

are common in those areas, such as along the Gulf Coast, where only lightly consolidated or unconsolidated sands are the disposal zones. These wells employ gravel-packed screen sections and are generally similar to large-capacity water wells in design. Other openhole completions are made in those areas where the disposal zones are in competent rocks, such as limestone, dolomite, and sandstone, and do not require casing. In places where the disposal liquid may attack the cementation of a sandstone or adversely affect a limestone or dolomite, casing is required for the full depth of the hole. Casing may be either of plastic materials or some of the more costly metals, such as stainless steel, Hastelloy, Carpenter 20, or zirconium.

Tubing and packer requirements vary depending on the nature of the waste stream. Lined tubing is required in almost all wells to avoid excess corrosion. Tubing lining may be either sprayed-on plastic or thin-gage metallic alloys swaged to the base metal. Packers must be made of the same materials as the tubing to insure longevity. Some wells employ hydraulic seals rather than packers. This is a good installation if injection is always under pressure.

Detailed designs of each type of injection well are shown, and in every case, safety of the installation is a paramount consideration.

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WATER-MINERAL REACTIONS

Reinjection of formation waters creates few chemical problems if no large change in temperature has occurred, no gas or vapor has separated, access of air has been prevented, and the fluids have had an opportunity to react with the minerals to the point of compatibility. Injection of incompatible fluids may cause chemical problems. There is a need for prediction of fluid-mineral reactions.

Most geochemists who have worked on mineral-fluid reactions have had inadequate data and have been reduced to assuming reaction states. The state most geochemists have assumed is one of equilibrium because it is uniquely defined and readily calculable. In an effort to test the applicability of an equilibrium model under real geologic conditions, real systems have been studied. Systems are chosen where reactions are known to occur and where the reactant minerals and fluids and product minerals and fluids can be identified and analyzed. Very seldom have stable equilibrium (minimum Gibbs free energy) conditions been found, although in some instances metastable equilibrium conditions have been found. The assumption of a stable equilibrium state is a very poor choice of model, especially at temperatures of 100°C and below.

The general lack of attainment of equilibrium in no way impairs prediction of reactions, however. Admittedly there is no *a priori* thermodynamic method of predicting what phase will react, nor can the necessary departures from equilibrium be predicted before a reaction will occur at a significant rate, because thermodynamic arguments are time-independent. However, in geologic systems now accessible, enough reactions are occurring that, by observation, an empirical knowledge will provide a base for predicting reactions.

The equations used for describing reaction states are

$$\Delta G_R = RT \ln(Q/K)$$

and

$$\Delta G_R = nF (Eh_{eq} - Eh_m)$$

where

ΔG_R is the Gibbs free energy of the reaction

R is the gas constant

T is the temperature in degrees Kelvin

Q is the reaction quotient

K is the equilibrium constant

n is the number of electrons in redox reactions

F is the volt-gram equivalent

Eh_{eq} is the Eh that would be measured if the reaction were at equilibrium

Eh_m is the measured Eh .

ΔG_R is the exact statement of the departure from equilibrium for the reaction of interest.

Reactions should be studied in both reaction directions. Most reactions are asymmetric in that the ΔG_R 's required to dissolve most phases are of different values than the ΔG_R 's necessary to form the mineral from solution. The reactions should all be treated as congruent reactions. All the species in solution generated by complete solution of the solid must be considered. Using incongruent reactions introduces the unwarranted assumption of equilibrium.

Some generalizations about the result can be made. Small, highly charged cations yield hydrous metastable phases ($Fe(OH)_3$, amorphous silica) or a stable phase ($Mg(OH)_2$) at very slight supersaturations. Subsequent dehydration is very sluggish. Simple anhydrous carbonates require greater departures from equilibrium for precipitation to occur, but dissolve fairly readily. Simple anhydrous silicates dissolve with modest unsaturation but the hydrous crystalline silicates require large supersaturations for precipitation. Sulfide minerals, although they may dissolve with oxidation of the sulfur to SO_4^{2-} , do not form except with enormous supersaturations. The problem is probably with the bisulfide ion. Siderite requires much less departure from equilibrium than pyrite for precipitation, yet both have Fe^{2+} as the cation.

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DEEP DISPOSAL SYSTEMS FOR RADIOACTIVE WASTES

As of July 1, 1971, approximately 100 million kilowatts of nuclear power-plant capacity was in operation or under construction and/or contract. During the 1960s, an extensive research, development, and demonstration program was carried out on the treatment and disposal of all types of gaseous, liquid, and solid radioactive wastes. Geochemical research coupled with extensive field exploration and demonstration studies have been carried out on several deep disposal systems for radioactive wastes including the application of hydrofracturing techniques in bedded shale for low-heat producing wastes and the use of bedded salt and crystalline bedrock for highly radioactive wastes.

The Atomic Energy Commission has adopted a regulatory policy which requires that all high-level liquid wastes from licensed irradiated fuel reprocessing plants must be solidified and shipped to a national repository on land owned and controlled by the Federal Government. A tentative selection of a site near Lyons, Kansas, has been made for an initial salt-mine repository for the demonstration of long-term storage for both solid high-level and long-lived *alpha*-contaminated wastes.

Because of a general requirement for adequate monitoring to assure the safe and effective operation of a