Pre- and Post-Mining Water Quality at ISL Sites

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Overview of Discussion Topics

Natural uranium and radium background levels in groundwater contacting uranium ore



Valid background water quality in proposed aquifer exemption zone

Excursions and upper control limits (UCLs)

Restoration values and timeframes



Long-term monitoring to assess plume migration and protect human health and the environment

Natural Background Levels

Difficult to measure due to reducing conditions in ore zones and exploratory drilling

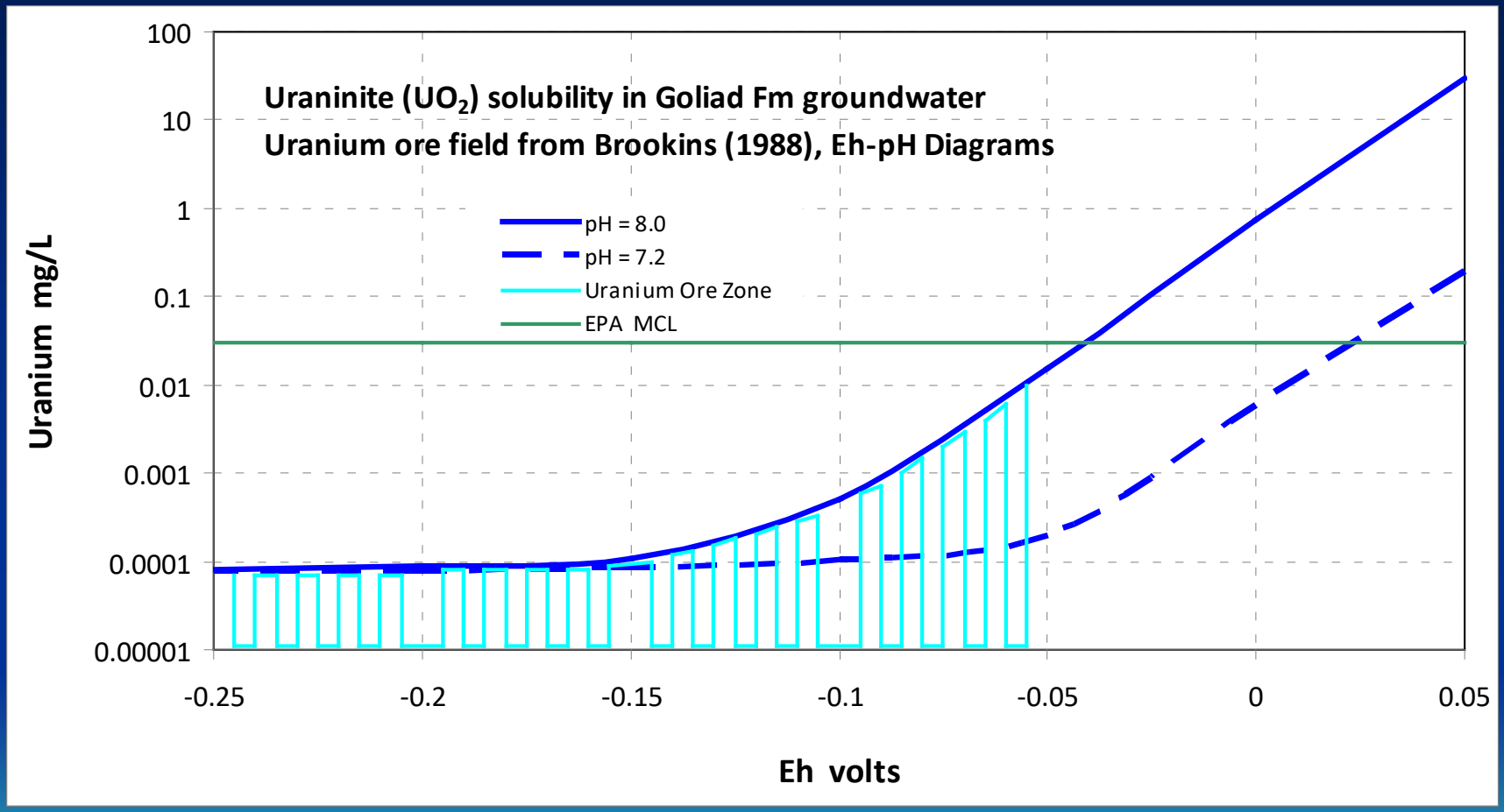
Drilling disturbs ore zone…potential to introduce oxygen and contamination (Laaksoharju et al., 2008)

Unknown if 'natural' background ever determined for uranium ore bodies

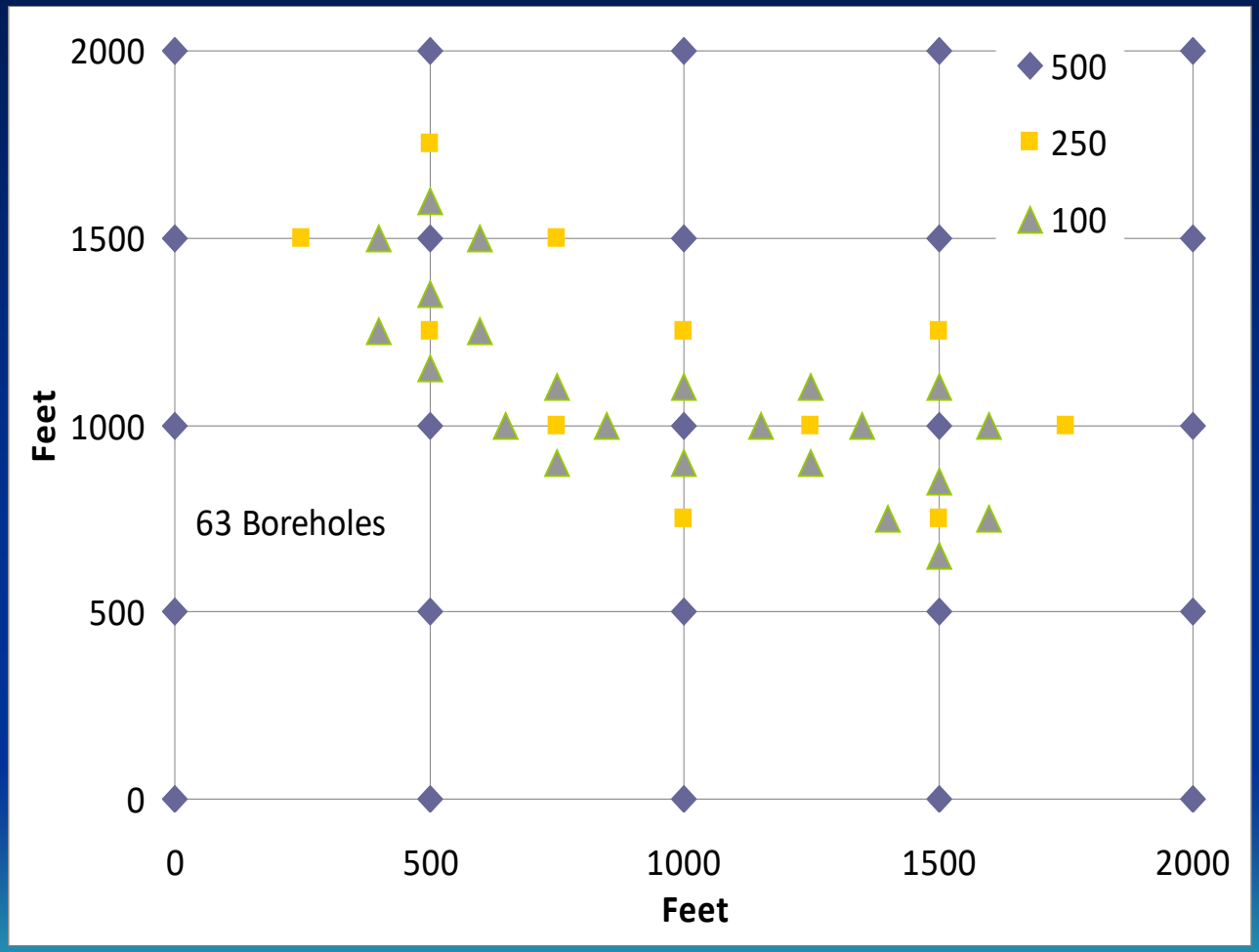
Possible to achieve with proper scientific approach (e.g., geoprobe methods or use of reducing drilling fluids during exploration)

Laaksoharju, M., J. Smellie, E. Tullborg, M. Gimeno, J. Molinero, I. Gurban, and L. Hallbeck, 2008, Hydrogeochemical evaluation and modeling performed within the Swedish site investigation programme, *Applied Geochemistry*, v. 23, no. 7.

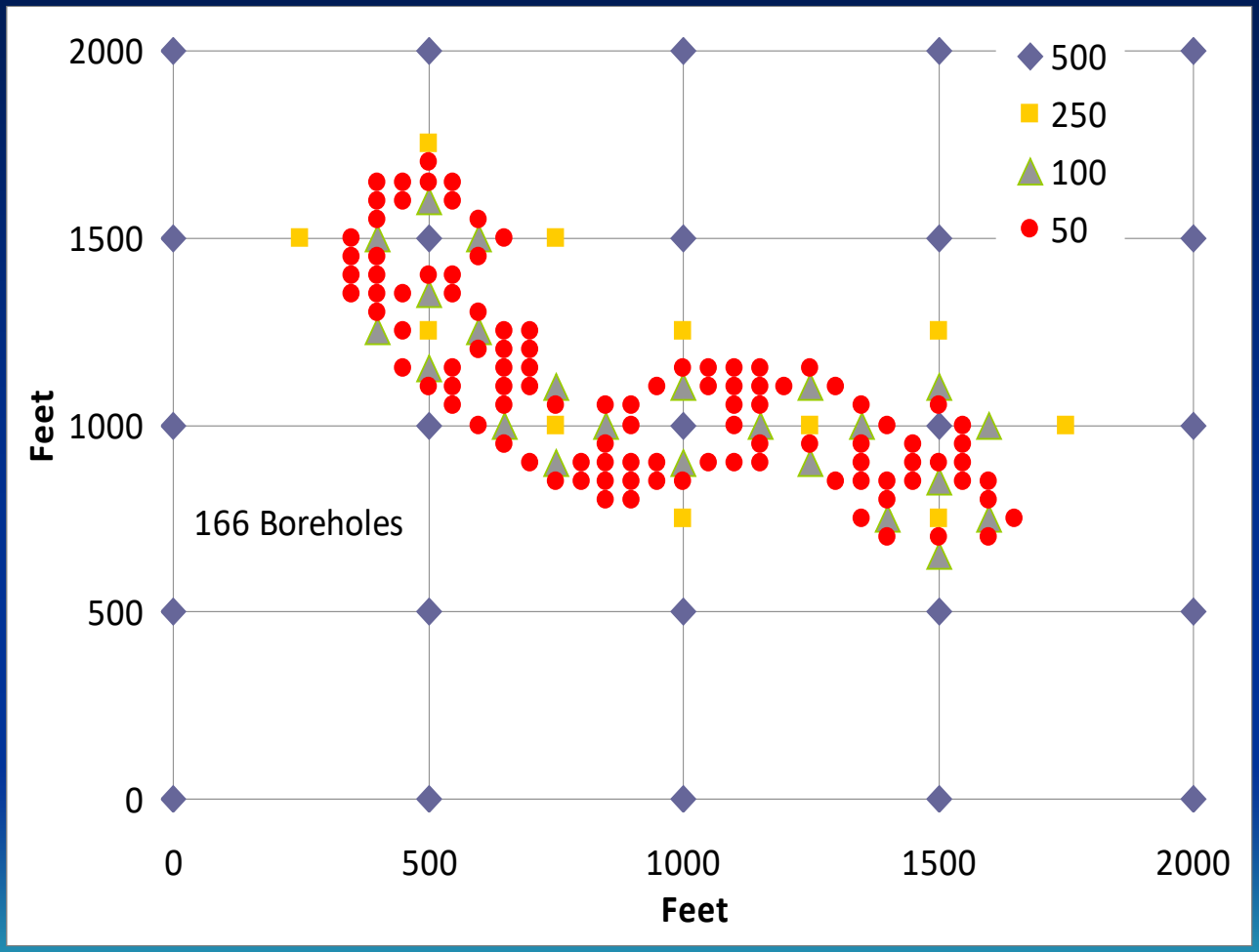
Uranium Levels in Undisturbed Ore Horizons



Exploration Boreholes – Early Phase

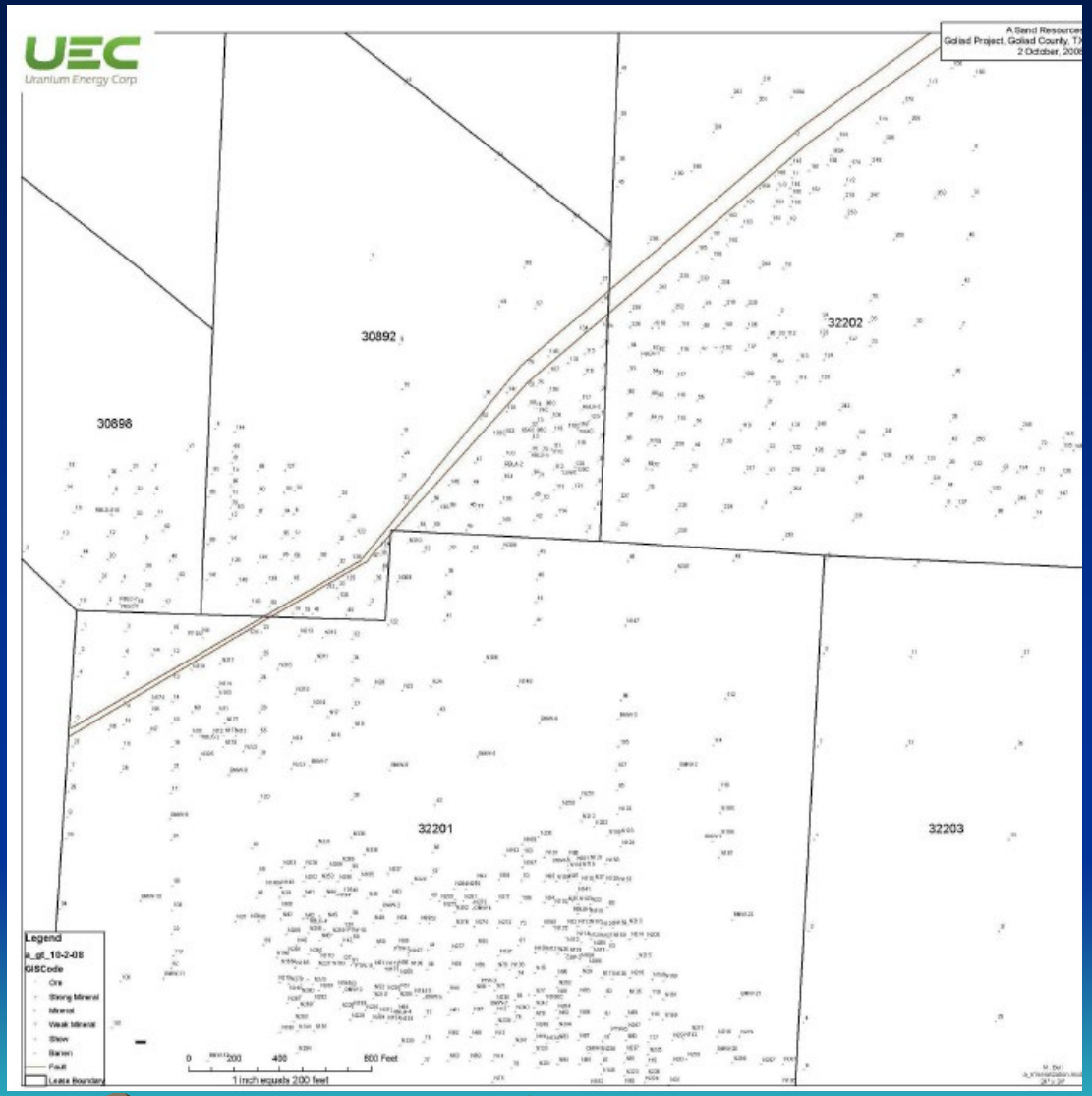


Exploration Boreholes – Late Phase



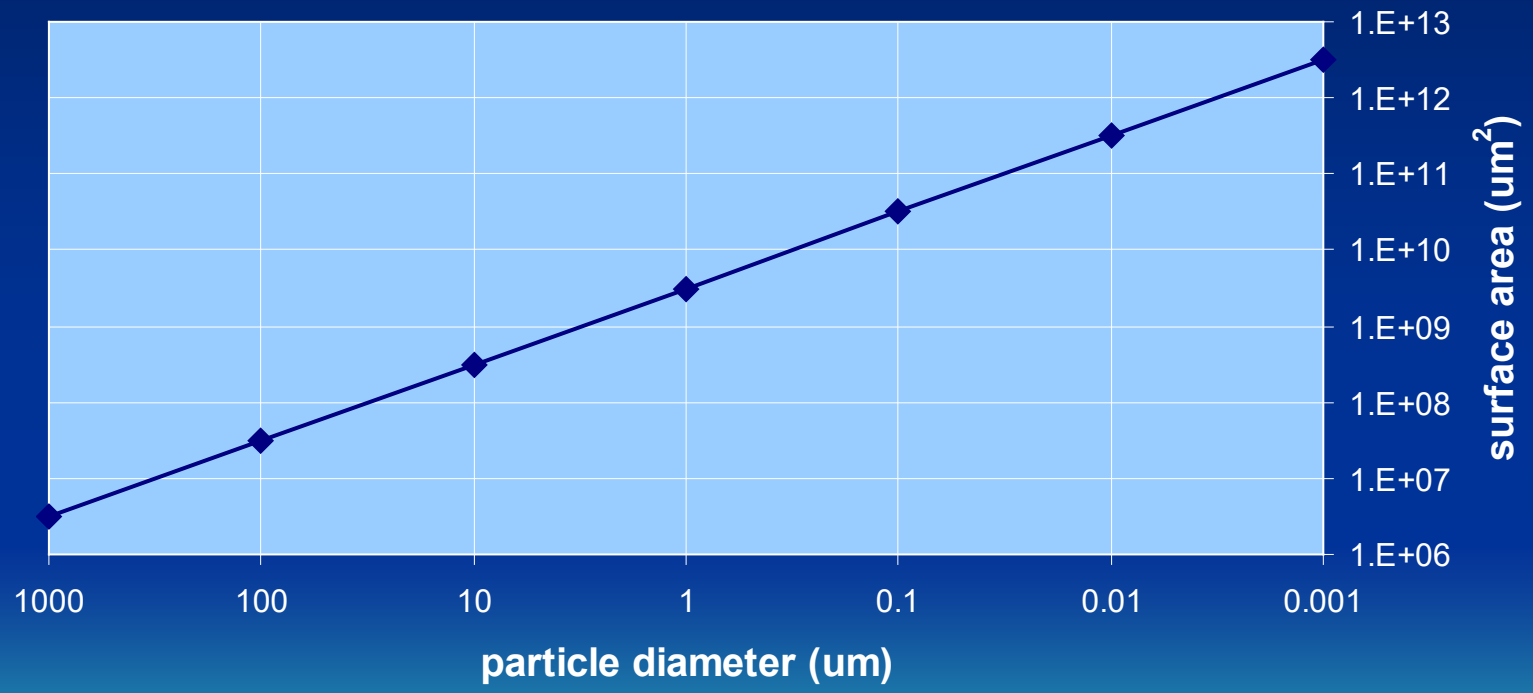
Exploration Boreholes – Late Phase

900 Boreholes at Goliad Project before baseline groundwater samples collected.



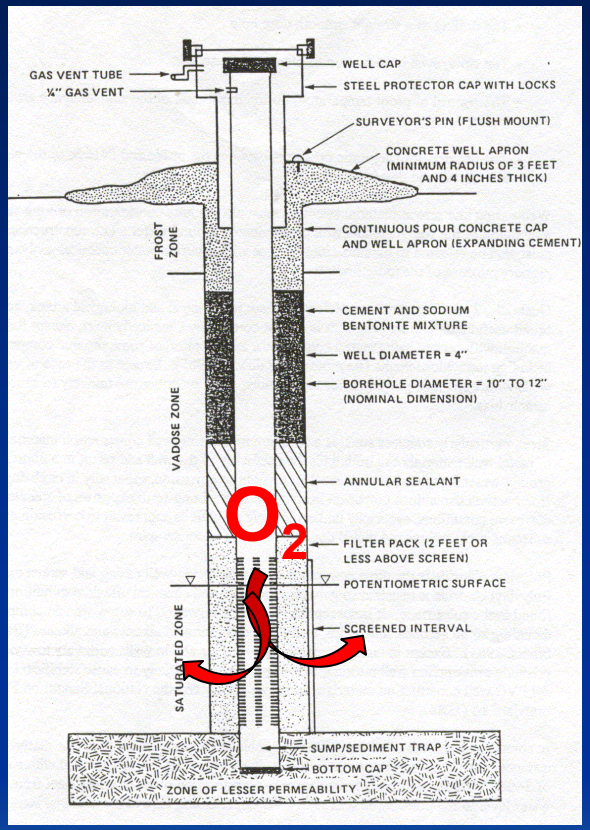
Drilling Issues Related to Mechanical Disturbance

Physical change to the ore minerals



Drilling Issues Related to Redox Disequilibrium

Airlift purge and pump adds O_2 to the ore zone



Oxidation reactions in the ore zone

$$\tfrac{1}{2}O_2 + 2H^+ + UO_2 \rightarrow H_2O + UO_2^{++}$$

$$\tfrac{7}{2}O_2 + H_2O + Fe_{1-x}As_xS_2 \rightarrow 2H^+ + 1\text{-}xFe^{++} + xAs^{++} + 2SO_4^{--}$$

Mineral Dissolution Rates

General form of rate law (Lasaga, 1995)[1]:

$$\text{Rate} = k_0 * A_{min} * e^{-Ea/RT} * a^n_{H+} * g(I) * \Pi_i a^n_i * f(\Delta G_r)$$

Increase in both surface area (A_{min}) and O_2 activity (a^n_{O2}) will increase dissolution rate.

1 Lasaga, A.C., 1995, Fundamental Approaches in Describing Mineral Dissolution and Precipitation Reactions, *in* Reviews in Mineralogy, Volume 31, Chemical Weathering Rates of Silicate Minerals, Mineralogical Society of America.

Ore Zone Wells and EPA MCLs

Site	Uranium (mg/L)	Radium-226 (pCi/L)
HRI Crownpoint, NM	0.010	0.09
Mobile Pilot Plant, NM	0.011	1.6
Strata Energy Ross, WY	0.031	3.2

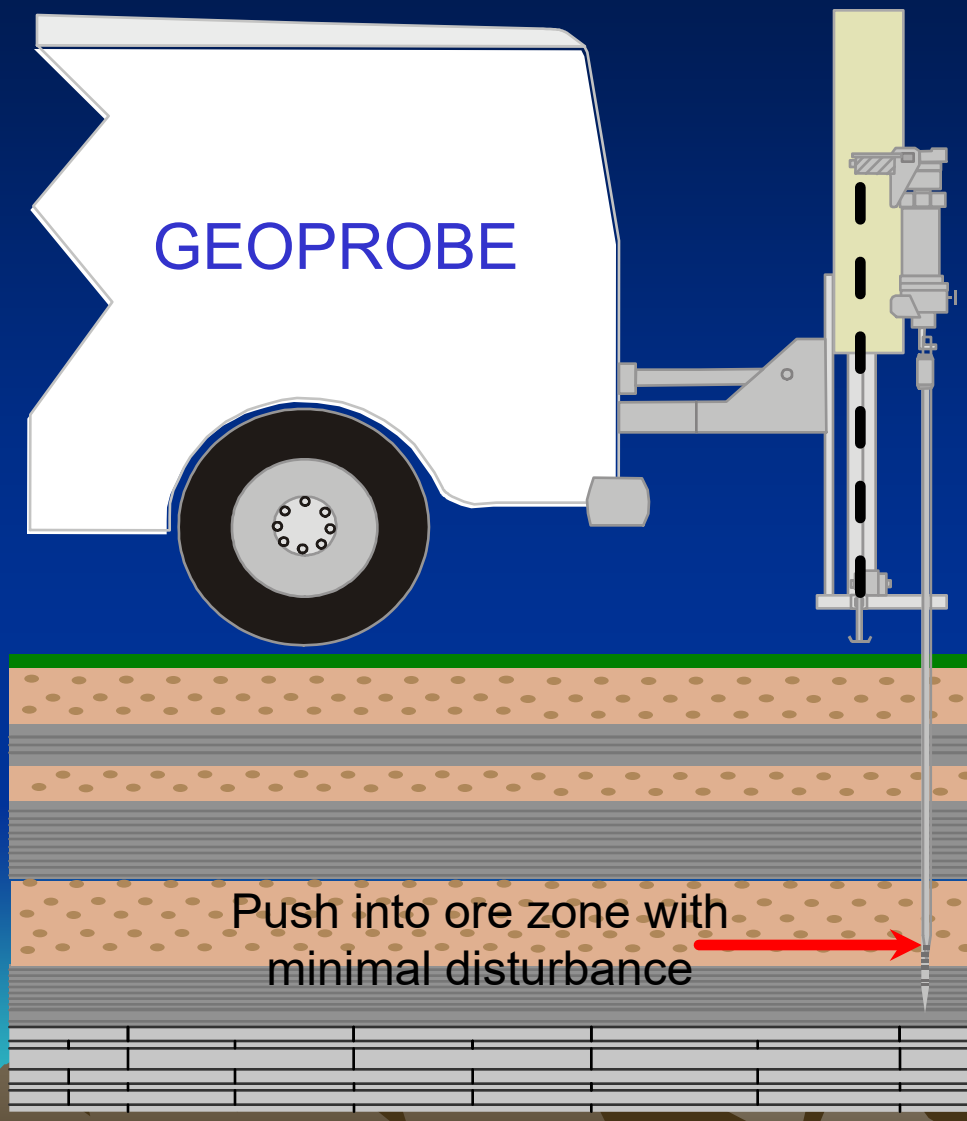
Median values; generally not N or LN distribution, due to some disturbance of ore

Hydro Resources, Inc., 1993a. Section 9 Pilot Summary Report. Prepared by HRI, Inc., Dallas, Texas, March 12. NB 6.2, ACN 9304130415.

Hydro Resources, Inc., 1993b. Church Rock Project Revised Environmental Report, March 16. NB 6.1, ACN 9304130421.

Strata Energy, 2010, Ross ISR Project USNRC License Application Crook County, Wyoming.

Minimize Disturbance of Ore Zone



No drill cuttings

Very accessible (top 400 feet)

Good water sampling

Quick setup

Small diameter well installation

Weakly cemented sediments

Natural Background Levels - Summary

Concentrations of uranium & radium in undisturbed ore zones should be below EPA MCLs

Establish groundwater quality early in exploration program and use Geoprobe or drill with reducing fluids

Large variation in reported water quality from drinking water aquifers – inconsistent protocols and enforcement from state to state

Valid Background Water Quality

Representative samples from proposed aquifer exemption zone (early exploration phase)

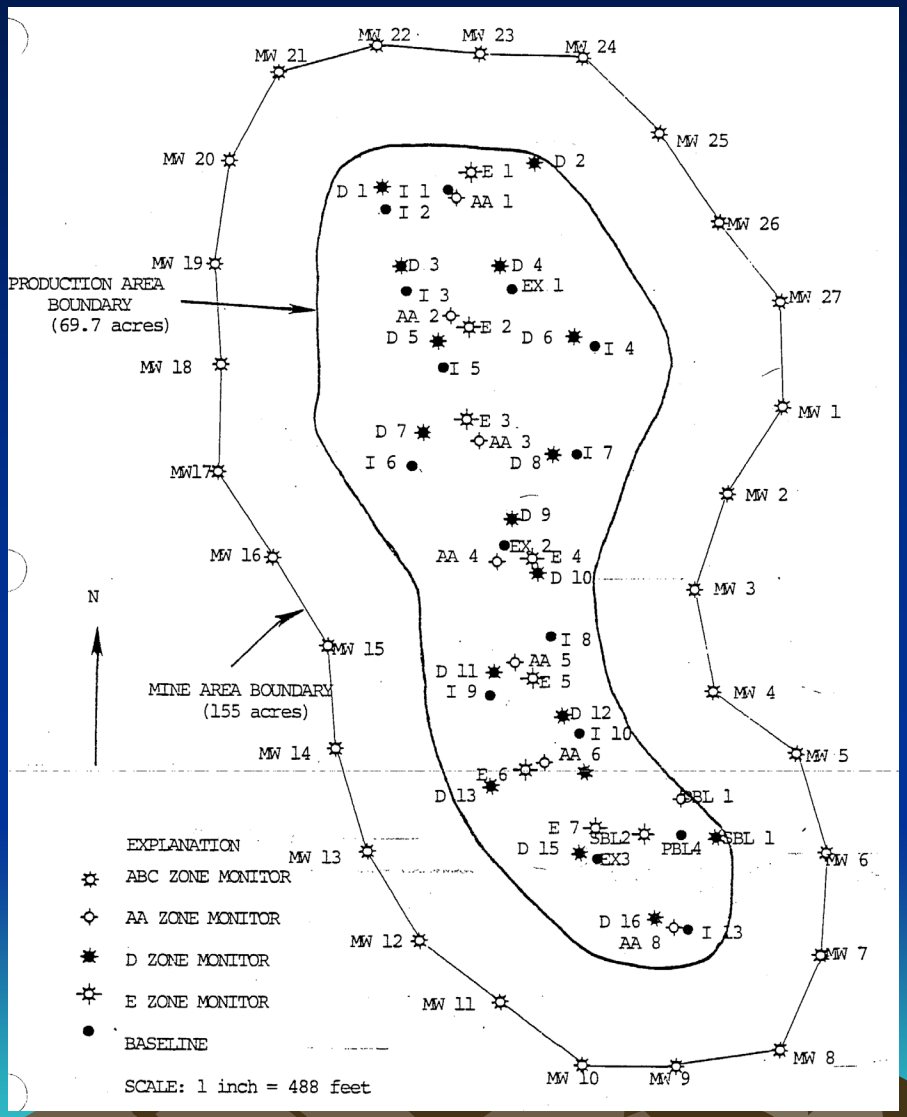
Appropriate drilling (reducing fluids), well development (low turbidity) and sampling methods

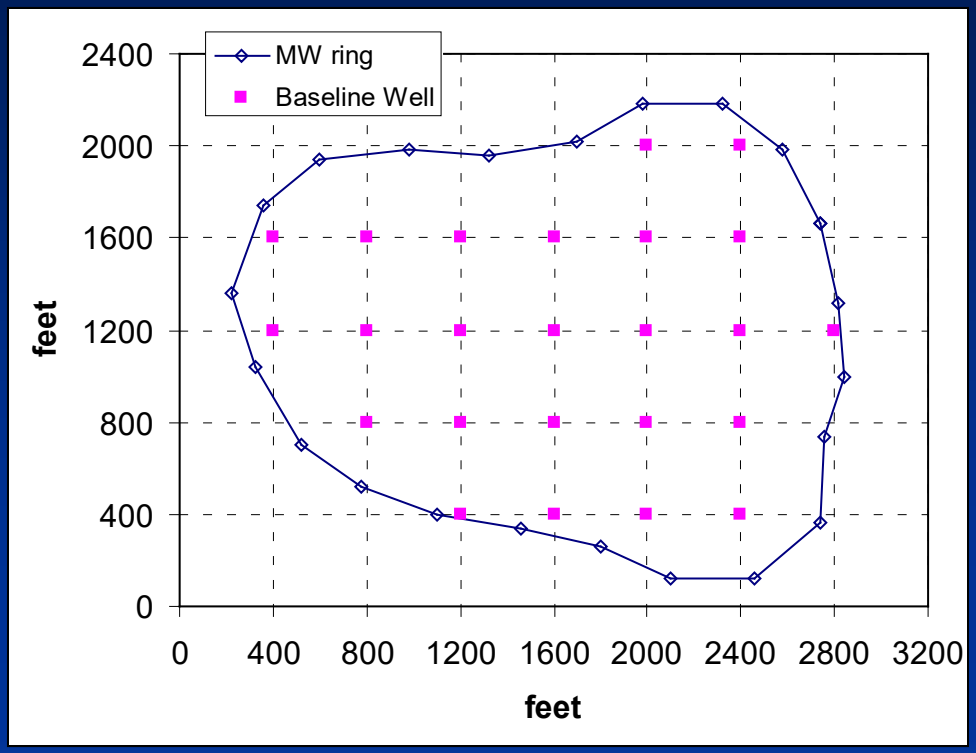
Minimum of 4 quarterly sample rounds

Robust QA for field & lab dups; data validation

Valid statistical methods for data manipulation used to derive background values

Representative Groundwater Samples





Systematic grid to cover the entire proposed aquifer exemption zone

PPA1; Kingsville Dome, TX

Representative Groundwater Samples

KING# 1E+05

STATE OF TEXAS WELL REPORT

OWNER: Uranium Energy Corp.

OWNER ADDRESS: 9801 Anderson Mill Rd Austin

ADDRESS OF WELL'S LOCATION:

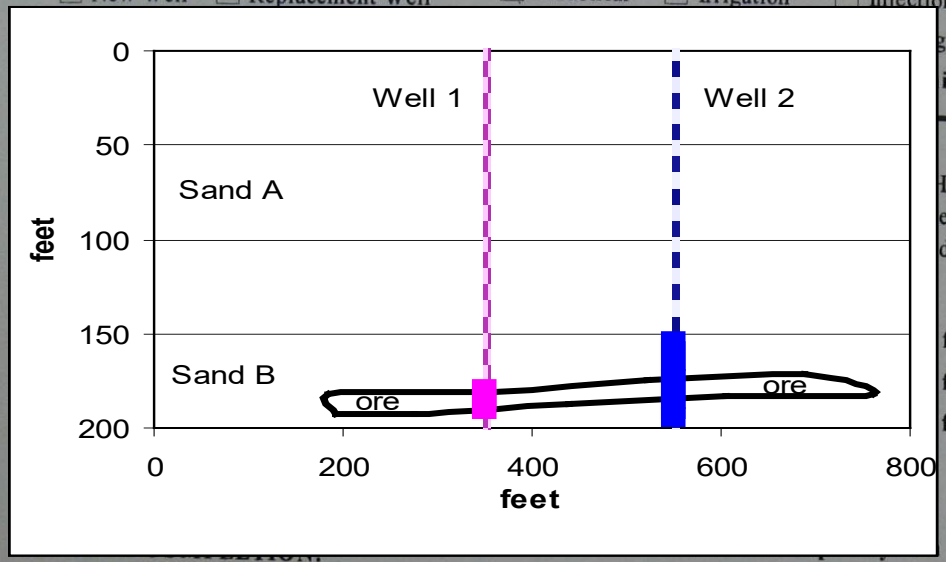
, TX

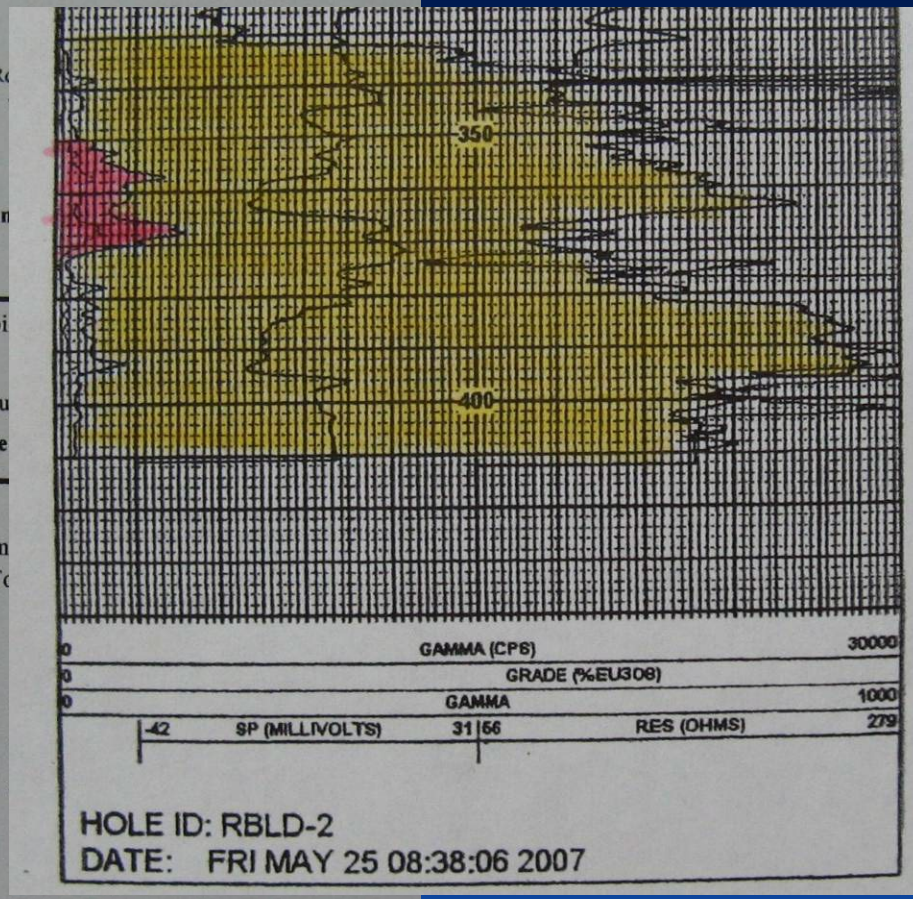
COUNTY: Goliad LATITUDE 285213 LONGITUDE: 972136

Owner's Well Number RBLD-2 ELEVATION:

TYPE OF WORK PROPOSED USE: ☑ Monitor Well ☐ Env. Soi

☐ New Well ☐ Replacement Well ☐ Industrial ☐ Irrigation ☐ Injection





☐ Surface Slab Installed ☐ Pitless Adapter Used

☐ Surface Sleeve Installed ☐ Alternative Procedure Used

Distance to Property Line:

Method of Verification

Approved by Variance No

DESCRIPTION AND COLOR OF FORMATION MATERIA

From (ft.) To (ft.) Descriptio

355-375 sand

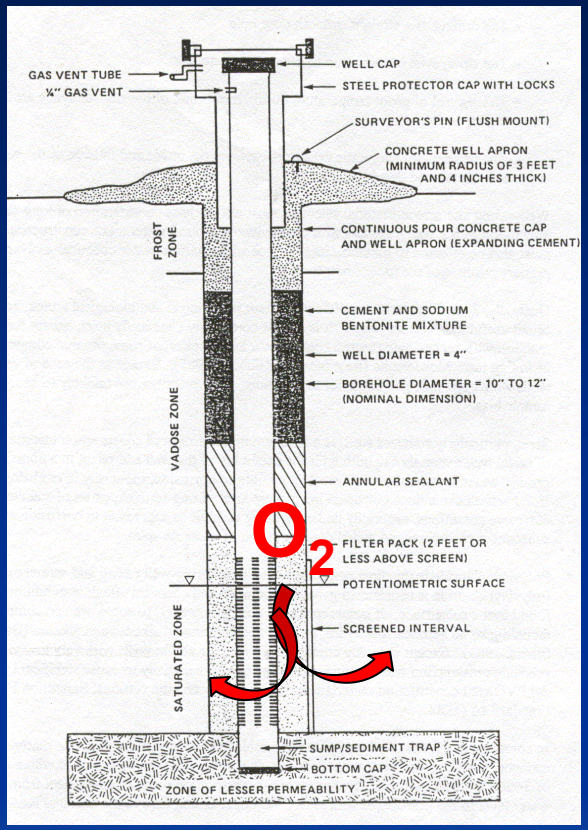
CASING, BLANK PIPE, AND WELL SCREEN DATA

Dia.	New/Used	Type	Setting From/To	Gage
3	N	PVC screen	355-375	0.01

Well Report and Log from Goliad Permit Application

Drilling Issues Related to Redox Disequilibrium

Airlift purge and pump adds O_2 to the ore zone



Oxidation reactions in the ore zone

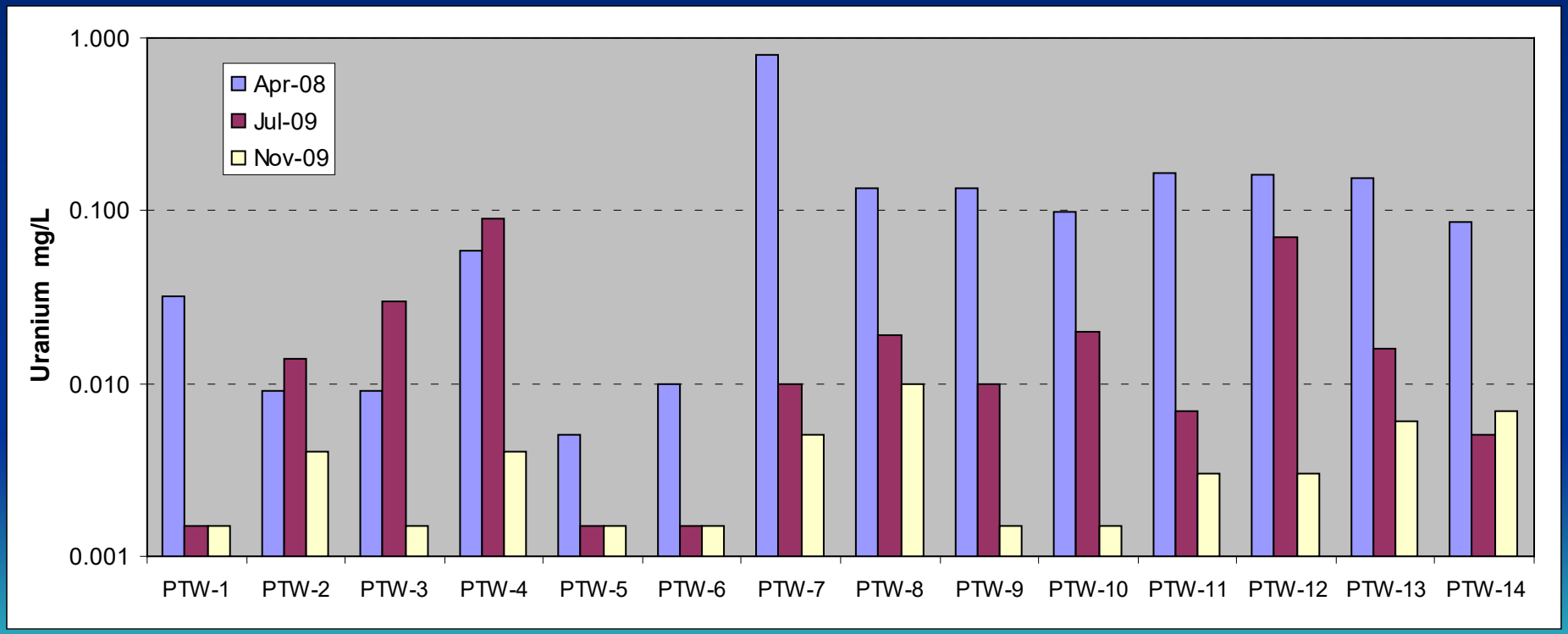
$$\tfrac{1}{2}O_2 + 2H^+ + UO_2 \rightarrow H_2O + UO_2^{++}$$

$$\tfrac{7}{2}O_2 + H_2O + Fe_{1-x}As_xS_2 \rightarrow 2H^+ + 1\text{-}xFe^{++} + xAs^{++} + 2SO_4^{--}$$

Goliad Production Test Wells Sand B

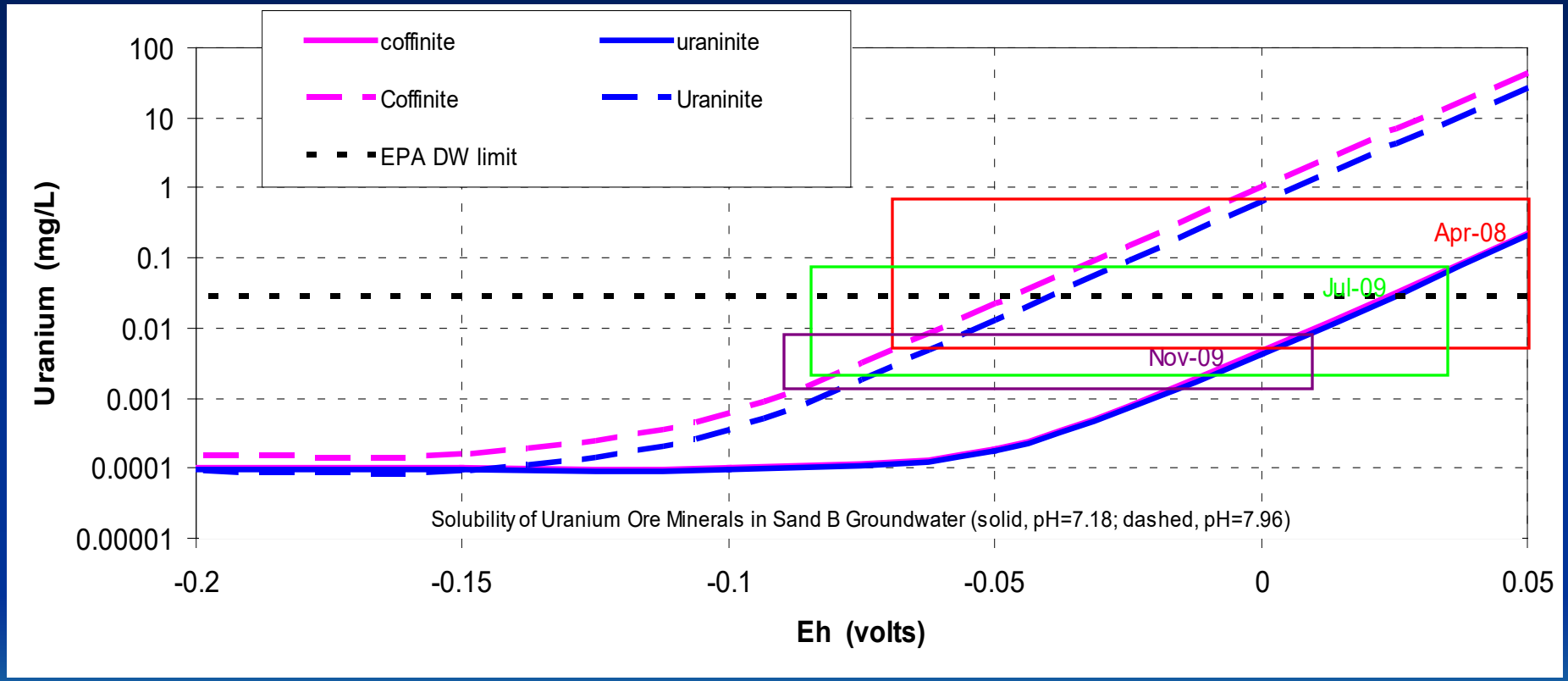
URANIUM:	Apr 2008:	0.005 to 0.804 mg/L
	July 2009:	<0.003 to 0.090 mg/L
	Nov 2009:	<0.003 to 0.010 mg/L

Anthropogenic induced oxidation; essentially reversed 18 months later (U^{+6} -> U^{+4})



Uranium Energy Corporation (UEC), 2007, Goliad Project, Goliad County, TX, Application to Conduct In Situ Uranium Recovery.

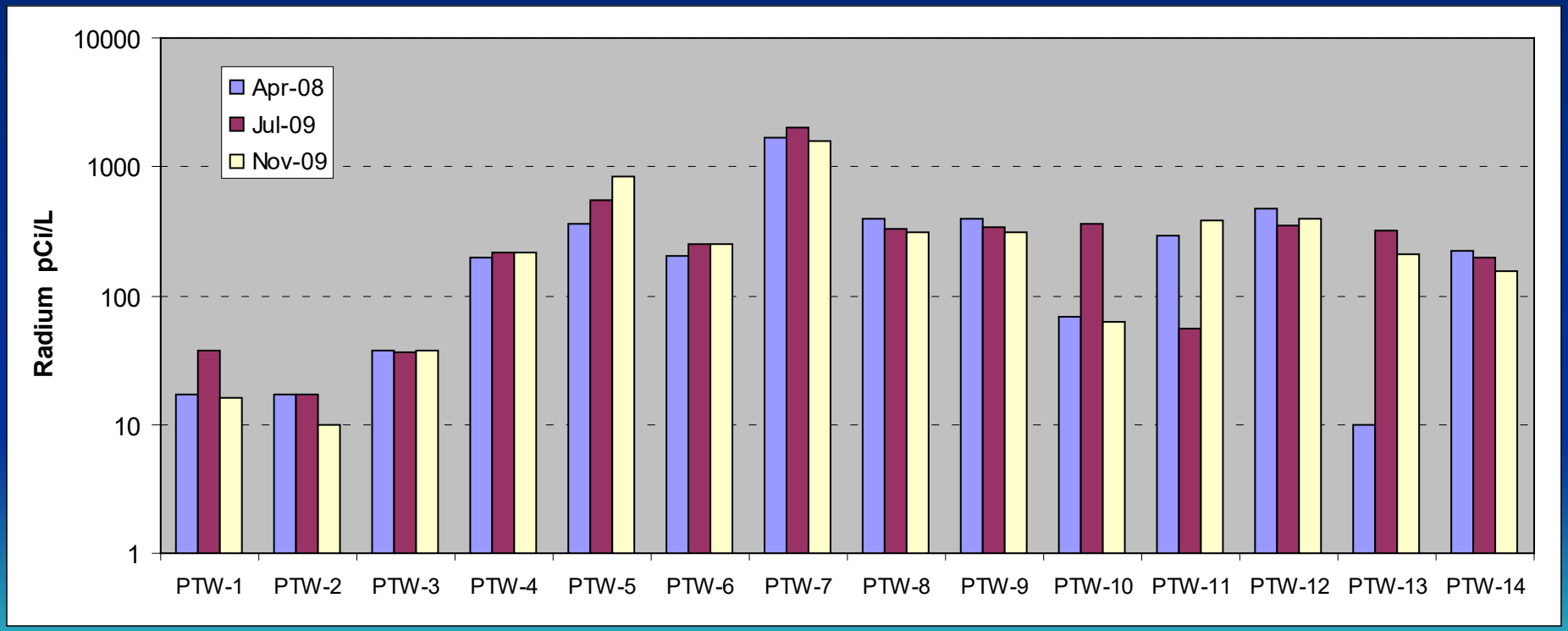
Uranium solubility as a function of Eh



Production Test Wells (PTW), Sand B

RADIUM:	Apr 2008:	10 to 1,680 pCi/L
	July 2009:	17 to 2,000 pCi/L
	Nov 2009:	10 to 1,590 pCi/L

Anthropogenic oxidation of U releases Ra; no reversal, as Ra has one oxidation state



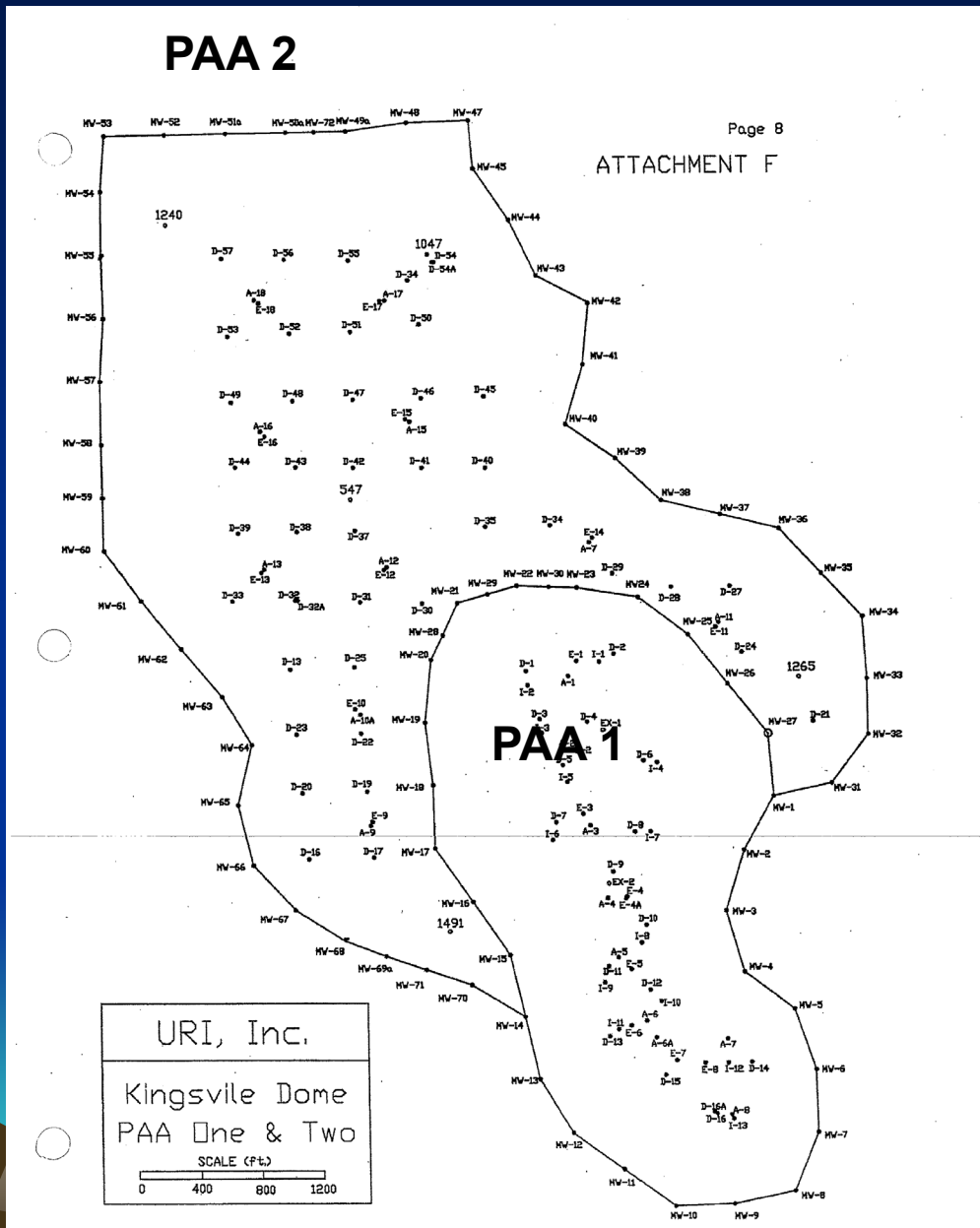
Uranium Energy Corporation (UEC), 2007, Goliad Project, Goliad County, TX, Application to Conduct In Situ Uranium Recovery.

Establish Baseline for the Entire Ore Body - Before Mining

PAA2 baseline established 2 years after mining began at PAA1

TCEQ Approval:
- PAA1: 12 April 1988
- PAA2: 28 June 1990

EPA (2011) recognizes that appropriate baseline is not recorded at many ISL sites



EPA (2011), Considerations Related to Post-Closure Monitoring of Uranium ISL/ISR Sites

2011 2nd Q Monitoring Results and TCEQ Restoration Values

	pH	Ec	U	Cl	Ca	HCO3	SO4	Mo	Ra-226
		umhos	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	pCi/L
PAA1 well average	7.3	1715	**1.00**	175	**124**	**364**	**318**	**1.38**	**nr**
PAA1 Permit Value	**8.7**	**1717**	0.164	**234**	20.8	268	204	0.06	21.6
PAA2 well average	7.5	1382	0.86	166	**84**	**337**	**132**	**1.78**	**nr**
PAA2 Permit Value	**8.66**	**1662**	**1.89**	**224**	25.3	327	224	0.38	92
PAA3 well average	7.1	**2528**	**2.50**	220	**186**	**411**	**773**	**0.61**	**nr**
PAA3 Permit Value	**8.5**	2017	0.338	**289**	18.0	232	364	0.33	21.6

Restoration values established with improper well placement & development protocols & invalid statistical methods (i.e., simple average; no test for N or LN distribution.

Background Water Quality - Summary

Representative samples should be collected from the entire aquifer exemption zone during the early exploration phase

Present practice creates a high bias by:

1) Establishing background after exploration drilling has disturbed the ore zone

2) Allowing background to be determined in adjacent Production Areas after mining begins

3) Placing background wells only in the ore zone

4) Screening the background wells only in the ore interval, rather than through the entire sand thickness

Excursions and Upper Control Limits (UCLs)

Wells in monitor well ring (MWR) are evenly spaced (400 feet); no consideration of sediment heterogeneity

Vertical pathways from abandoned boreholes

No scientific or statistical basis for the values derived for UCLs (maximum value, plus arbitrary factor)

Production zone wells are used to establish UCLs, rather than wells from MWR

Invalid methods allow legal pollution of groundwater

Monitor Wells spaced 400 feet apart do not capture preferential flow paths within fluvial sediments



Vertical Pathways from Abandoned Boreholes

"Direct contamination of groundwater and cross-contamination of aquifers have been documented throughout the United States. One potential groundwater contamination source is abandoned wells and boreholes which penetrate aquifers or which breach a zone that provides a significant barrier to contaminate migration."

William Nork, 1992.
Decomissioning of Wells and Boreholes

Presentation to AGWSE Board of Directors and National Ground Water Association Board of Directors

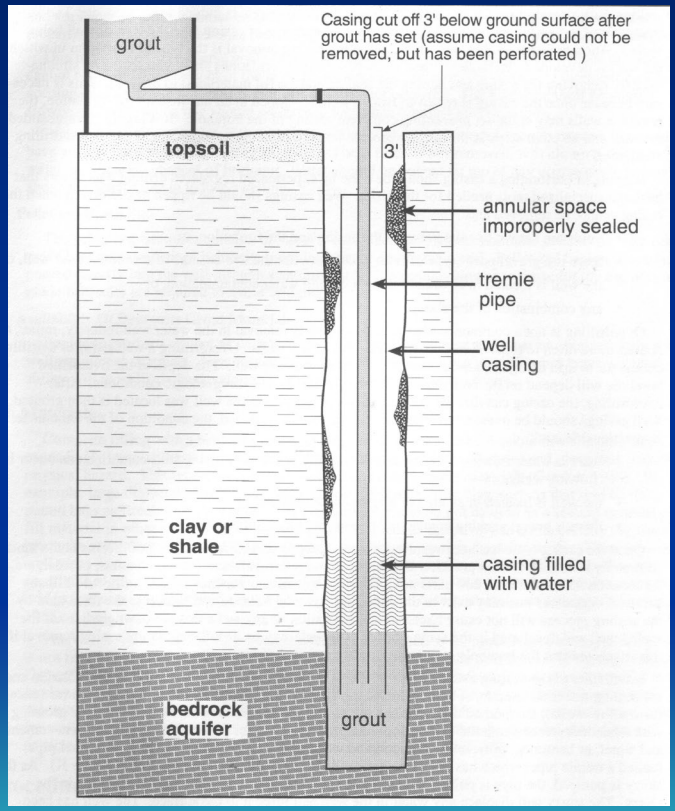
Improper Abandoned Wells at Goliad, TX

May 2006. UEC drills exploratory boreholes.

March 26, 2007. NOV from TRC 74 exploratory boreholes were not properly sealed.

December 2007. Commissioner Long documented additional open boreholes.

Poor oversight of operator when wells are abandoned



Upper Control Limits for excursion monitoring are invalid

Maximum values in the Production Zone (PZ) are used to set upper control limits (UCL) at the Monitor Well Ring (MWR)

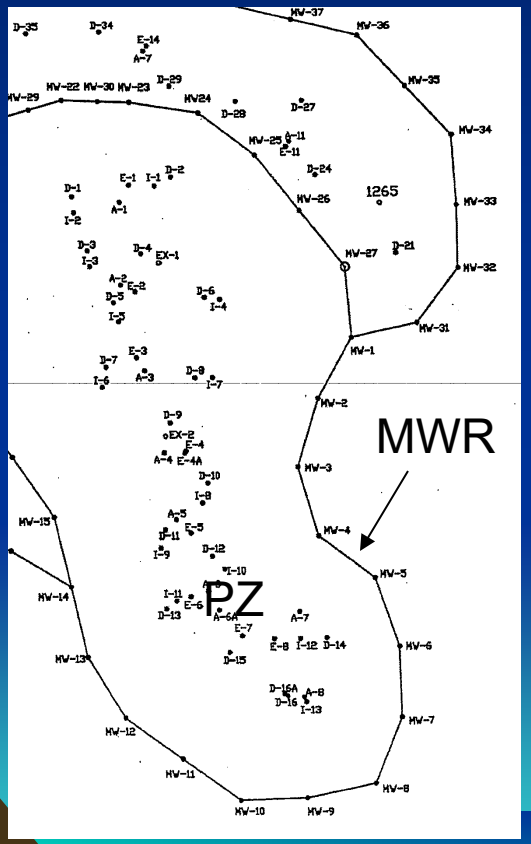
Chloride and Conductivity: max value + 25 percent

Uranium: max value + 5 mg/L

Uranium UCLs and average U at MWR:

	U UCL	Avg U at MWR
PAA1:	5.927 mg/L	0.057 mg/L
PAA2:	8.75 mg/L	0.019 mg/L
PAA3:	6.54 mg/L	0.023 mg/L

Data from Permits for Kingsville Dome, TX



NOTE: This practice allows legal pollution of the groundwater outside the MWR!

Uranium values in Garcia Well W-24 (~300 ft to MWR)

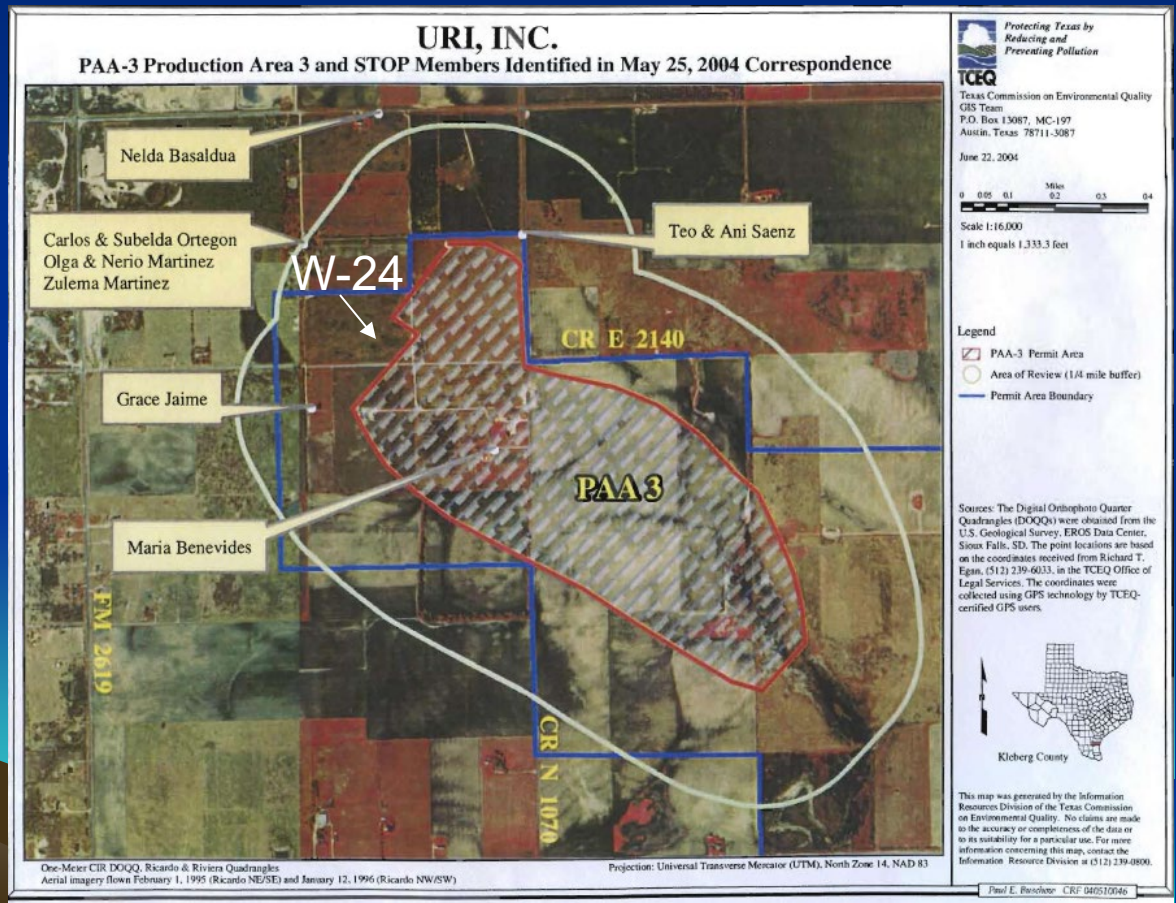
date	U (mg/L)	Data Source
6/18/98	0.152	EPA Region VI, 2004 investigation
9/19/00	0.187	EPA Region VI, 2004 investigation
Spring 2010	0.771	Texas A&M, Kingsville

PAA3 mined 1998 to mid 1999

No mining & no bleed mid 1999 - 2006

March 2007, mining resumed in PPA3

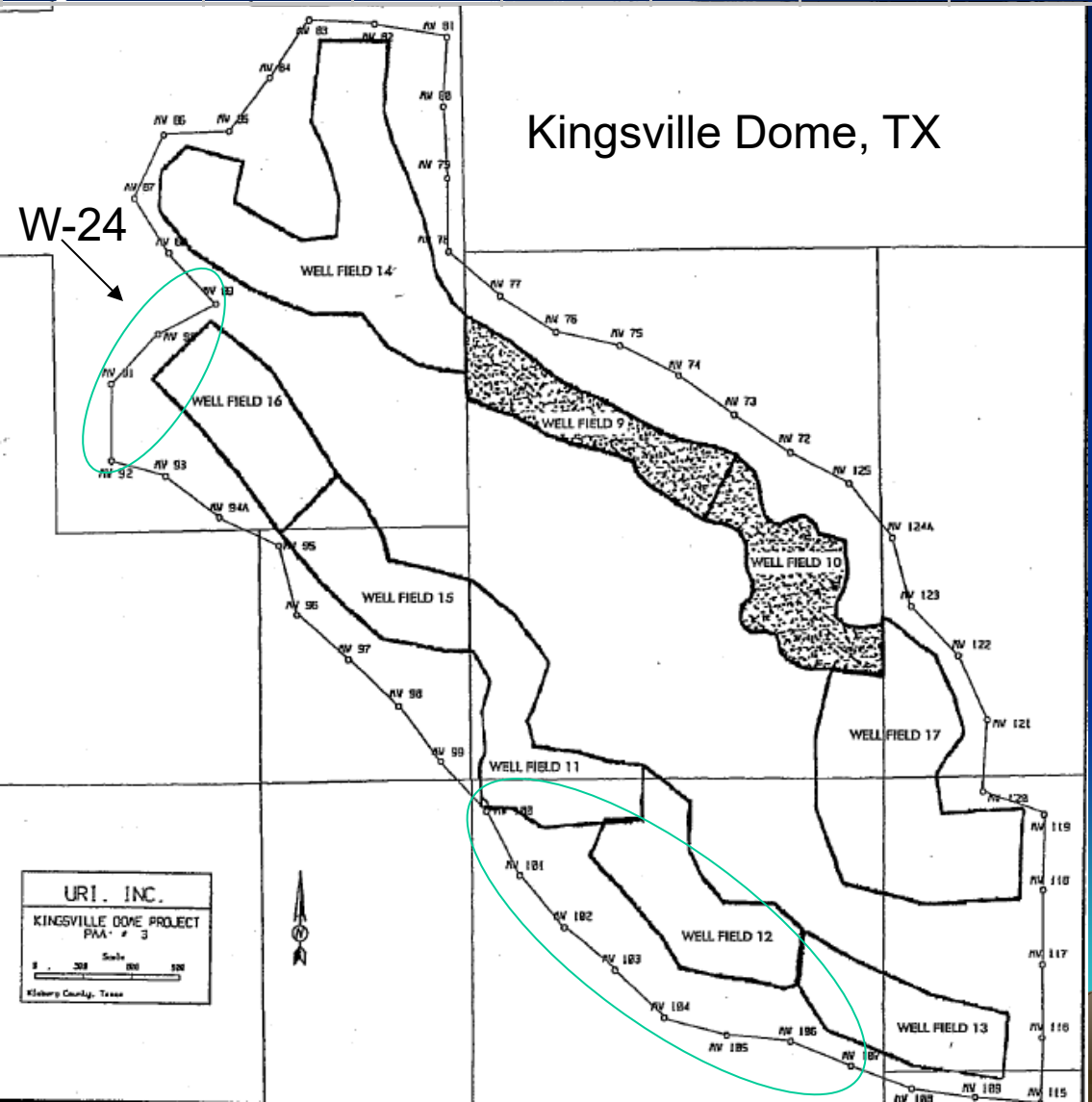
August 2007, elevated U levels at MWR



Kingsville Dome, TX

Uranium Values for Select PPA3 MWR

	MW-89	MW-90	MW-91A	MW-92	MW-100	MW-101	MW-102	MW-103	MW-104	MW-105	MW-106
baseline 1997	0.022	0.024	0.031	0.036	0.030	0.053	0.020	0.016	0.036	0.031	0.032
August 2007	1.69	1.32	2.14	1.67	3.60	2.52	5.17	2.79	2.14	2.32	1.26



No excursions because the uranium control limit is 6.54 mg/L

Most wells reported as 'too wet' to sample

Many results reported as <1 mg/L uranium

Legal contamination of water source outside the MWR

Excursions & UCLs - Summary

Wells in MWR are evenly spaced and may miss channel features that are less than 400 ft wide

Production zone wells are used to establish UCLs, rather than wells from MWR

No scientific or statistical basis for the values derived for UCLs – allows legal pollution of groundwater

Garcia Well W-24 appears to be impacted by uranium contamination moving past the MWR in PPA3

Restoration Values & Timeframes

Establish early in the exploration process, after rough delineation of the ore body (systematic grid)

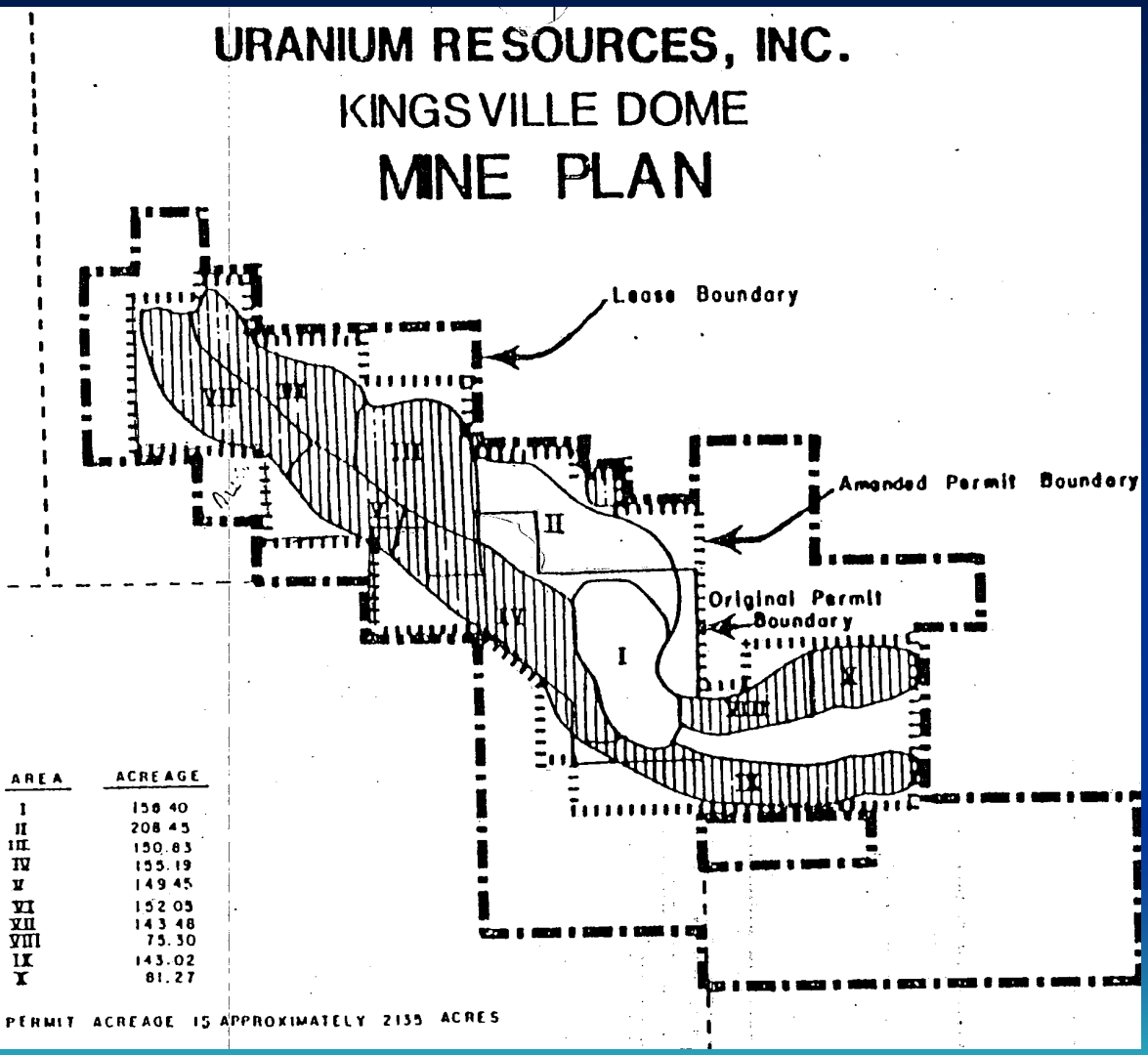
Proper drilling and development (or geoprobe) of wells to minimize disturbance of ore

A minimum of 4 quarterly sample rounds and valid statistical theory and methods to derive the restoration standard

No ISL well field has been restored to original restoration values in the mining permit

Decades may be needed to restore original chemical conditions in aquifer

Delineation of the Ore Body



Initial Permit Dec 1986

PAA1 restoration values April 1988

PAA2 restoration values June 1990

PAA3 restoration values May 2006

Lagged approach for developing restoration values allows mining fluids in one PAA to bias adjacent PAA

2011 2nd Q Monitoring Results and TCEQ Restoration Values

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Restoration values established with improper well placement & development protocols & invalid statistical methods (i.e., simple average; no test for N or LN distribution.

ISL Restoration in Texas is a Failure

‘Regarding the original question of whether or not groundwater has been restored to baseline in Texas uranium ISR well fields, it was observed that no well field for which final sample results were found in TCEQ records returned every element to baseline.’

USGS Open-File Report 2009-1143

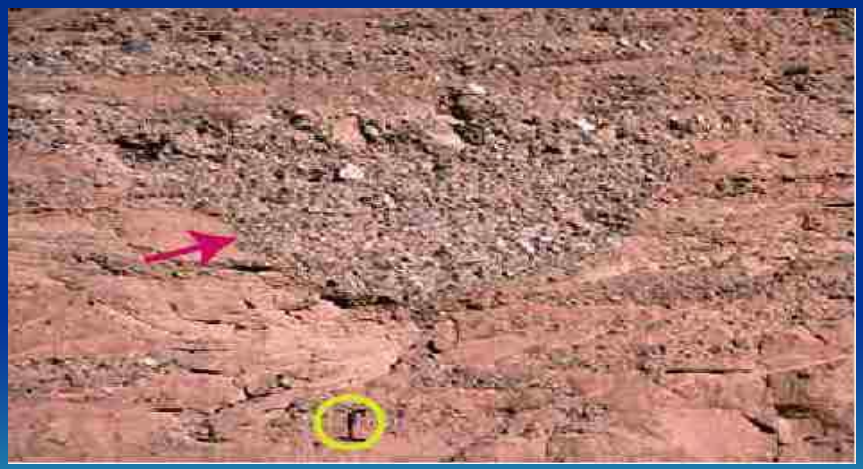
If restoration is unsuccessful when invalid, biased baseline values are used, how can there be success when baseline values are derived with proper statistical theory and methods?

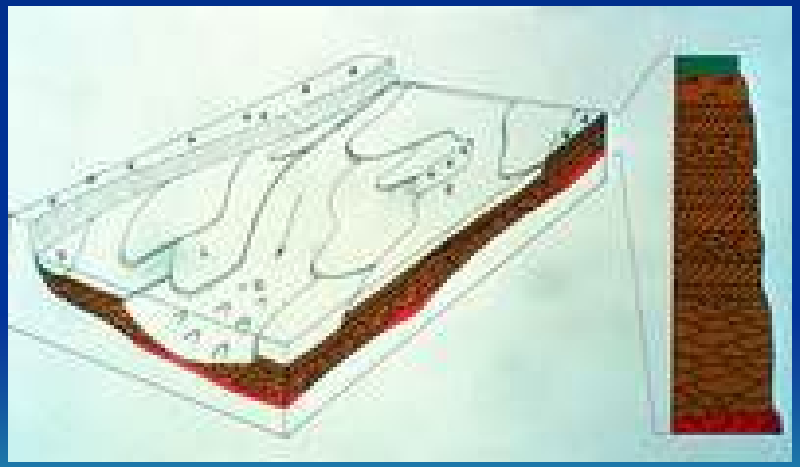


Timeframes to Restore Aquifer

"..because of heterogeneities in the aquifers, the fresh groundwater that is brought into the ore zone does not completely displace the residual lixiviant.."

"..lixiviant that has mixed into the groundwater with lower mobility during the mining operations (and mineral surfaces exposed to that groundwater) will continue to provide a source of contamination even after long periods of pumping and treatment.."





Consideration of Geochemical Issues in Groundwater Restoration at Uranium In Situ Leach Mining Facilities, NUREG/CR-6870, January 2007, Prepared by USGS for NRC

Timeframes to Restore Aquifer

"..groundwater sweep may cause oxic groundwater from ugradient of the deposit to enter into the mined area, making it more difficult to re-establish chemically reducing conditions.."

"..it is difficult to predict how much time is required or even if the reducing conditions will return via natural processes. The mining disturbance introduces a considerable amount of oxidant to the mined region.."

Consideration of Geochemical Issues in Groundwater Restoration at Uranium In Situ Leach Mining Facilities, NUREG/CR-6870, January 2007, Prepared by USGS for NRC

Long-term monitoring and research studies at closed ISL sites are needed to assess present chemical conditions in the aquifer and the kinetics of important reactions



Surface Reclamation

Often ignored, but also an important part of the overall site restoration process







Long-Term Monitoring of ISL Sites

In its anticipated revisions to 40CFR192, EPA (2011) considers long-term monitoring of ISL sites to be an integral part of the regulatory standards.

NRC license-established period is generally 6 months

Actual period to stabilize groundwater will be at least as long as the period of mining, and probably decades

Responsible actions by industry and regulators to protect human health and the environment



EPA (2011), Considerations Related to Post-Closure Monitoring of Uranium ISL/ISR Sites

Summary of Discussion Topics

Natural uranium and radium background levels in groundwater contacting uranium ore



Valid background water quality in proposed aquifer exemption zone

Excursions and upper control limits (UCLs)

Restoration values and timeframes

Long-term monitoring to assess plume migration and protect human health and the environment

