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DEPARTMENT OF ENVIRONMENTAL PROTECTION

Bureau of Radiation Protection

PA O&G TENORM Study Overview

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ISCORS Meeting at EPA HQs

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Presentation Objectives

- Review PA O&G TENORM Study
- Discuss criteria for regulatory control of TENORM
- Look at where TENORM regulatory control, and where it is headed

D. Allard [2013], adopted from an IRPA 11 meeting graphic

RADIATION PROTECTION SYSTEM

SOCIETAL AND POLITICAL INFLUENCES

TENORM

RADIATION BIOLOGICAL EFFECTS

RADIOLOGICAL PROTECTION STANDARDS, STATUTES AND REGULATION (FEDERAL AND STATE)

RADIATION MEASUREMENTS –INSTRUMENTATION & DOSIMETRY

RADIATION PROTECTION OF WORKERS

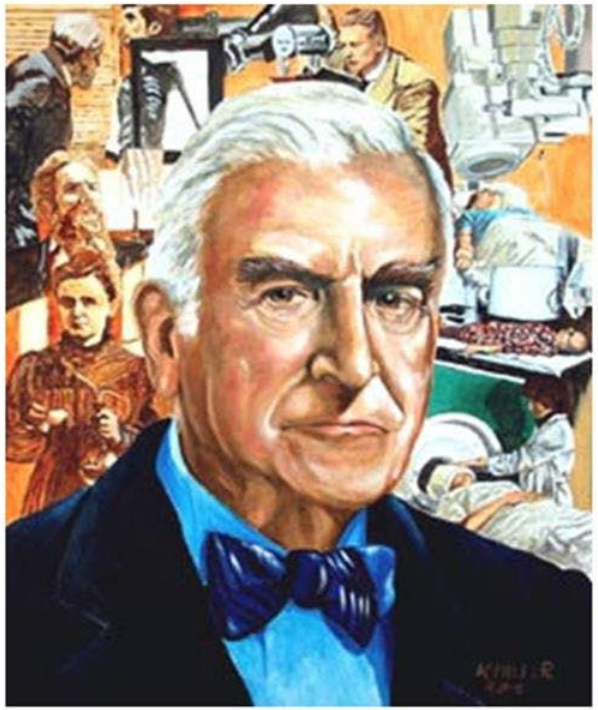
RADIATION PROTECTION OF THE ENVIRONMENT

RADIATION PROTECTION OF PATIENTS

RADIATION PROTECTION OF THE PUBLIC

BASIC & APPLIED RESEARCH, INCIDENTS, ACCIDENTS AND ANALYSIS

NCRP - Lauriston S. Taylor



Taylor painting by Ken Miller

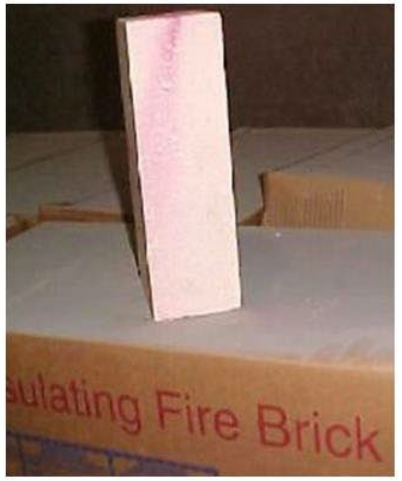
Radiation protection is not only a matter of science. It is a problem of philosophy, and morality, and the utmost wisdom."

(L.S. Taylor, 1956)

NCRP
National Council on Radiation Protection & Measurements

TENORM Generation

- Oil & Gas Industry [pipe scale, produced water, sludges, etc.]
- Drinking water treatment, paper / pulp
- Mineral Sands, refractory zircons, fertilizers, phosphogypsum, geothermal energy, uranium mining, coal, etc.



TENORM Regulatory Framework

- Environmental Protection Agency (EPA)
- Nuclear Regulatory Commission (NRC)
- Dept. of Energy (DOE)
- Dept. of Labor - Occupational Safety & Health Administration (OSHA)
- Dept. of Transportation (DOT)
- States (e.g., Pennsylvania)

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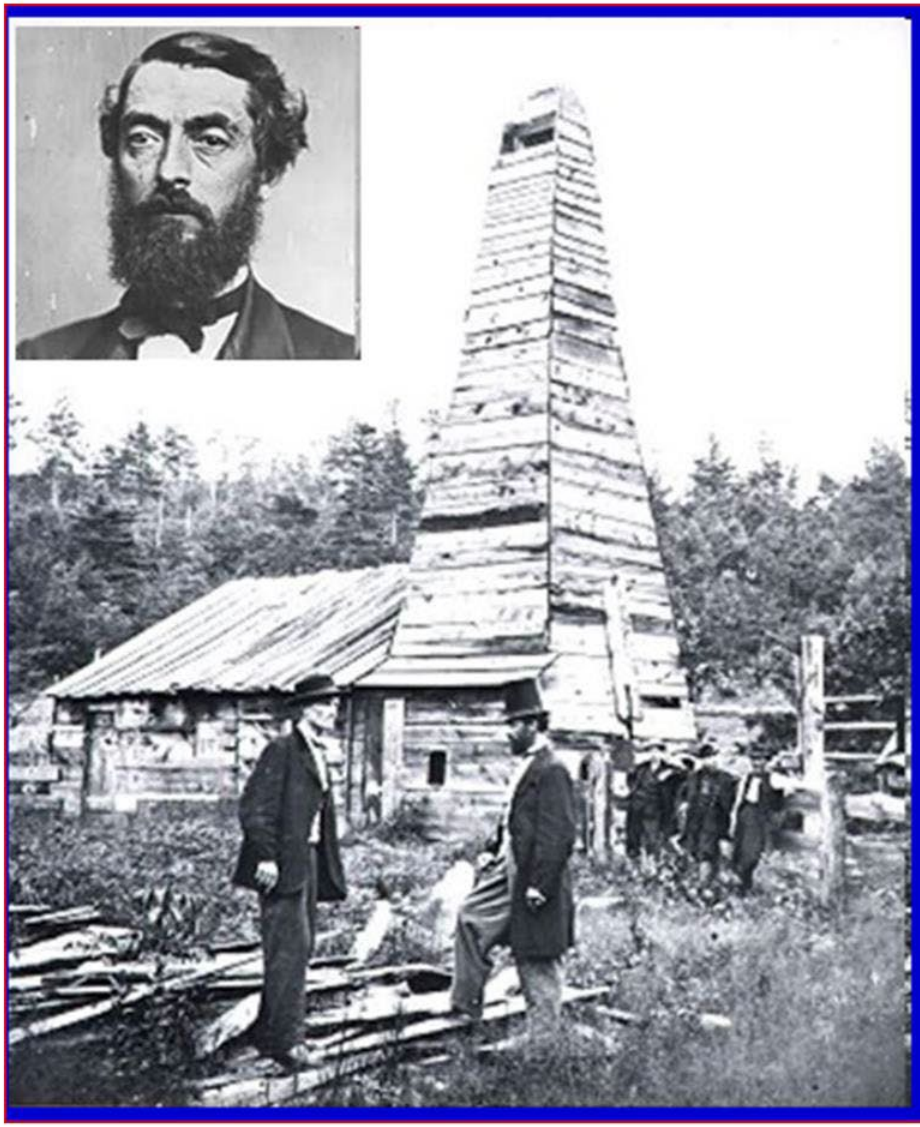
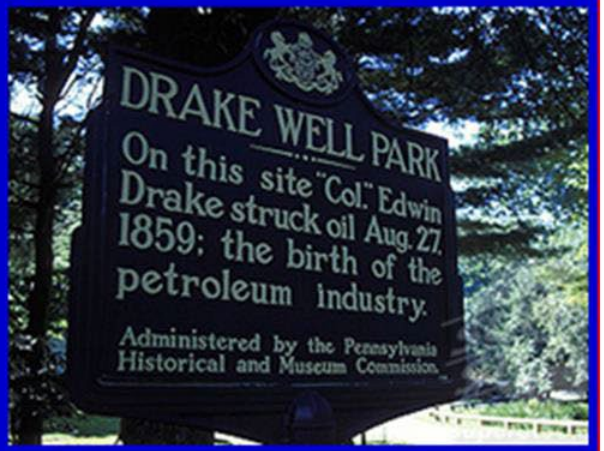
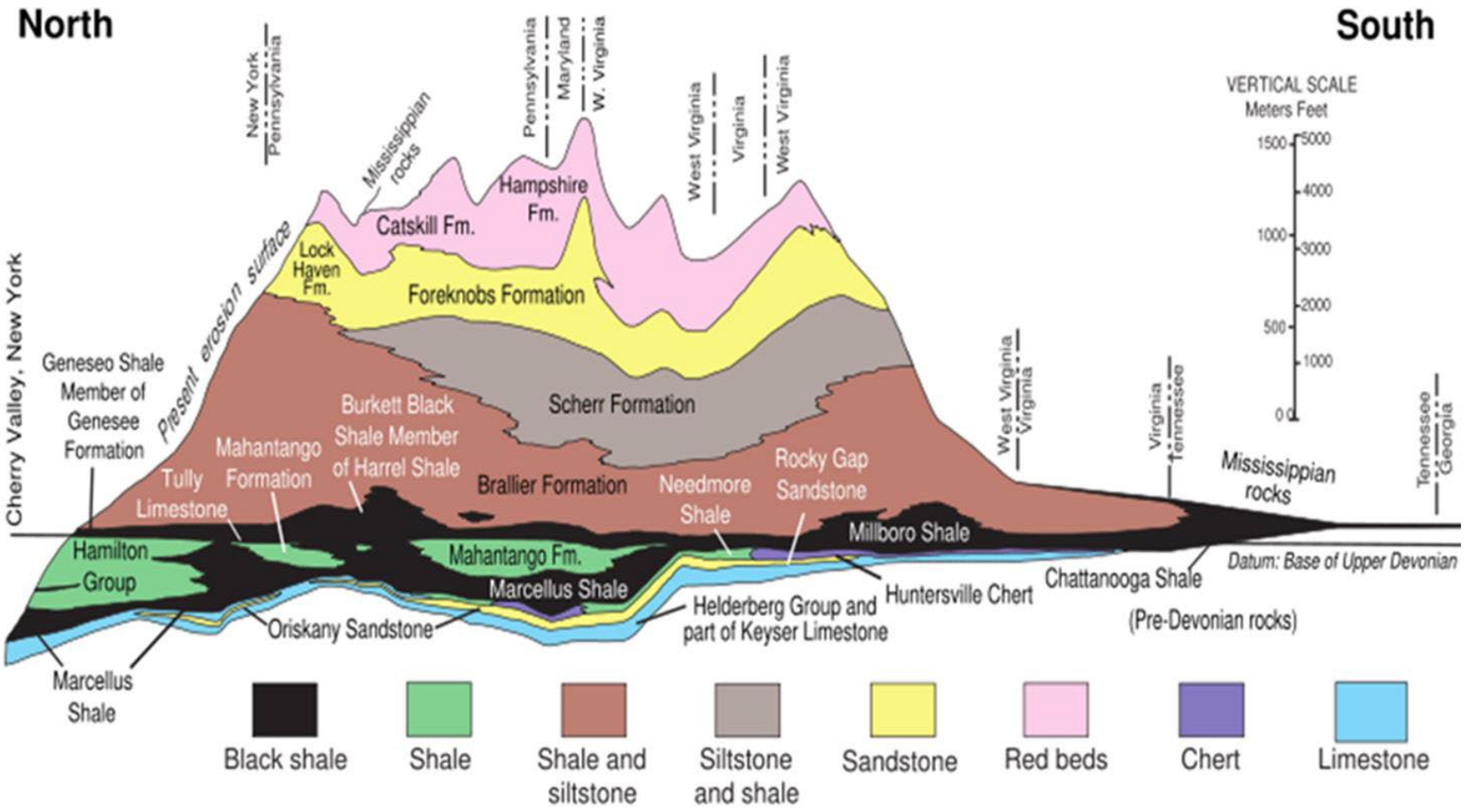
Oil & Gas in Pennsylvania



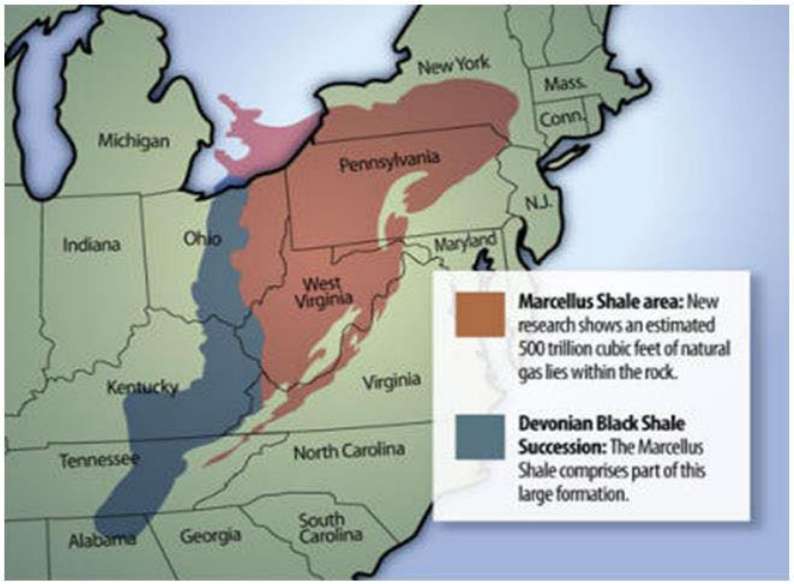
Drakes' Oil Well c1859



Marcellus Shale

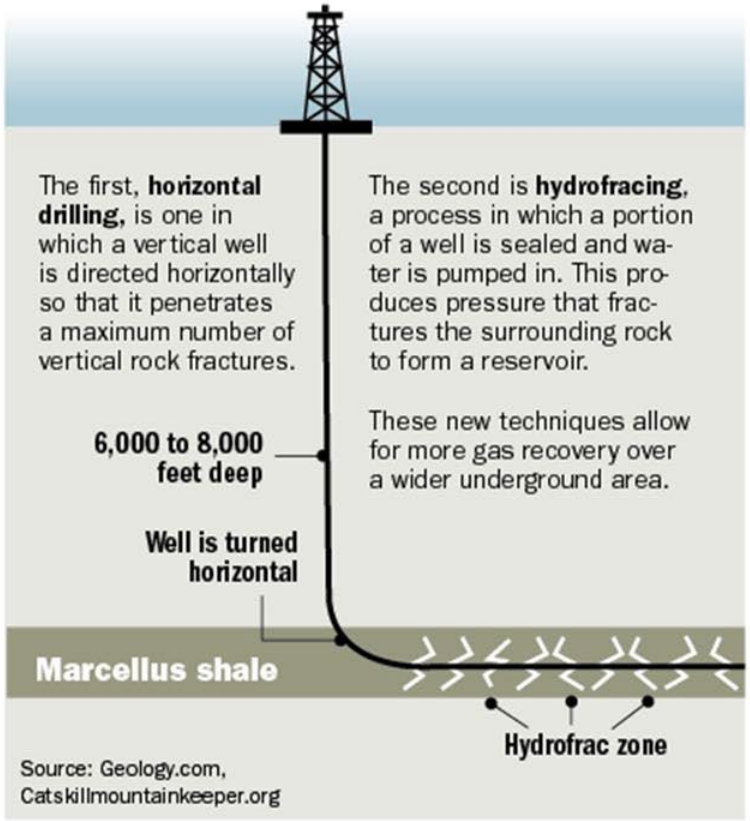


Marcellus Shale Drilling & Fracturing



New techniques, better recovery

Two technologies relatively new to the Appalachian Basin are employed in wells drilled into the Marcellus formation.



Source: Geology.com, Catskillmountainkeeper.org

Post-Gazette

Marcellus Shale

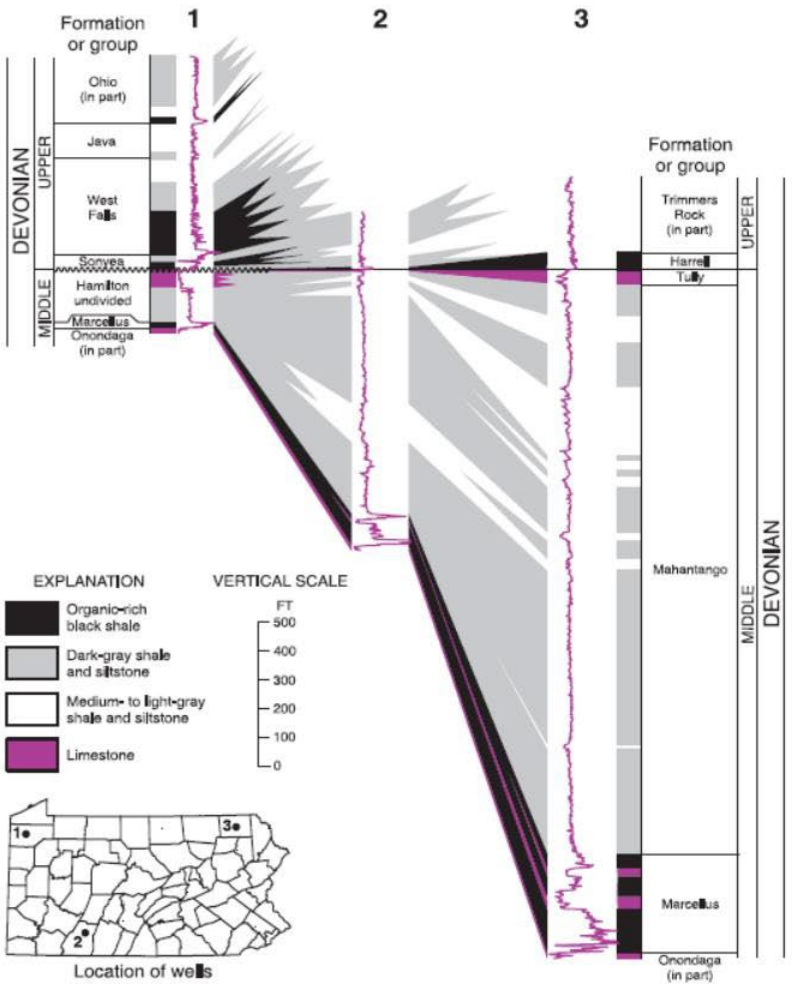


Figure 2. Correlation of Middle and Upper Devonian organic-rich shale facies and interbedded strata in three wells in Pennsylvania, based on gamma-ray log signatures (the jagged purple lines) and descriptions of well cuttings. Note that the black shales correspond in large part to higher-than-normal gamma-ray readings (radioactivity increases to the right in all log signatures).

URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium-238	4.47 billion years
α	thorium-234	24.1 days
β	protactinium-234m	1.17 minutes
β	uranium-234	245000 years
α	thorium-230	8000 years
α	radium-226	1600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
α	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
β	polonium-214	0.000164 seconds
α	lead-210	22.3 years
β	bismuth-210	5.01 days
β	polonium-210	138.4 days
α	lead-206	stable

U-238 w Series Geochem

From: IAEA TCS No. 40 May 2010

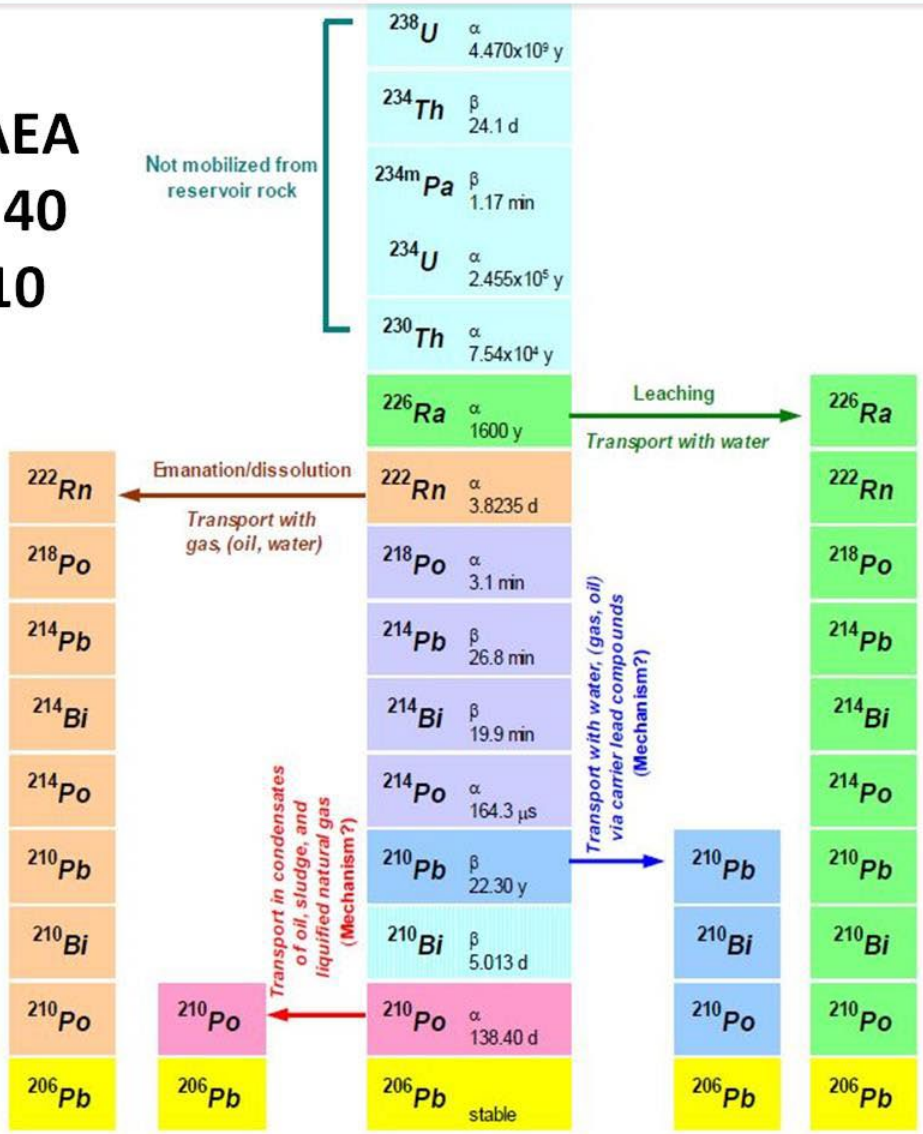
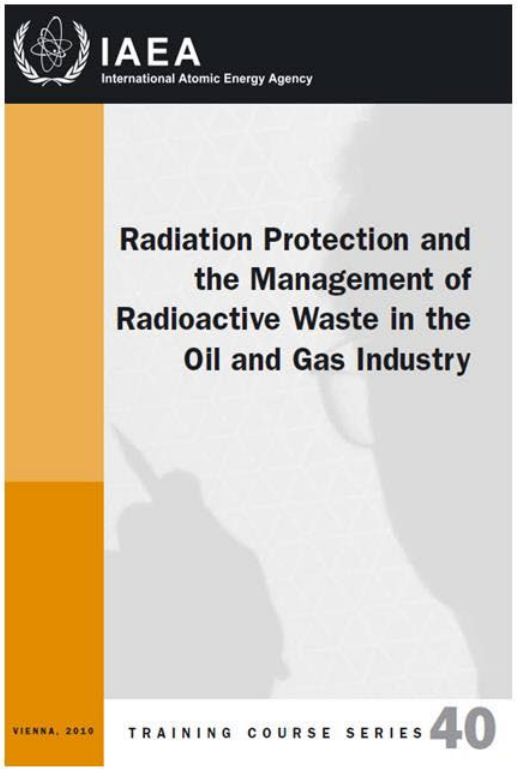


FIG. 41. Transport of ^{238}U progeny in oil and gas production



PA DER Study c1991

NORM Survey Summary [1]

([1] This article was prepared in April 1995 for the *IOGA NEWS*. The attached NORM Survey Summary was prepared September 1, 1992.)

Since 1991, the Bureau of Oil and Gas Management and Bureau of Radiation Protection have been conducting surveys and collecting samples at wells sites and related facilities in 26 counties.

About sixty percent of the well sites had readings at or below background levels. Thirty four percent had readings within 10 microroentgens per hour (microR/hr) of background, three percent were in the range of 11-20 microR/hr above background, and two percent were 21-54 microR/hr above background. One site was 195 microR/hr above background.

Sludge and soil collected at well sites were generally at or below the level of 5 picocuries per gram (pCi/g). Louisiana, Texas and Mississippi have adopted levels of 30 pCi/g and Arkansas adopted a level of 5 pCi/g.

No significant radiation levels were seen at pipe yards from pipe taken from Pennsylvania wells. One elevated reading was found from pipe from another state.

Several brine treatment facilities surveyed had radiation levels above background, but were not sufficiently elevated to require controls for the protection of the general public.

Road surveys for gamma radiation were generally at or below background levels. All areas with elevated readings are attributed to shale outcroppings.

In summary, our survey results indicate that NORM is not a problem at oil and gas well sites in Pennsylvania. Consequently, development of regulations to address this issue is a low priority.

PA DER Study c1991

NORM Survey Summary [1]

The radium-226 in the brine samples ranged from 3.29 pCi/l to 2,575 pCi/l with one at 4,685 pCi/l. The average was 742 pCi/l. Radium-228 in the brine samples ranged from 7.17 pCi/l to 2,196 pCi/l. The average was 676 pCi/l. Following is a listing of the results by well type.

		Radium 226 (pCi/l)			Radium 228 (pCi/l)		
Well Type	#	Avg.	High	Low	Avg.	High	Low
All	38	742	4,685	8.34	676	2,196	12.06
Deep Gas	9	1,243	4,685	203	1,475	2,110	499
Shallow Gas	17	946	2,575	20	665	2,196	13
Shallow Oil	12	86	275	8.34	94	456	12.06

Solid Waste Radiation Monitoring

PA DEP Required SW Radiation Monitoring in 2001, and the facility to have an 'Action Plan.'

TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS

TENORM

TENORM & NORM Defined

Technologically **E**nhanced **N**aturally **O**ccurring **R**adioactive **M**aterial

- *TENORM*, a naturally occurring radioactive material not subject to regulation under the laws of the Commonwealth or the Atomic Energy Act of 1954, whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities.
- *NORM - Naturally occurring radioactive material* - NORM is a nuclide, which is radioactive in its natural physical state - that is, not man-made - but does not include source or special nuclear material.

PA DEP Regulations, Title 25, Chapter 271

Marcellus Shale - c2010 Rad. Data

- **MS uranium content: 10 - 100 ppm**
- **MS U-238 content: ~3.4 - 34 pCi/g**
- **MS Ra-226 content: ~3.4 - 34 pCi/g**
- **MS frac H_20 Ra-226: ~300 - 9,000 pCi/L***
- **Treated frac H_20 sludge: BG - 250 μR/h**

- ***DW MCL_a Ra-226 plus 228 / gross α: 5 / 15 pCi/L***

* From DEP 26R forms

Study Background

Generation of TENORM waste had increased significantly. This was mainly due to the expansion in unconventional natural gas exploration and production in the Commonwealth.

In 2013 DEP determined several issues with O&G TENORM needed to be addressed.

These issues include:

- Potential Worker Radiation Exposure
- Possible Public Radiation Exposure
- Unknown Environmental Contamination
- Waste Disposal

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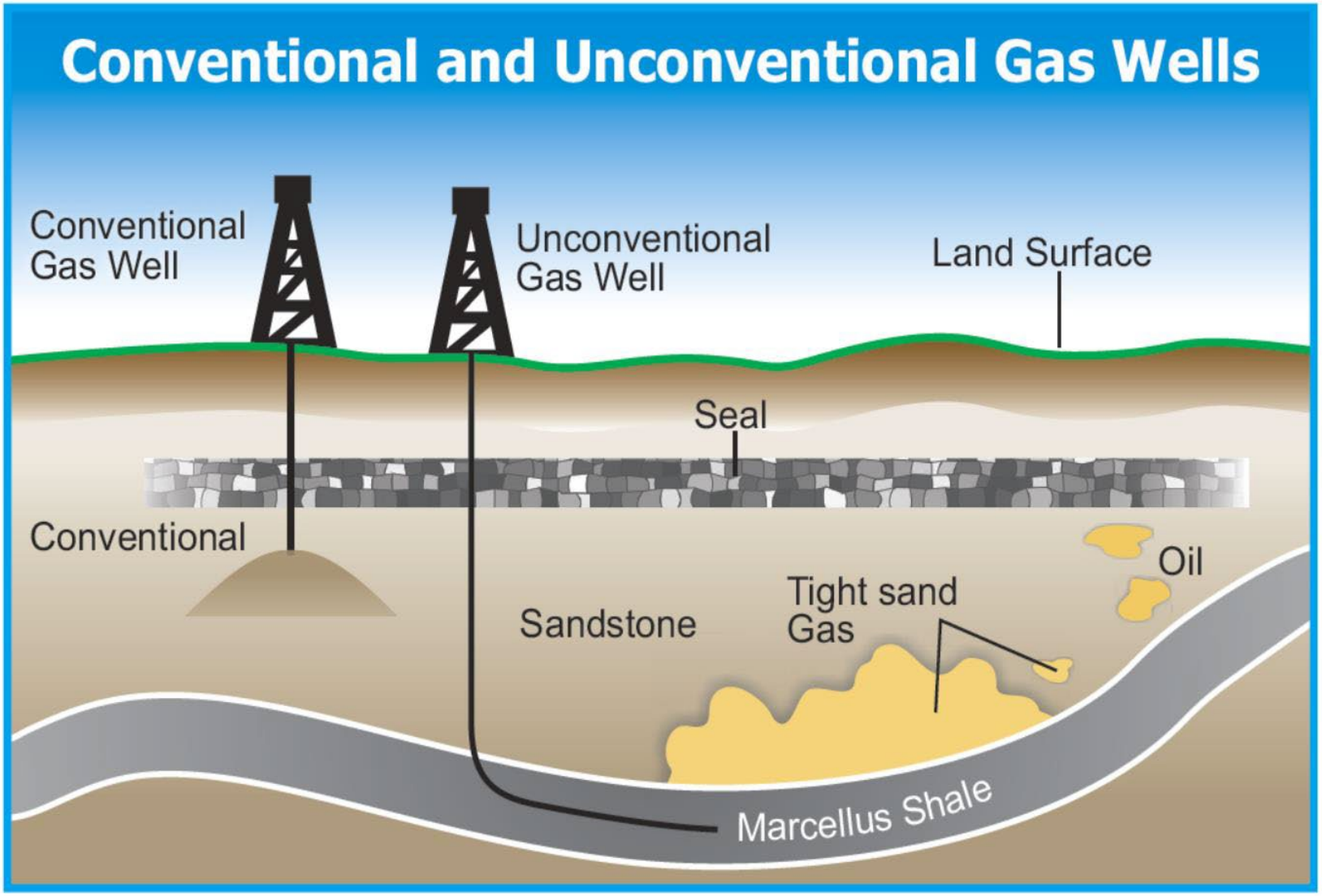
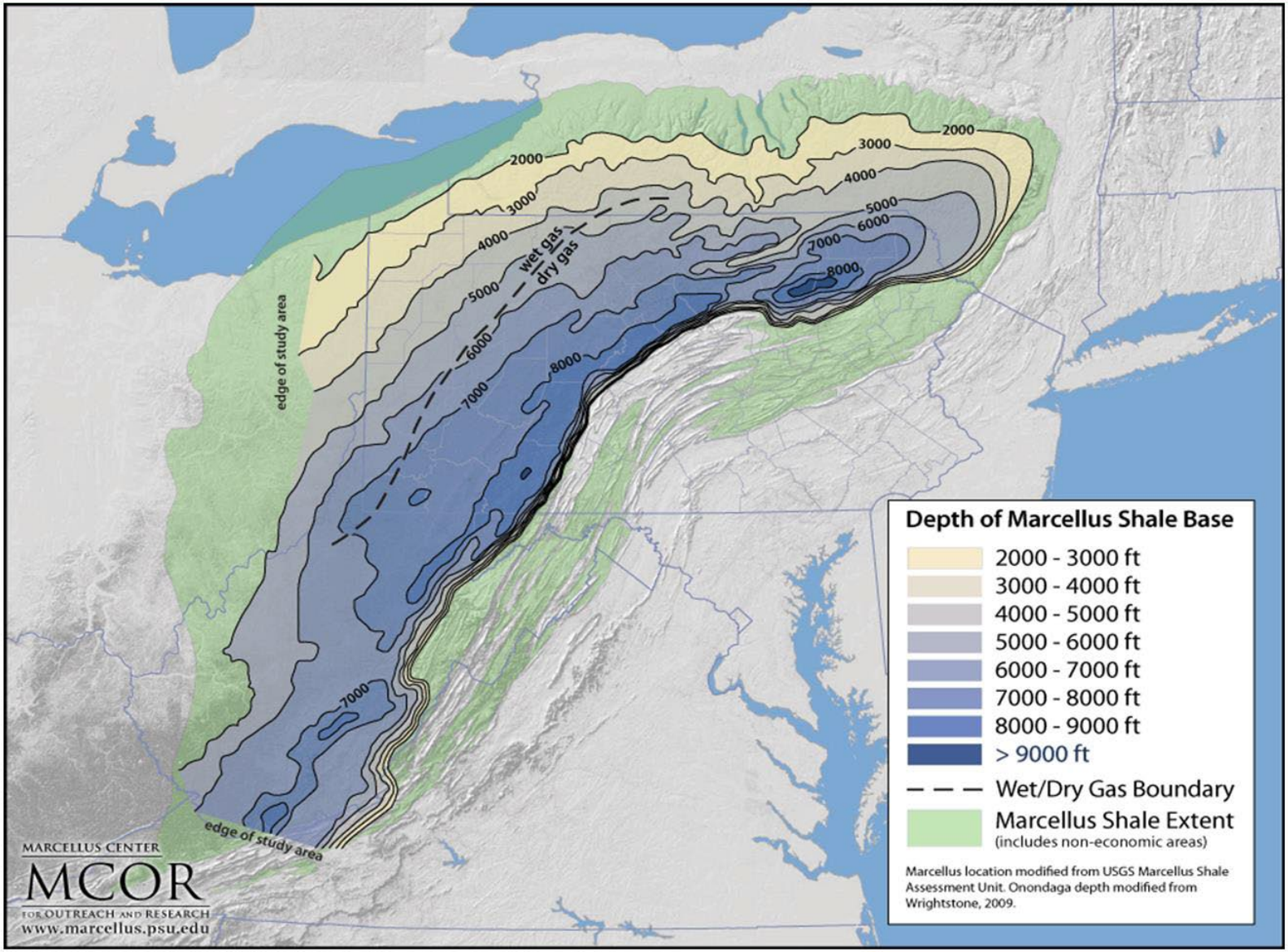
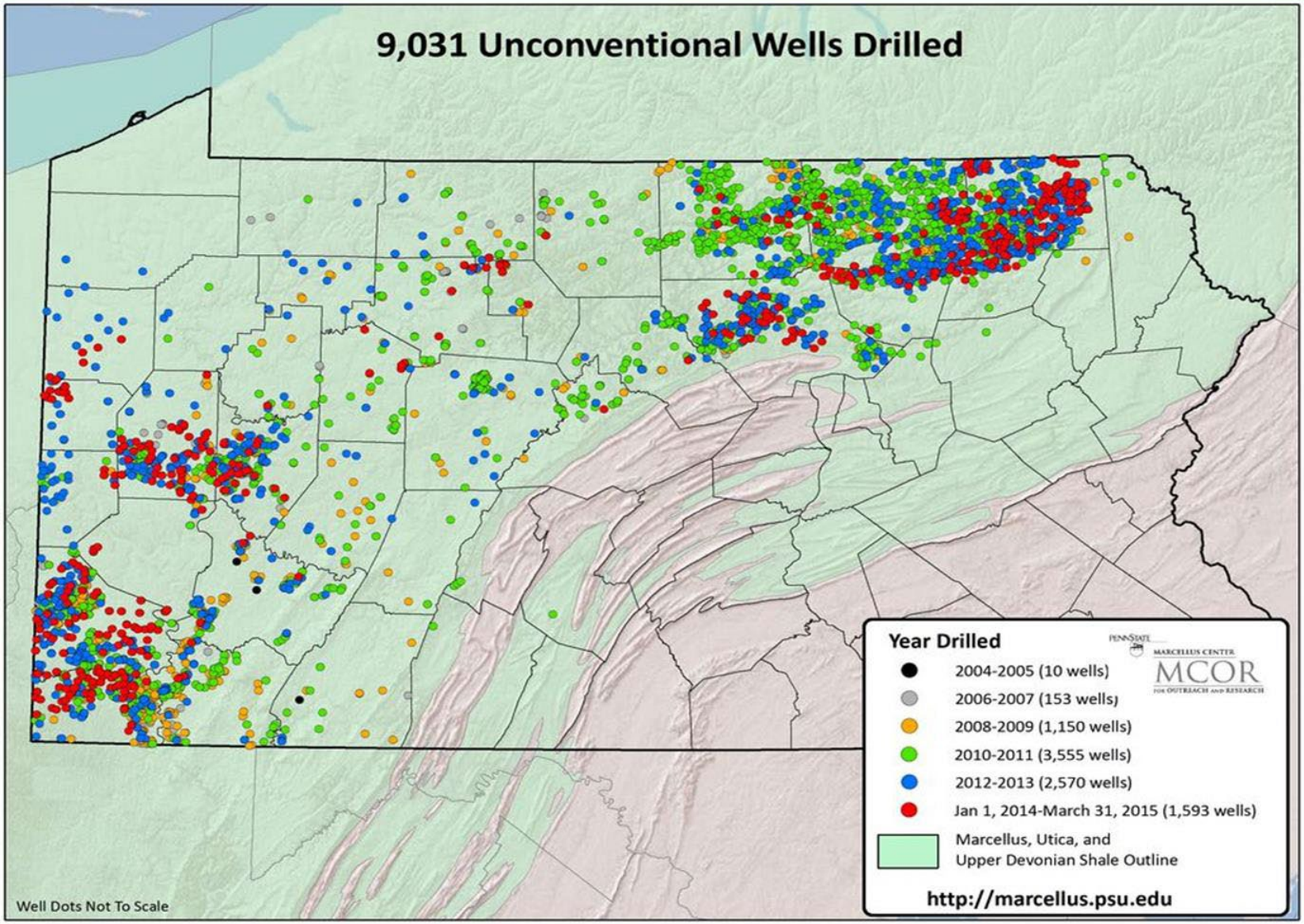
O&G Well Types



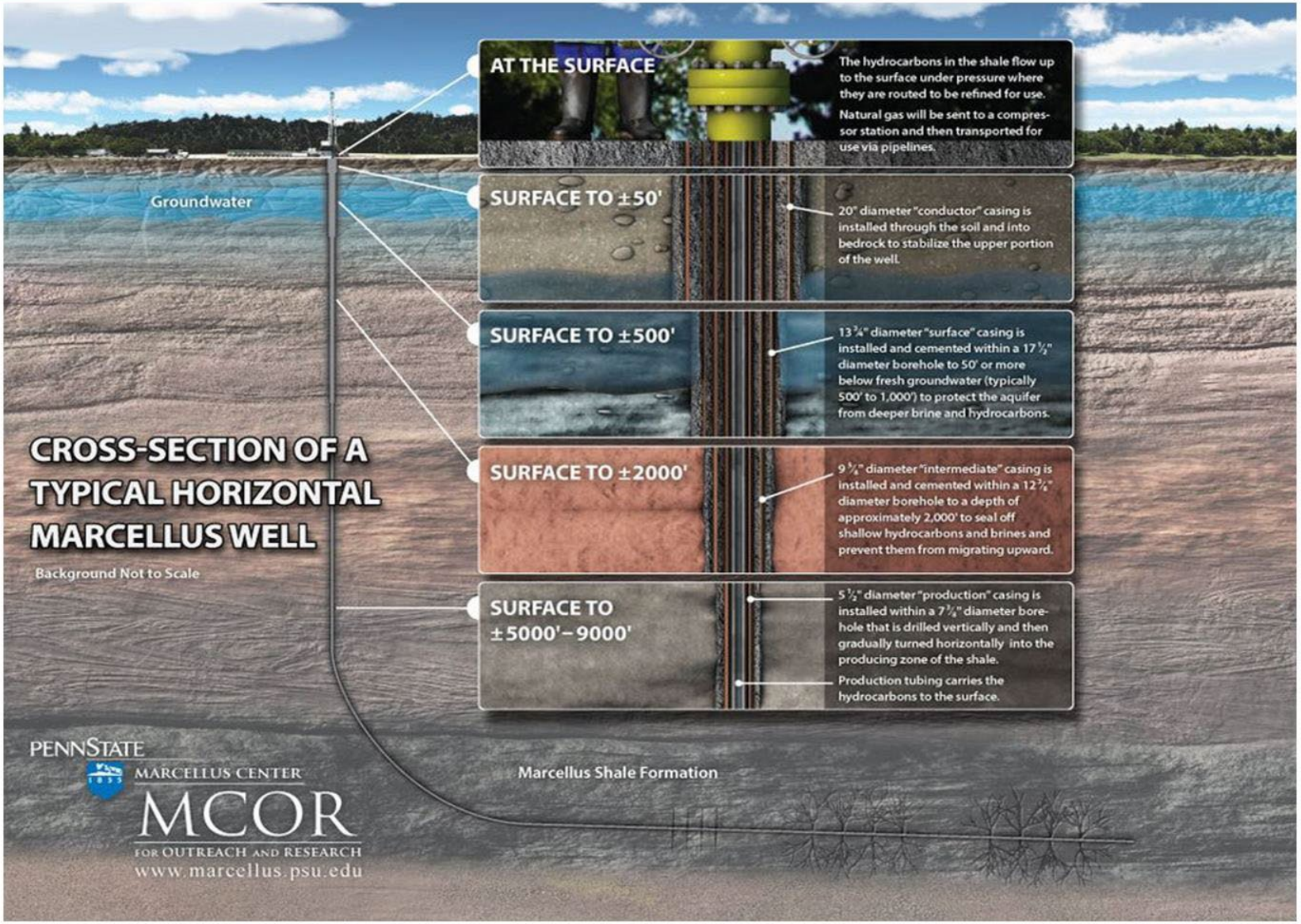
MS - Wet vs. Dry Gas



MS Gas Wells Thru 2015



O&G Well Design



Study Schedule

- Scope, Field Sampling Plan and QAP in 2012
- Work began April 2013 and was completed in August 2014
- Sample analysis, data analysis and report preparation was through fall 2014
- Internal DEP final review thru early winter
- Peer review over winter 2014 holidays
- Final study report posted January 2015
- O&G industry sample data being reviewed now

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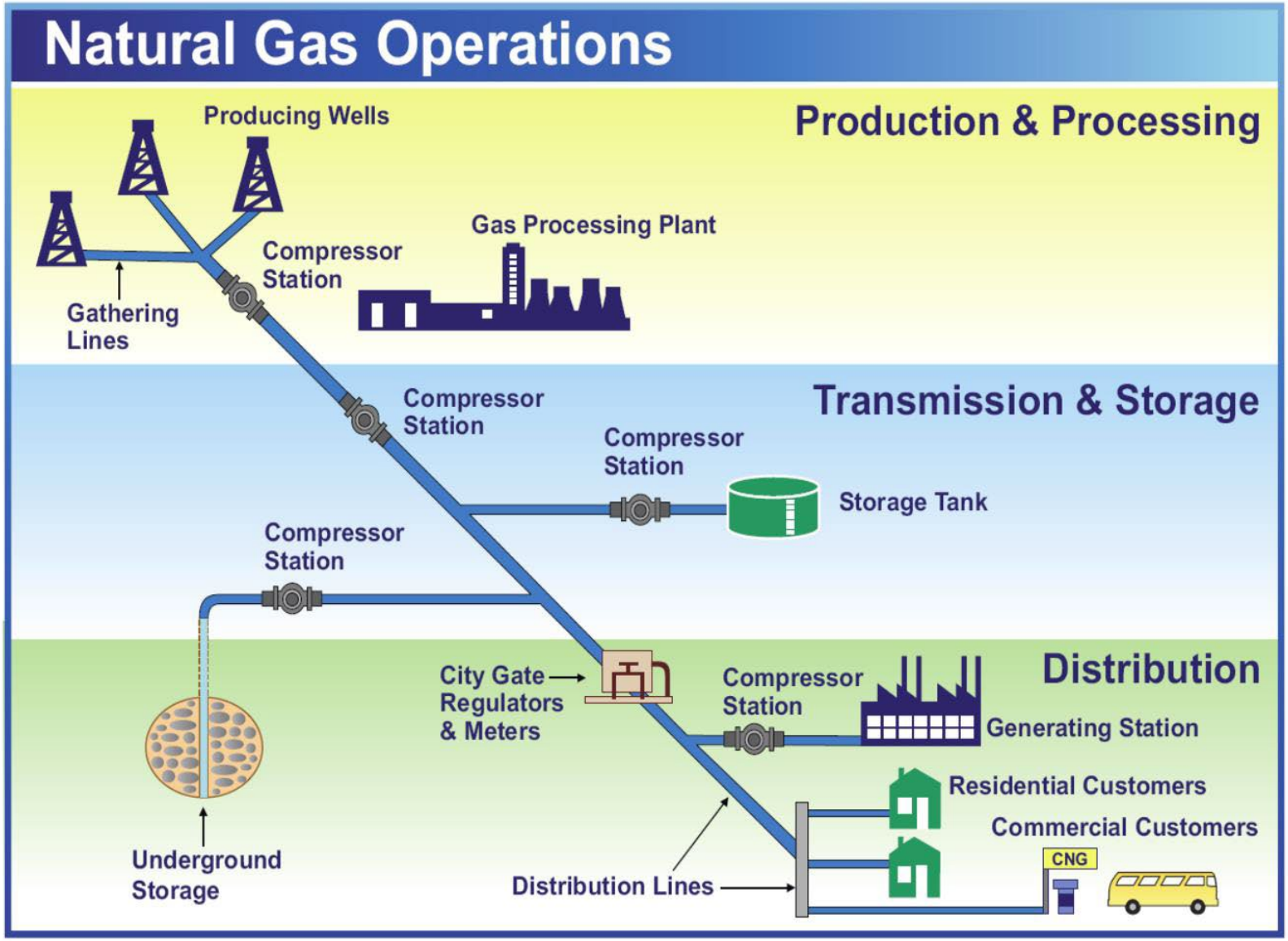
Natural Gas Production & Use



Sample Types

- Solid samples (i.e., drill cuttings, muds, proppant, sludge, soils and sediment)
- Liquid samples (i.e., pre-frac, flowback and produced water)
- Natural gas samples
- Radiation surveys (i.e., µR/h, direct surface dpm/100 cm^2
- 'Smear' samples for removable radioactivity

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Sample Analysis

- The samples were analyzed for the presence of alpha, beta and gamma radiation (gross counting and spectroscopy)
- Some solid and liquid sample analyzed by XRF, ICP-MS and neutron activation
- The gas was sampled for radon-222 concentrations

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Site Categories for Sampling

- Well pads
- Waste water treatment plants (WWTPs)
- Waste sludge loads to landfills
- Landfills
- Underground natural gas storage sites
- Gas-fired electricity generating facilities
- Compressor stations
- Gas processing facility
- Beneficial use sites (e.g., roads)
- Decommissioned well casings

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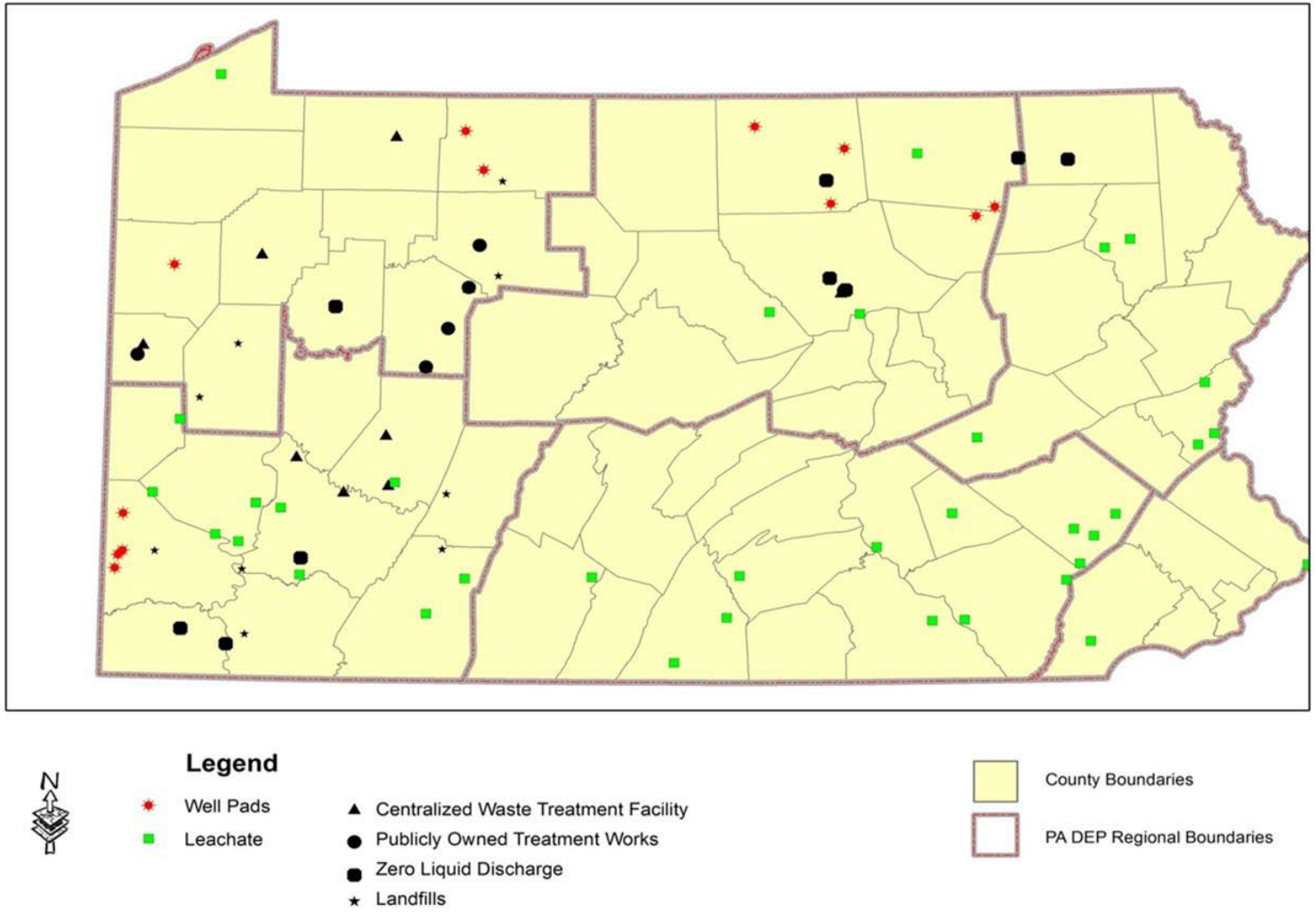
Field Work - Locations



Field Work

MS Well pad [Patriot News photo]

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Field Work

Drilling Operations rock cuttings

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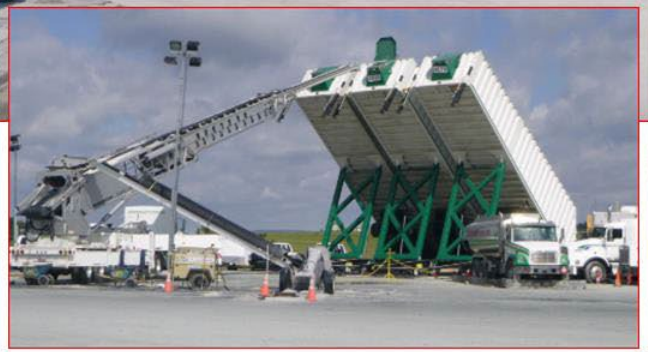
Field Work



Frac-water, proppant and flowback sampling at a well pad

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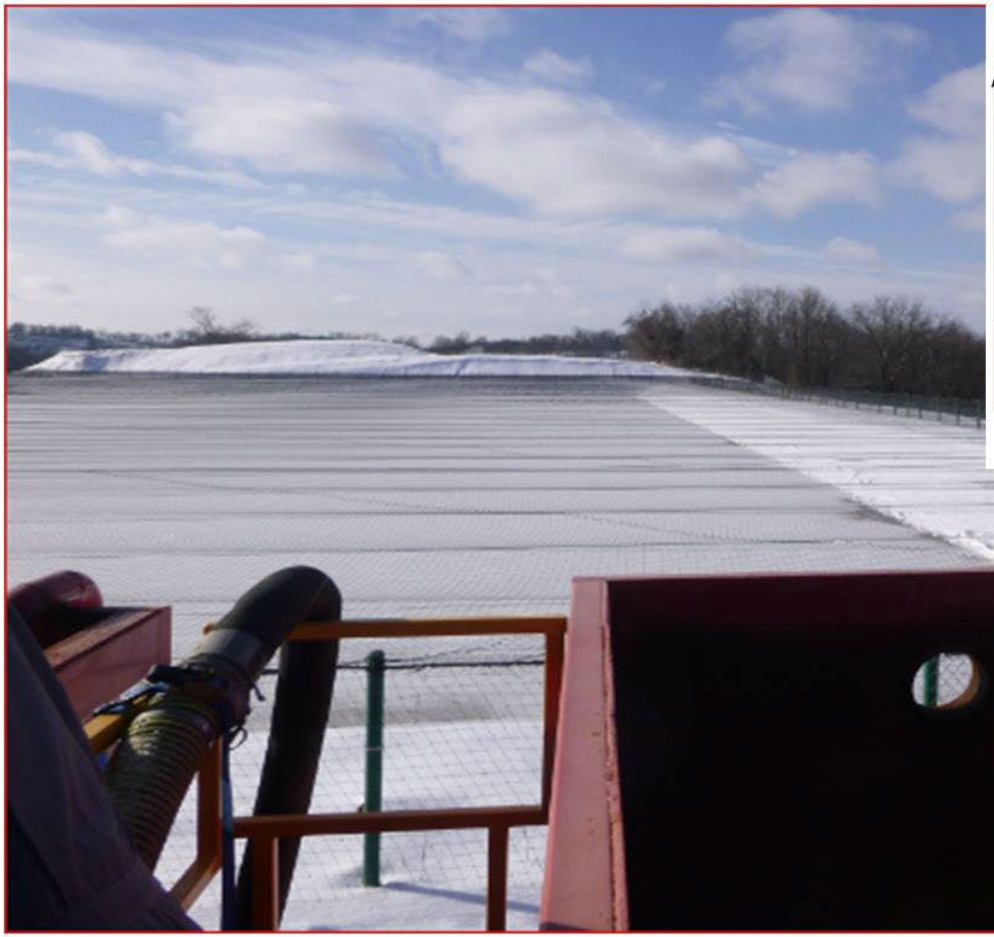
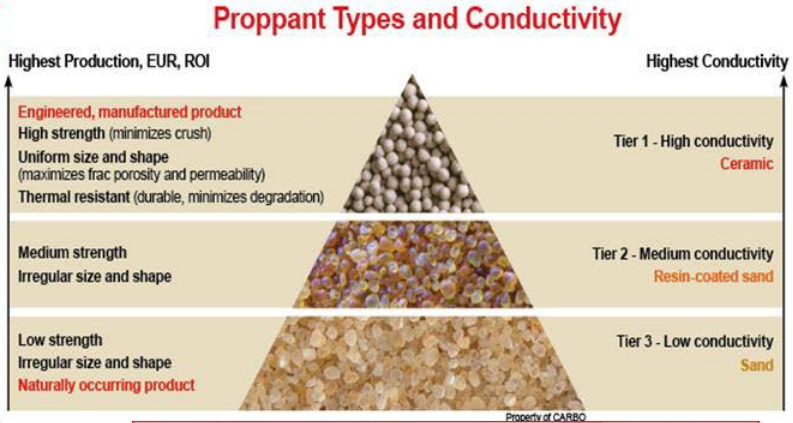
Field Work





Wastewater Impoundment

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Field Work

Rn testing at unconventional well in production

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Field Work

Conventional well pad survey

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Field Work

Radon testing at a gas power facility

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Field Work

Radon testing at a gas storage facility

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Field Work

Surveys at gas processing facility

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Field Work

Source: GAO.

Figure 12: Storage Tank for Produced Water

Wastewater Treatment

Field Work

Wastewater Treatment

Field Work

Wastewater Treatment

Field Work

Wastewater Treatment

Field Work

Wastewater Treatment

Field Work

Wastewater Treatment

Field Work

Pipe recycle

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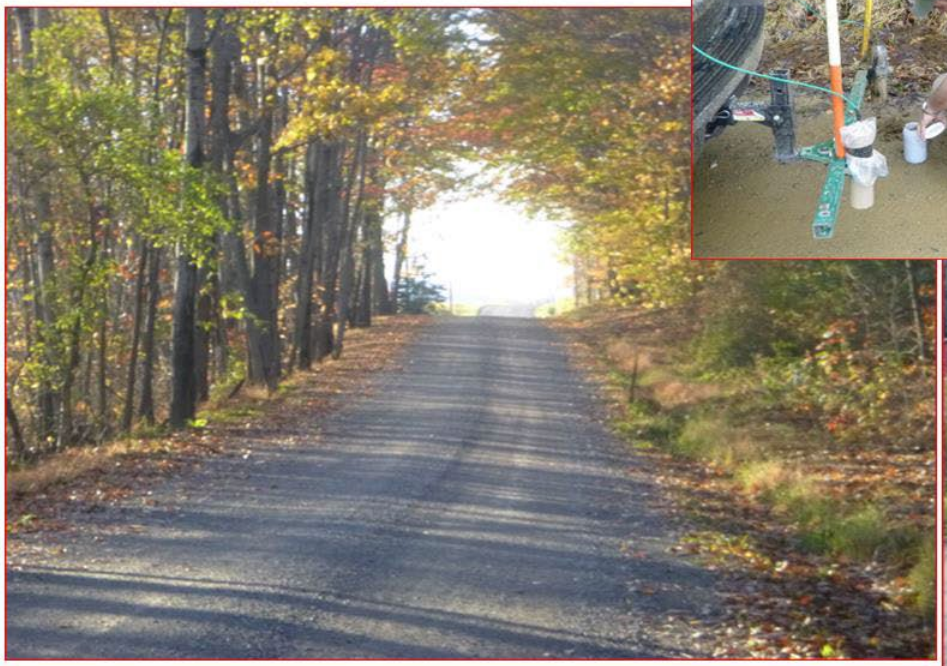
Field Work



Beneficial Use of brines

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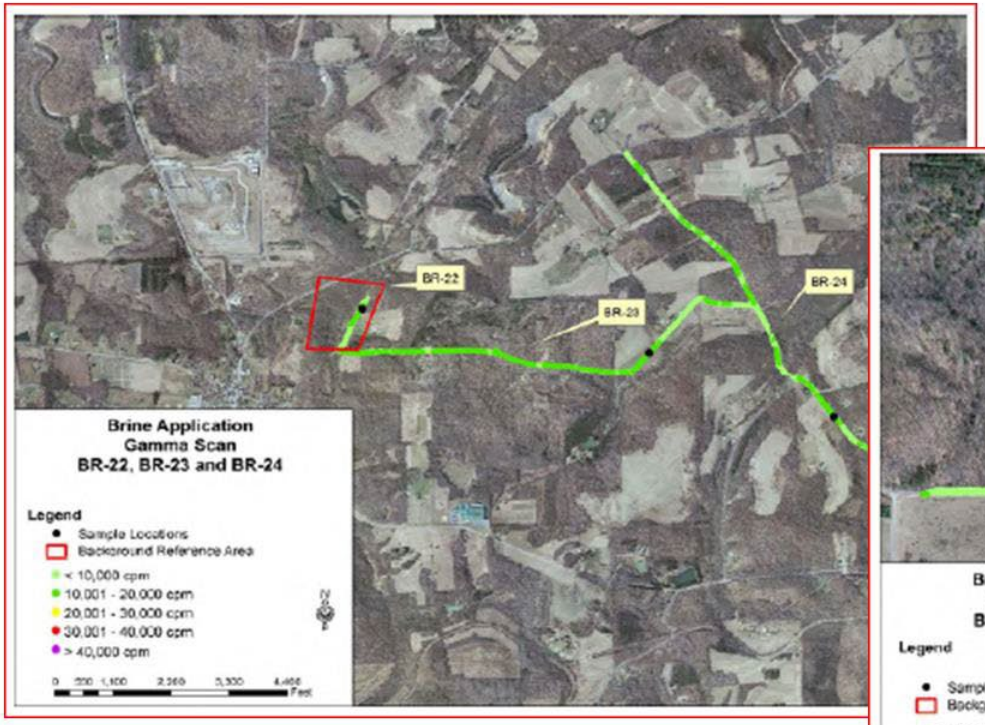
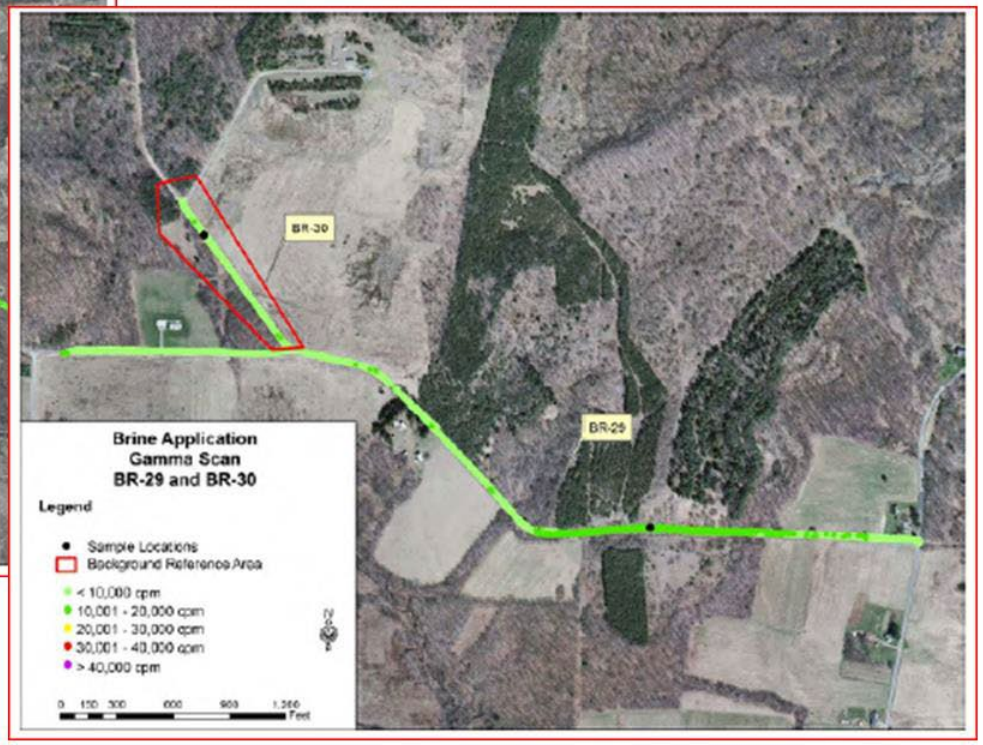
Field Work





Beneficial Use of brine on roads

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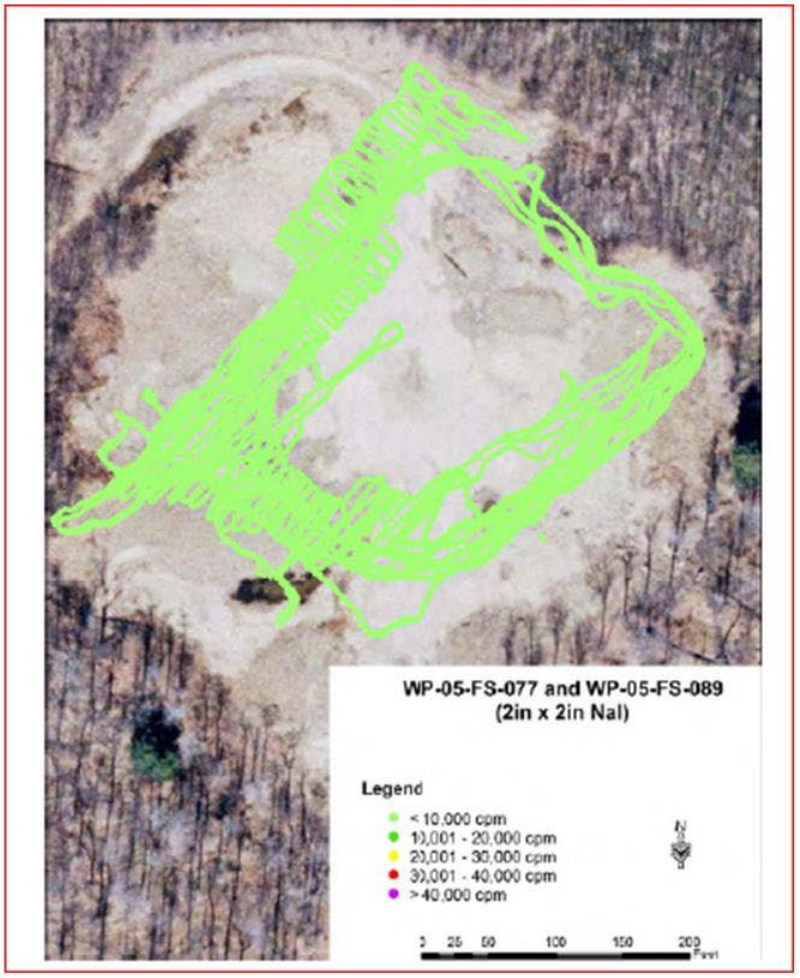
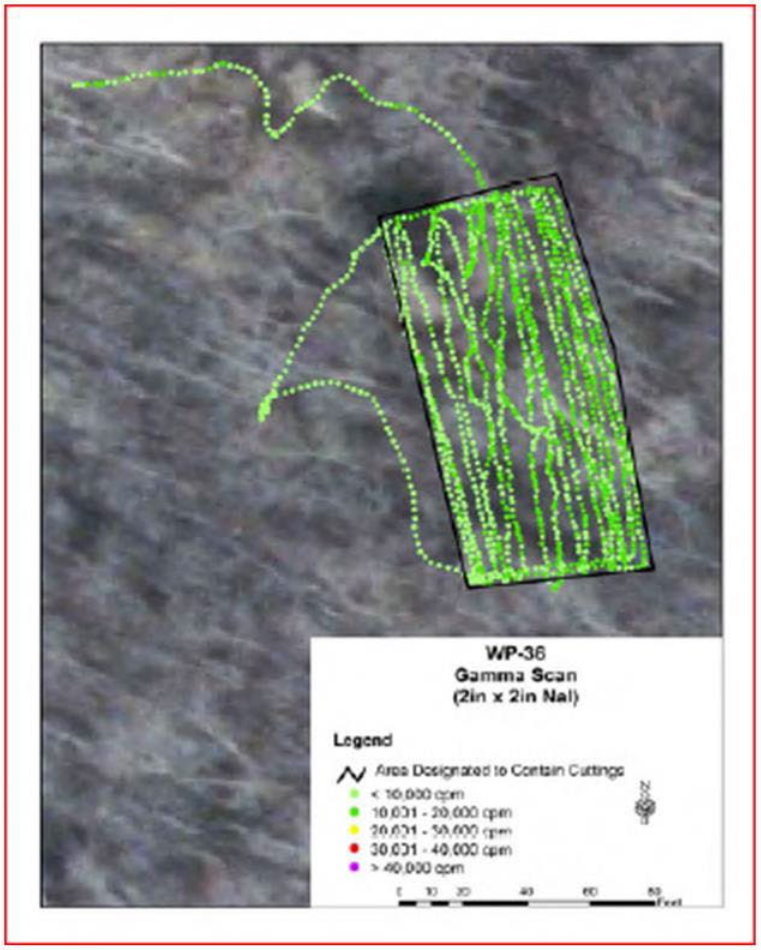
Field Work





Well Pads

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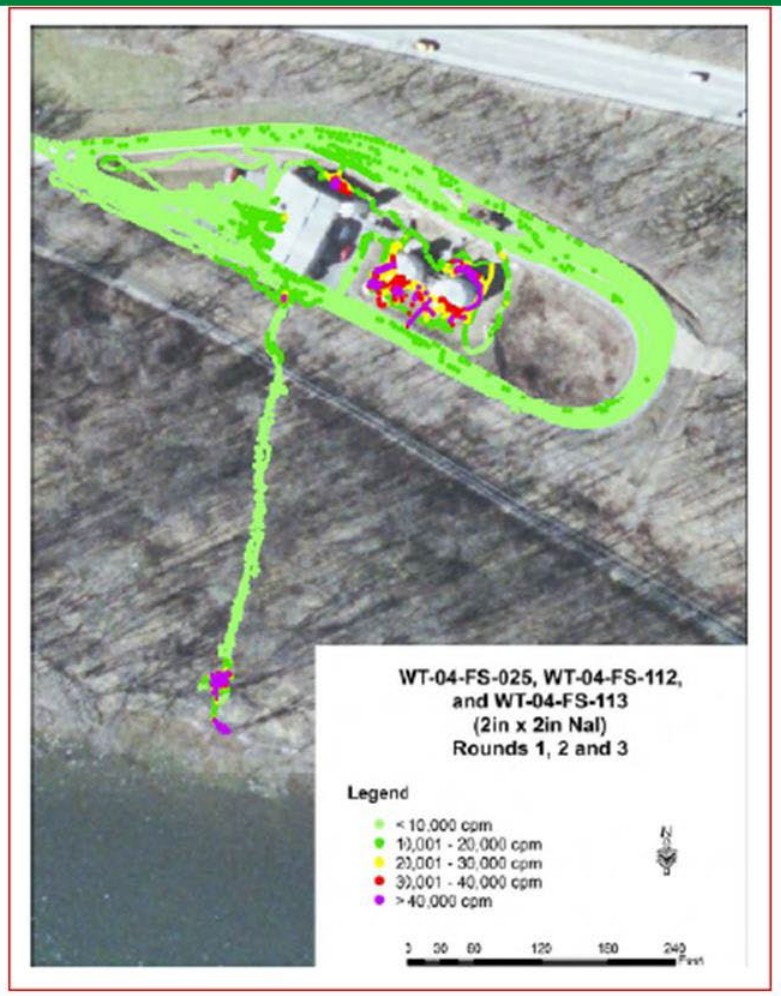
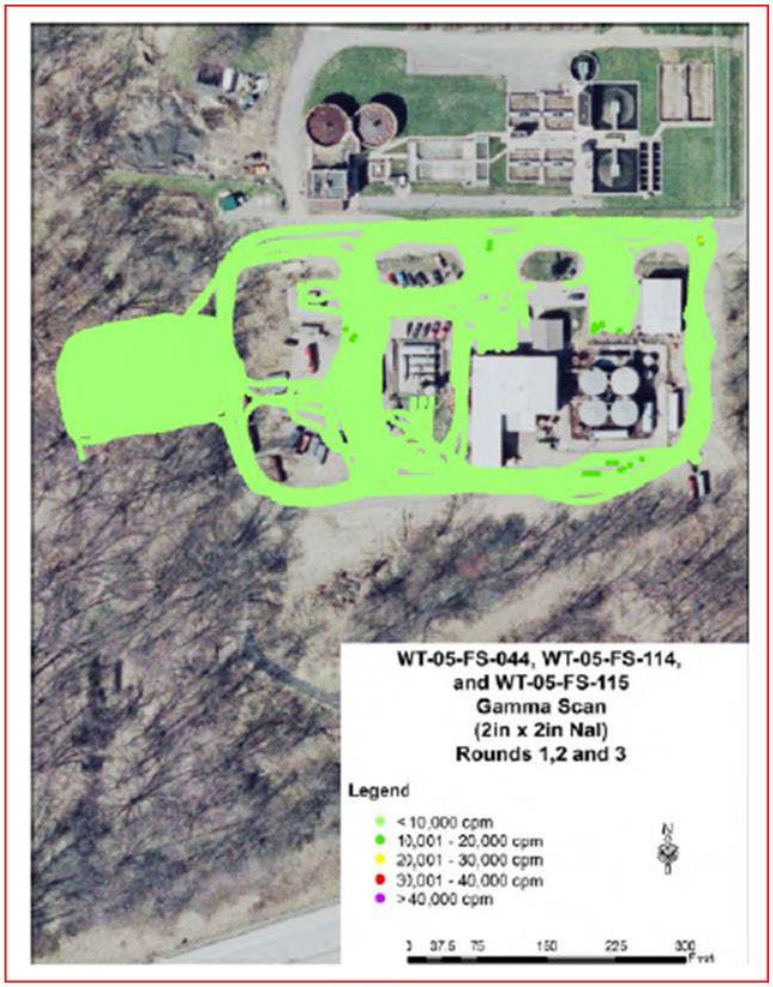
Field Work





Wastewater Treatment Facilities

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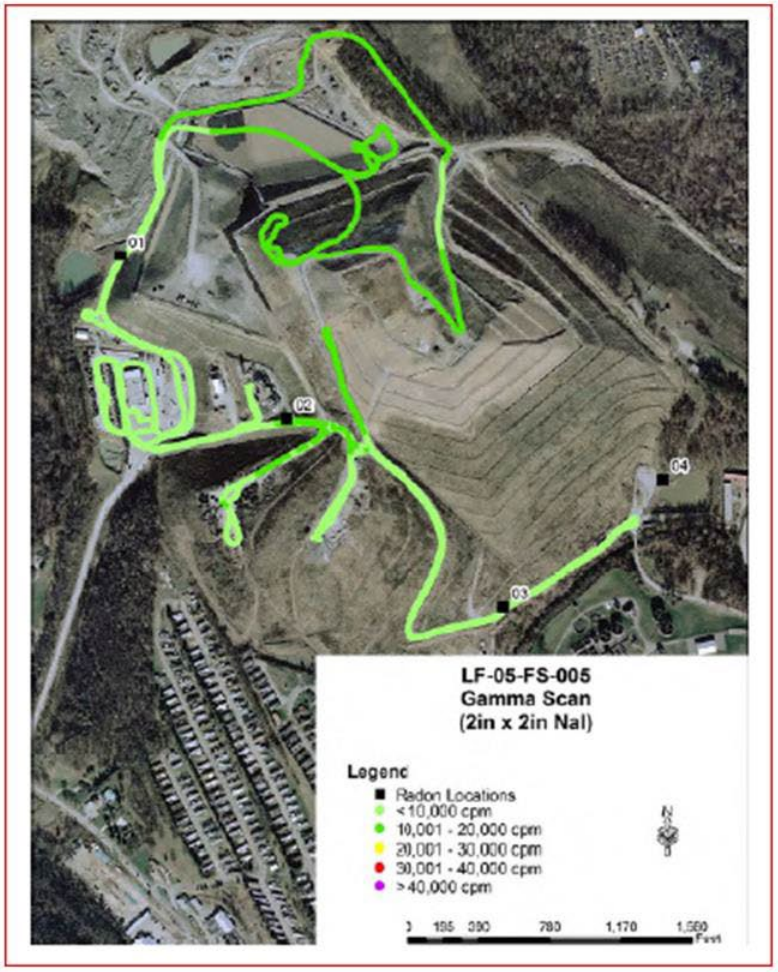
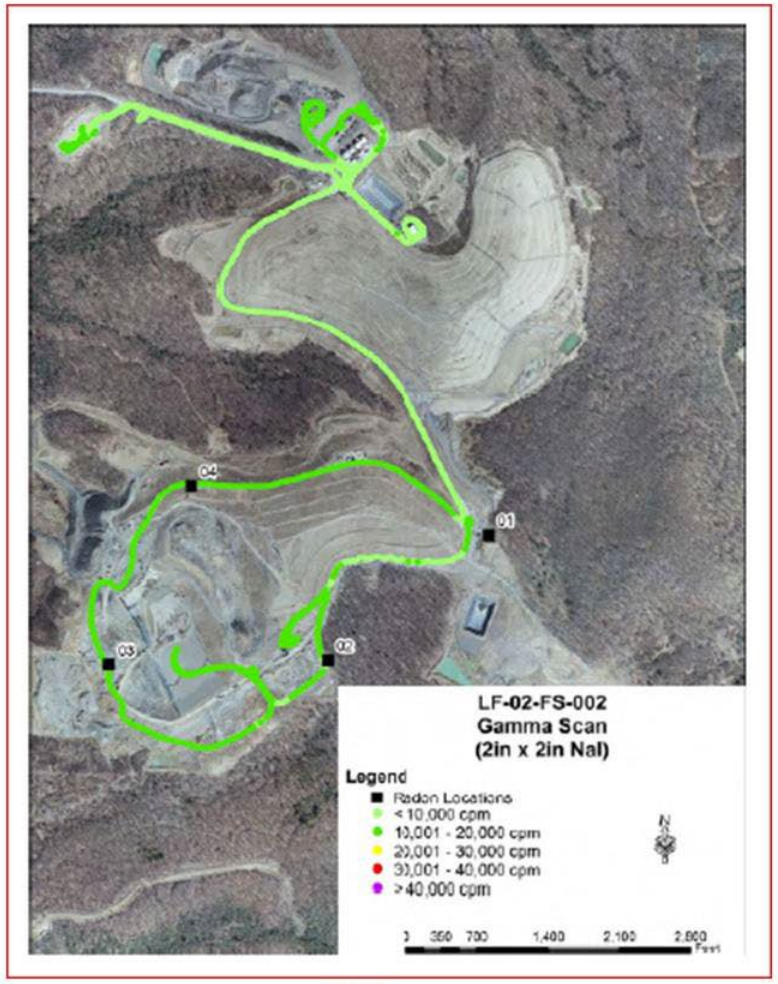
Field Work





Landfills

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Field Work

PA RCRA D landfill

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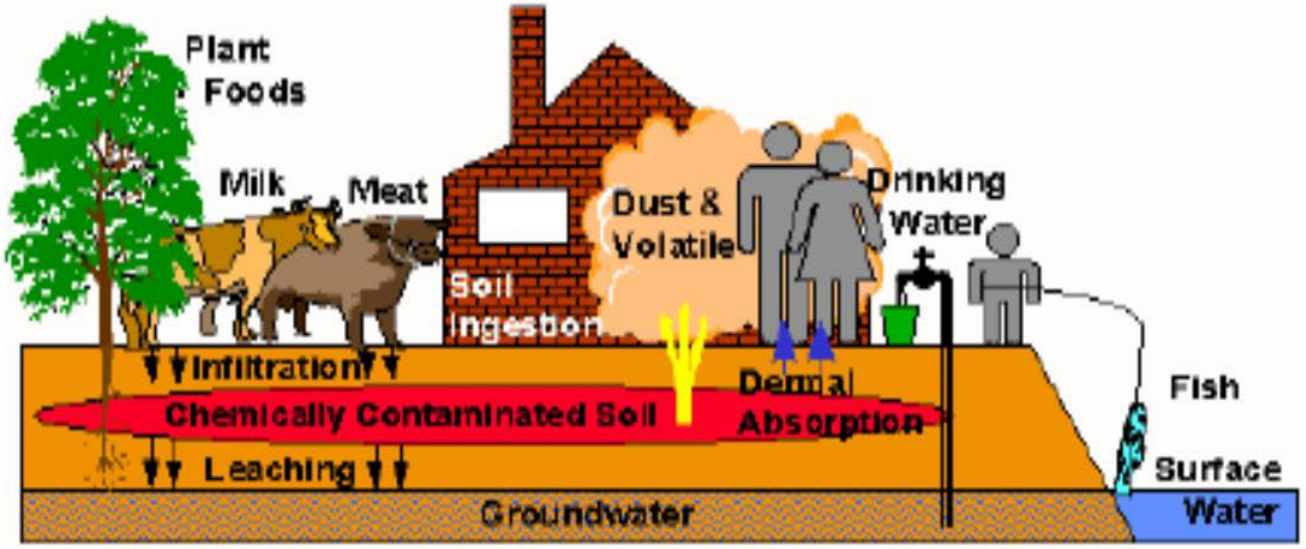
TENORM Waste Disposal

TENORM -

RESRAD code runs circa 2002 : "resident farmer" evaluation, public dose limit 25 mrem/yr, all pathways (i.e., radon, ground shine and drinking water), looking out 1000 years.



Pipeline 'Pigging' Operations

***In Situ* Rn-222 Decay…**

Po-218 => Pb-214 => Bi-214 => Po-214 => Pb-210 => Bi-210 => Po-210 => Pb-206

Do we have data!

Study Results

Well Sites and Pads

Vertical Cuttings -

Ra-226: 0.7 to 17 (2.8 ave.) pCi/g [g-spec]

U-238: 0.5 to 4.5 (1.5 ave.) pCi/g [XRF & calc]

MS Horizontal Cuttings

Ra-226: 0.1 to 13 (5.2 ave.) pCi/g [g-spec]

U-238: 2.0 to 17 (8.6 ave.) pCi/g [XRF & calc]

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Study Results

Well Sites and Pads

Hydro Frac Fluid -

Ra-226: 64 to 21,000 (5,290 ave.) pCi/L [g-spec]

Ra-228: 4.5 to 1,640 (469 ave.) pCi/L [g-spec]

Flowback Water -

Ra-226: 551 to 25,500 (8,490 ave.) pCi/L [g-spec]

Produced Water -

Ra-226: 41 to 26,600 (5,880 ave.) pCi/L [g-spec]

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Study Results

Well Sites and Pads

Ambient Radon: 'background' 0.2 to 0.7 pCi/L

Radon in Natural Gas: 3.0 to 148 (48 ave.) pCi/L

Drill Muds Ra-226: 0.66 to 3.7 (2.3 ave.) pCi/g

Proppant Ra-226: 0.17 to 0.36 (0.24 ave.) pCi/g

Contamination: 'potential w spills'

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Study Results

POTW, Impacted & Non-impacted

Filter Cake -

[POTW-I] Ra-226: 20.1 ave. pCi/g

[POTW-N] Ra-226: 8.89 ave. pCi/g

Radon: 0.2 to 8.7 pCi/L

Ambient gamma: 5 to 36 μR/h [max 63 mrem/y]

Contamination: some fixed, little removable

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Study Results

Centralized Wastewater Treatment Plants

Filter Cake -

Ra-226: 3.38 to 294 (108 ave.) pCi/g

Radon indoor areas: 2.0 pCi/L (ave.)

Soils: BG to 500 pCi/g

Ambient gamma: max 24 μR/h [max 38 mrem/y]

Contamination: mostly fixed, some removable

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Study Results

Zero Liquid Discharge Plants

Filter Cake -

Ra-226: 3.08 to 480 (112 ave.) pCi/g

Radon indoor areas: 2.3 pCi/L (ave.)

Ambient gamma: max 43 μR/h [max 76 mrem/y]

Contamination: mostly fixed, some removable

Wastewater truck driver: < 1 mrem/y

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Study Results

Landfills

Leachate -
Ra-226: 54 to 416 (112 ave.) pCi/L

Radon local environs: 'BG' 0.2 to 0.9 pCi/L

Ambient gamma: 5 to 13.5 μR/h [max 17 mrem/y]

Surface Contamination: minimal from gamma drive-overs

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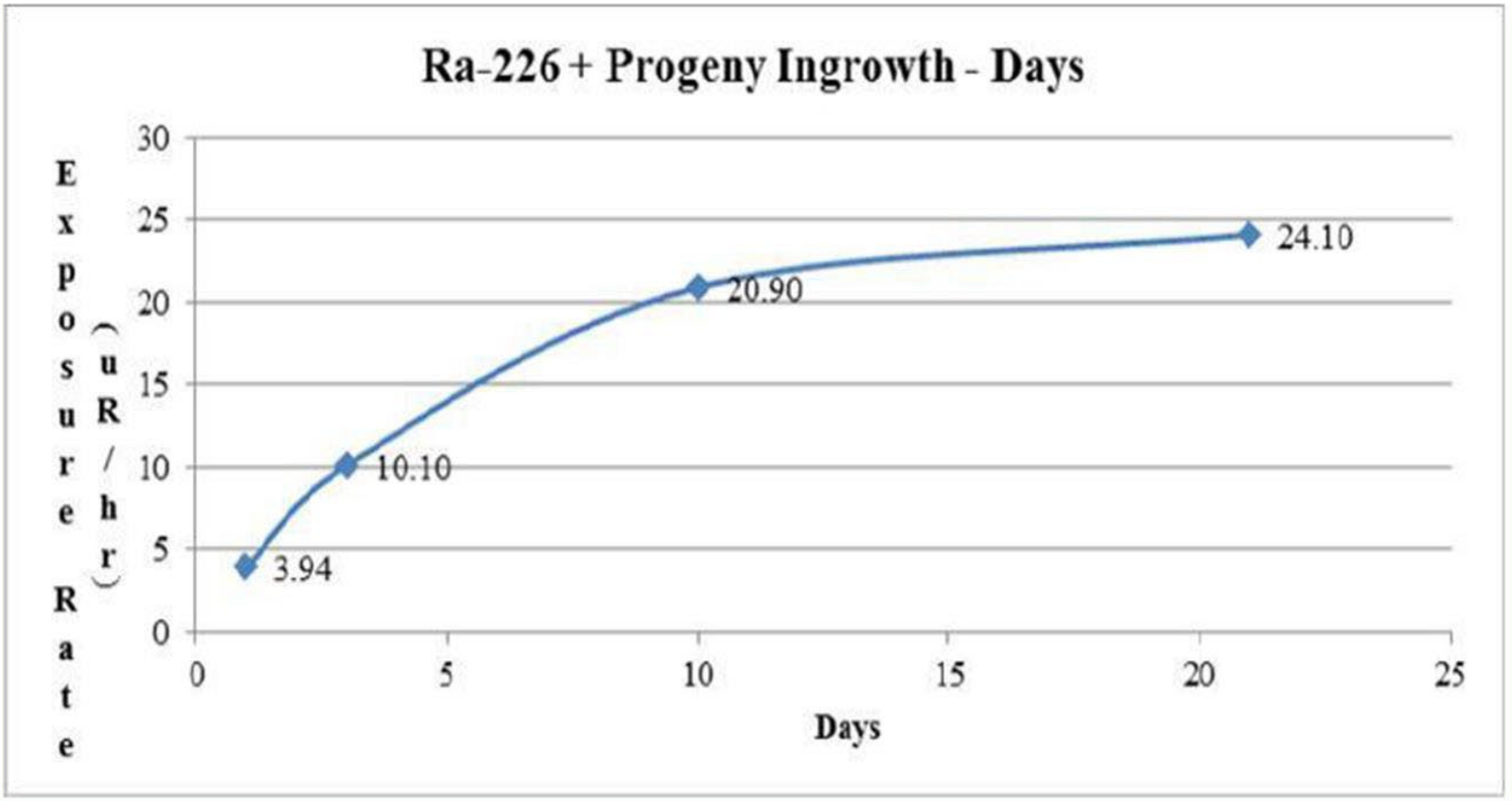
Study Results

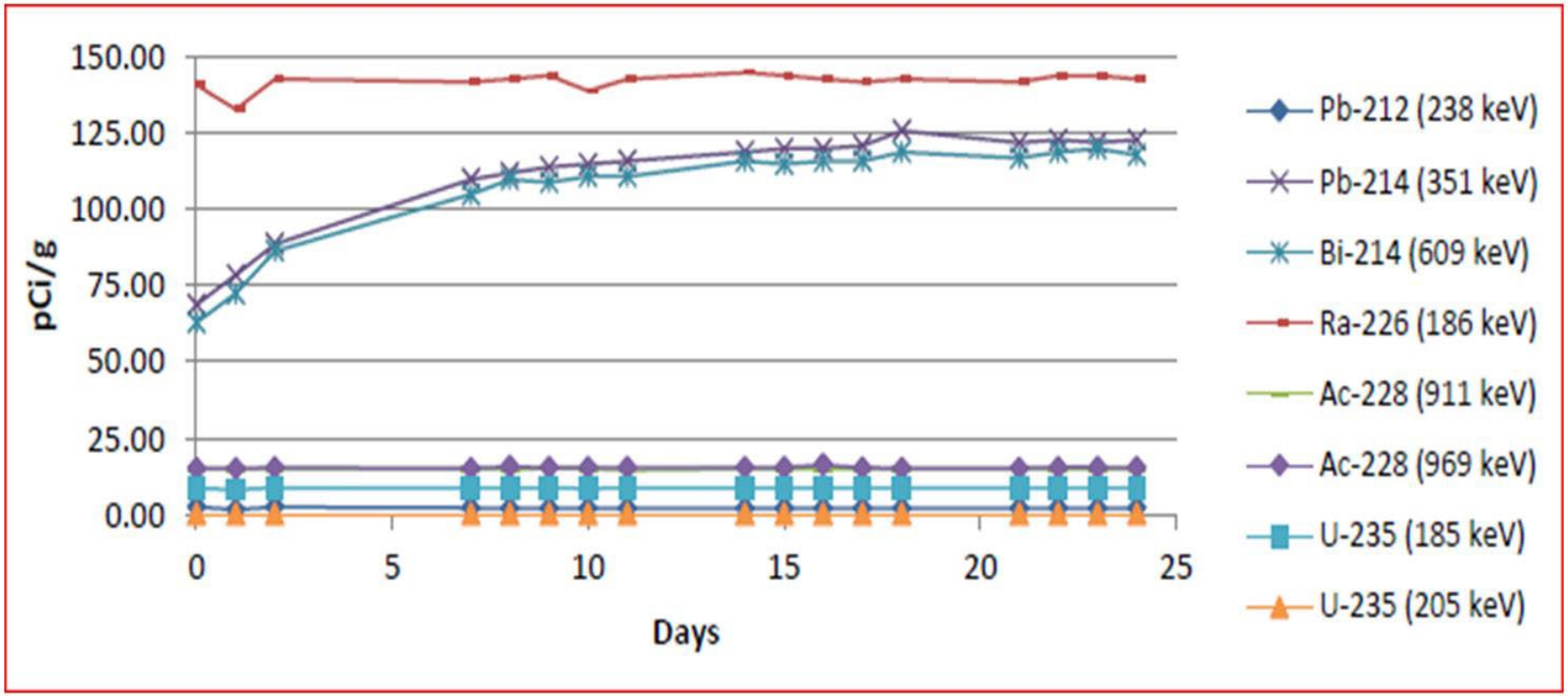
Rn-222 [+d] Ingrowth vs. μR/h

Figure 5-1. Ra-226 Progeny Ingrowth (Days Post Removal) versus Exposure Rate from 13.34 pCi/g Ra-226



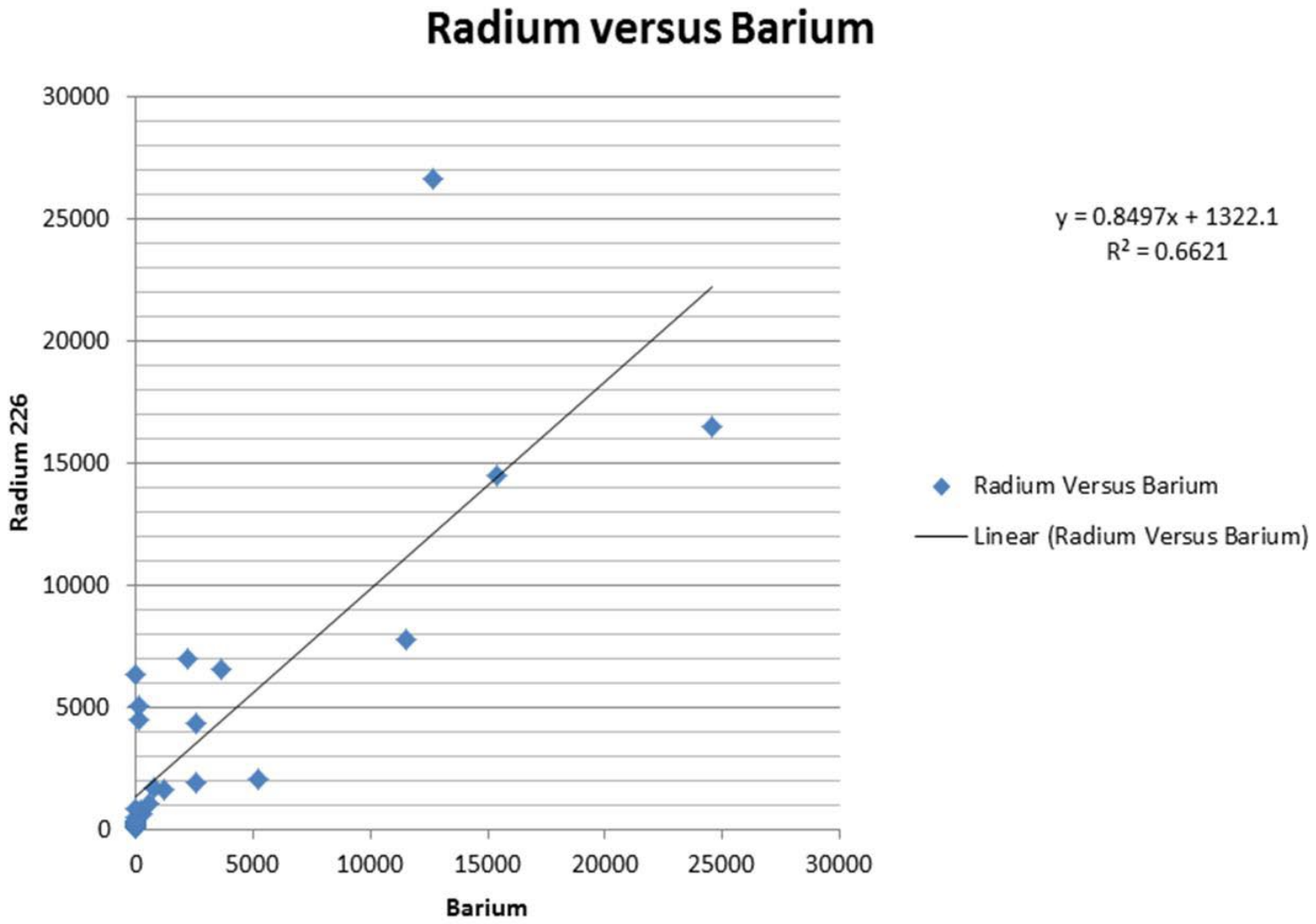
Study Results

Radiochem of Filter Cake vs. Time



Study Results

Non-Rad Chem. Data on Flow-back H2O



PA TENORM Waste Issues

- O&G sludge, rock cuttings and 'other' (e.g., zircons)
- Numerous sludge samples exceeded DOT criteria for Ra-226 and Ra-228
- Initial disposal RESRAD modeling performed c2002
- Additional c2002 MicroShield® calculations assumed Ra-226 / Rn-222 decay product equilibrium
- New Study data has informed DEP for the need to update our approach for TENORM disposal

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Study Results

Radon

Underground Storage -

Gas in: 20 to 30 pCi/L

Gas out: 5.1 to 11 pCi/L

Radon at well head: 3.0 to 148 (48 ave.) pCi/L

Ambient Rn Compressor Station: 0.1 to 0.8 pCi/L

Ambient Rn Power Plant: 0 to 0.4 pCi/L

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USGS Radon in Natural Gas Study

The PA DEP-BRP Study got very similar results…

USGS
science for a changing world

Radon-222 Content of Natural Gas Samples from Upper and Middle Devonian Sandstone and Shale Reservoirs in Pennsylvania: Preliminary Data

Open-File Report Series 2012–1159

By E.L. Rowan and T.F. Kraemer

Abstract

Samples of natural gas were collected as part of a study of formation water chemistry in oil and gas reservoirs in the Appalachian Basin. Nineteen samples (plus two duplicates) were collected from 11 wells producing gas from Upper Devonian sandstones and the Middle Devonian Marcellus Shale in Pennsylvania. The samples were collected from valves located between the wellhead and the gas-water separator. Analyses of the radon content of the gas indicated ^{222}Rn (radon-222) activities ranging from 1 to 79 picocuries per liter (pCi/L) with an overall median of 37 pCi/L. The radon activities of the Upper Devonian sandstone samples overlap to a large degree with the activities of the Marcellus Shale samples.

DEP BRP Conclusions

- Study one of the most comprehensive to date
- Well sites and pads have low worker exposure
- O&G well frac and produced water high in Ra
- Potential for environmental impact with spills
- Unclear impact with the use of brines on roads
- Several wastewater treatment plants and environs require follow-up for clean-up
- ~25 % of TENORM sludge over DOT Class 7 limits
- Long-term Ra in LF leachate monitoring needed

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DEP BRP Conclusions

- Sludge from wastewater treatment not in equilibrium between Ra-226 and Rn-222 decay products
- We are reviewing O&G industry data on samples taken during DEP study
- Landfill TENORM disposal protocols developed circa 2002 need to be re-examined
- Follow-up needed on ‘pigging’ and gas processing plants for potential worker Pb-/Po-210 exposure

TENORM Study Information

- Study-related documents are available at www.dep.state.pa.us Keyword "TENORM"
- Overview of Study is being provided to the appropriate DEP advisory committees and other stakeholders
- Overview of Study also being presented at various scientific meetings and conferences

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RP Regulatory Framework

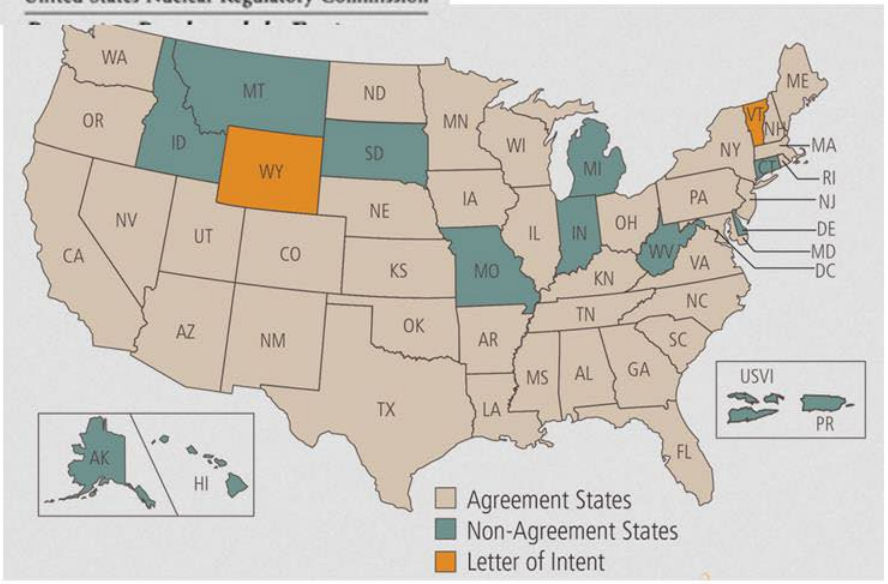
- **The President of the USA**

- Environmental Protection Agency (EPA)
- Nuclear Regulatory Commission (NRC)
- Dept. of Energy (DOE)
- Dept. of Labor - Occupational Safety & Health Administration (OSHA)
- Dept. of Transportation (DOT)
- FDA, FEMA, DoD, NASA, et al.
- States (e.g., Pennsylvania)

TENORM RP Regulatory Framework

U.S.NRC
United States Nuclear Regulatory Commission

- States / OAS / CRCPD



http://www.crcpd.org/

June 2015

E-42 TASK FORCE REPORT

REVIEW OF TENORM IN THE OIL & GAS INDUSTRY

New E-45 WG

SR-N [now active]

SSRCR Volume I - April 2004

PART N

REGULATION AND LICENSING OF TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIAL (TENORM)

Health Physics Society / ANSI Std.

ANSI/HPS N13.53-2009

Approved: March 2009

Control and Release of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

HPS
Health Physics Society
Specialists in Radiation Safety

ANSI
American National Standards Institute

TENORM RP Regulatory Framework

TENORM regs under RP law, or Solid Waste?

Regulatory Scope?

- TENORM Definition
- Basic RP Standards
  - Occupational 5 rem/y
  - Public 100 mrem/y
  - Disposal 25 mrem/y
  - Clean-up 5 pCi/g

Licensing?

- TENORM exemption
- Specific license
- General license
- Disposal or decon
- Other RP Permit
  - RP Action Plan
  - RP Management Plan

Worker training…
and, what about TENORM [Ra-226] measurement!

State Regs TENORM Disposal

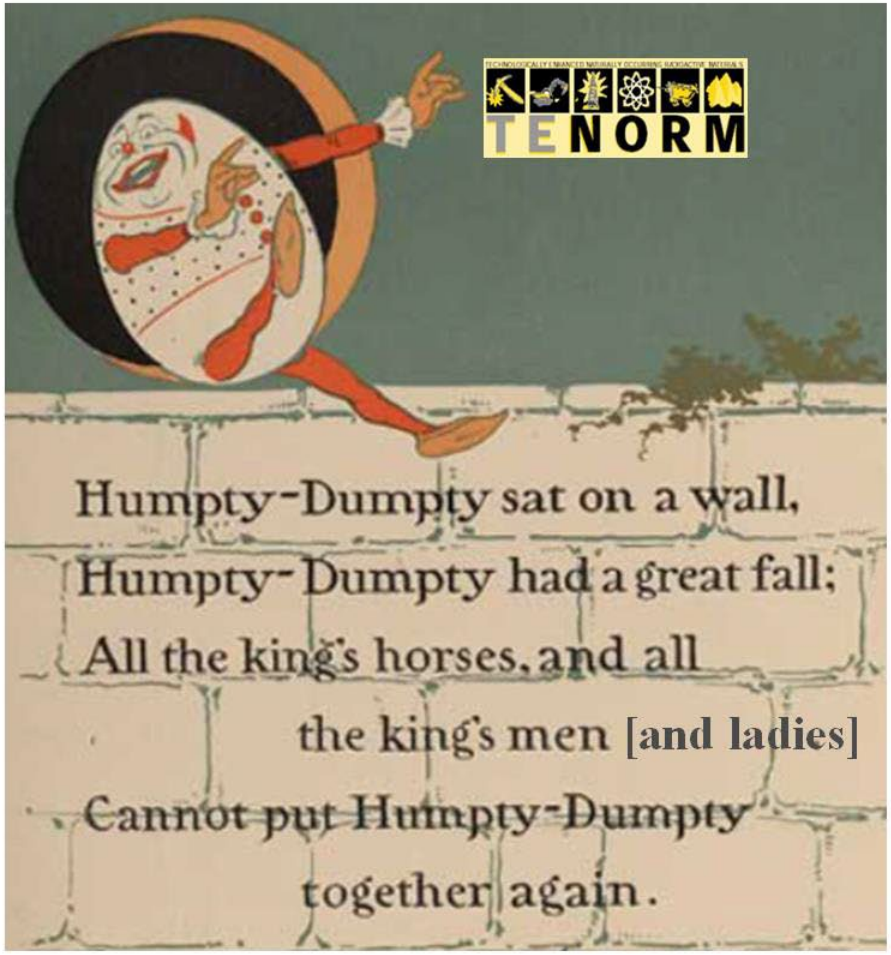
Proposed ND Regs – 50 pCi/g [Dec. 2014]

NORTH DAKOTA DEPARTMENT of HEALTH

State	Disposal Limit (picocuries per gram)	Radionuclide	Type of Limit
California	1800	total picocuries/gram	landfill permit
Colorado	2000	total picocuries/gram	landfill permit
Idaho	1500	Ra-226 and Ra-228	landfill permit
Illinois	200	Ra-226	state rule for drinking water treatment sludge
Louisiana	30	Ra-226	state rule
Michigan	50	Ra-226 and Ra-228	state rule
Minnesota	30	Ra-226	state rule for drinking water treatment sludge
Mississippi	30	Ra-226 and Ra-228	state rule
Montana	30	Ra-226 and Ra-228	state policy
New Mexico	30	Ra-226 or Ra-228	state rule - landspreading
Texas	30	Ra-226 or Ra-228	state rule - landspreading
Utah	10000	Ra-226 and Ra-228	landfill permit
Washington	10000	Ra-226 and Ra-228	landfill permit
Wyoming	50	Ra-226 and Ra-228	state policy

TENORM RP Regulatory Framework

In the USA - fragmented !!



But we're hopeful…

SC 5-2 Working Group on TENORM

Acknowledgements

DEP Staff -

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CO & RO BRP Staff

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GEL Lab Staff -

Bob Seyer, et al.

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Questions?