Deep-Well Injection of Liquid Radioactive Wastes

“Come, come!” I cried, dragging my uncle along; for the first time, he made no resistance to my wishes.”

—Henry Lawson in “Journey to the Center of the Earth” by Jules Verne.

Definitions

Deep-well injection is the controlled emplacement of liquid wastes into geological reservoirs that are below a Underground Source of Drinking Water (USDW) which is defined as an "aquifer which supplies any public water system, or contains less than 10,000 mg/L total dissolved solids [TDS].” TDS is a measure of salinity (water quality).

GROUNDWATER PROTECTION COUNCIL

Deep-well injection is not a new idea.

We inject:

Industrial wastewater.

RCRA-defined liquid hazardous wastes.

Oil-field brines.

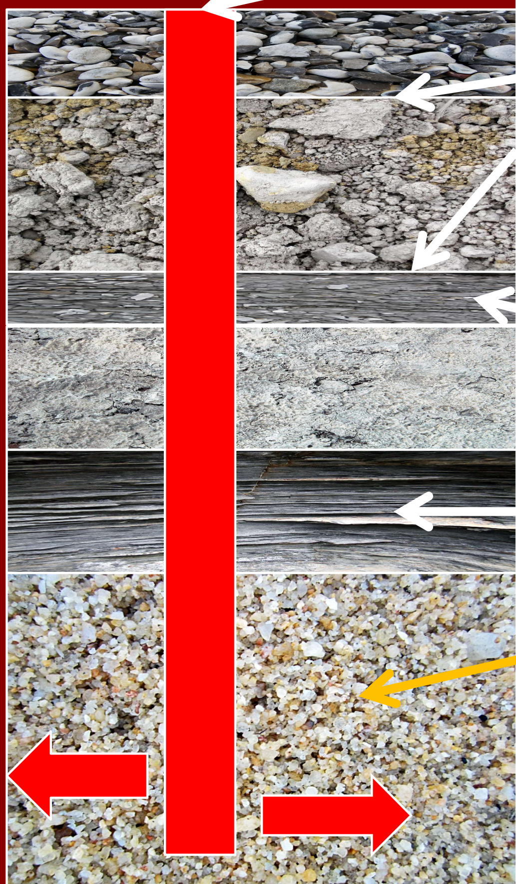
Natural gas storage

Compressed-air storage

Carbon dioxide (sequestration)

What about liquid radioactive wastes such as reprocessing raffinate or low-level liquid wastes?

Basics of deep-well injection/disposal



Surface. Wastes are pumped down into the well.

Top of the saturation zone (fresh water)

Lower most underground source of drinking water (USDW)

Secondary seal or impermeable layer.

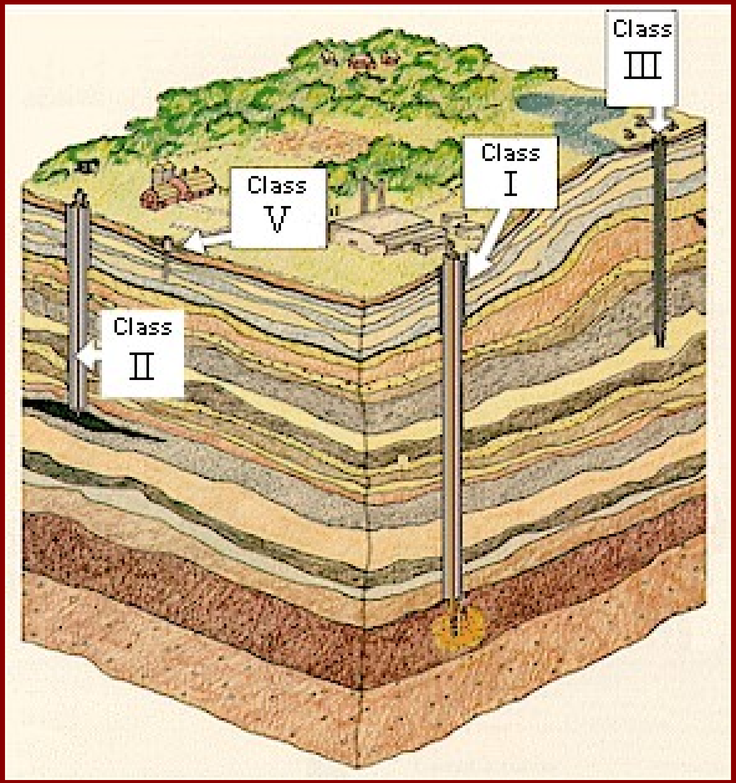
Primary seal or impermeable layer.

Injection formation or zone.
Sandstone or porous limestone.
Saturated with saline brine.

Five classes of wells (U.S. EPA)

Class I	Wells injecting hazardous or non-hazardous waste below the lowest Underground Source of Drinking Water (USDW). Class I wells are commonly referred to as the deep wells. Presently there are four Class I wells operating in Illinois.
Class II	Wells injecting fluids associated with production, storage and recovery of oil and natural gas. In Illinois the Class II Program is administered by the Illinois Department of Natural Resources, Office of Mines and Minerals.
Class III	Wells used to extract minerals following the injection of fluids into an ore bed such as uranium. No Class III wells exist in Illinois.
Class IV	Wells used to inject hazardous waste into or above a USDW. Class IV wells are banned by regulation.
Class V	Wells used to inject non-hazardous waste into or above a USDW. Class V wells are commonly referred to as the shallow wells. This is the largest class of injection wells with over 6000 Class V wells in Illinois alone.

Class 1 Wells



Class 1 well are the deepest.

Class 1 wells and the U.S. EPA: http://water.epa.gov/type/groundwater/uic/wells_class1.cfm

Class I Facilities in Illinois

Please contact the Illinois Environmental Protection Agency (IEPA) for more detailed information about these wells.

Active Industrial Injection Wells in Illinois

Facility	County	H or NH*	Well Name	Depth (ft)	Year Drilled	Injection Formation
Cabot Corp.	Douglas	H	Well #2	5318	1966	Potosi, Eminence
		H	Well #3	5300	1975	
Equistar Chemicals	Douglas	NH	WDW #1	5524	1970	Oneata, Eminence, Potosi, Franconia
ArcelorMittal Hennepin (formerly LTV Steel Co.)	Putnam	H	Well #1	4868	1967	Mt. Simon

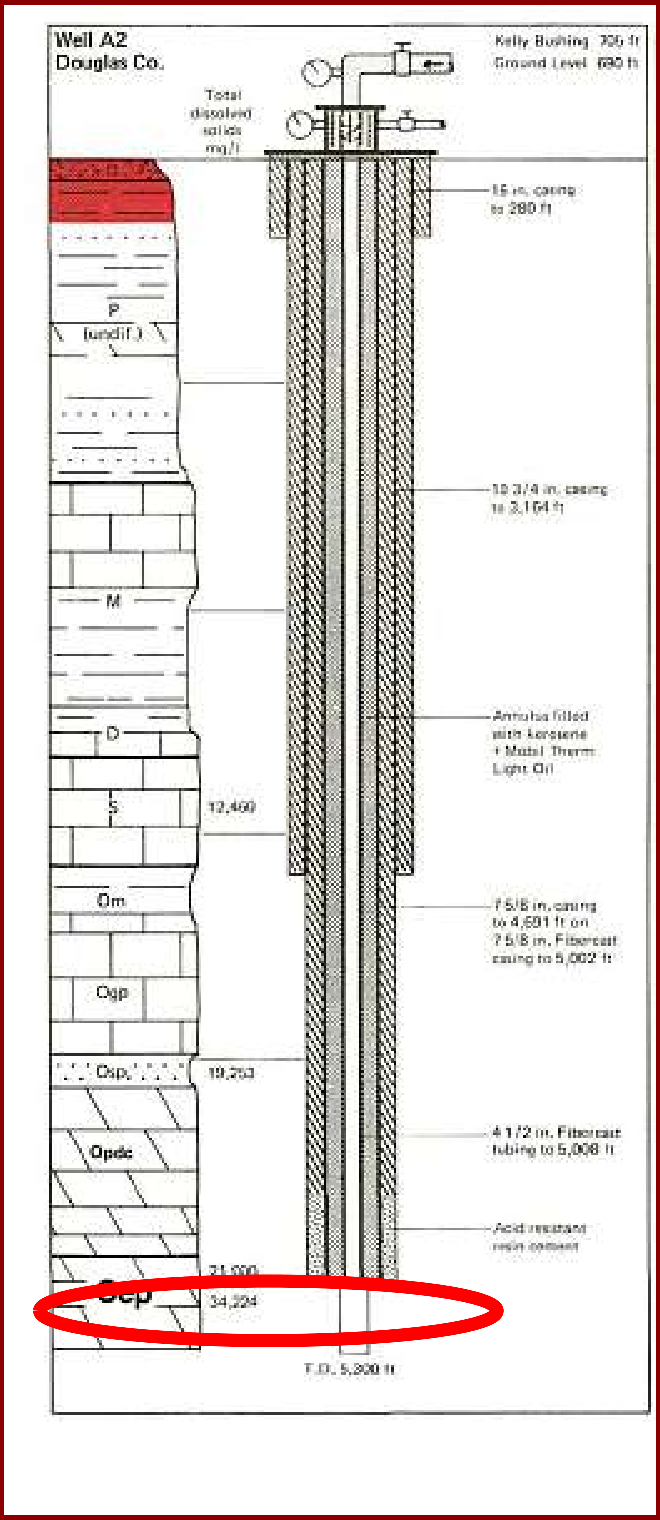
*H = Hazardous, NH = Non-Hazardous

Cabot Corp. Injection Wells

Near Tuscola, Illinois
An acidic, inorganic liquid waste that is a by-product of the production of food-grade amorphous silica.
Injected into the Potosi Dolomite (a calcium, magnesium carbonate)
Waste contains 0.09% HCl

Cabot injection wells and HCl waste

pH	2.0
Al	8.6 mg/L
Ca	83.9
Cl	829
Fe	23.5
Na	15.6
Sulfate	121



Parr Reactor

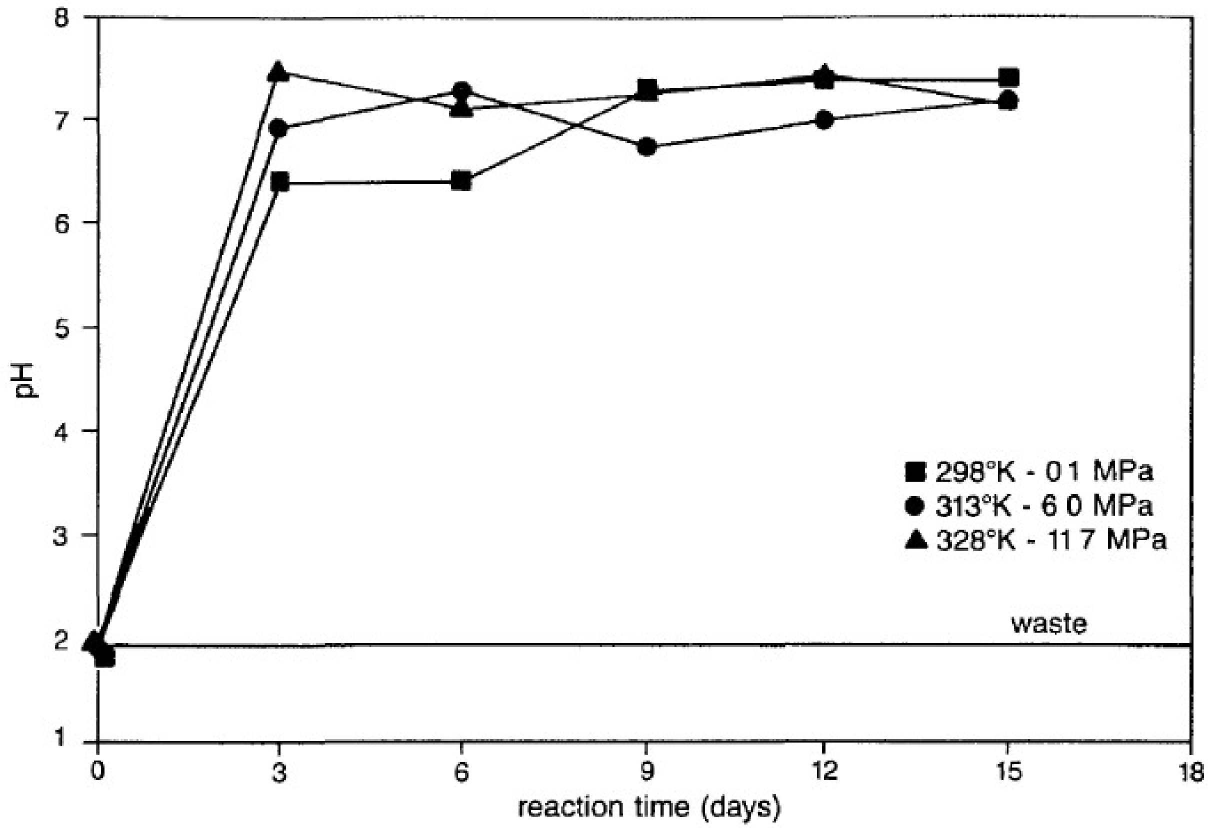


Figure 3 Change in solution pH of the acidic waste when mixed with the Potosi Dolomite in a closed and low-oxygen system as a function of time, temperature, and pressure (based on a solid-to-liquid ratio of 1:4, wt/vol)

Geochemical Interaction of Hazardous Wastes with Geological Formations in Deep-Well Systems

W. R. Roy,
S. C. Mravik,
I. G. Krapac,
D. R. Dickerson,
R. A. Griffin

Illinois State Geological Survey

$$CaMg(CO_3)_2 \text{ (dolomite)} + 4H^+ \rightleftharpoons Ca^{2+} + Mg^{2+} + 2CO_2 \text{ (g)} + 2H_2O$$

The Four Types of Class I wells

1. Hazardous Waste Disposal Wells. Hazardous waste, as defined by RCRA.

2. Non-Hazardous Industrial Waste Disposal Wells. These wells, which inject non-hazardous industrial waste, operate in 19 states. The majority of these wells are in Texas.

3. Municipal Wastewater Disposal Wells.

The Four Types of Class I wells

4. Radioactive Waste Disposal Wells. This sub-class of well may be used to inject waste which contains radioactive material below the lowermost formation containing a USDW within one quarter mile of the well bore. ***There are no known radioactive waste disposal wells operating in the U.S.***

Why?

Deep-well injection at Oak Ridge National Lab

From 1965 to 1984, pH-neutralized Purex liquid wastes and others were injected into an impermeable shale on site at a depth of 700 to 1,000 feet (210 to 305 m) by fracking.

Deep-well injection at Oak Ridge National Lab

Wastes contained 1 M $NaNO_3$ and about 1 Ci/gallon (9.8 GBq) (mostly ^{137}Cs and ^{90}Sr).

The liquid waste was mixed with cement and injected as a slurry to harden below ground after injection.

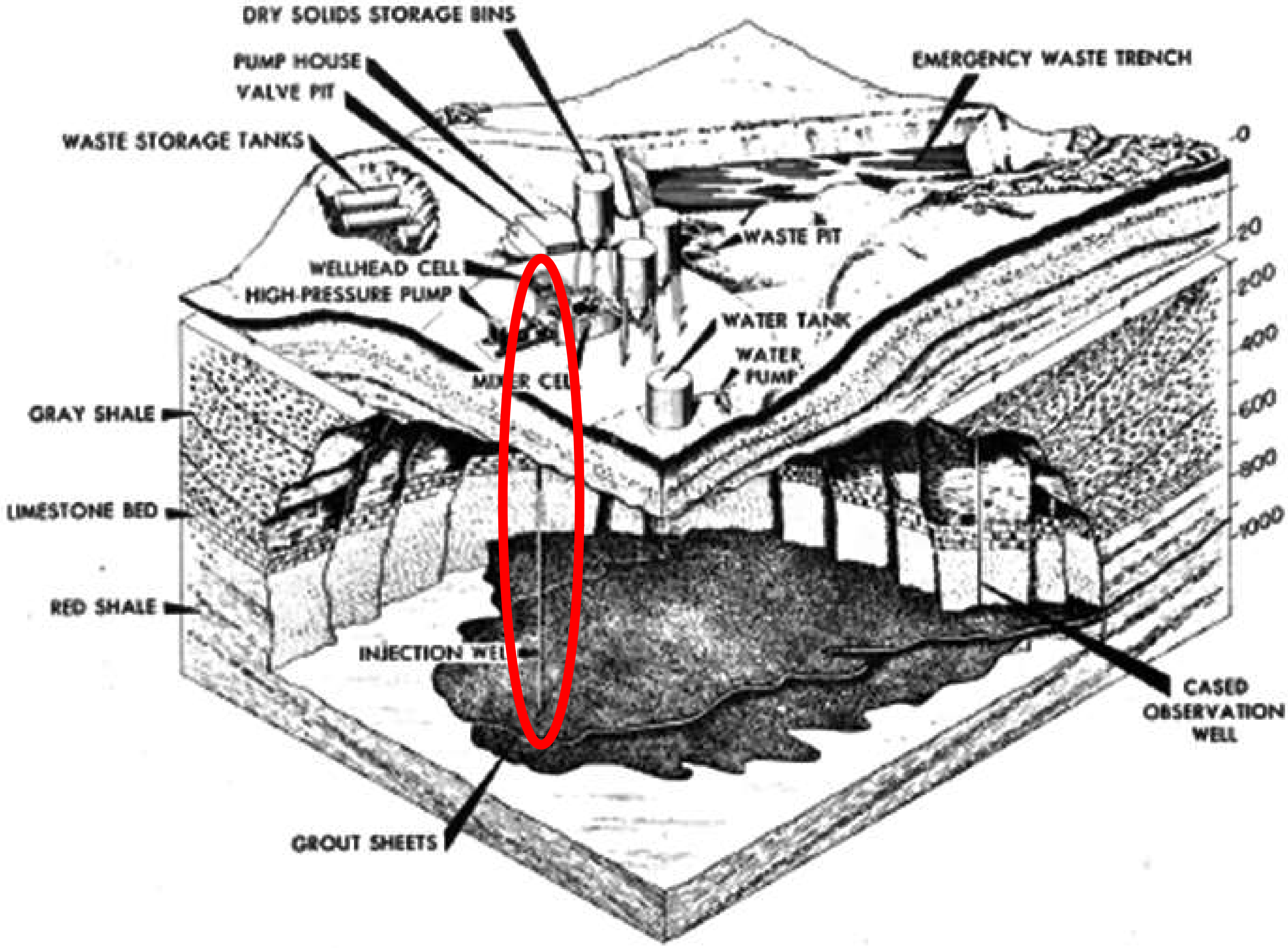


Fig. 1. ORNL shale fracturing disposal plant.

Injection at Oak Ridge

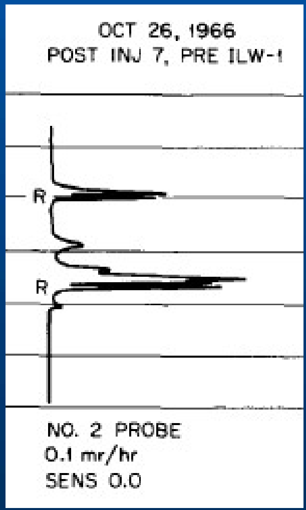
From 1966 to 1972, 1.5 million gallons (5.7 million L) of waste slurry were pumped in the shale. The slurry contained 444,000 Ci (16,430 TBq) of ^{137}Cs and 29,000 Ci (1,070 TBq) of ^{90}Sr.

Injection at Oak Ridge

The purpose of the pressure fracturing was to create voids in the shale for waste slurry. At first, the fractures were along bedding planes.

Injection at Oak Ridge

With time, however, gamma-ray logs suggested that there was vertical fracturing as well, and that it was becoming impossible to determine where the slurry was moving with any confidence.



"Groundwater contamination was detected (no details)." Although no link was shown between injection and the contamination, injection was stopped.

Injection in USSR/Russia

Krasnoyarsk-26 (kras-nie-arsk) is an underground facility that produced plutonium for weapons in Siberia during the Cold War.

Liquid radioactive wastes are transported 16 km to the Severny Site for injection into geological formations.

There are 12 injection wells, and injection began in 1962.

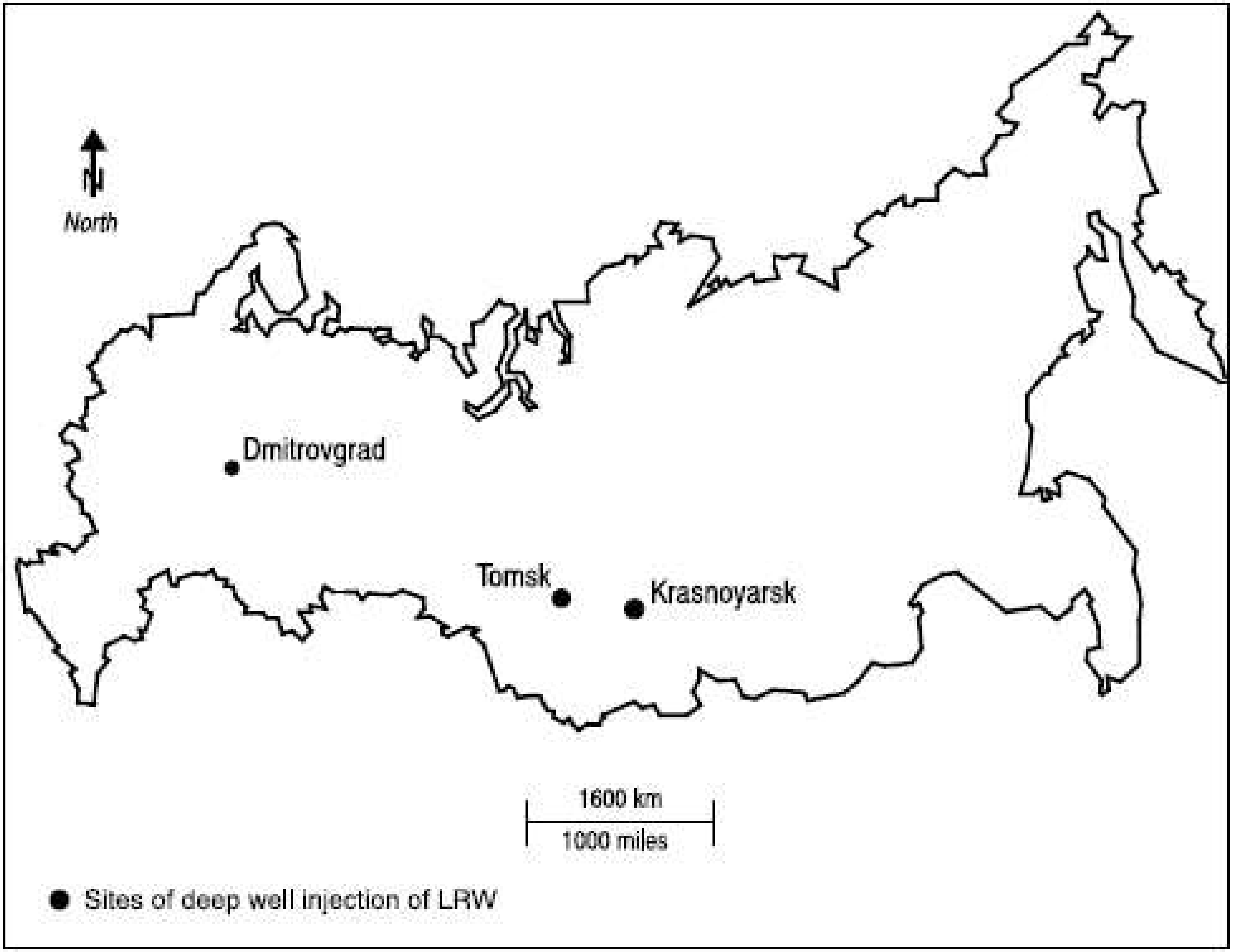


Figure 1.1. Map of major deep well injection facilities in the FSU.

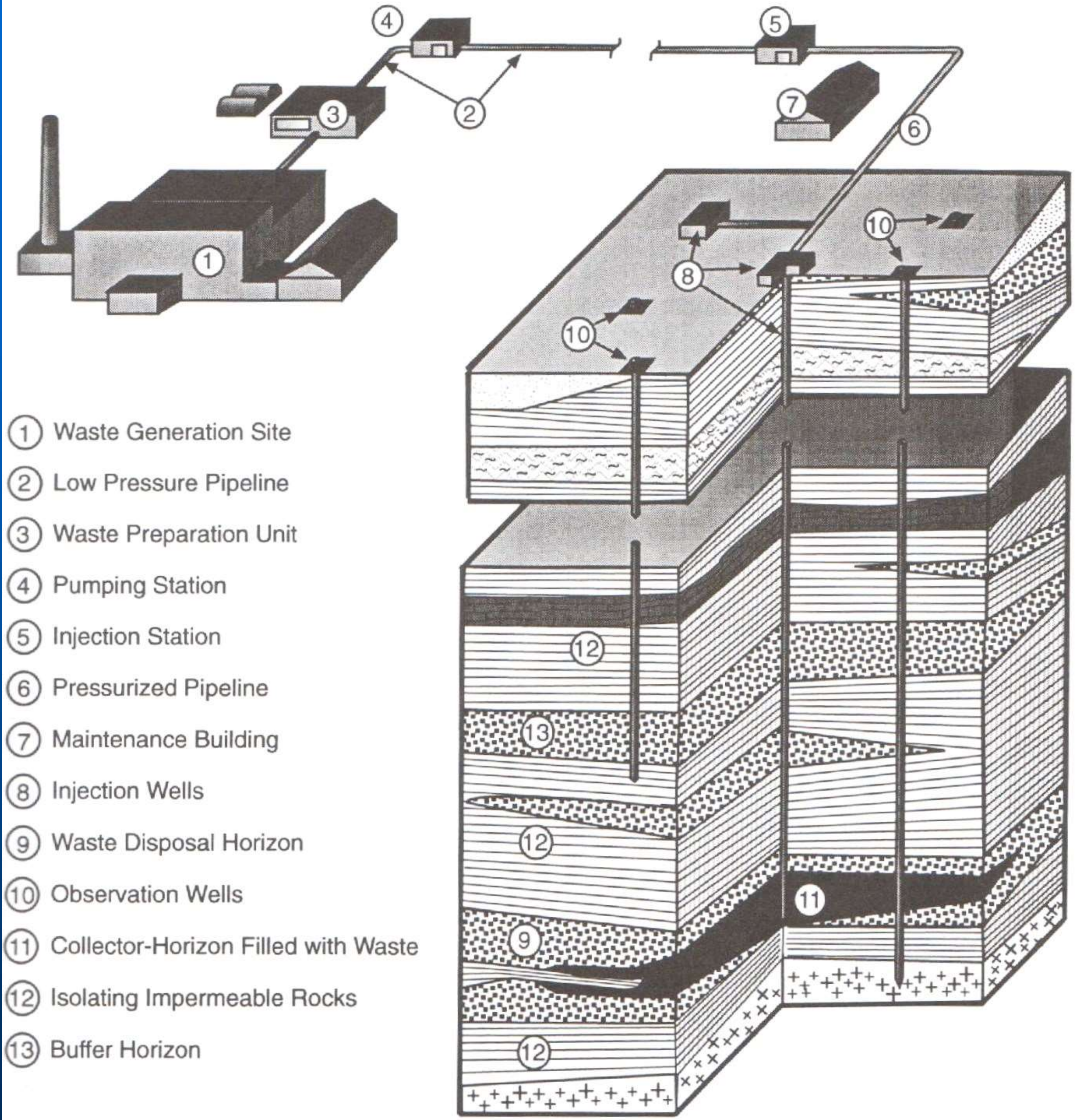


Figure 12.1. General Diagram of Radioactive Waste Disposal by Deep-Well Injection

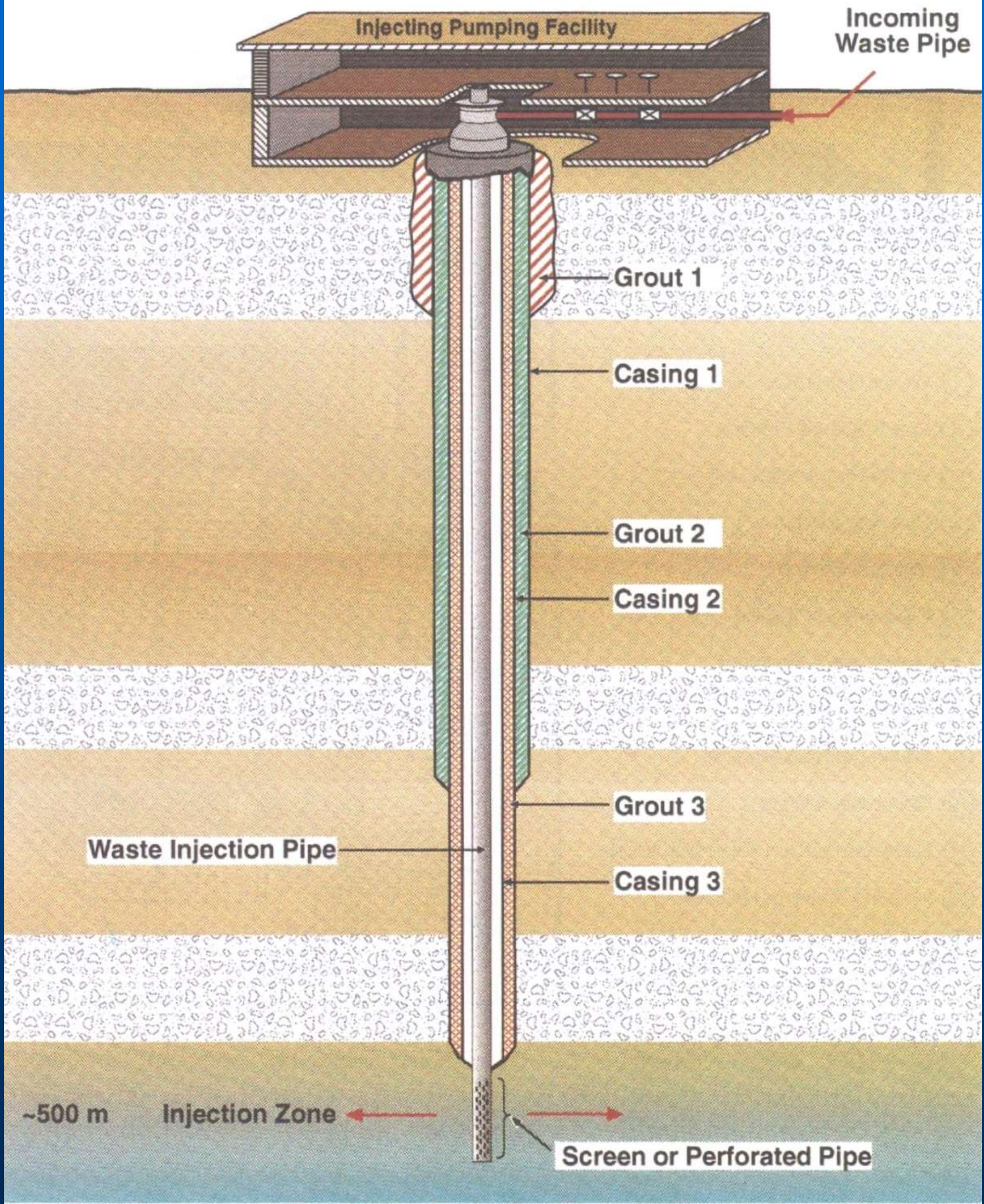
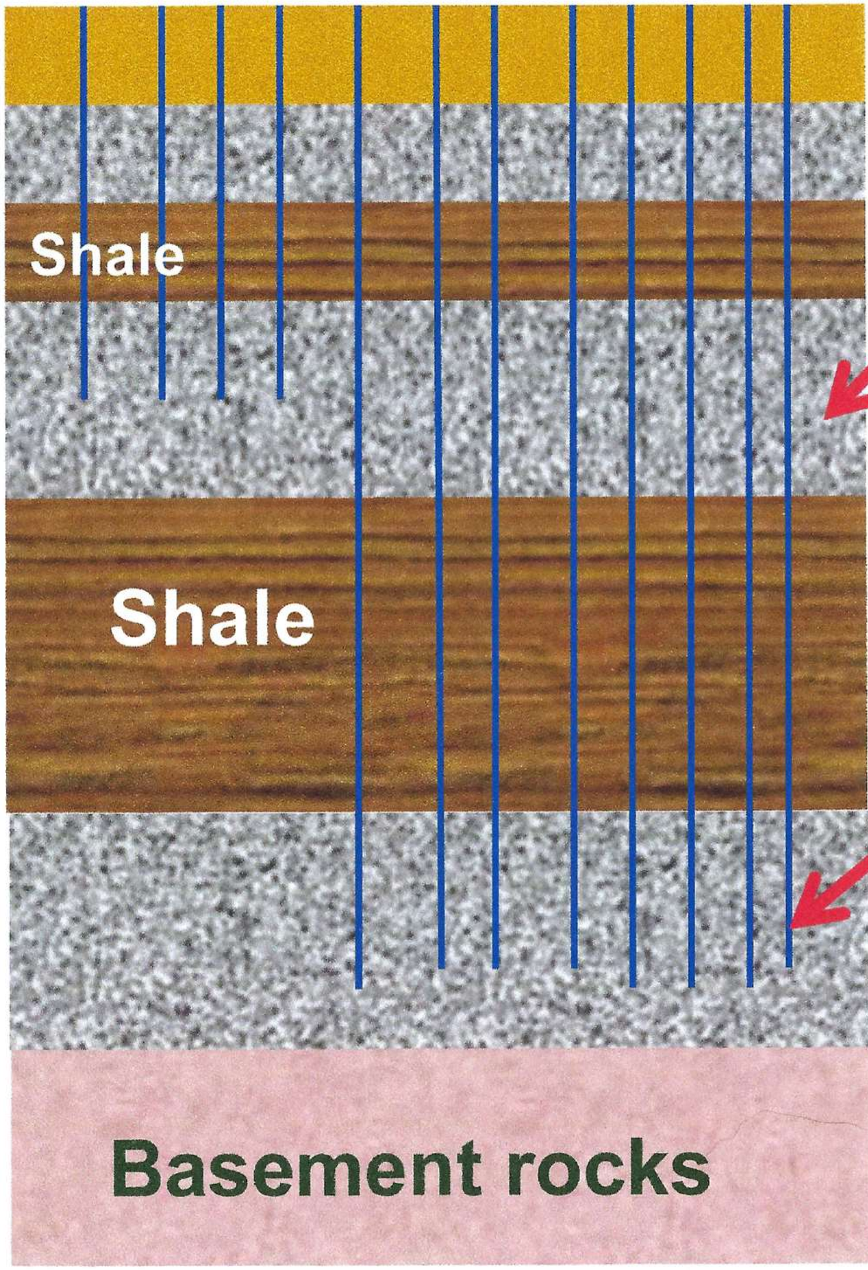


Figure 12.2. General Schematic of Liquid Radioactive Waste Injection Well

The Severny Site



Horizon 2. Sandstone. 180 to 280 (591 to 919 feet) deep. Receives LLRW using 4 injection wells.

Horizon 1. Sandstone. 370 to 465 m (1,214 to 1,526 feet) deep. Receives ILW and HLW using 8 injection wells.

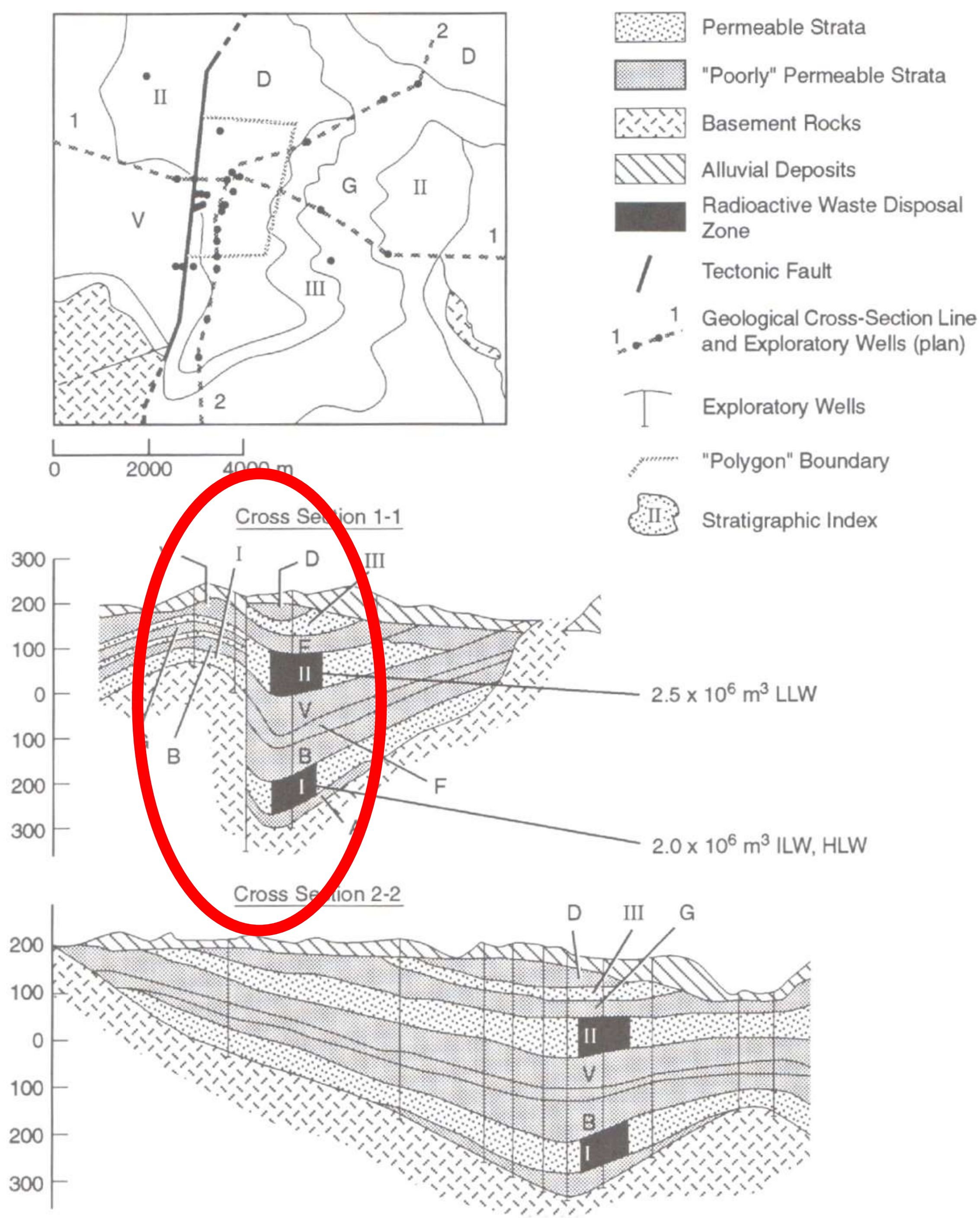


Figure 12.5. Injection Polygon at Krasnoyarsk-26 Showing the Bounding Tectonic Fault and a Cross-Section of the Layered Injection Scheme for Low-, Intermediate-, and High-Level Liquid Wastes

Partial composition of the wastes

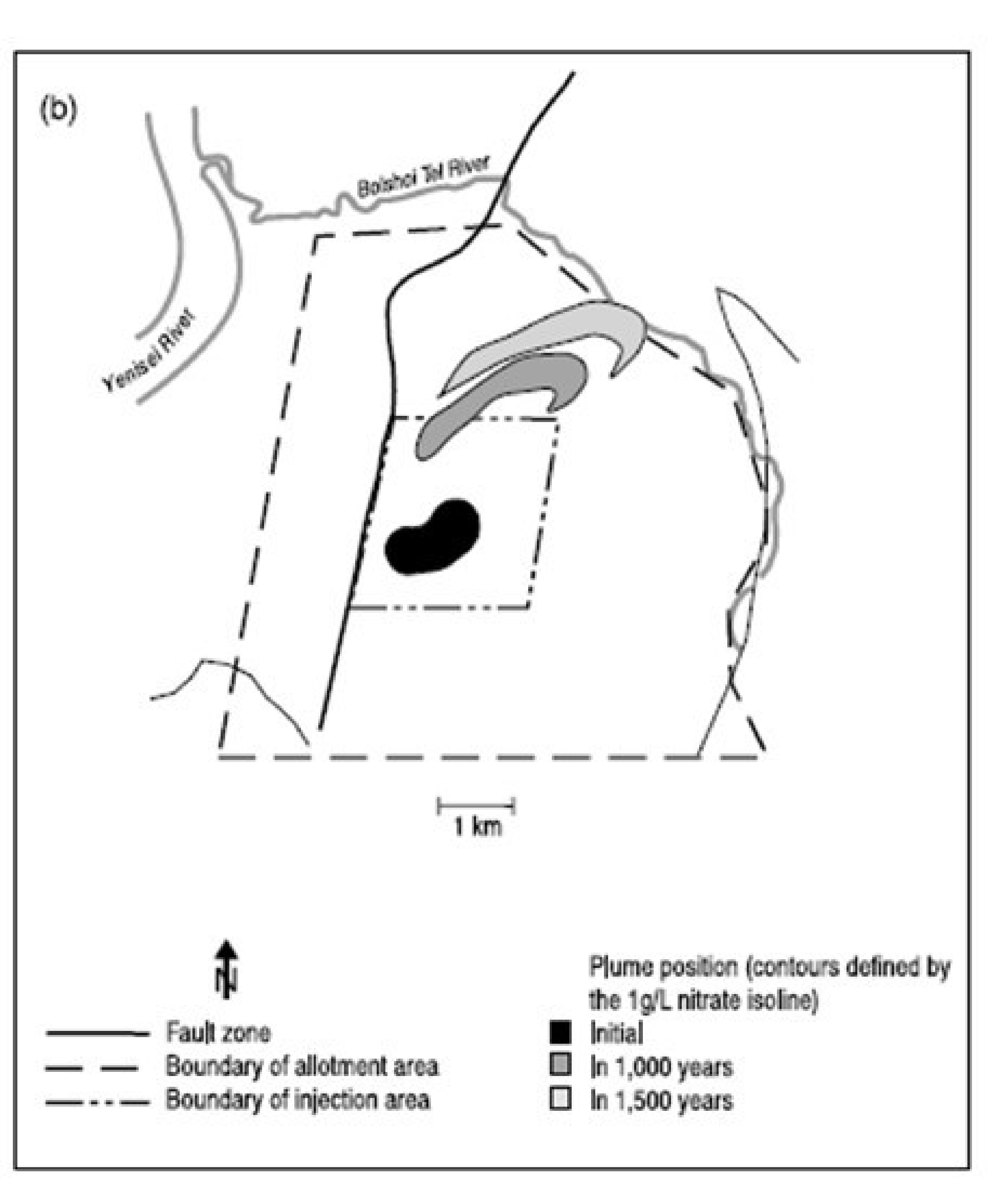
	HLW Process waste	Intermediate waste	Low-level waste
pH	1 to 3	~ 13	~8
TBP	50 mg/L	30 mg/L	None
^{90}Sr	2.49 Ci/L	0.51 mCi/L	2.97 µCi/L
^{137}Cs	0.30 Ci/L	0.41 Ci/L	4.05 µCi/L
^{239}Pu	100 to 500 µg/L	10 to 30 µg/L	< 1 µg/L

Impact assessment

Groundwater-flow modeling indicated that the plume of radionuclides in Horizon 1 would not reach the site boundary within 1,000 years (1 ka). "Most of the activity will decay to Russian drinking water standards within the 1,000-year limit."

Impact assessment

Groundwater flow rate estimated to be about 5 m/year. Sorption was not taken into account in the travel-time analysis.



(b)
Bolshoi Tel River
Yenisei River
1 km
N
Fault zone
Boundary of allotment area
Boundary of injection area
Plume position (contours defined by the 1g/L nitrate isoline)
Initial
In 1,000 years
In 1,500 years

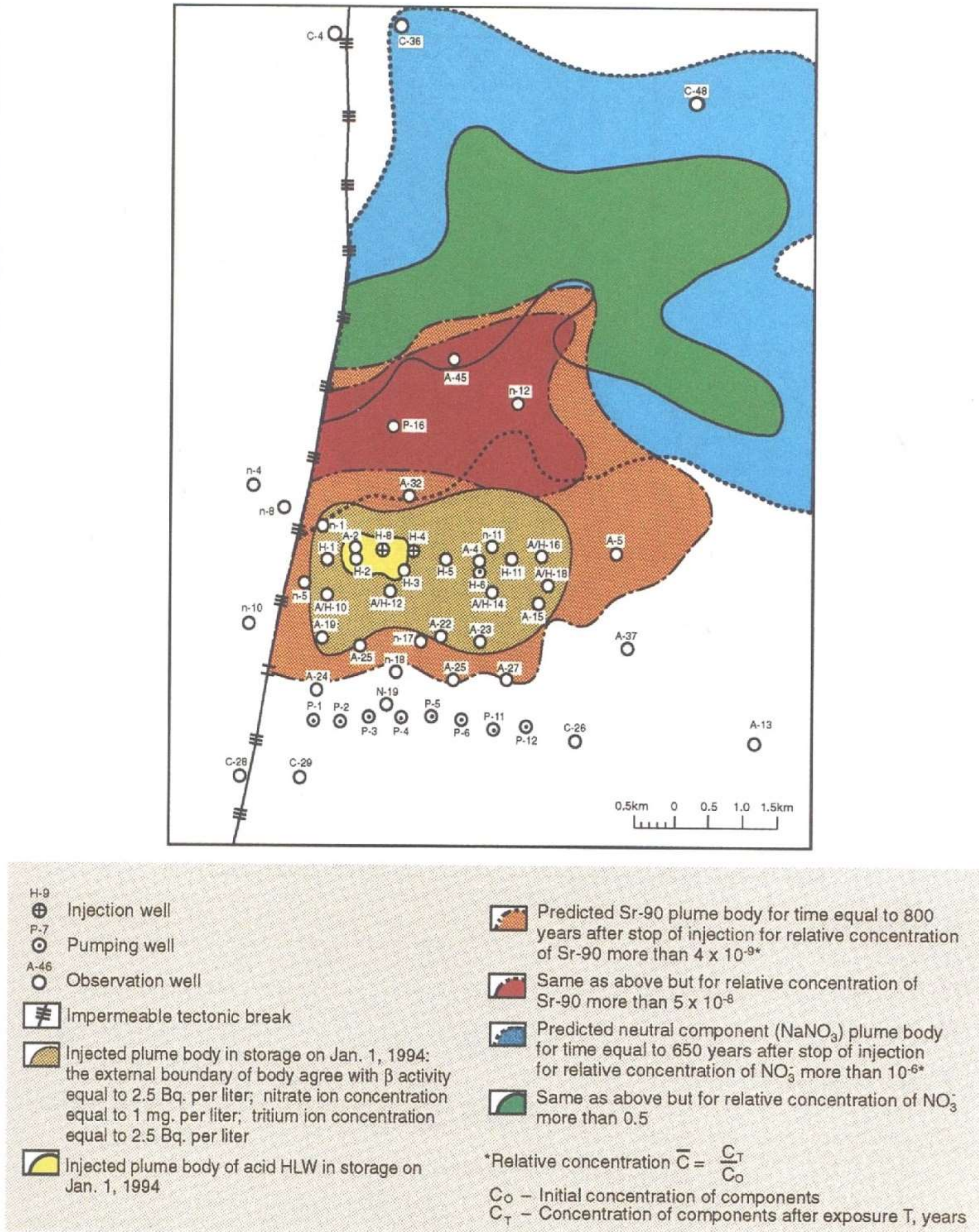


Figure 12.7. Map of the Injection Horizon I (intermediate- and high-level waste) at Krasnoyarsk-26 Showing Current and Projected Injection Plumes

Impact assessment

Groundwater-flow modeling indicated that the plume of radionuclides in Horizon 2 would reach the site boundary in about 100 to 300 years, but that "in [small] concentrations at the site boundary."

Groundwater flow rate estimated to be about 20 m/year. Sorption was not taken into account in the travel-time analysis.

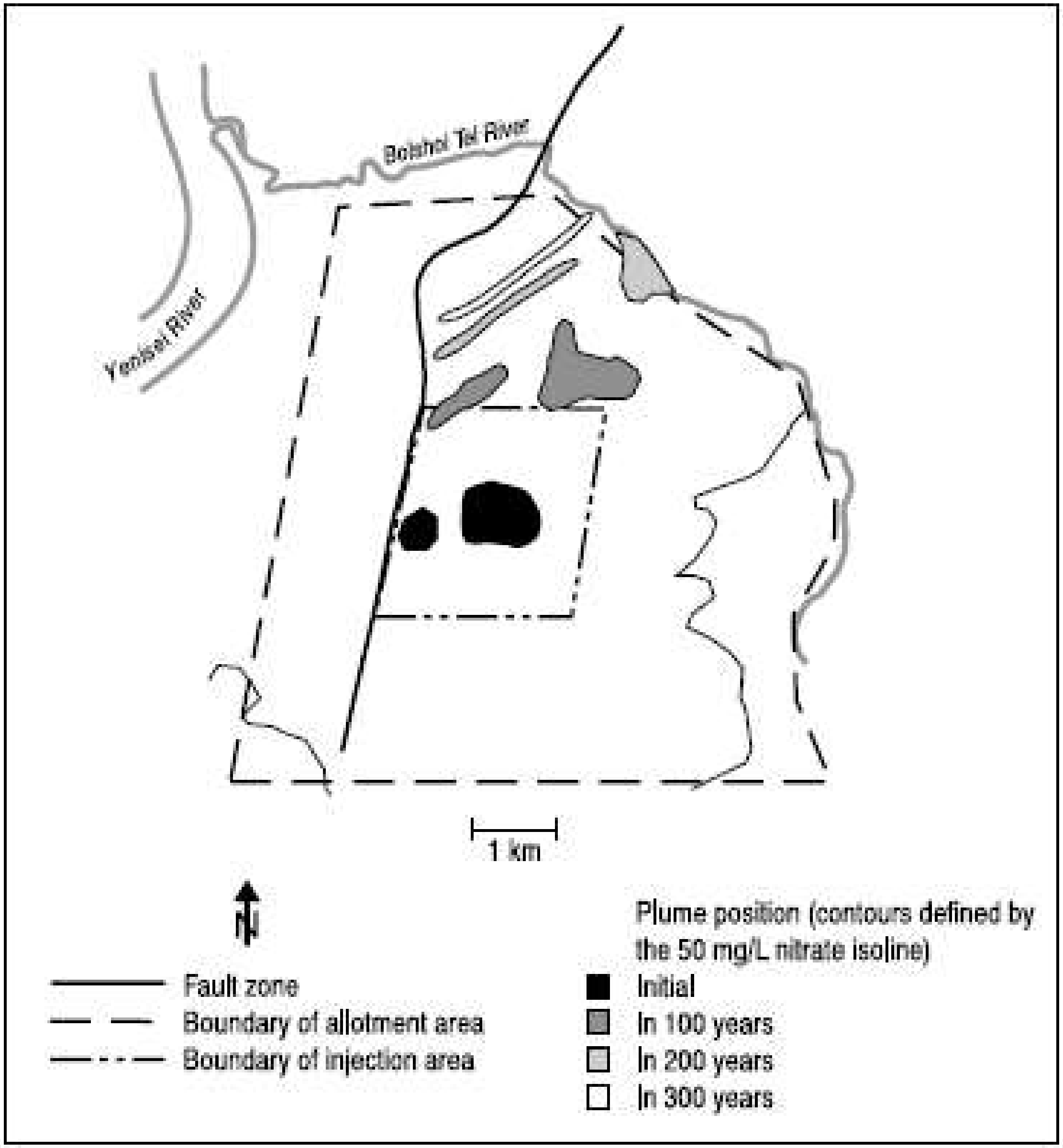


Figure 3.7. Horizon II modeling results: IIASA.

Impact assessment

“ . . . Underground deep injection does not appear to present any major short-term risk of public exposure or of significant contamination of surface waters . . . primarily [because of] the [slow] groundwater velocities, the degree of sorption that may be expected, and the potential for [groundwater] dilution.”

Compton et al. (2000)

IAEA opposes deep-well injection

The International Atomic Energy Agency is critical of deep-well injection because the method "has no packaging or engineered barriers, and relies on the geology alone for safe isolation."

Not an acceptable option for Member States of the European Union.

(Russia is not a member)

(My) Conclusions

Deep-well injection of liquid radioactive wastes should at least be considered in the U.S. It would be, however, unpopular.

(My) Conclusions

If the U.S. decides to reprocess used nuclear fuel, deep-well injection of the process wastes may be a viable complement to placing vitrified and ceramic waste forms in a geological repository. Research on the chemical fate and movement of radionuclides is needed.