Assessment of TENORM Disposal in North Dakota Industrial Waste and Special Waste Landfills

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Argonne National Laboratory Was Established in 1946

Operated by UChicago Argonne, LLC for the U.S. Department of Energy

Multidisciplinary science and engineering research center

Pioneering research to help pave the way to a secure nation with a plentiful supply of safe, sustainable energy; a healthy environment; and a competitive economy.

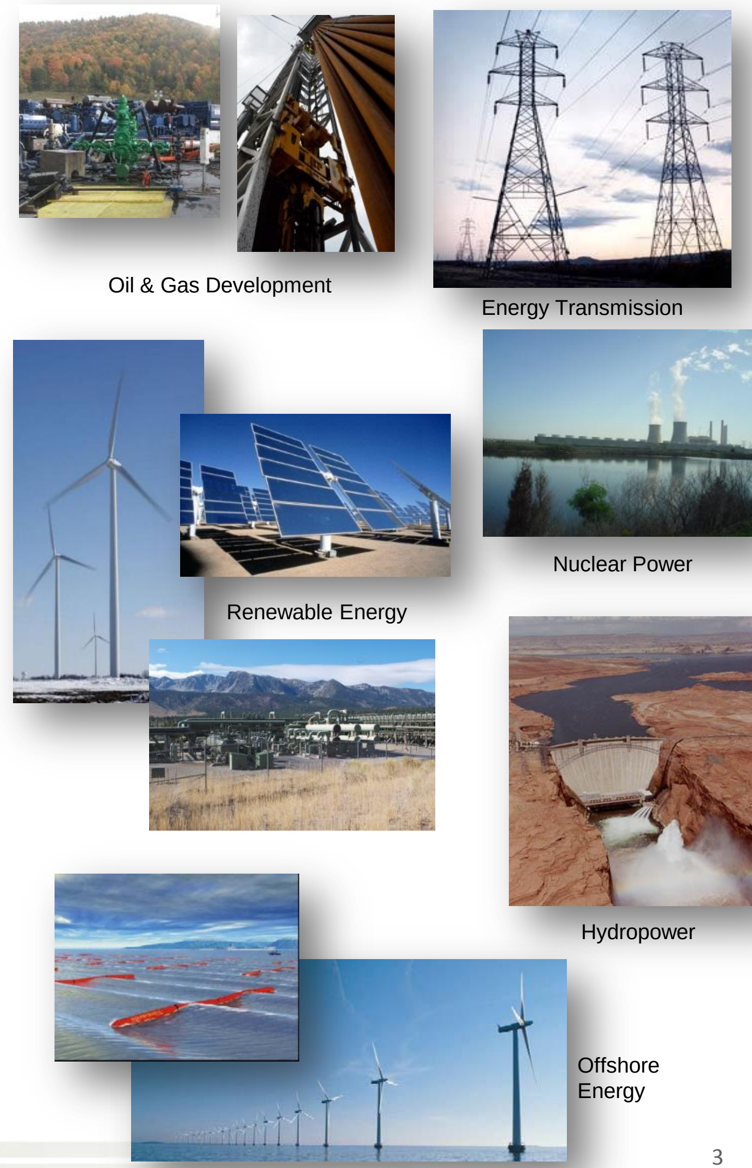
CORE CAPABILITIES:

- Energy
- Environment
- National Security

Argonne's Environmental Science Division Conducts Research on a Broad Array of Energy and Environmental Decision Making

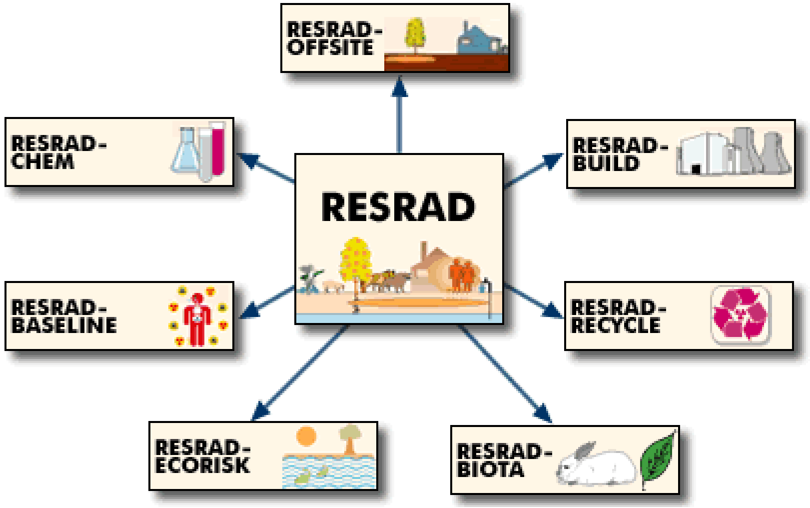
Research Mission

- Conduct basic and applied research on how natural systems behave in response to change, and how to mitigate adverse change.
- Conduct science-based analyses of emerging environmental issues, with a focus on energy development.
- Support formulation of policies and regulations ensuring safe, environmentally responsible, and economically sustainable energy development.



Argonne Has Developed Computer Codes to Assess Radiological Risk

- The RESRAD code was developed with funding from the U.S. Department of Energy and U.S. Nuclear Regulatory Commission.
- It is used to develop site-specific guidelines for managing residual radioactive materials:
  - Estimate radiation doses and cancer risks for future site users,
  - Evaluate the effectiveness of various disposal and remediation actions in terms of limiting future radiation exposures,
  - Evaluate uncertainty associated with key site and/or waste parameters, and
  - Establish appropriate cleanup criteria from a risk-based perspective.
- Argonne also has developed the TSD-DOSE code to evaluate risk from specific treatment, storage, and disposal (TSD) activities.



RESRAD = RESidual RADioactivity

Argonne Has Studied the Management and Disposal of Petroleum Industry TENORM Wastes for Decades

- Initial work funded by the U.S. Department of Energy, starting in early 1990s
- Additional analyses conducted for other states and national and international oil companies
- Studies have covered:
  - TENORM overview
  - Dose and risk assessments
    - Equipment decontamination and smelting
    - Landspreading disposal
    - Underground injection
    - Salt cavern disposal
    - Landfill disposal
  - Cost assessments
  - Site characterization
- These studies have supported the development of TENORM policies and regulations, as well as company-specific TENORM management strategies.

Study Objective

Support the North Dakota Department of Health's (NDDH) evaluation of issues associated with the management and disposal of TENORM.

The study was structured with two separate parts.

The objectives were to evaluate potential doses to workers and the general public resulting from:

1. Disposal of TENORM wastes in permitted Industrial Waste and Special Waste Landfills in North Dakota.
   - Transportation of TENORM to landfills
   - Landfill operations
   - Future use of the landfill property
2. Oilfield activities involving TENORM
   - Worker exposures from wellsite operations
   - Accidental public exposures to mismanaged filter socks and proppants

Naturally Occurring Radioactive Material (NORM) is Present in our Environment

- Radionuclides occur naturally in air, water, and soil.
- Background radiation comes from
  - Cosmic radiation
  - Terrestrial radiation
  - Internal radiation
- Background radiation levels vary by geographic location, depending upon local elevation and geology.
- Radionuclides also occur in food we eat, and in materials commonly present in our homes, offices, and schools.

Radioactivity in Foods

A number of food items naturally contain potassium-40 and radium-226:

- Bananas
- Carrots
- Potatoes
- Lima beans
- Red meat
- Brazil nuts
- Beer
- Drinking water

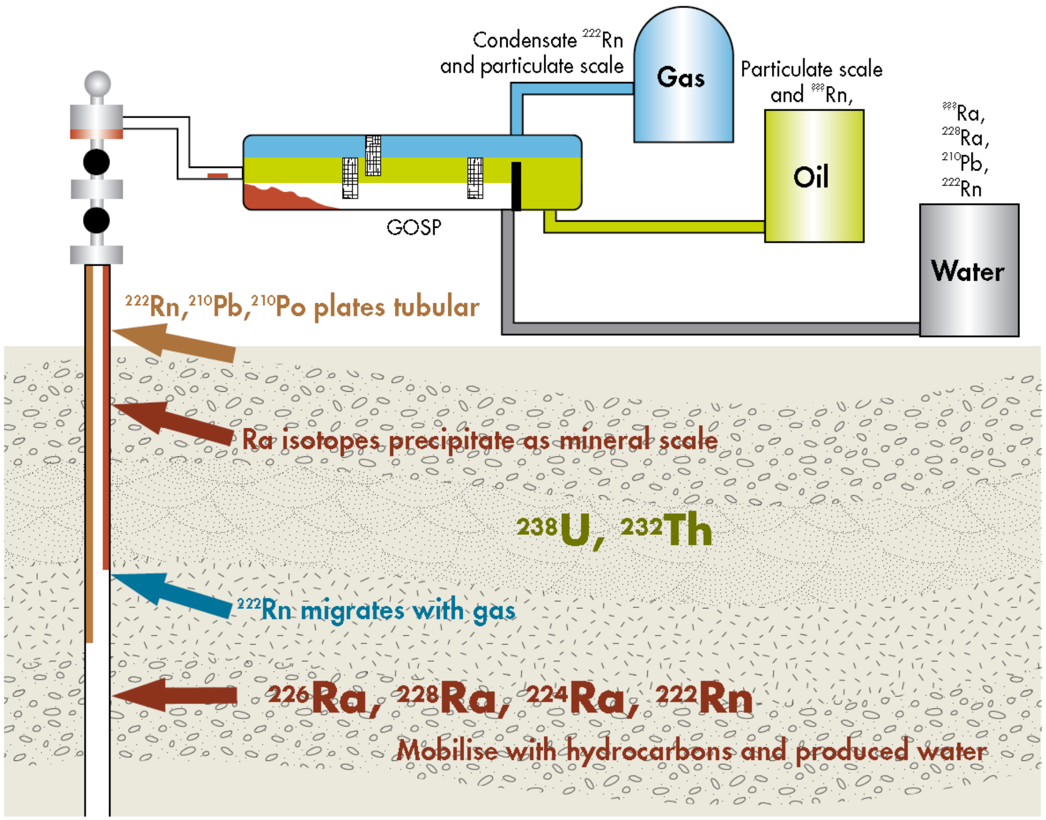
Radioactivity in Consumer Products

Many items in and around our homes, offices, and schools contain radionuclides:

- Smoke detectors
- Compact fluorescent lights
- Watches and clocks
- Ceramics
- Glassware
- Fertilizers
- Granite countertops

What is TENORM?

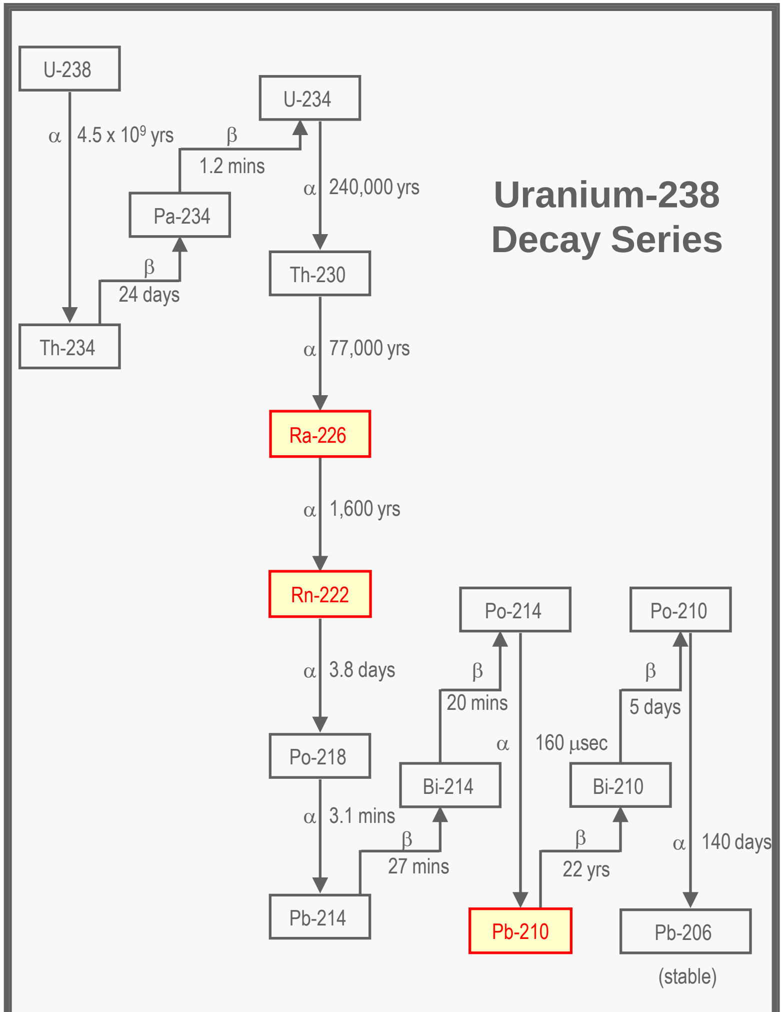
- Some petroleum industry waste streams contain radioactive materials.
- These materials come from naturally occurring radionuclides present in underground rock formations from which oil and gas are produced.
- In some instances, these wastes contain radiation above background concentrations.
- These materials are referred to as ***technologically enhanced naturally occurring radioactive materials*** or **TENORM**.

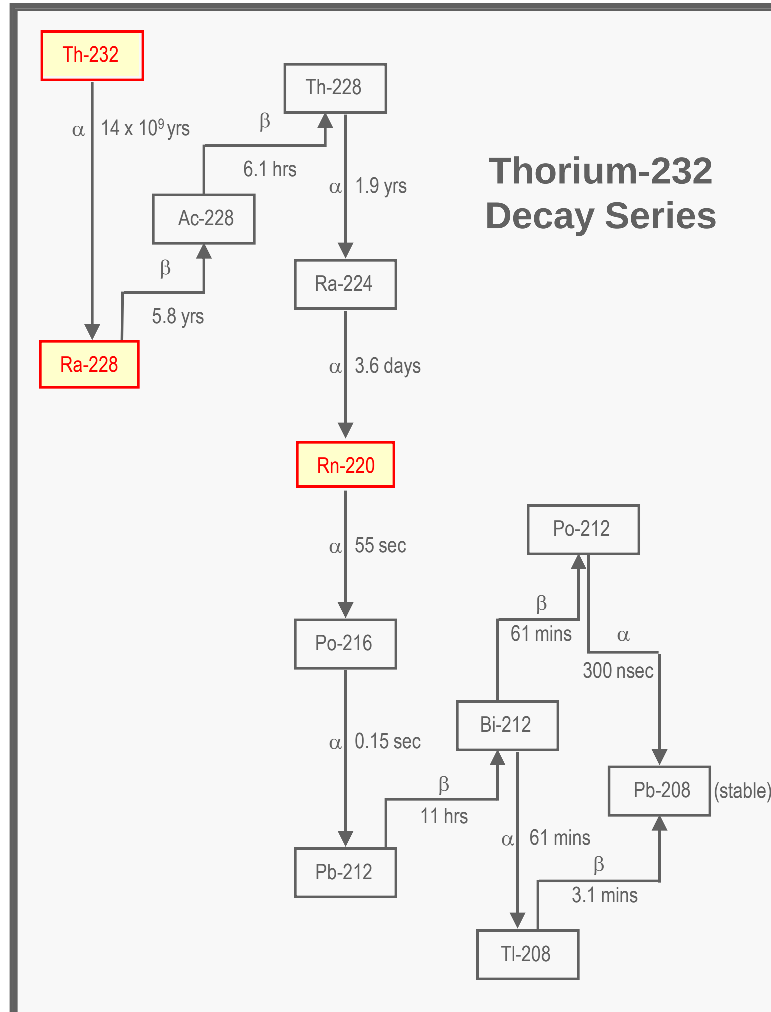


Origins of TENORM and Where It May Accumulate

Source: International Assoc. of Oil & Gas Producers, Report No. 412 (2008)

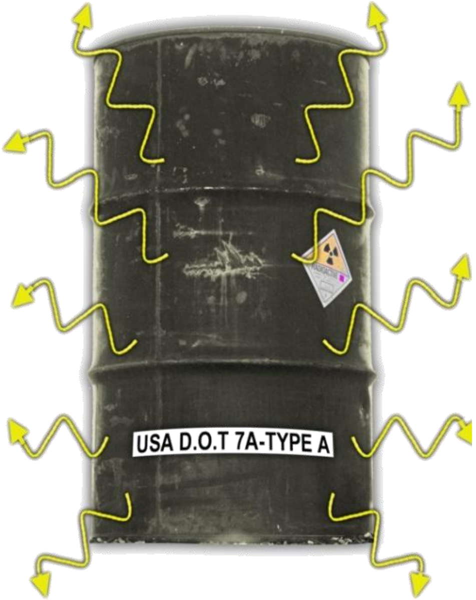
Radionuclides of Concern in Petroleum Industry TENORM



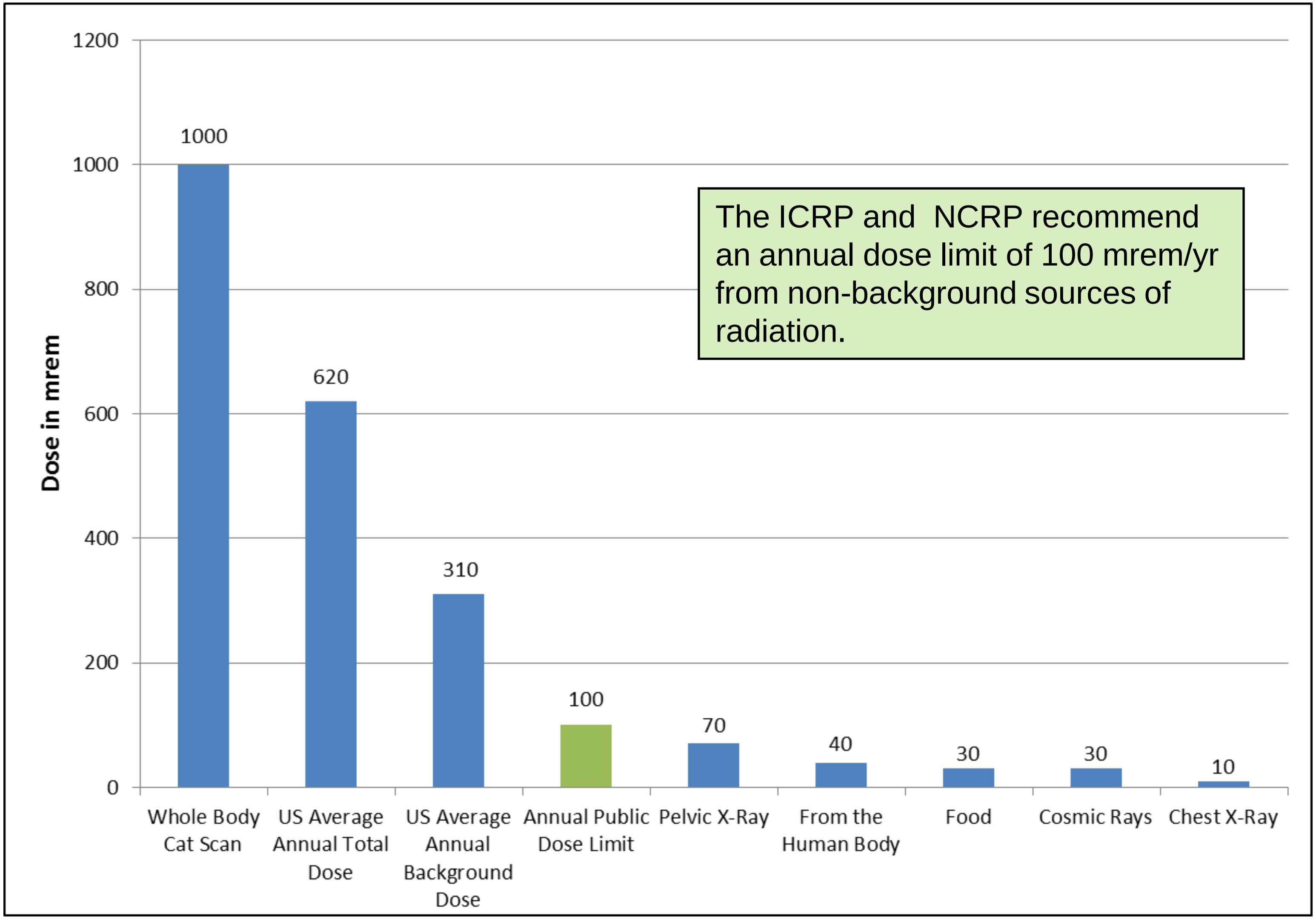


Radiation Terminology

- Radiation is a type of energy that travels in waves or particles.
- Radioactivity is measured in units of pCi/g.
- When a person is exposed to radiation, the energy penetrates the body.
- Exposure is measured in dose units of mrem/yr.



Typical Radiation Exposure Levels for Common Activities (Source: NRC 2014)

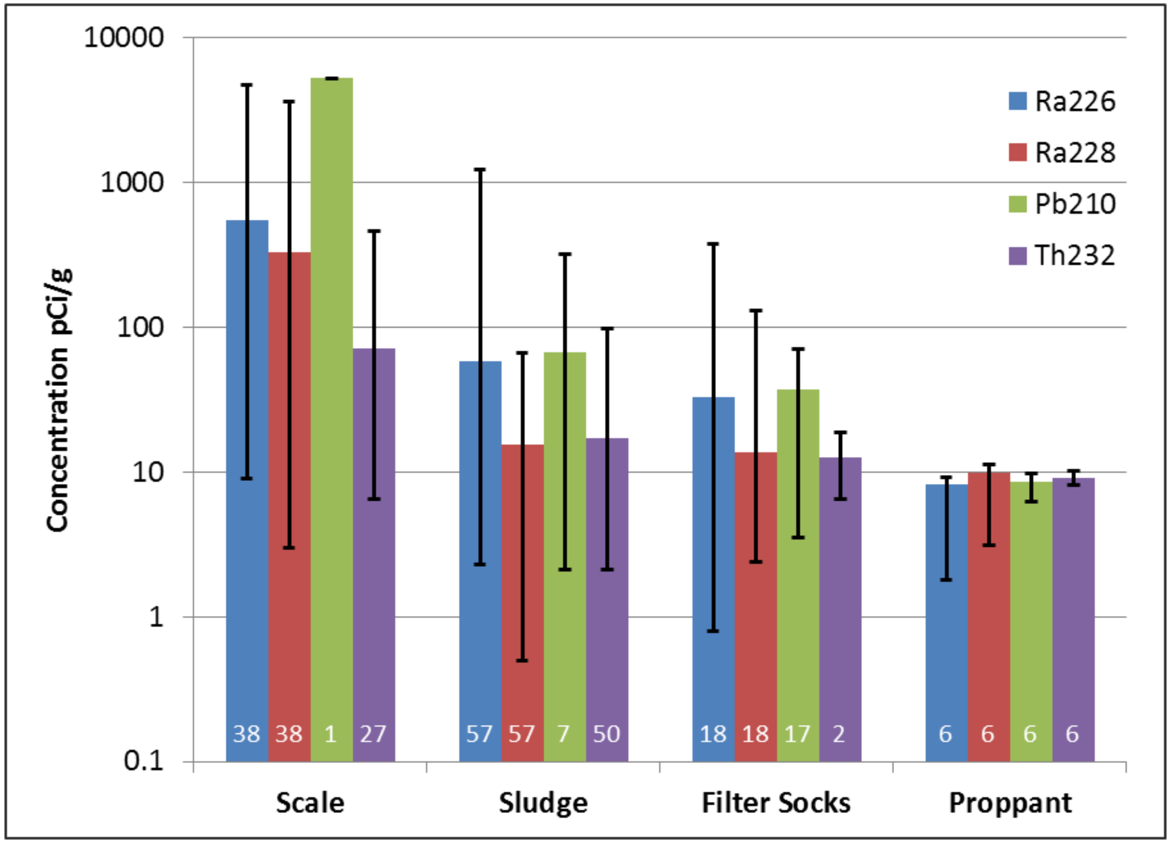


ICRP = International Commission on Radiological Protection
NCRP = National Council on Radiation Protection and Measurements

TENORM Waste Streams from Oil and Gas Development in North Dakota

- Produced Water
  - Formation water that is produced along with hydrocarbons. Radionuclides that are mobilized in formation water are brought to the surface in this waste stream.
- Scale
  - Hard and relatively insoluble deposits that accumulate inside production and processing equipment and on solid debris (e.g., sand grains) that comes in contact with produced water (typically $BaSO_4$ or $SrSO_4$). Radionuclides can co-precipitate with the sulfate scales.
- Sludge and Filter Cake
  - Solid material including mud, sand, scale, and rust that settles or is filtered out of produced water. It is found in vessels used to store or manage produced water and in filter socks.
- Filter Socks
  - Disposable filters used for filtering produced water accumulate sludge and filter cake over time which may contain radionuclides
- Synthetic Proppants
  - Some imported synthetic proppants can contain low concentrations of radionuclides
- Contaminated Soils and Equipment

Radionuclide Concentrations Based on Available Data for North Dakota TENORM

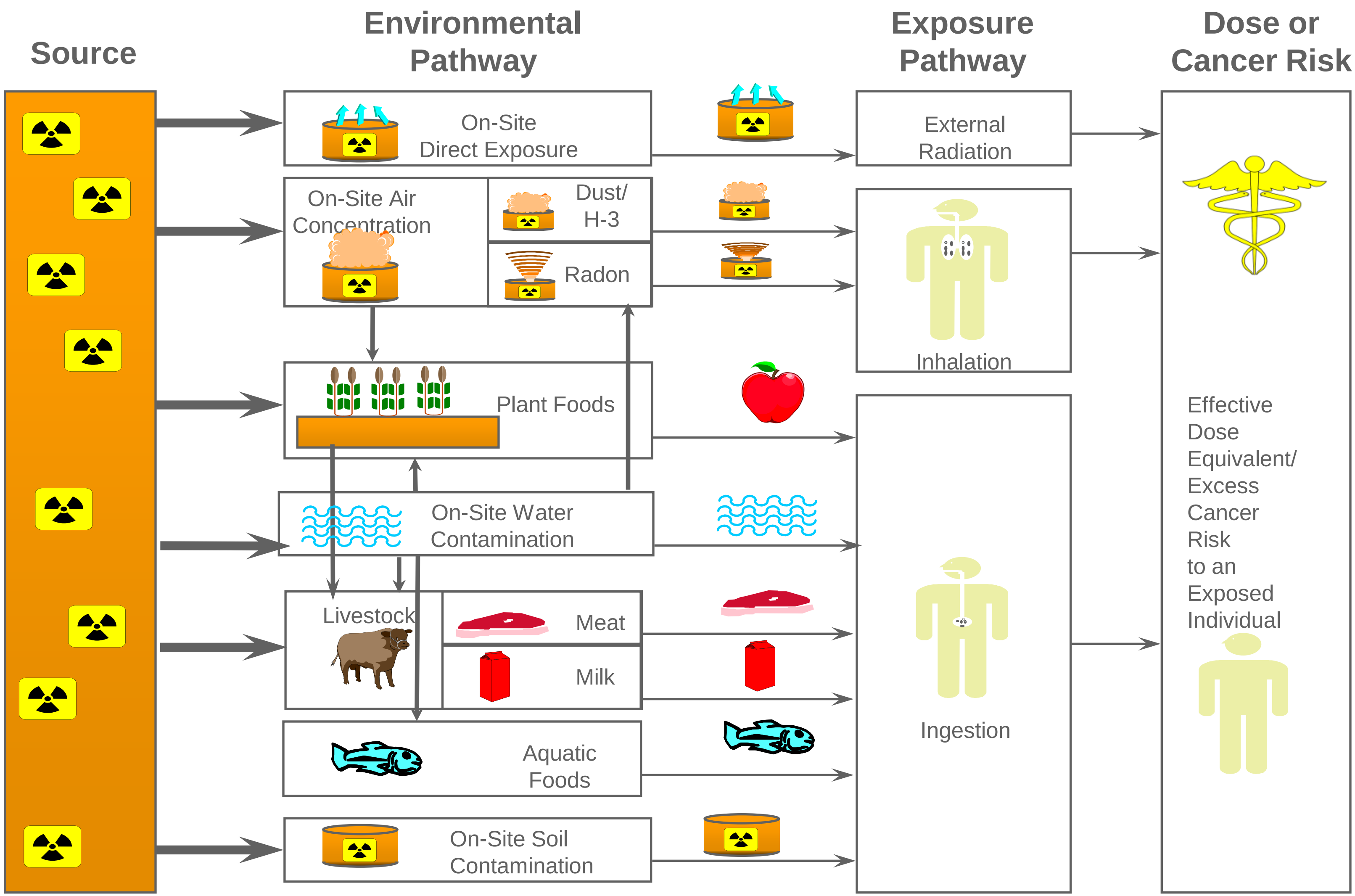


Based on data provided by the NDDH. Columns represent average radionuclide concentrations, error bars represent minimum and maximum value, white numbers represent the total number of samples represented

The average and maximum values for each radionuclide were used to assess potential doses associated with oilfield operations.

The analysis of doses associated with landfill disposal was not based on these data.

Pathway Analysis Is Used to Assess Radiological Dose and Risk



Doses are converted to carcinogenic risk using risk factors identified by the ICRP.

Several Different Pathway Analysis Codes Were Used to Support the Radiological Dose Assessments

- RESRAD
  - Future use of the property following landfill closure
- RESRAD Build
  - Oilfield operations
  - Mismanaged filter socks and proppants
- RADTRAN
  - Transportation of TENORM to landfills
- TSD-DOSE
  - Landfill operations
- RESRAD Offsite
  - Used to evaluate groundwater transportation of TENORM, including decay

Hydrologic Modeling Was Conducted to Support Dose Assessments for Some Exposure Scenarios

Hydrologic modeling evaluated the possible movement of radionuclides:

- Through the landfill into subsurface groundwater and
- Through the subsurface to a drinking water well

Several landfill performance scenarios were modeled using three models:

- HELP (U.S. Environmental Protection Agency)
  - Models infiltration and percolation through landfill materials
- MODFLOW (U.S. Geological Survey)
  - Models groundwater flow
- MT3DMS (U.S. Army Corps of Engineers)
  - Models contaminant fate and transport processes (e.g., from landfill to water well)

The human dose assessments related to exposure to contaminated leachate and groundwater were based on the worst-case scenarios (e.g., failure of both the landfill cap and liner systems).

Different Modeling Methodologies Were Used to Evaluate Various Scenarios

Well Site Operations and Accidental Public Exposures

- Dose rates are based on average and maximum radionuclide concentrations as presented in available waste characterization data provided by NDDH.
- The proposed new TENORM disposal rule does not address any of these oilfield operation scenarios.

Landfill Operation and Future Use of Landfill Property

- The analysis calculated the maximum concentration of radionuclides that could be disposed of in the landfill without resulting in doses greater than 100 mrem/yr for any receptor.
- Dose rates for transportation-related exposures were based on the maximum concentrations calculated for the landfill disposal option.

Well Site Operations Scenarios

Scenario	Waste Stream	Assumptions
Well pad workers		
Mixing hydraulic fracturing fluid	Proppant	Exposure time: 2,000 hrs/yr Worker wears PPE
Produced water filtration	Filter cake, filter socks	Exposure time: 250 hrs/yr
Equipment cleaning workers		
Pipe cleaning	Scale	Exposure time: 2,000 hrs/yr Worker wears PPE
Storage tank cleaning	Sludge	Exposure time: 100 hrs/yr Worker wears PPE
Gas processing	Pb-210 film	Exposure time: 2,000 hrs/yr Worker wears PPE
Sludge treatment workers		
Sludge treatment	Sludge	Exposure time: 2,000 hrs/yr Worker wears PPE

Personal protective equipment (PPE) includes respirators, eye protection, and gloves

Well Site Operations Dose Assessment Results Based on Average Concentrations

Operations	Exposure Source	Total Dose (mrem/yr)
Mixing hydraulic fracturing fluid	Proppant	20
Produced water filtration	Filter socks, filter cake	0.47
Pipe cleaning	Scale	14
Storage tank cleaning	Sludge	3.8
Equipment cleaning at gas processing	Pb-210 film	0.0003
Sludge treatment workers	Sludge	1.6

Based on average TENORM concentrations and assuming appropriate use of PPE, all workers receive a dose significantly less than 100 mrem/yr

Well Site Operations Sensitivity Analysis Results

Operations	Maximum Concentration		Average Concentration	
	With PPE (mrem/yr)	Without (mrem/yr)	With PPE (mrem/yr)	Without (mrem/yr)
Mixing hydraulic fracturing fluid	23	30	20	26
Pipe cleaning	127	650	14	390
Storage tank cleaning	70	73	3.8	7.4
Equipment cleaning at gas processing facility	0.012	670	0.0003	18
Sludge treatment	30	85.8	1.6	15.4

The use of PPE can effectively reduce potential exposures for many workers.

Based on maximum concentrations, doses for the equipment cleaning workers could be elevated even if PPE are used.

It may be necessary to limit exposure time to keep exposures to these workers below 100mrem/yr.

Accidental Public Exposure Assessment Results

Scenario (Exposure Time Over One Year)	Maximum Concentration	Average Concentration
	Total Dose (mrem/yr)	Total Dose (mrem/yr)
Child playing with filter socks (24 hrs)	0.21	0.051
Adult exposed to filter socks in a dumpster (40 hrs)	4.4	0.40
Child playing in area where synthetic proppant has been dumped on the ground (100 hrs)	1.4	1.2

These scenarios are not representative of all possible exposures.

For the scenarios modeled, the risks of short term exposure to improperly disposed of filter socks and synthetic proppant are low.

Transportation Risk Assessment Scenarios and Results

Receptor	Base Case[a] (1,000 Shipments/yr)	Maximum Case (2,000 Shipments/yr)
	Dose (mrem/yr)	Dose (mrem/yr)
Routine Conditions		
Driver	20	20
Individual	1.6×10^{-6}	3.2×10^{-6}
General population[b]	6.5×10^{-5}	1.3×10^{-4}
Accident Conditions		
General population[b]	3.6	7.2

[a] Assumes 25,000 tons/yr TENORM wastes transported to a single landfill, truck capacity of 25 tons, based on maximum allowable TENORM concentrations from landfill scenarios.

[b] Doses to the collective general population are expressed in units of person-rem/yr.

Potential doses associated with transportation of TENORM wastes are very low both for drivers and members of the general public.

Landfill Operations and Future Use Scenarios

Landfill Operations

- Up to 25,000 tons of TENORM per year disposed of in a single landfill; TENORM wastes would comprise no more 10% of the total landfill volume
- Worker exposures
  - Waste receiving and handling
  - Waste transport within the landfill
  - Waste placement
  - Workers operating the leachate management system
- General public exposures

Future Use of the Landfill Property

- Onsite resident
- Industrial worker
- Recreational visitor
- Intruder
- Offsite resident

Estimated Allowable TENORM Concentrations Were Calculated to Ensure Potential Doses Were Below 100 mrem/yr for All Receptors

	Allowable TENORM Concentration (pCi/g)			
	Based on Worker Scenarios		Based on Future-Use Scenarios	
Radionuclide	pCi/g	Limiting Scenario	pCi/g	Limiting Scenario
Pb-210	4,200	Waste Placement	11,000	Intruder
Ra-226	98	Receiving and Handling	130	Resident
Ra-228	180	Receiving and Handling	700	Intruder
Th-232	48	Waste Placement	410	Intruder

In general the landfill worker scenarios were more restrictive than the future use scenarios for all radionuclides.

Calculation of Maximum Allowable Radium Concentration for TENORM Disposal in the Landfills

The TENORM landfill disposal rule needs to establish a maximum allowable total radium concentration that

1. Ensures doses to not exceed the recommended limit of 100 mrem/yr for the general public, and
2. Factors in the possible presence of thorium.

The following calculations were made:

- The ratios of Th-232/total radium and Ra-226/total radium were calculated based on available waste characterization data.
- The sum of fractions rule was used to calculate the maximum total radium concentration using these ratios.
- A conservative calculation was run using these ratios plus one standard deviation.
- The results indicated that the 100 mrem/yr dose limit would not be exceeded if the maximum total radium concentration was 51 pCi/g, assuming a thorium concentration of no more than 24 pCi/g.

Recommendations Regarding Regulation of the Disposal of TENORM in Landfills

- To ensure that potential exposures to any landfill worker or member of the general public does not exceed 100 mrem/yr
- The average concentration of total radium should not exceed 50 pCi/g of total radium provided the following conditions were met:
  - No more than 25,000 tons of TENORM wastes were disposed of in a single landfill per year.
  - The average thorium activity concentration in the waste did not exceed 24 pCi/g.
  - TENORM wastes were covered by at least 2 m (6 ft) of clean cover material.