_2) above its melting point and quickly cooling to the solid state. In order to decrease the viscosity of molten glass from that of pure silica and allow it to melt at a lower temperature, it is necessary to add a flux, or network modifier, that will soften the glass by generating nonbridging oxygen atoms. Alkali metals, such as sodium, make excellent fluxes in their oxide forms.

Alkalis can be incorporated into the glass as carbonates or other salts that react, at elevated temperatures, with silica to form a siliceous liquid. The reaction of fluxes is complex, but aside from lowering the viscosity of the glass, they also have the effect of lowering the melting point of the raw material mix. This helps decrease the energy requirements of the melting process.

Unfortunately, adding alkali to the glass generally decreases its chemical resistance from that of silica glass. At high alkali concentrations, the glass will even become water soluble (the basis for the soluble silicate industry). To decrease the aqueous solubility of alkali glasses, but to maintain the lower melting points, alkaline earth fluxes may also be used. Oxides of calcium and magnesium are the most common alkaline earth or stabilizing fluxes. However, adding too much calcium can cause calcium silicates and aluminates to form and these may crystallize (devitrify) on cooling.

Soda ash (sodium carbonate) is commonly used in industry to supply alkali fluxes, while lime (calcium oxide) is commonly added to supply alkaline earth fluxes. Thus, glass made from silica and alkali and alkaline earth fluxes is commonly called soda-lime glass. Soda-lime glass is the most common type of glass, and is used in most container glass and window glass applications. The typical composition of soda-lime glass is compared with the composition of two waste glasses in Table 2-1.

Typical raw materials for industrial glass making consist of various formulations of the following main ingredients:

- Sand - SiO_2
- Feldspar - $KAlSi_3O_8$

Table 2-1. Sample Compositions of Soda-Lime Glass, Borosilicate Glass, and ISV Glass

Oxide	Typical Soda-Lime Glass[1] (wt %)	SRS Borosilicate Benchmark Glass[2] (wt %)	Sample ISV Glass[3] (wt %)
SiO_2	65-75	48.95	71.20
Al_2O_3	1-2	3.67	13.50
Na_2O	12-16	16.71	1.55
K_2O	0.1-3	0.04	2.47
MgO	0.1-5	1.66	1.87
CaO	6-12	1.13	3.58
B_2O_3	-	11.12	-
Fe_2O_3	-	8.08	4.63
FeO	-	0.89	-
La_2O_3	-	0.41	-
Li_2O	-	4.28	-
MnO	-	1.34	0.11
NiO	-	0.61	0.12
TiO_2	-	0.71	0.76
ZrO_2	-	0.41	0.07
SrO	-	-	0.02
BaO	-	-	0.10

[1] From McLellan and Shand, 1984.
[2] From Goldston and Plodinec, 1991.
[3] This glass was produced by ISV of INEL soils. From Farnsworth, Oma, and Reimus, 1990.

- Dolomite - $CaMg(CO_3)_2$
- Limestone - $CaCO_3$
- Soda ash - Na_2CO_3

These are mixed with a variety of other constituents to produce glasses with whatever physical and chemical properties manufacturers may desire, such as heat resistance, chemical inertness, various optical properties, various colors, etc. The selection of materials from which to make a waste glass, on the other hand, generally involves compromises based on the product and processing characteristics desired.

While soda-lime glass may serve as a waste glass, many waste glasses are borosilicate glasses and contain B_2O_3. Waste glasses also generally contain less silica and more aluminum and iron than soda-lime glasses. Most soils and the ISV glass derived from their melting also have more aluminum and iron and less silica and sodium than typical soda-lime glass. The "aluminum-bearing glasses" are generally more typical of glass compositions produced in waste vitrification.

It is interesting to note that many metals of environmental concern are readily incorporated into a glass matrix and are commonly used as colorants in glassmaking. This suggests that vitrification processes may be particularly attractive for immobilizing metals found in certain waste streams. Table 2-2 presents a list of metal compounds commonly used as glass colorants.

2.2 Stabilizing Mechanisms

Hazardous constituents can be immobilized in vitrification processes by two main interactions with the glass matrix:

- Chemical bonding
- Encapsulation

Certain inorganic species can be immobilized by chemical bonding with the glass-forming materials, particularly silica, present in the wastes to be vitrified. The most notable chemical bonding within a vitrified material occurs when certain metals or other inorganics bond covalently with the oxygen atoms in a silica network and thus become part of the network. Inorganics that interact in this way are network formers since they essentially replace silicon in the glass network structure.

Other inorganic species can bond ionically with oxygen or other elements in the glass network. This ionic bonding incorporates the material into the glass but disrupts the network's continuity, thereby modifying the vitrified material's physical and chemical properties. As mentioned earlier, materials that interact in this fashion are called network modifiers.

Hazardous constituents may also be immobilized without direct chemical interaction with the glass network. Since vitrification constitutes a molten phase during some portion of the process, materials that do not interact chemically or have not completely entered solution can be surrounded by a layer of vitrified material and encapsulated, as the melt cools. This layer of vitrified material protects the encapsulated constituents from chemical attack and inhibits their ability to escape from the vitrified product (McLellan and Shand, 1984).

2.3 Chemical Attack Mechanisms

Vitreous materials are often thought of as being "inert," which is somewhat justified since these materials exhibit high corrosion resistance compared with many other materials. It is important to note, however, that all vitrified products are chemically reactive to some degree. This section discusses the nature of chemical attack on vitreous silicate materials and the factors that affect the rate and degree of attack.

There are two major forms of chemical attack on vitrified materials:

- Matrix dissolution
- Interdiffusion

2.3.1 Matrix Dissolution

Matrix dissolution is characterized by alkali attack. It begins by hydration of the silica network and may proceed to dissolution of the vitreous material. In pure silica glass, the matrix dissolution process can be described by the following equation:

$$2\,NaOH + SiO_2 \rightarrow Na_2SiO_3 + H_2O$$

The alkali silicate (Na_2SiO_3 in the example shown) is water soluble, so as the silica network is attacked and dissolved congruently, the other constituents in the vitrified material are released. The rate of alkali attack is generally linear with time; however, the rate can change if soluble materials accumulate in solution, or if insoluble reaction products adhere to the material's surface, blocking the reaction.

Table 2-2. Inorganic Colorants for Glass (Tooley, 1984)

	Color Produced	
Material	Under Oxidation	Under Reduction
Cadmium Sulfide	None	Yellow
Cadmium Sulfide, Selenium	None	Ruby
Cobalt Oxide	Blue-violet	Blue-violet
Copper Oxide	Greenish blue	Greenish blue
Cuprous Oxide	Greenish blue	Ruby
Cerium Oxide	Titania Yellow	Yellow
Chromic Oxide	Yellowish green	Emerald green
Gold	Ruby	
Iron Oxide	Yellowish green	Bluish green
Manganese dioxide	Amethyst to purple	None
Neodymium oxide	Violet	Violet
Nickel oxide	Violet in K_2O glass	Violet in K_2O glass
Nickel oxide	Brown in Na_2O glass	Brown in Na_2O glass
Selenium	Fugitive	Pink
Sulfur	None	Yellow to amber
Uranium	Yellow with green fluorescence	Green with fluorescence

Alkali attack is highly pH dependent. The rate of attack generally increases by a factor of 2 to 3 for each pH unit increase. The influence of temperature on the rate of alkali attack follows an Arrhenius relationship with the rate of attack increasing by a factor of 2 to 2.5 for each 10° C temperature rise.

2.3.2 Interdiffusion

Interdiffusion is typified by acid attack on vitrified materials. While alkali attack (matrix dissolution) leads to surface dissolution of the vitreous material, interdiffusion is an ion exchange process which preferentially extracts elements present as network modifiers, leaving the silica structure almost intact. Generally, interdiffusion involves the exchange of hydronium ions in solution for ionically bonded elements in the vitreous network (McLellan and Shand, 1984).

Interdiffusion has sometimes been called leaching, but interdiffusion is the more precise term. "Leaching" is commonly used to denote loss of constituents from a material without specifying a mechanism. As used here, interdiffusion is a mechanism; thus, to call it "leaching" is confusing.

The reaction rate in interdiffusion is influenced by temperature in a relationship similar to that for alkali attack; however, the interdiffusion reaction rate increases only by a factor of 1.5 to 2 for each 10°C temperature rise.

Depending on the composition of the vitrified material, especially its silica content, the pH of the leaching solution influences the rate of acid attack. Generally, that influence is not as strong as the influence on the rate of alkali attack.

The rate of acid attack on glass is generally proportional to the square root of time. Since the process is controlled predominantly by diffusion, the rate of leaching decreases as the thickness of the leached layer near the glass surface increases. However, this effect can be limited if the layer dissolves or sloughs off.

The leachability of trace constituents is difficult to predict, but it is reasonable to assume that in addition to the alkali and alkaline earth elements (sodium, potassium, calcium) there may be preferential extraction of other network modifiers of potential environmental concern, such as: barium (Ba), beryllium (Be), cobalt (Co), copper (Cu), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), silver (Ag), strontium (Sr), and zinc (Zn).

Water attacks vitrified materials to some degree, although the attack is much less aggressive than that of alkali and is generally less vigorous than acid attack. Water can exhibit both acid and alkali attack mechanisms since it can produce both hydronium and hydroxyl ions. However, in a static environment water attack quickly becomes alkali attack as the alkali present in the glass is extracted into the water and then takes part in the reaction.

Attack by salt solutions is thought to correspond to the attack by water, but the mechanism has not been thoroughly defined. However, typical attack rates at room temperature are still very low. Many chelating compounds attack glasses at a rate comparable to that of strong alkali. Citrate, gluconate, oxalate, tartrate, EDTA, and malate all attack glass in alkaline solution. Alkaline phosphate and acetate also attack glass readily. Hydrofluoric acid has a unique ability to dissolve silicate glasses, forming a solution of alkali fluorides and silicon fluorides.

2.3.3 Three -Stage Model of Waste Glass Corrosion

While dissolution and interdiffusion describe leaching under many conditions, the leaching of many waste glasses appears to be modified by the formation of surface gel layers (Wicks, 1985). Layer formation is favored in static or near-static conditions and where silica is present, as in many groundwaters. As matrix dissolution occurs, the surface layers, composed of insoluble glass components, arise. The formation of these layers proceeds in a three-stage process.

Stage one is dominated by interdiffusion as network modifiers, such as sodium, diffuse out of the glass and into solution, and water diffuses in. The result is a modifier- deficient surface layer. During this stage the pH of the leachant increases (becomes more basic), because alkali hydroxides form in solution.

Stage two is dominated by matrix dissolution. As described earlier, matrix dissolution is an alkaline attack; thus, its rate is primarily governed by the pH of the leachate, glass composition, and temperature.

Stage three is characterized by the formation of surface layers. These surface layers are formed from the precipitation and adsorption of insoluble compounds onto the surface of the glass. These compounds are the more insoluble waste glass constituents that are "left behind" as more soluble constituents dissolve and move into solutions. For example, these surface layers may contain substantial iron and manganese hydroxides. Where a surface layer forms, it can exert a strong limiting effect on leaching of the waste glass underneath. Under static or near-static conditions, leaching may be reduced further as silica concentrations build up in the leachate and approach saturation, thus reducing even more the tendency of silica in the glass to move into solution.

2.3.4 Factors Impacting Waste Glass Leaching

The use of vitrification to treat HLW has produced a wealth of knowledge about waste glasses and their production, particularly in terms of chemical composition, waste loading, temperature, time and pH.

Chemical Composition. Chemical composition plays an important role in product durability (Wicks, 1985). In general, as the ratio of oxygen to network formers (such as silicon) decreases, more bridging oxygens are produced, resulting in a more durable product. Network modifiers such as alkalis and alkali earth oxides tend to decrease glass durability. This occurs because these oxides increase the oxygen-to-network former ratio and produce more singly-bonded oxygen, thus breaking up the glass network. However, these elements do lower melt viscosity and lower processing temperatures and therefore have potential as fluxing agents. In general, oxides with valences greater than 1 may increase glass durability.

Composition of the incoming feed can have enormous effects on product durability and processing parameters. Table 2-3 displays some of the effects of various inorganic oxides on processing and glass durability. Modification of the waste stream through additives and/or material removal can have dramatic impacts on processing and product characteristics. However, as Table 2-3 shows, most additives have both desired and undesired effects. Therefore, modification of the feed will often involve compromises based on treatment goals, processing limitations, and waste character.

Waste Loading. Increased waste loading does not necessarily increase product leachability (Wicks, 1985; Mendel, 1973). Research on borosilicate glass for the immobilization of nuclear waste has indicated that glass leachability is reduced as the waste loading increases from 0 wt% to 35 wt%, with only small changes in leachability as the waste loading increases from 35 wt% to 50 wt% (Rankin and Wicks, 1983). Thus, the amount of waste immobilized by borosilicate glass may not be limited by product durability, but by processing considerations. The reason for the beneficial effects of increased waste loading on durability is due to the formation of surface layers that form during leaching and that are made up of the major constituents found in the waste composition.

Temperature. Leachability of waste glass increases with temperature (Wicks, 1985). The mechanism of corrosion varies with temperature: at temperatures near ambient conditions, diffusion effects can dominate glass corrosion, but at temperatures near 100°C or higher, network dissolution can dominate. The exact temperature for the shift in mechanism varies with test conditions and glass composition.

Time. At a given temperature, the largest leach rates occur during the early stages of leaching (Wicks, 1985). Therefore, leach rates usually decrease over time. Two mechanisms appear to be involved in this leach rate decrease. First, under static or near static conditions, such as groundwater in proposed repositories, the solution becomes saturated as elements are extracted from the glass and enter solution. Increased saturation reduces the solution's solubility and its ability to corrode the glass. Secondly, with time, a layer forms on the glass's surface, thereby further inhibiting leaching (Jantzen, 1988).

pH. In solutions of about pH 3 to 9, glass leaching may be substantially or minimally affected by solution pH, depending on the chemical composition of the glass (Wicks, 1985). At pH values above 9 (basic conditions), two mechanisms function to increase leaching: silica solubility increases and matrix dissolution dominates. The effect of acidic conditions on glasses varies more than the effect of basic conditions. Most silicate glasses are dominated by interdiffusion at low pH values. For these glasses, leach rates are proportional to the square root of time and the effect of low pH values is small. However, borosilicate glasses are dominated by matrix dissolution at low pH values. Their leach rate increases linearly with time and the effect of acid attack (below pH 5) may be quite dramatic. Thus, the expected pH of the disposal site or use location may be important in determining the desired composition of the waste glass.

secondary combustion chamber. For example, in Retech's plasma heat process, combustion takes place primarily in a secondary combustion chamber adjacent to the centrifugal furnace (Eschenbach, Hill, and Sears, 1989). Organic contaminants that fail to pyrolyze or combust must be removed by the off-gas treatment system.

Pyrolysis destroys not only organics, but asbestos as well. In the melt, asbestos breaks down into its constituent groups (atoms or molecules), and these constituents are incorporated into the waste glass or removed by the off-gas system.

Metals (including radioactive metals) are not destroyed but are immobilized in the solidified glass or metal slag or are vaporized. Immobilization may occur when the contaminant is incorporated into the glass network or encapsulated (or surrounded) by the glass. These two immobilization processes also prevent some radioactive decay products from escaping into the environment. The off-gas treatment system should be designed to capture vaporized inorganics.

During ISV treatment, contaminants may migrate along three different pathways. The first pathway occurs when vitrification fails to either destroy or immobilize the contaminant and the contaminant subsequently passes through the off-gas system without being removed. The second pathway is the movement of contaminants into uncontaminated, adjacent soil during ISV. The existence and importance of this pathway are debated at present. Finally, contaminants may also migrate during excavation, transportation, pre-treatment, and other steps demanding handling of the contaminated material. Contaminant migration during material handling is a common concern for all ex situ treatments, vitrification as well as non-vitrification treatments, and so will not be addressed in this document.

Following is a discussion of the applicability of vitrification to metal and radioactive inorganics, non-metal inorganics, and organics.

4.2.1 Metal and Radioactive Inorganic Contaminants

Metals are not destroyed during vitrification; therefore, there are only three possible pathways for metals during treatment: (1) removal in the off-gas treatment, (2) chemical and/or physical immobilization in the glass product or metal precipitate, (3) escape into the environment.

Depending on treatment goals, chemical and/or physical immobilization is generally preferred to off-gas treatment. But when vitrification fails to incorporate metals into the melt, they must be removed by the off-gas system and receive additional treatment as secondary wastes. However, it is sometimes desirable not to chemically or physically immobilize metals in the vitrification process. For example, mercury is removed during pre-treatment prior to HLW vitrification at the SRS DWPF. Or, if recovery of the metals is a concern, the metals may be recovered from the off-gas system and thus reused. In this scenario, non-incorporation in the melt and removal by the off-gas system would be preferred. Recovery of mercury in this way is being explored by the Department of Defense (DOD) for remediation of the M-1 holding ponds at the Rocky Mountain Arsenal, Colorado.

Retention efficiencies vary with type of metal; different metal oxides will have different solubility limits in glass. The solubility limits of most metal oxides and salts in glass can be found in the *Handbook of Glass Manufacture* (Tooley, 1984) and other documents on glass production. Oxides for which extensive solubility information is available are: alumina, antimony oxide, arsenic oxides, barium oxide, cadmium oxide, chromium oxide, copper oxides, cobalt oxides, iron oxides, lead oxides, manganese oxides, nickel oxides, selenium oxides, tin oxides, and zinc oxides (USEPA, 1990a). Waste glass will retain metals with varying efficiency depending on the type of vitrification process used and its operating parameters. These limits will also be influenced by other metals in the waste and the chemical composition of the glass. Table 4-1 presents measured solubilities of elements in silicate waste glass. These values should be read very generally due to the multitude of processing variations which can affect element solubility.

Data for retention efficiencies of selected metals by ISV is presented in Table 4-2. ISV is not as amenable as other vitrification types to manipulation of operating parameters and so its retention factors give a rough estimate of difficult metals. For that reason, the data presented in this

Table 4-1. Approximate Solubility of Elements in Silicate Glasses (adapted from Volf, 1984)

less than 0.1 wt%:	Ag, Ar, Au, Br, H, He, Hg, I, Kr, N, Ne, Pd, Pt, Rh, Rn, Ru, Xe
between 1 and 3 wt%:	As, C, Cl, Cr, S, Sb, Se, Sn, Tc, Te
between 3 and 5 wt%:	Bi, Co, Cu, Mn, Mo, Ni, Ti
between 5 and 15 wt%:	Ce, F, Gd, La, Nd, Pr, Th, B, Ge
between 15 and 25 wt%:	Al, B, Ba, Ca, Cs, Fe, Fr, K, Li, Mg, Na, Ra, Rb, Sr, U, Zn
greater than 25 wt%:	P, Pb, Si

Table 4-2. Metals Retention Efficiency Test Results for ISV (Hansen, 1991)

Class	Metal		Retention Efficiency, % [a]	Scale[b]
Volatile	Mercury	(Hg)	0	Engineering
Semi-Volatile	Arsenic	(As)	70-85	Engineering
	Cadmium	(Cd)	67-75	Pilot
	Cesium	(Cs)	99-99.9	Pilot
	Lead	(Pb)	90-99	Pilot
	Ruthenium	(Ru)	99.8	Pilot
	Antimony	(Sb)	96.7-99.9	Pilot
	Tellerium	(Te)	50-99	Pilot
Non-Volatile	Americium	(Am)	99.99	Pilot
	Barium	(Ba)	99.9	Engineering
	Cerium	(Ce)	98.9-99.9	Pilot
	Cobalt	(Co)	98.7-99.8	Pilot
	Copper	(Cu)	90-99	Engineering
	Chromium	(Cr)	99.9	Engineering
	Lanthanum	(La)	98.9-99.98	Pilot
	Molybdenum	(Mo)	99.9-99.999	Pilot
	Neodymium	(Nd)	99-99.98	Pilot
	Nickel	(Ni)	99.9	Engineering
	Plutonium	(Pu)	99.99	Pilot
	Radium	(Ra)	99.9	Engineering
	Strontium	(Sr)	99.9-99.998	Pilot
	Thorium	(Th)	99.99	Engineering
	Uranium	(Th)	99.99	Engineering
	Zinc	(Zn)	90-99	Engineering

(a) Percentage of original amount remaining in the melt.

(b) Engineering-scale tests involve a melt depth of 1-2 ft. Pilot-scale tests involve a melt depth of 3-7 ft.

table should not be regarded as precise measurements of expected retention efficiencies. Table 4-2 also shows how metals can be divided based on tendency to volatilize.

4.2.1.1 Increasing the Retention of Metals

Retention of metals, if that is the treatment goal, may be increased by a number of mechanisms. These include:

- Reduction of generated gas
- Presence of a cold cap
- Recycling volatilized metals
- Decreasing melt temperature
- Modification of melt composition through additives

Reduction of Generated Gases. Gases evolved during vitrification can help carry metal particles and vapors to the surface. Greater gas evolution results in a more rapid movement to the surface, decreased exposure of the metals to the melt, and thus, decreased probability of the metals dissolving in the melt. Because the burning of combustibles during vitrification produces increased quantities of gas, gas-assisted movement of contaminants to the melt surface is one reason that combustibles are of concern during vitrification (see Chapter Seven).