Rads

Engineering Evaluation of the Control of Radionuclides in Missouri Public Water Supplies

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Overview

About Radionuclides

Radionuclide Removal Technologies

Case Study #1: PWSD #9 of Boone County

Case Study #2: Leadwood, MO

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About Radionuclides

Pronunciation

Definition

What They Do

Health Effects

Rads in Regs

Pronunciation

+ NEW +

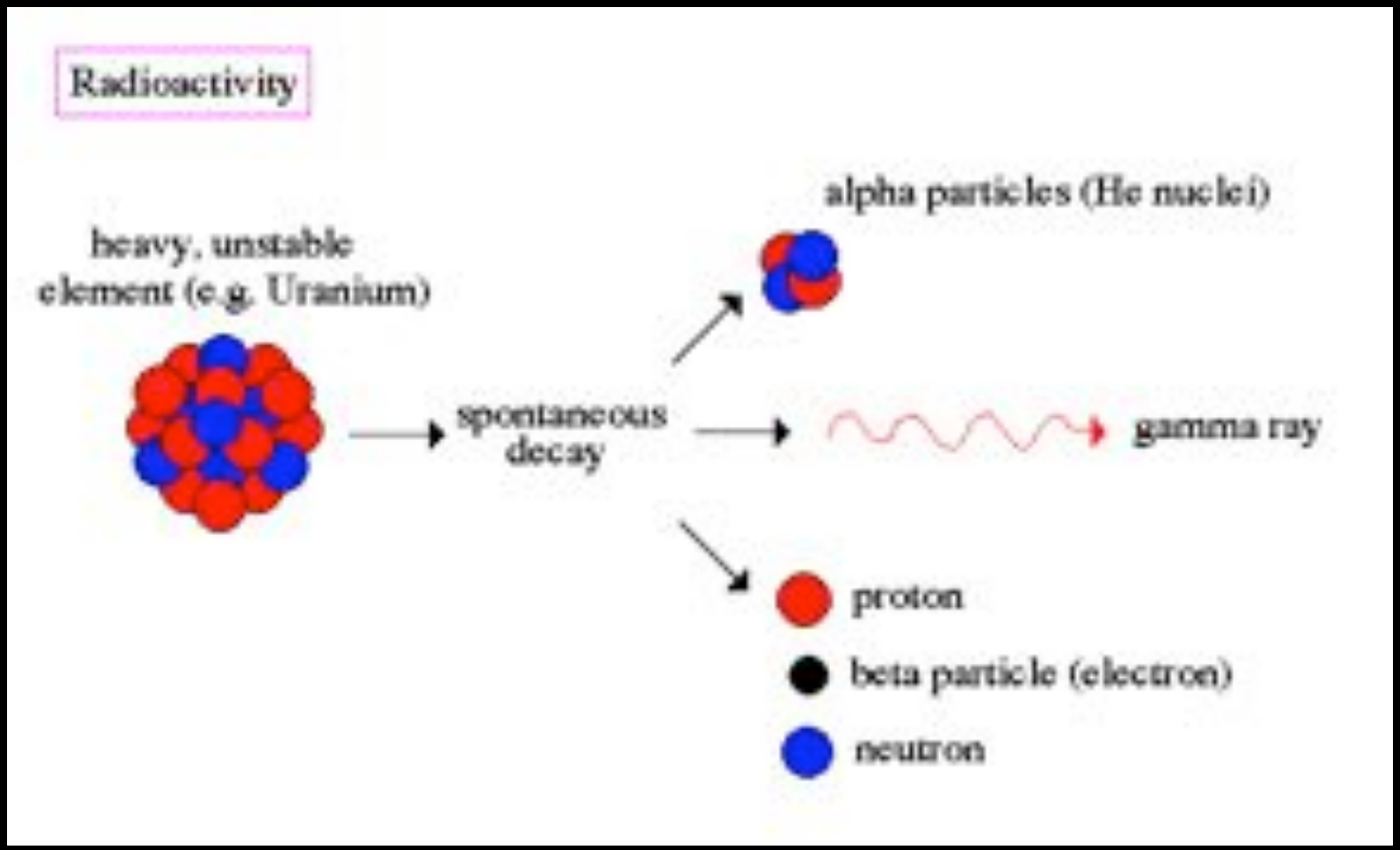
Radionuclide

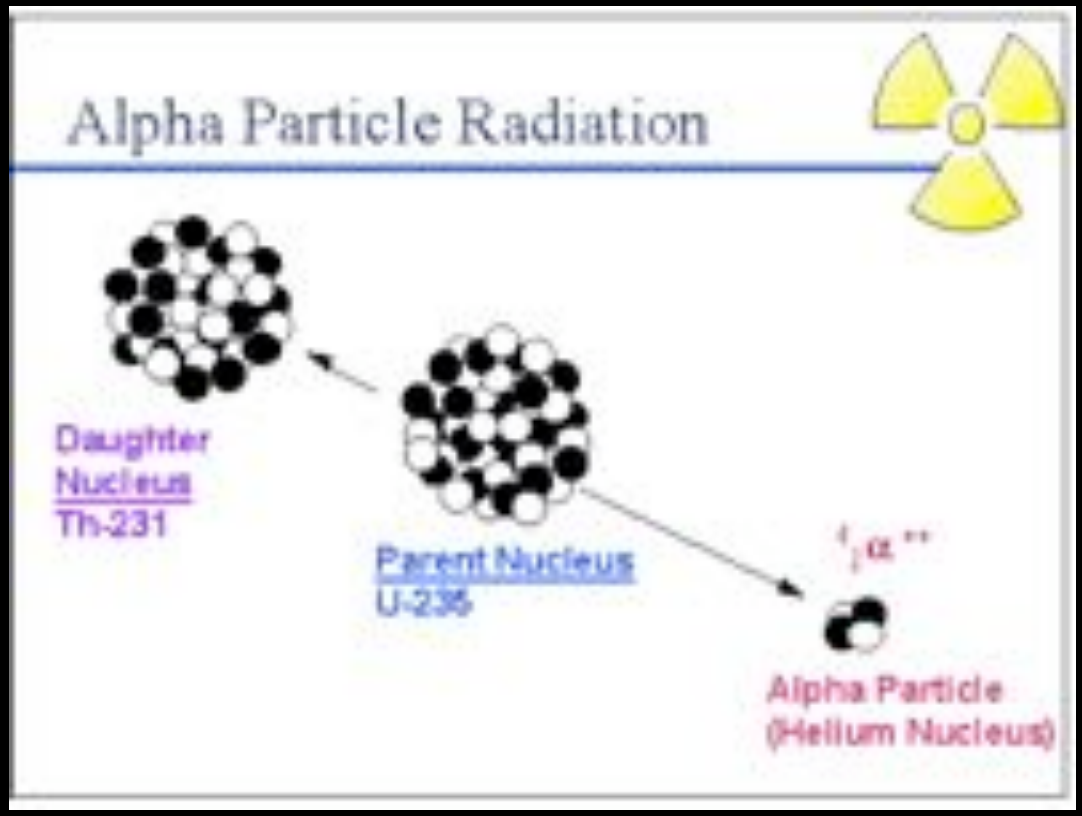
+ NEW +

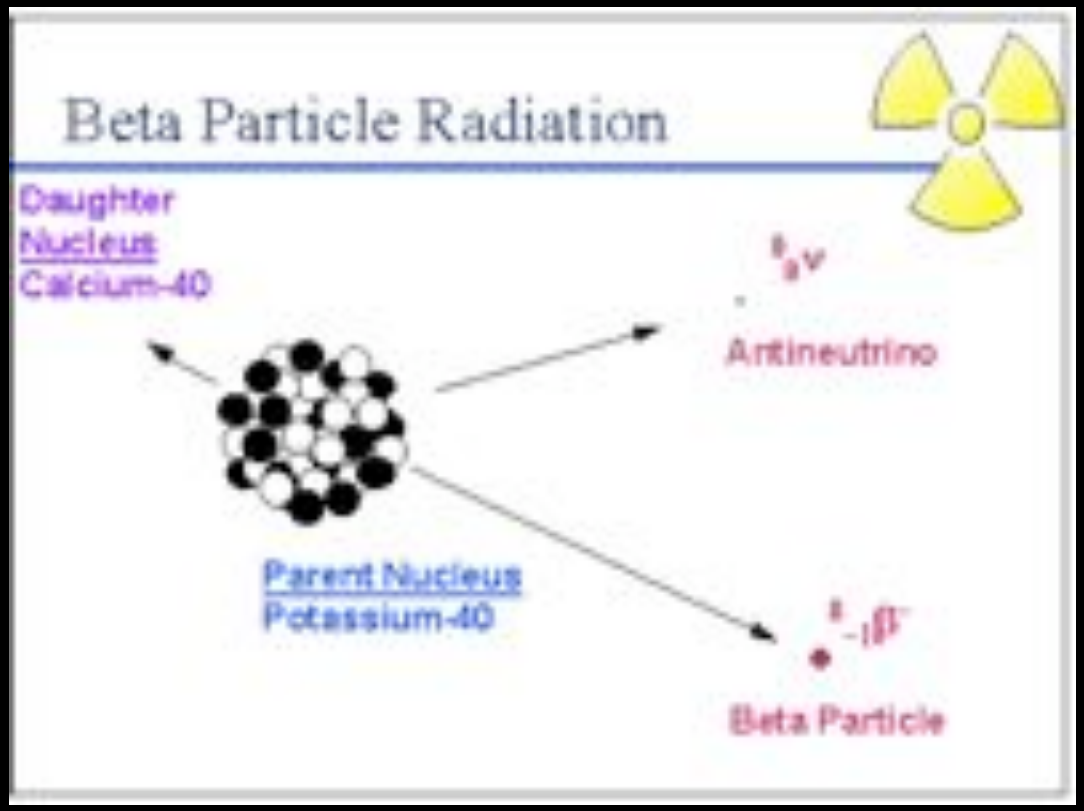
RADIO NEW CLYDE

What are Radionuclides?

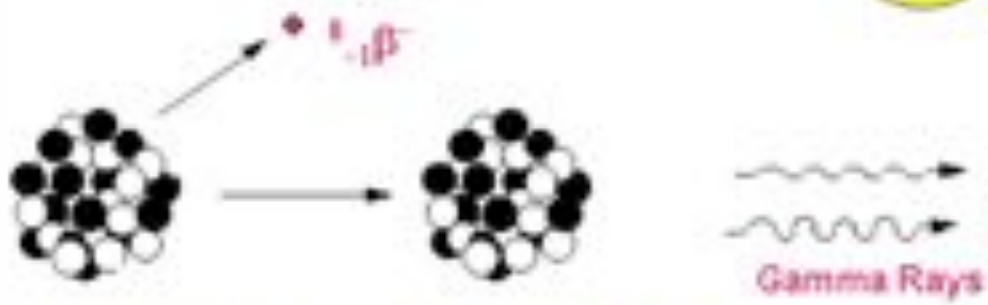
Radioactive material capable of giving off radiant energy in the form of particles or rays as alpha, beta and gamma rays by the disintegration of atomic nuclei.


Radioactivity
heavy, unstable element (e.g. Uranium)
spontaneous decay
alpha particles (He nuclei)
gamma ray
proton
beta particle (electron)
neutron


Alpha Particle Radiation
Daughter
Nucleus
Th-231
Parent Nucleus
U-235
$^{4}_{2}\alpha^{++}$
Alpha Particle
(Helium Nucleus)

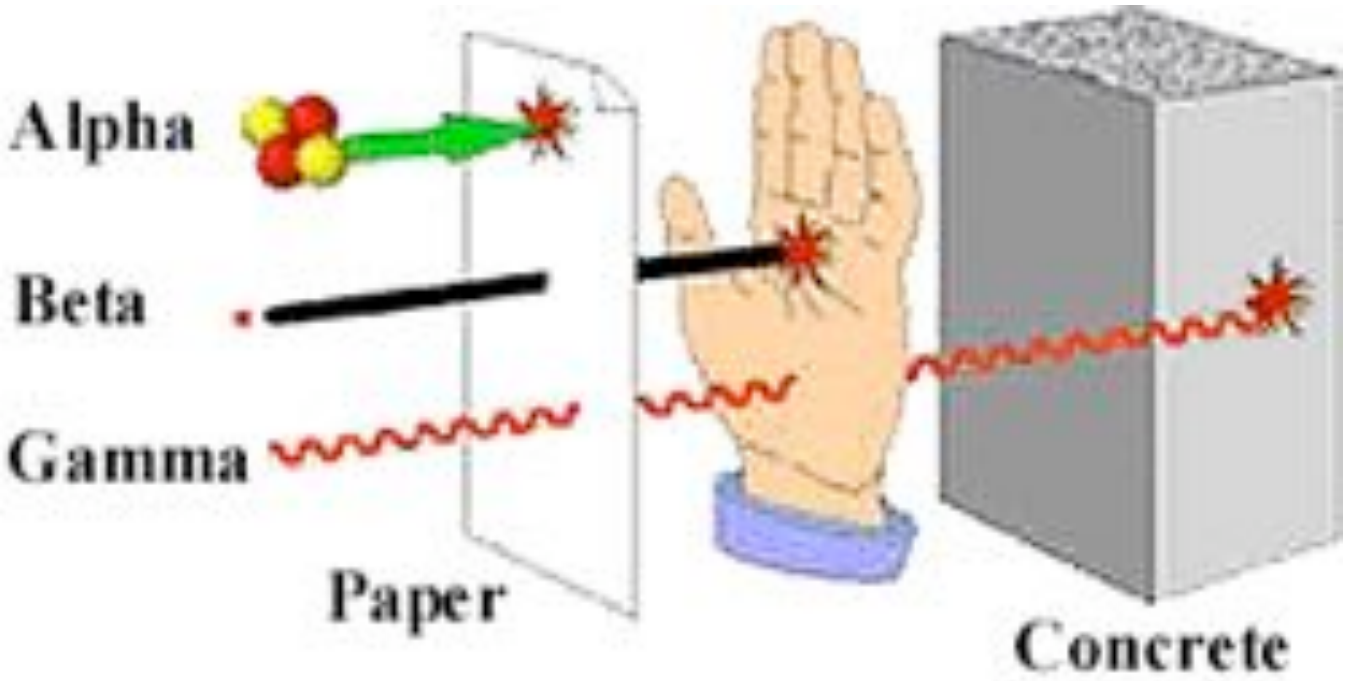

Beta Particle Radiation
Daughter
Nucleus
Calcium-40
Antineutrino
Parent Nucleus
Potassium-40
Beta Particle

Gamma-Ray Radiation



Parent Nucleus
Cobalt-60

Daughter Nucleus
Ni-60


Alpha
Beta
Gamma
Paper
Concrete

Radium

Radium-226 / -228

- naturally-occurring
- half-lives of 1,620 / 5.8 years
- primarily alpha / beta emitters
- behave like calcium
- removed by lime softening or ion exchange
- reverse osmosis also a BAT

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Health Effects

Radionuclides Notice of Data Availability
Technical Support Document, March 2000

"EPA recognizes that, at these levels, the actual health impact from ingested radionuclides will be difficult, if not impossible, to distinguish from natural disease incidences, even using very large epidemiological studies employing sophisticated statistical analyses."

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Health Effects

Radium Dial Painters

Health Effects

Radium Dial Painters

benign bone growths,
osteoporosis,
severe growth retardation,
tooth breakage,
kidney disease,
liver disease,
tissue necrosis,
cataracts,
anemia,
immunological suppression,
death

Health Effects

The Three Studies: #1

"Peterson et al. (1966) found an elevated rate of fatalities from bone malignancies among residents of Iowa and Illinois with elevated radium-226 in drinking water.

However, the statistical significance was marginal and confounding factors could not be ruled out."

Health Effects

The Three Studies: #2

"Bean et al. (1982) found an increased incidence of four out of 10 cancers investigated among Iowa residents of small communities with elevated radium-226 content of the water supply.

However, confounding by radon exposure could not be ruled out and cancer sites were different from those observed in dial painters."

Health Effects

The Three Studies: #3

"Lyman et al. (1985) found a small consistent excess of leukemias in Florida counties with elevated radium-226 or radium-228 in private wells,

but there was no evidence of a dose-response trend. Rates of colon, lung and breast cancer and lymphoma showed no consistent excess."

Health Effects

Computer Modeling

"Using RADRISK modeling, EPA estimated that continuous consumption of 15 pCi/L of most alpha particle emitters in drinking water at 2 l/day would pose a lifetime cancer risk between 10^{-6} and 10^{-4}."

Regulatory History

1976 Radionuclides Rule

1991 Proposed Radionuclides Rule

EPA proposed to retain the 15 pCi/L MCL for gross alpha particle activity, but modify it by excluding radium-226, as well as uranium and radon. MCLs of 20 pCi/l for radium -226 and -228 were proposed.

2000 Final Radionuclides Rule

Rads in Regs

Radionuclides of Concern in Drinking Water

Radionuclide	*MCL*
Combined Radium-226 / -228	5 pCi/l
(Adjusted) Gross Alpha	15 pCi/l
Beta Particle and Photon Radioactivity	4 mrems/yr
Uranium	30 μg/l

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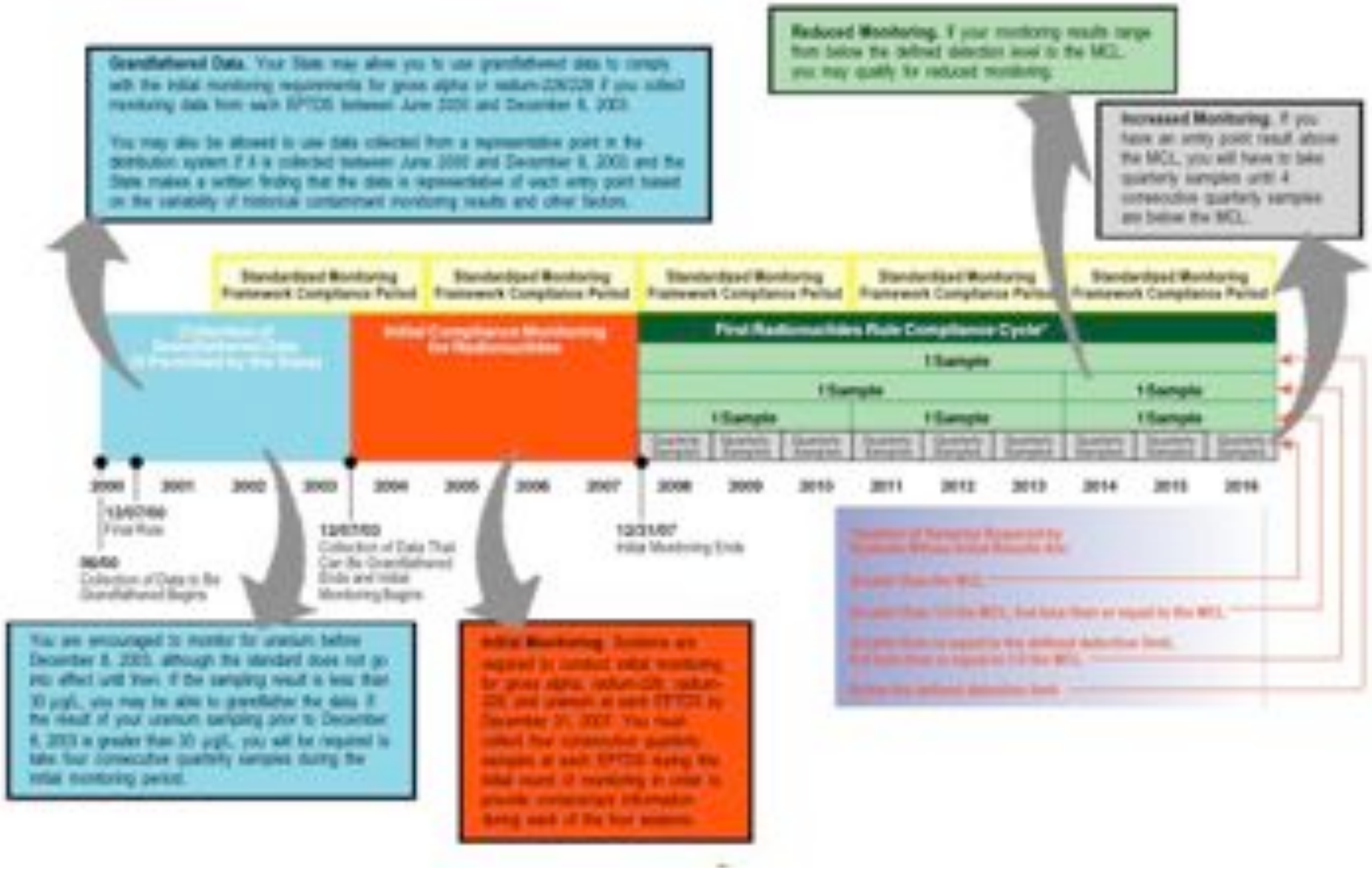
Annotated Radionuclide Montoring Timeline (2000 - 2016)



Removal Technologies

EPA's Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996 (September 1998)

Removal Technologies

- Ion exchange
- Reverse osmosis
- Lime softening
- Greensand filtration
- Co-precipitation with barium sulfate
- Selective sorbents
- Electrodialysis/electrodialysis reversal
- Pre-formed hydrous manganese oxides

Ion Exchange

BAT for radium removal (gross alpha follows)

80 - 98% radium removal

point-of-entry, point-of-use (POE/POU)

Radium sorbs preferentially to Ca and Mg

Ion Exchange Waste

Rinse and Backwash Water

- 2 - 10% of product water volume
- 23 - 500 pCi/l

Exhausted Resin

- 9 pCi/g

Radium-Selective Resin

Dowex RSC

Z-88

Can treat millions of bed volumes over several years

RSR Wastes

Resin

- is not regenerated
- is a low-level radioactive waste
- must go to a LLRW landfill (UT)

Reverse Osmosis

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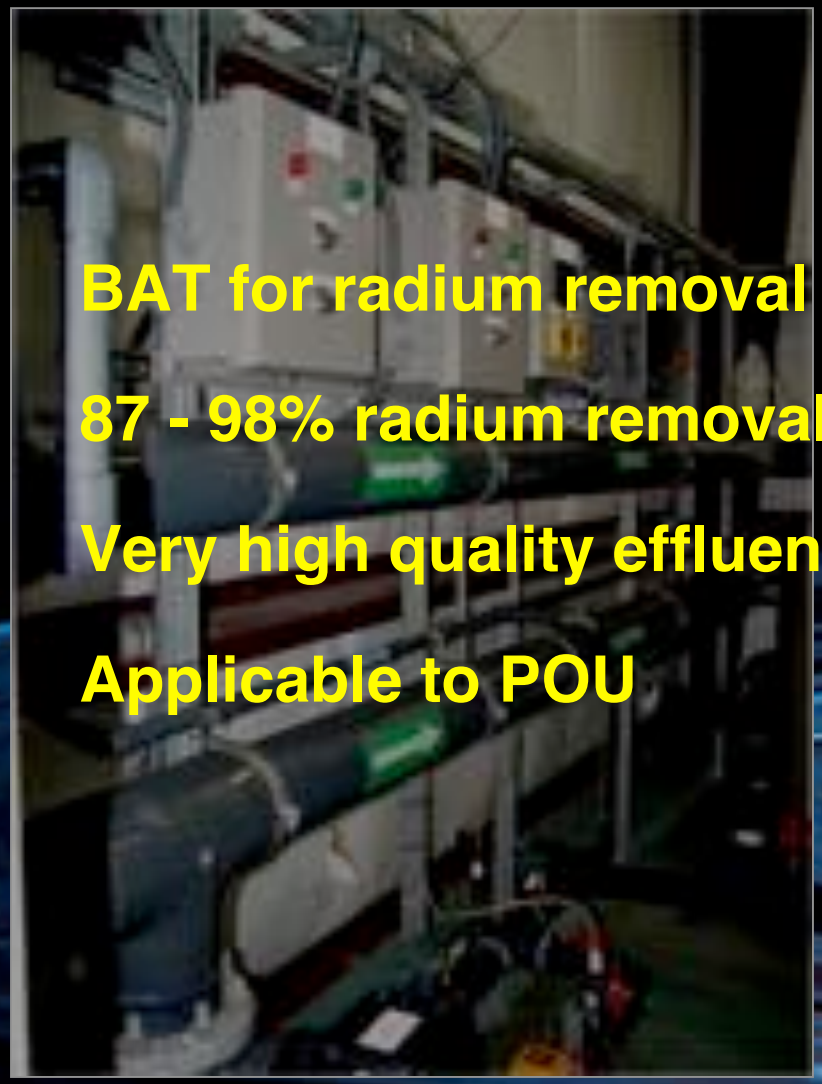
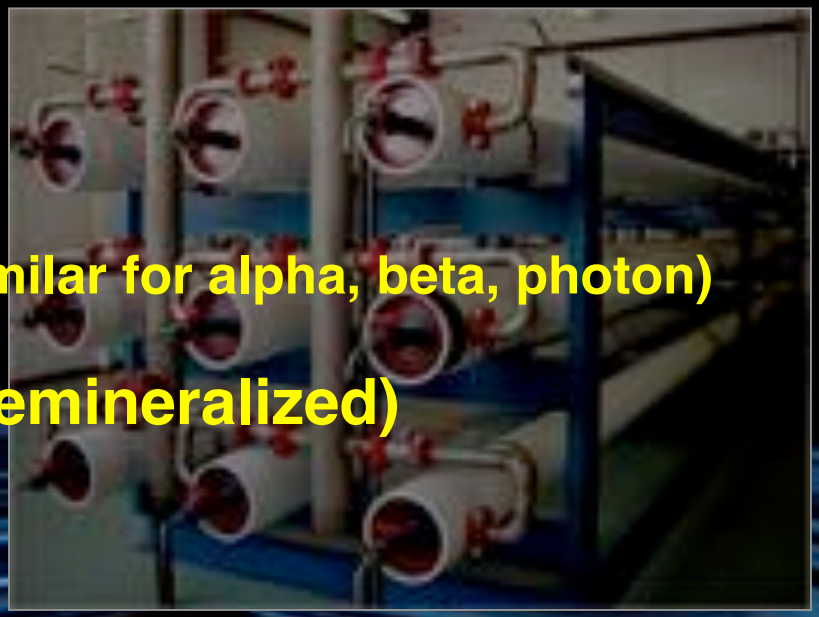
Reverse Osmosis





BAT for radium removal

87 - 98% radium removal (similar for alpha, beta, photon)

Very high quality effluent (demineralized)

Applicable to POU

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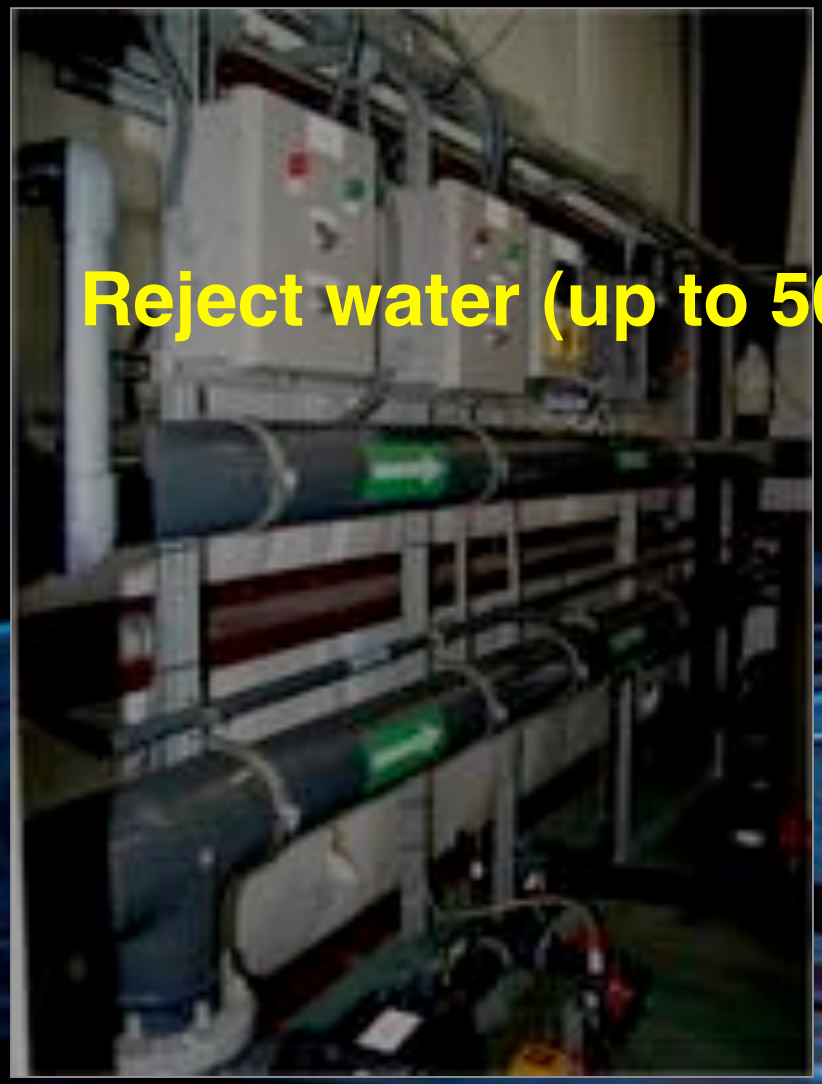
RO Waste



Reject water (up to 50%)

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Lime Softening

Radium precipitates as radium carbonate

80 - 95 % Radium removal

Lime Softening Wastes

Lime sludge (~2,000 pCi/l wet, 8 pCi/g dry)

Filter backwash liquid and sludge (6 - 50 pCi/l)

Sludge supernatant (20 - 25 pCi/l)

Greensand Filtration

Potassium permanganate pretreatment

56 - 90 % radium removal

Detention increases removal efficiency

Greensand Filtration Wastes

Backwash sludge and supernatant (65 - 170 pCi/l)

Eventual media disposal (30 - 250 pCi/g)

Pre-formed HMO

Hydrous Manganese Oxide

HMO (MnO_2) formed by oxidizing manganese sulfate

Brief detention time

Filtration to remove suspended MnO_2 (containing sorbed Ra)

71 - 96 % radium removals

Pre-formed HMO Wastes

Hydrous Manganese Oxide

- HMO sludge
- Filter backwash
- Sludge supernatant

Table VII-9

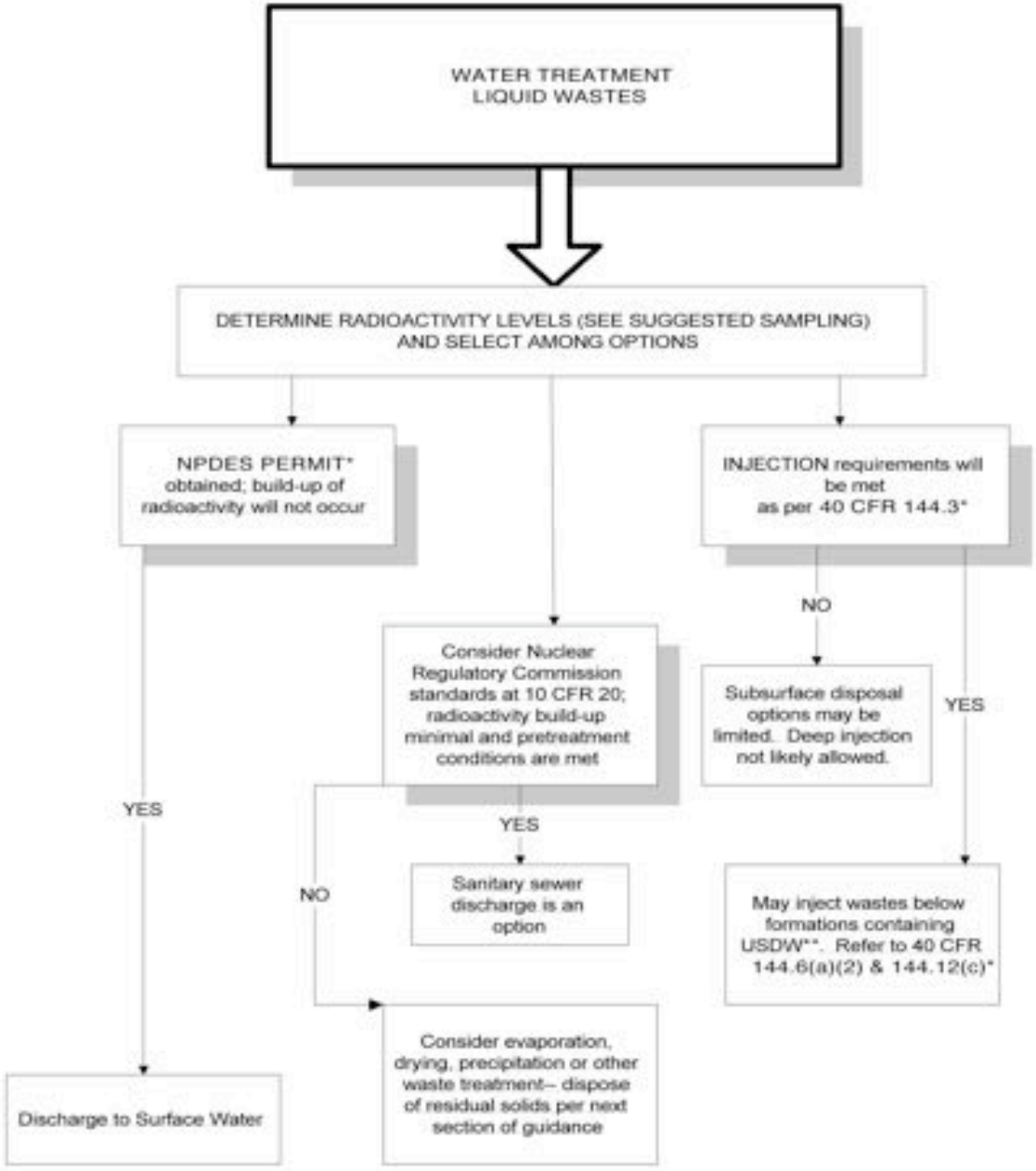
CASE STUDIES: PRODUCTION COSTS FOR REMOVAL OF RADIONUCLIDES FROM COMMUNITY WATER SYSTEMS
(Dollars per thousand gallons treated)

Treatment to Remove Radium from Ground Water [1]

	Small Systems[2]		Large Systems[3]	
	Range	Average (No. of Studies)	Range	Average (No. of Studies)
Cation Exchange	$0.08 - $3.69	$1.10 (7)	$0.27 - $1.58	$0.89 (3)
Lime Softening	$2.91	NA (1)	$0.15 - $1.80	$0.97 (2)
Reverse Osmosis	$0.54 - $4.34	$2.19 (6)	NA	NA
Greensand Filtration	$0.63 - $1.47	$1.03 (3)	NA	NA
Other Oxidation/Filtration[4]	$0.01 - $2.40	$0.82 (9)	$0.04 - $1.83	$0.63 (5)

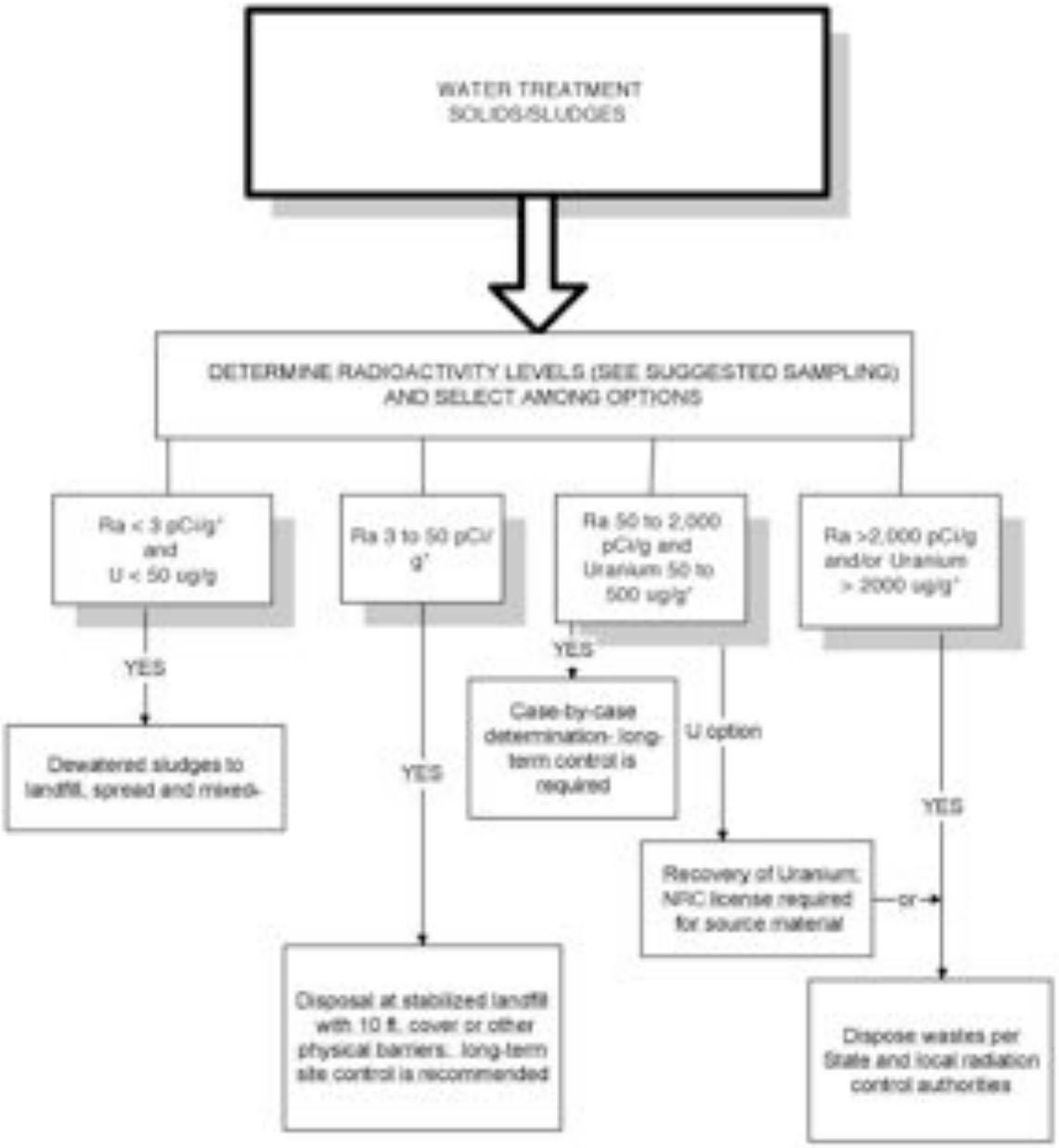
Notes:
1. Data source is EPA 1998a, "Actual Costs of Compliance with the Safe Drinking Water Act Standard for Radium-226 and Radium-228", otherwise stated otherwise.
2. Small systems are defined as those serving 10,000 persons or fewer.
3. Large systems are defined as those serving greater than 10,000 persons.
4. Data source is EPA 1998b.

Liquid Wastes



* Bold type indicates actual regulatory requirements; other options are EPA suggested disposal methods.
**USDW is underground source of drinking water

Solids & Sludges



+ Provisions under 40 CFR 257, 258 and 260 thru 266 may apply.
* Bold type indicates Federal regulatory requirements; other options are EPA suggested disposal methods.

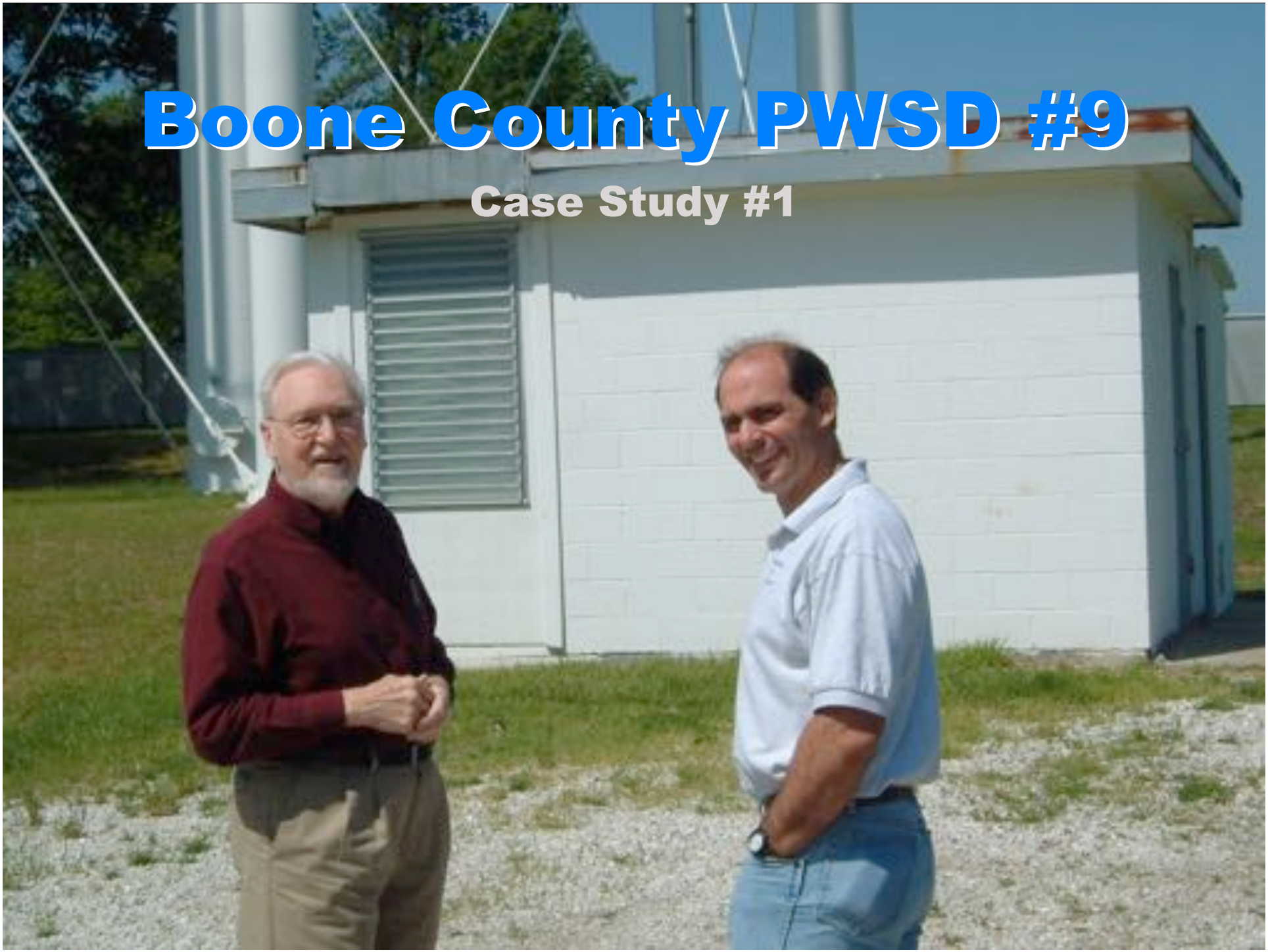
Case Studies

Boone County PWSD #9

Leadwood, MO

Boone County PWSD #9

Case Study #1



Wells

		installed	*yield (gpm)*	*% of supply*
Well #3	**(Harg)**	**1972**	**700**	**33.3**
Well #4	**(Murry / Route Z)**	**1977**	**600**	**33.3**
Well #5	**(Air Park)**	**1981**	**175**	**0 (standby)**
Well #6	**(Route J / Mlrsbrg)**	**1985**	**700**	**33.3**

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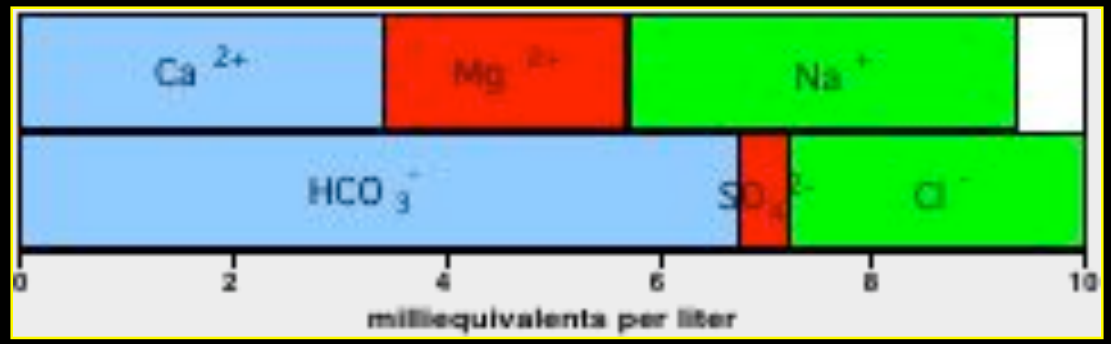
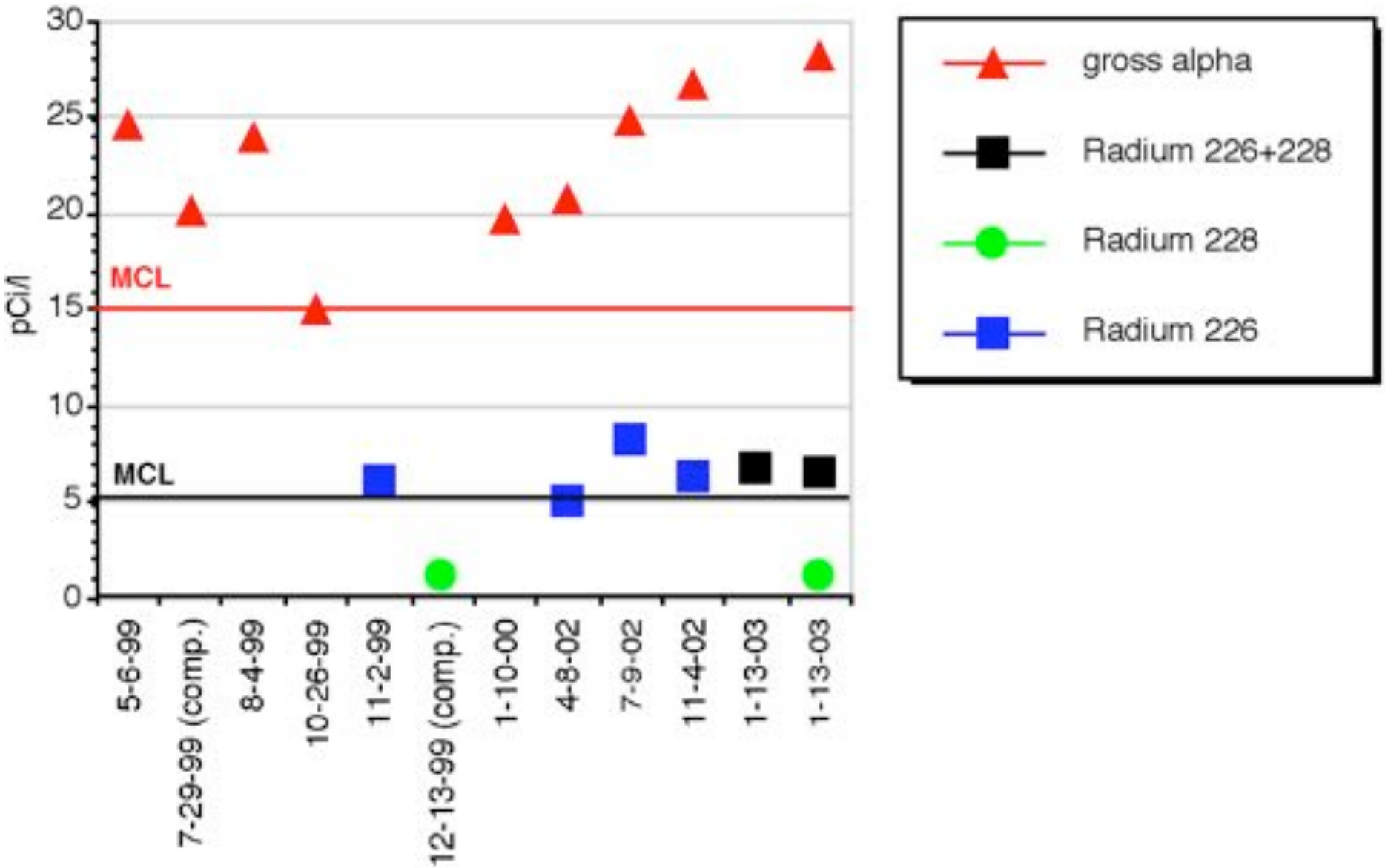
Water Quality

Average of all wells

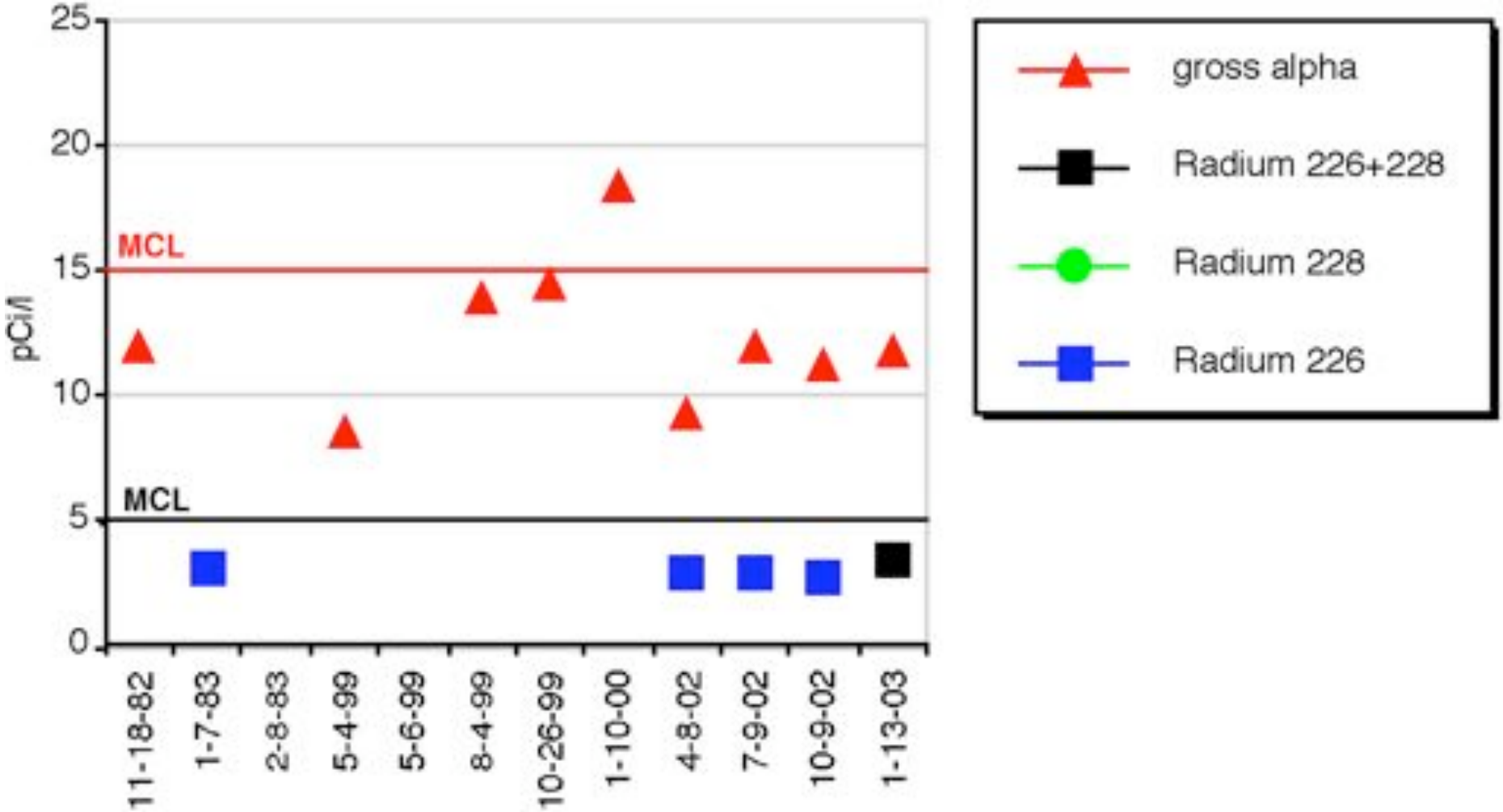
Hardness	300 mg/l as $CaCO_3$
Alkalinity	361 mg/l as $CaCO_3$
Sulfate	20 mg/l
Fe & Mn	little to none



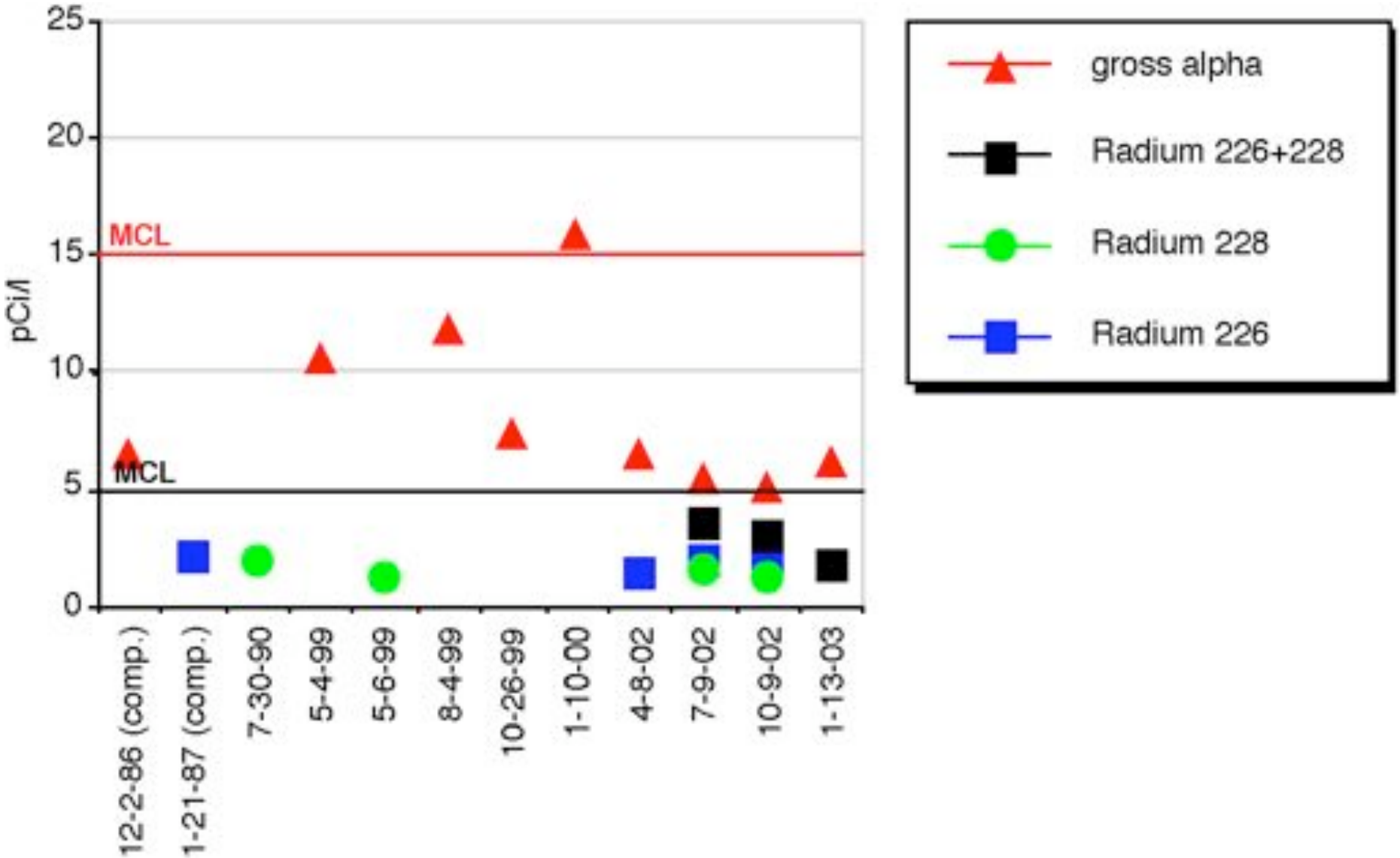
Well # 3 Radionuclides



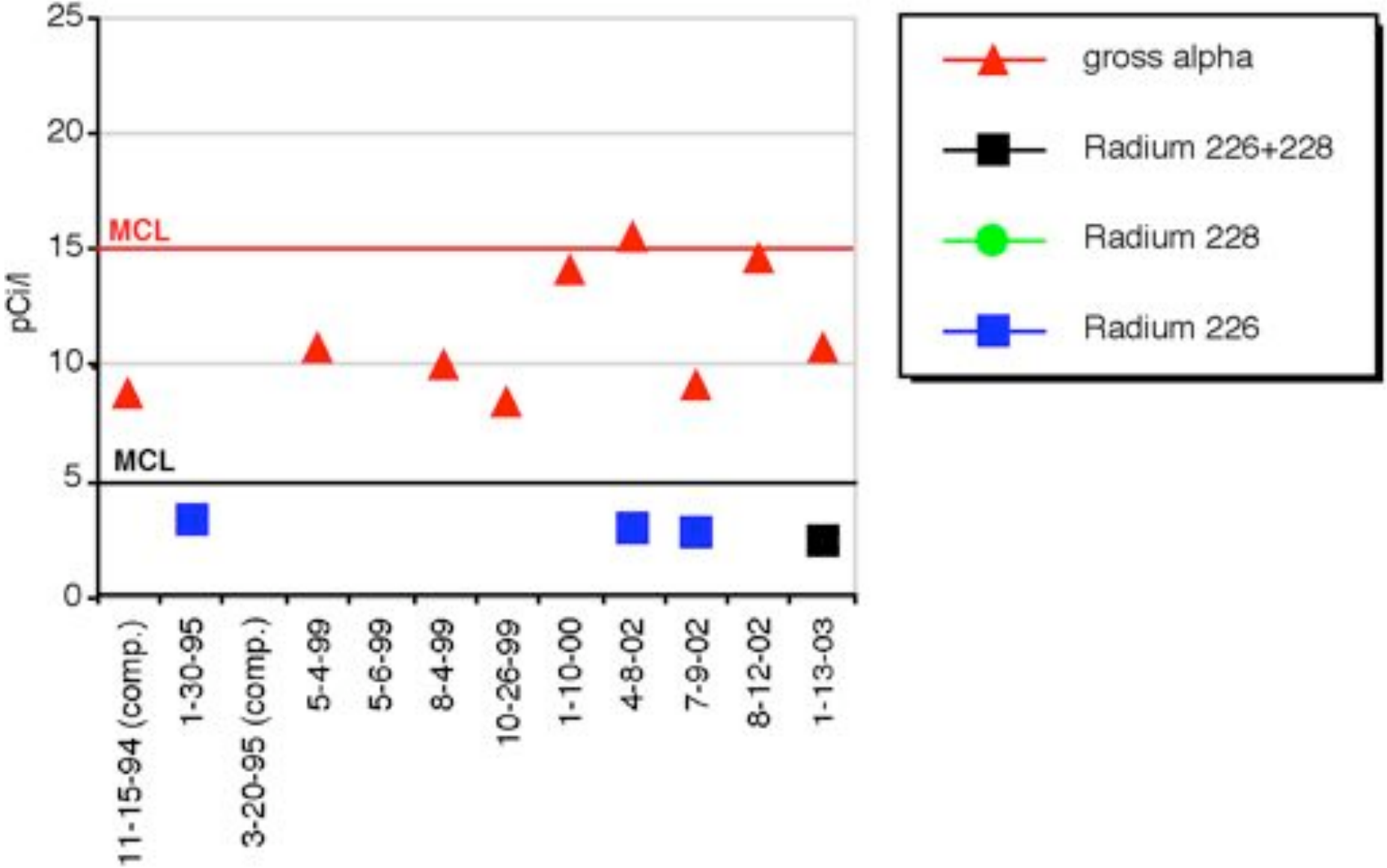
Well # 4 Radionuclides



Well # 5 Radionuclides



Well # 6 Radionuclides



Issues

- Present treatment: chlorination only (DS II)
- Only one well out of compliance
- Disposal challenges (no nearby sewer)
- Didn’t have a bazillion dollars lying around

The Universe of Options

TREATMENT

NON-TREATMENT

Recommendations: Non-Treatment Alternatives

- upgrade Well #4 to 1,000 gpm ($85,000)
- return Well #5 to routine service (H_2S?)
- Blend Well #5 with Well #3 to meet rads regs

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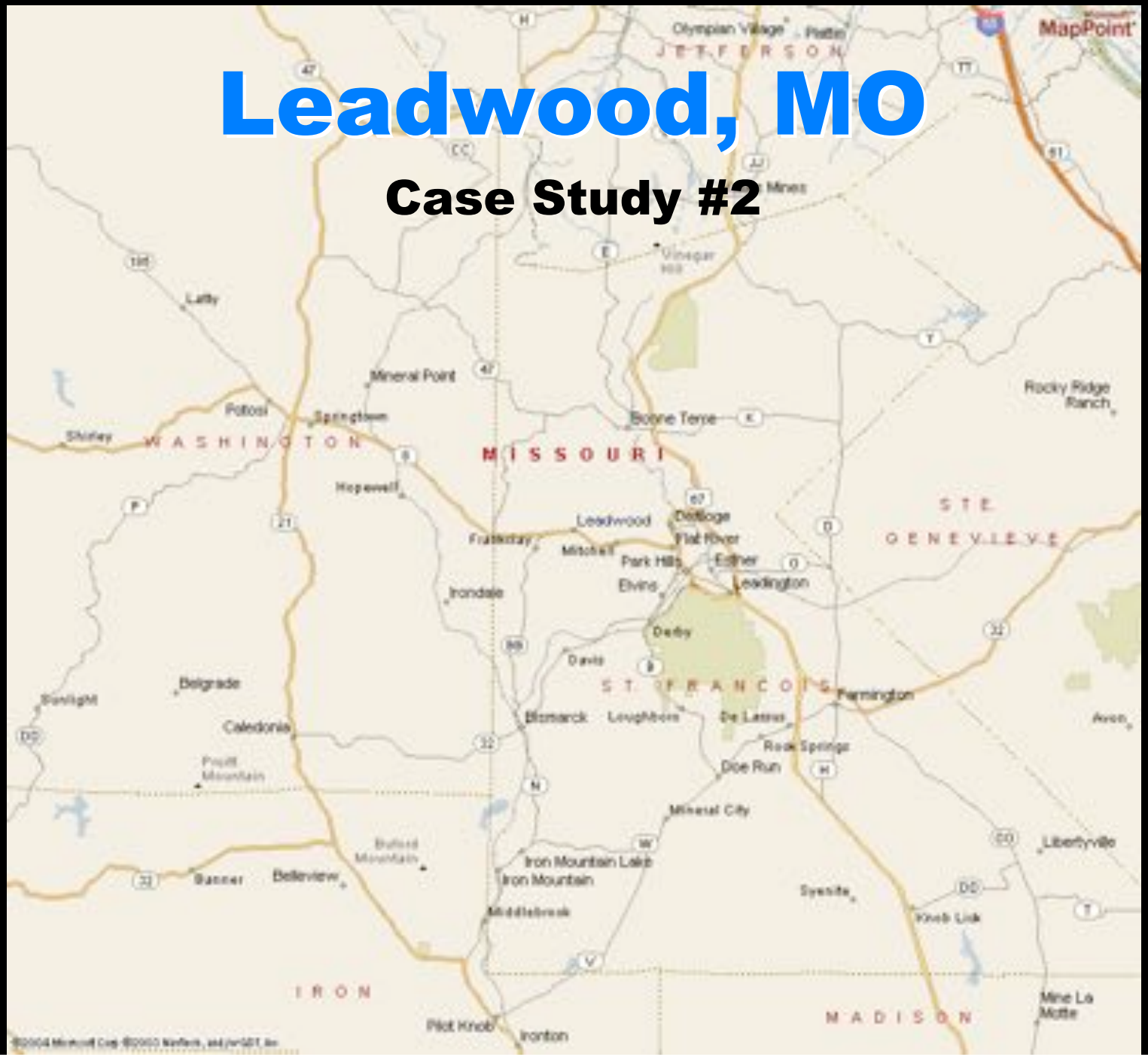
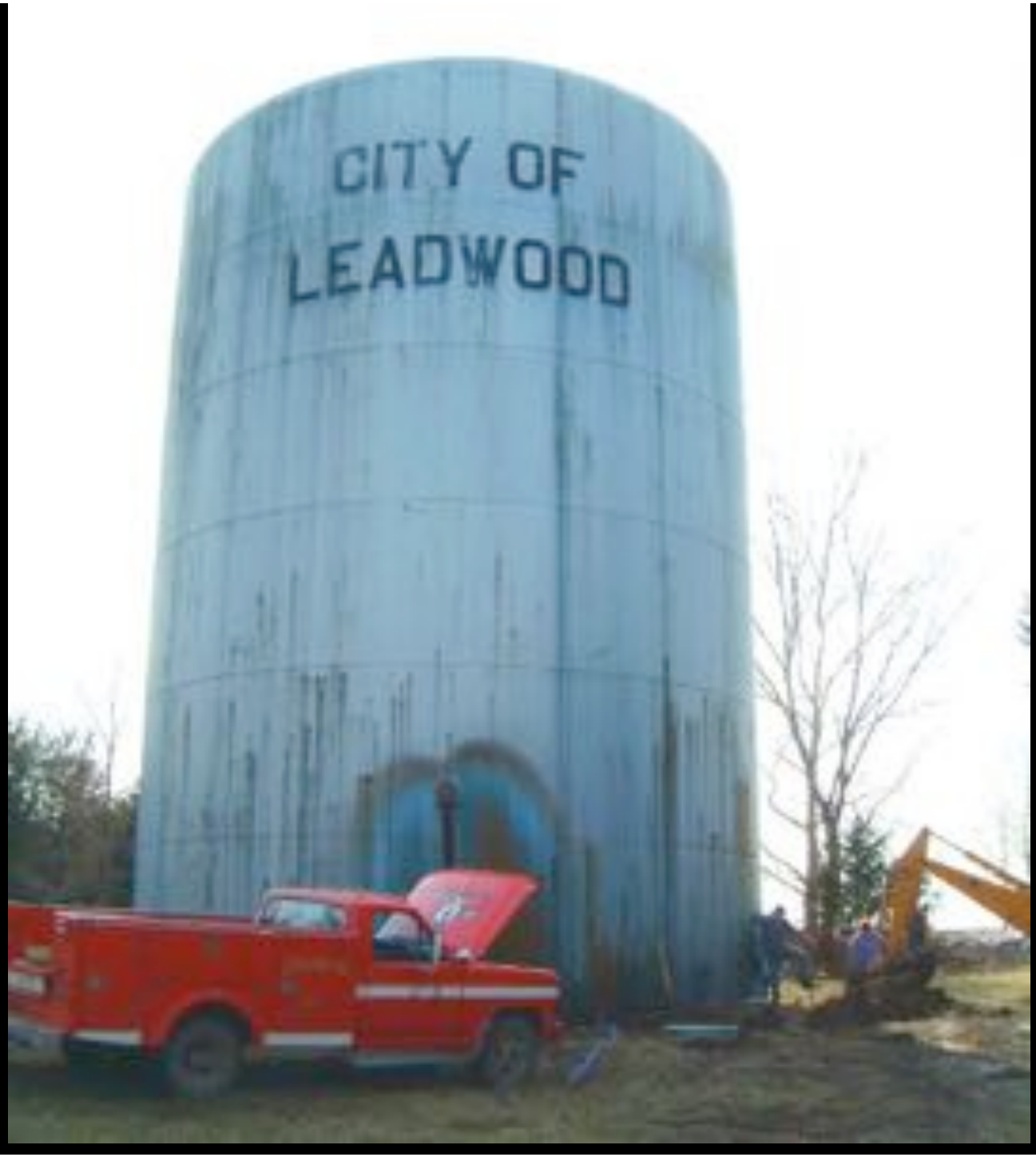
Leadwood, MO

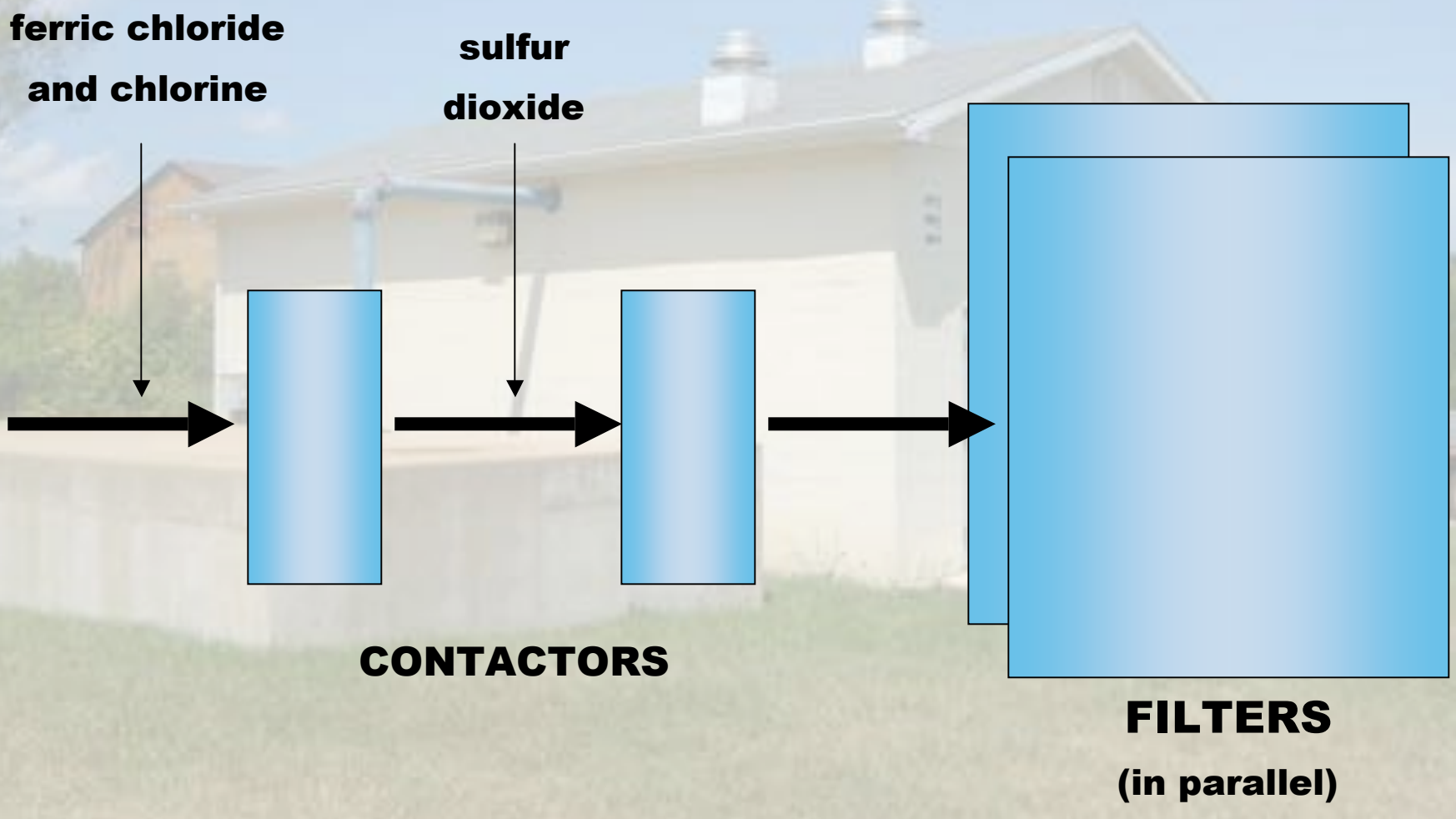
Case Study #2




CITY OF
LEADWOOD


Radioactivity in Well #2
Gross Alpha
Ra 228
Th 230
Ra 226 + Ra 228
Radioactivity, pCi/l
45
40
35
30
25
20
15
10
5
0
gross alpha MCL
Ra 226 + Ra 228 MCL
2/1988
5/1988
8/1988
1/1989
4/2000
3/2001
12/2001

Filtronics System



Filtronics

- Iron and manganese removal
- Not on EPA's list of rads removal technologies
- "It worked in the pilot study…"

H_2O'C Engineering's Job

client: MDNR

1) Evaluate plant performance (rads removal)

2) Restore plant to factory specifications

3) Re-evaluate plant performance

4) Recommend improvements if necessary

Contactors

Sulfur Dioxide

Filters

Electromedia I

H_2O'C Engineering's Job

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1) Evaluate plant performance (rads removal)

2) Restore plant to factory specifications

3) Re-evaluate plant performance

4) Recommend improvements if necessary


Radioactivity in Delivered Water
Gross Alpha
Ra 228
Ra 226
Ra 226 + Ra 228
Radioactivity, pCi/l
45
40
35
30
25
20
15
10
5
0
Gross Alpha MCL
Ra 226 + Ra 228 MCL
Prior to
After Installation of Treatment Facilities

H_2O'C Engineering's Job

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1) Evaluate plant performance (rads removal)

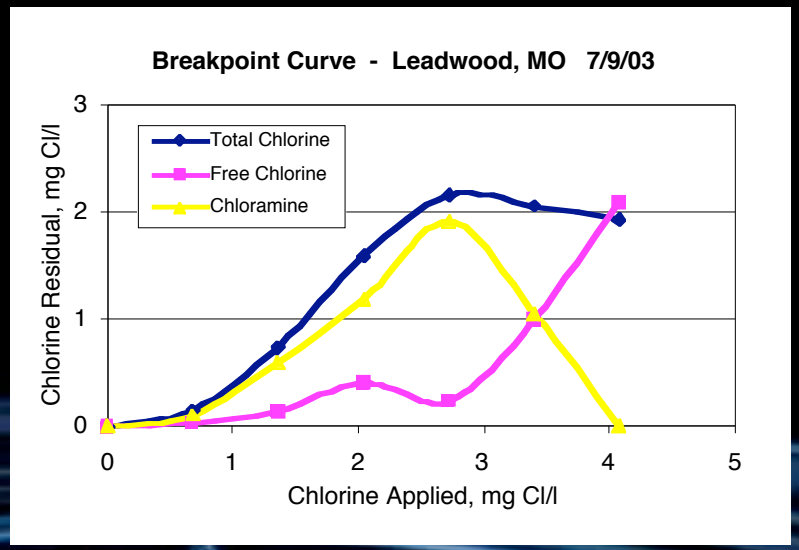
2) Restore plant to factory specifications

3) Re-evaluate plant performance

4) Recommend improvements if necessary

Plant Restoration

- Backwash rates
- Filter flow rates
- Breakpoint curve
- Chemical feeds
- Media replenishment (one filter only)
- Filtronics' approval



H_2O'C Engineering's Job

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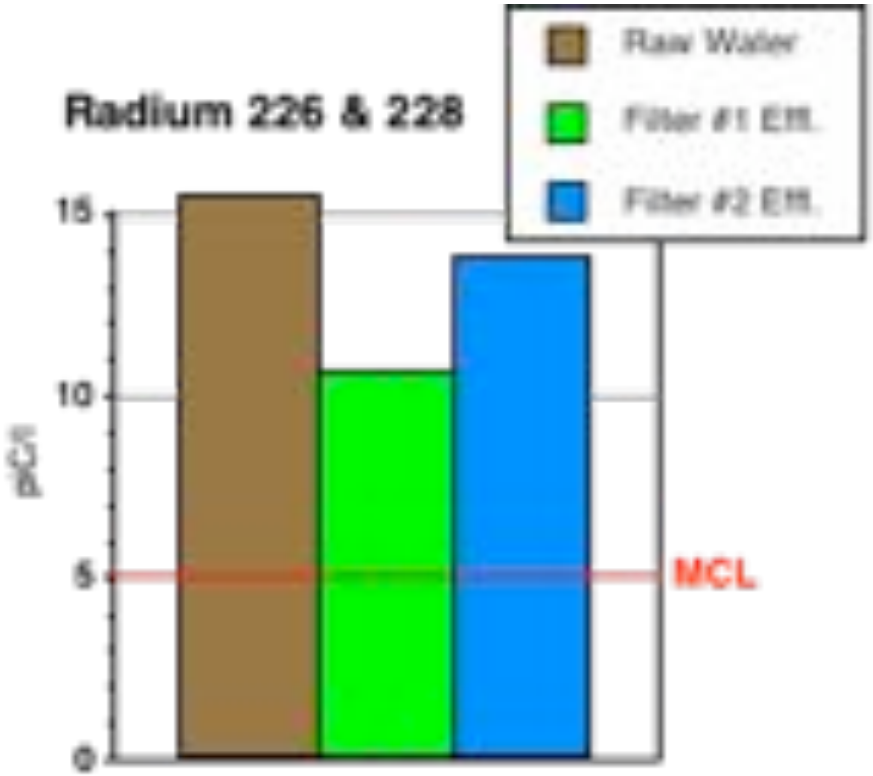
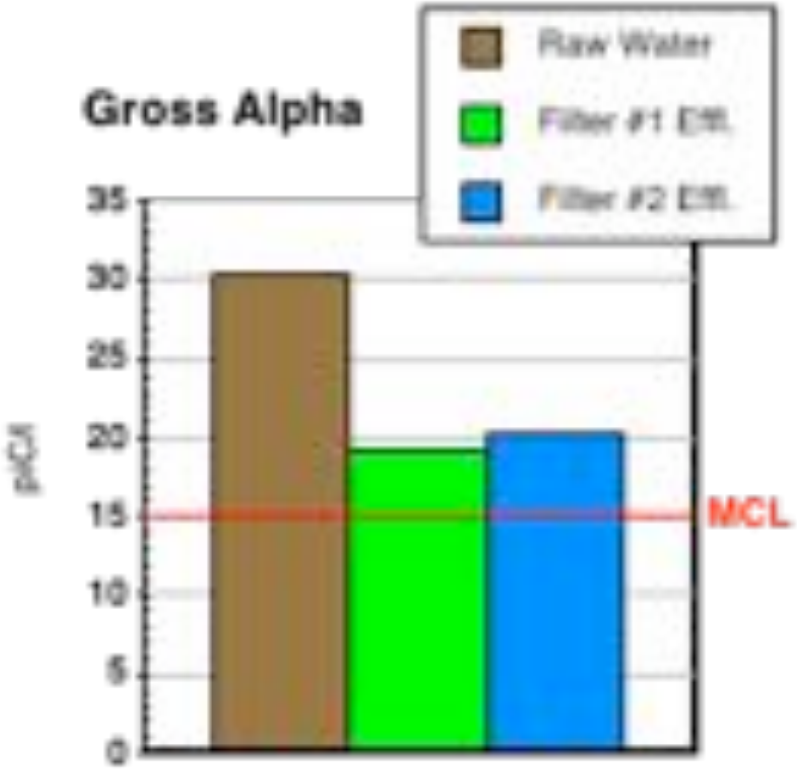
Restored Plant Performance





Restored Plant Performance

- Modest removals
- Comparable to historical data
- Removals insufficient to meet MCLs
- Depleted filter performed slightly better

H_2O'C Engineering's Job

client: MDNR

1) Evaluate plant performance (rads removal)

2) Restore plant to factory specifications

3) Re-evaluate plant performance

4) Recommend improvements if necessary

Best Bets of BATs

1. Pre-formed Hydrous Manganese Oxide (HMO) Filtration
2. Greensand Filtration
3. Coprecipitation of Radium with Barium Sulfate
4. Ion Exchange

HMO Filtration

1) Change of chemical feed from ferric sulfate to manganese sulfate

2) Elimination of sulfur dioxide feed (officially)

3) Projected rads removals: ~80% (Valentine, 1992)

3) Capital cost: $0 (zero, zilch, nada, bupkis, bagel)

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Non-Treatment Solutions

Source Substitution

Well Replacement, Selective Withdrawal, Purchasing

Blending

Regionalization

Do Nothing

"A Radiological SNC is a PWS which… exceeds the unreasonable risk to health level identified for that contaminant. The unreasonable health level is 2 times the MCL." (EPA's Implementation Guidance for Radionuclides)

Rads Recap

About radionuclides

Radionuclide removal technologies

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