TECHNICAL FACTORS INVOLVED WITH THE DEMONSTRATION OF NO-MIGRATION TO SUPPORT LAND BAN EXEMPTION PETITIONS

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OBJECTIVES

- Class I hazardous wells and Land Ban Exemption Petition overview
- Parameters required to assess impacts of injection and constituent migration
- Projection of pressure buildup due to injection
- Lateral and vertical plume migration projections
- Summary and Questions
LAND BAN EXEMPTION PETITION OVERVIEW

- Injection of hazardous waste into Class I wells requires the USEPA to issue an exemption to the ban on the land disposal of hazardous wastes.

- Requires a Petition to USEPA demonstrating that to a reasonable degree of certainty, there will be “No Migration” of hazardous constituents from the injection zone for as long as the waste remains hazardous (40 CFR 148.20 Subpart C), and no endangerment of human health or the environment.

- Geologic characterizations of the Injection Zone (Injection Interval and Arrestment Interval), as well as the Confining Zones, are required to demonstrate “No Migration”.

- Site and operating conditions and waste properties are such that injected fluids will be rendered non-hazardous in-situ, or will not migrate within 10,000 years:
  - Vertically upward out of the Injection Zone (Arrestment and Injection Intervals); or
  - Laterally to a point of discharge out of the authorized Injection Zone.
Key components include geologic/hydrogeologic characterization of the Injection Zone and Confining Zones (thickness and depths, porosity, permeability, lateral continuity).

Properties of waste stream and formation brine; operational rate/volume and well lifespan.

Relative to Class I non-hazardous and Class II wells, additional factors must be determined, such as:

- Geologic dip
- Vertical permeability (Arrestment Interval and Confining Zone)
- Reservoir heterogeneity and dispersivity
- Formation brine and waste density and viscosity
- Waste constituent diffusion coefficients
- Regional background hydraulic gradient
Boundaries are projected beyond which the injected waste will not migrate, based on worst-case (conservative) modeling scenarios conducted to evaluate confinement of waste within the Injection Zone for 10,000 years.

Analytical or numerical modeling of pressure impacts from injection and plume migration distances are required to demonstrate “No Migration.”

Pressure transient evaluation includes injection rates/volumes, well life, and critical pressure rise.

“No-Migration” boundaries are based on concentration reduction factors (dilution) to Health-Based Limits (HBL) for hazardous waste constituents.
LAND BAN EXEMPTION PETITION OVERVIEW

Confining Zone

Arrestment Interval

Injection Interval

Injection Zone

Confining Zone
Unique component of Class I hazardous well Land Ban Exemption Petitions is that it predicts where the waste will not reach to define the “No Migration” boundaries.

Conservative scenarios utilized to demonstrate fluid containment in the authorized Injection Zone.
TECHNICAL FACTORS ASSOCIATED WITH PETITION

- Geologic characterization of the Injection Zone (comprised of the Injection and Arrestment Intervals) and Confining Zones, including thickness, lateral continuity, porosity, and permeability
- Structural geology of zones of interest, presence of faults and/or fractures, and geologic dip
- Hydrogeologic evaluation of water quality in the Injection Zone, identification of lowermost USDW, local/regional flow gradient
Reservoir pressure buildup and plume migration modeling evaluated via analytical or numerical methods.

- Requires information regarding depths, net thicknesses, porosity, permeability, temperature, original reservoir pressure, formation and total compressibility, structural dip, and lateral continuity.

- “Worst-case” Arrestment Interval properties.

- Offset pressure sinks (production) and/or sources (injection), and boundaries (e.g., faults or stratigraphic pinchouts).
MODELING

- Formation brine and waste stream properties (specific gravity, density, viscosity, compressibility)
- Dispersion and constituent diffusion coefficients
- Evaluate health-based limit ($C_{HBL}$) and maximum wellhead concentration ($C_O$) of waste constituents
- EPA Land Ban Health Based Limit Guidelines assign values, or may use detection limit (DL)
- Assess worst-case concentration reduction factor (lowest $C/C_O$, where $C = C_{HBL}$ for waste constituent) to define plume (i.e., constituent requiring highest dilution)
- Data precision is very important for 10,000 year projections
MODELING OF PRESSURE RISE FROM INJECTION

- Modeling of pressure transient conditions required to assess the impacts of injection and protect USDWs
- Identify and incorporate potential pressure sinks (hydrocarbon production) or sources (offset injection) in the Injection Interval, and boundary conditions
- Evaluate critical pressure rise ($P_c$), including potential vertical migration through abandoned boreholes
- Cone-of-endangering influence (COEI) bounds the area within which pressure increases due to injection could force subsurface brines or injected waste into the lowermost USDW (e.g., oil and gas wells, fault)
MODELING OF PRESSURE RISE FROM INJECTION

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Wellbore Flowing Pressure

Large Critical Pressure, $P_c$

COI Radius (Large $P_c$ Example)

COI Radius (Small $P_c$ Example)

Pressure Increases

Radius Increases

0

Small Critical Pressure, $P_c$

Large $P_c$, Small COI

Small $P_c$, Large COI
Critical Pressure (Pc) calculation assuming hypothetical open borehole between injection zone and lowermost USDW

- \[ P_c = 0.433 \text{ psi/ft} \left[ \gamma_B D_B + \gamma_W (D_W - L) \right] - P_o \]

- Assuming relatively dense brine (1.15 g/cm\(^3\)), and fresh water (1.0 g/cm\(^3\)), a significant distance between USDW (depth 300 ft, water level = 50 ft) and Inj zone (\(D_x = 5,000\) feet); \(P_o = (0.46 \text{ psi/ft} \times D_x)\)

- \[ P_c = 0.433 \left[ 1.15 (5,000' - 300') + 1.0 (300' - 50') \right] - 2,300 \text{ psi} \]

- \(P_c = 149\) psi
CRITICAL PRESSURE RISE

Hydrostatic Pressure of Mud-Filled Borehole:

\[ P_m = \left( \frac{\rho_{mud}}{\rho_w} \right) \times 0.433 \text{ psi/ft} \times D_m \] (not including gel strength)

\[ P_c = P_m - P_o \]

Assuming depth of mud \( D_m \) = 8,000 ft; \( \rho_{mud} = 9.0 \) lb/gal, \( \rho_w = 8.34 \) lb/gal, original reservoir gradient of 0.44 psi/ft \( (P_o = 8,000' \times 0.44 \text{ psi/ft} = 3,520 \text{ psi}) \)

\[ P_c = \left[ \frac{9.0}{8.34} \times 0.433 \times 8,000 \right] - 3,520 \text{ psi} = 3,738 \text{ psi} - 3,520 \text{ psi} = 218 \text{ psi} \]

Evaluate reservoir pressure rise at this well location to assess vertical pathway potential (may also conservatively subtract mud fallback in borehole)

Plume migration influenced by natural regional hydraulic gradient, reservoir geometry, offset pressure sinks and sources, fluid dispersion and diffusion, density differences between waste and brine, and reservoir pressure increase due to injection.

Dispersion is smearing of waste front due to advective movement of fluid, and diffusion is smearing due to Brownian motion of molecules.

- Dispersion is dominant over short periods of time during injection.
- Diffusion is dominant for projecting vertical migration over 10,000 years and determines whether there is sufficient thickness of Arrestment Interval.
Numerical or analytical modeling required for demonstration of No-Migration Petition

Modeling of lateral plume movement must incorporate temperature and density differences

**SWIFT (Sandia Waste Isolation Flow and Transport)** numerical model is one example of a model historically used and accepted by USEPA

- Transient, 3D, finite-difference model that simulates flow and transport (diffusion/kinematic dispersion) of fluid, solutes, and thermal energy in porous or fractured media

- Can incorporate spatial variations in reservoir properties and confinement, as well as temperature/concentration dependent fluid properties (e.g., density and viscosity)
Combination of modeling methods is common, especially for operational lifetime vs. 10,000-year timeframes, or lateral vs. vertical migration projections.

Required to assess post-operational plume migration for period of 10,000 years.

Plume front defined by Health Based Limit concentrations ($C_{HBL}$).

- Initial concentration ($C_o$) typically defines maximum constituent value.
- Plume edges are often shown as $C/C_o$ ratios (dilution ratio).
- Determine smallest reduction factor; i.e., identify the constituent requiring largest dilution to meet the HBL value.
Evaluate vertical migration through the rock matrix of the Arrestment Interval, or migration up a hypothetical borehole (if applicable).

Vertical movement in Arrestment Interval possible due to advective transport (dispersion) in response to pressure buildup, which is dominant during operational and short-term post-operational time.

Diffusion is based on molecular motion of waste constituents due to concentration gradients, and generally only important over longer time periods.
Dispersion reflects the fact that different pathways result in different flow vectors, resulting in a net spreading of the solute plume.
Various studies indicate that advective dispersion is scale dependent; i.e., dispersivity is larger over greater distances.

On a large-scale (reservoir), differences in dispersion are generally due to differences in hydraulic conductivity (K) and the larger the variability of K, the greater the dispersion, and this increases with travel distance.

Need some “ballpark” of plume distance to assign dispersivity values.

In general, dispersion ($\alpha$) can be defined by travel distance (L) and some coefficient (a) and exponent (x):

- $\alpha = aL^x$ or $\alpha = a(\log L)^x$
Diffusion is due to molecular motion of waste constituents due to concentration gradients.
For the most conservative scenario of vertical migration, identify the highest $C_O/C_{HBL}$ waste constituent (requiring highest dilution), combined with the largest constituent diffusion coefficient.

May result in larger vertical diffusion distance than would be calculated otherwise.

Diffusion coefficient is temperature dependent, and is dependent on molecular size and shape.
Viscosity is dependent on temperature and specific gravity (density).
Structural dip and the relative density differences between waste and formation brine impact long-term (10,000-year) plume migration.
SUMMARY

- Land Ban Exemption Petitions for Class I hazardous wells involve very detailed geologic and reservoir characterization to make conservative projections of pressure and injectate migration over operational lifetime and 10,000-year post-operational timeframe to demonstrate “No Migration.”

- Modeling that can incorporate these additional parameters is required and must account for the interrelated nature of many of these parameters.

- Philosophically, projections are made to show where waste will not reach, rather than projecting actual fluid movement.