TENORM IN UNCONVENTIONAL OIL & GAS PRODUCTION WORKSHOP

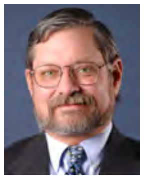
sponsored by the

National Council on Radiation Protection and Measurements

Monday, February 1, 2016

Plenary

8:20 am



William E. Kennedy, Jr.

Dade Moeller & Associates

has extensive experience as a project manager, task leader, and individual contributor covering a broad range of health physics and nuclear engineering topics. He received his BS and MS degrees in Nuclear Engineering from Kansas State University. Mr. Kennedy has been involved in the development of environmental pathway and radiation dosimetry models used to assess potential health and environmental impacts that resulted from releases of radionuclides to the environment. He specializes in the use of these models in environmental dose reconstruction, radioactive materials transport, radioactive waste disposal, and evaluation of nuclear facility operating practices. Over the past 37 y, Mr. Kennedy has led and contributed to a variety of projects for the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, the Electric Power Research Institute, and private industry. He has been involved with development of the technical basis for revised standards and regulations, and serves as the chair of ANSI/HPS N13.12, *Surface and volume Radioactivity Standards for Clearance*. He served as a consultant to the International Atomic Energy Agency (IAEA), Vienna, Austria, and was a member of the IAEA Advisory Groups to evaluate the Derivation of Exempt Quantities for Application to Terrestrial Waste Disposal and Derivation of Exempt Quantities for Recycle of Materials from Nuclear Facilities. He was an invited lecturer for IAEA training courses on Management of Radioactive Waste from Nuclear Power Plants at Argonne National Laboratory; on Safety Assessment Modeling for Low and Intermediate Radwastes in Rio de Janeiro, Brazil and in Cairo, Egypt; and on Environmental Monitoring in Kiev, Ukraine. In 1990, he received the Health Physics Society's (HPS) prestigious Elda E. Anderson Award. He served as a member of the HPS Board of Directors from 1998 through 2001 and was selected as a fellow of the society in 2002. He was a member of the U.S. delegation to the 10th Congress of the International Radiation Protection Association in Hiroshima, Japan.

NCRP Scientific Committee 5-2 on TENORM Waste

NCRP established Scientific Committee (SC) 5-2 to develop *Recommendations for a Uniform Approach for Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced NORM (TENORM) Waste Management and Disposal for the Oil and Gas Industry.* This effort is consistent with the overall mission of NCRP to formulate and widely disseminate information, guidance and recommendations on radiation protection which represents the consensus of leading scientific experts. Since the early 20th century, it has been understood that rock formations, including those that host oil and gas production contain primordial concentrations of NORM radionuclides, typically the decay chains of uranium and thorium. Radium in pipe scale from oil production facilities is an example of TENORM concerns in years past. With increased demand for oil and natural gas, newer technologies using horizontal drilling coupled with hydraulic fracturing have been deployed. The U.S. Environmental Protection Agency has estimated that about 1,500,000 $m^3\ y^{-1}$ of waste are produced by the oil and gas industry, including produced water, well casing scales, tanks, pipes sludge, and equipment. Some of this waste contains elevated concentrations of TENORM. There is no federal guidance for TENORM waste management; the regulatory authority lies with the states. Individual states that host hydraulic fracturing operations are left to cope with emerging TENORM waste management issues on an *ad hoc* basis with little scientific support. SC 5-2 is preparing a commentary that provides recommendations for a science-based, uniform NORM/TENORM waste management approach. In parallel with this midyear meeting of the Health Physics Society, NCRP is hosting a workshop on Monday afternoon and Tuesday morning to begin the discussions needed to develop the commentary.

Session 1: Logistics & Background (overview of states)

1:30 pm

Masoud Beitollahi

University of Utah

is a Health Physicist working for the Radiological Health Department of the University of Utah. He received his BSc in Nuclear Science and Technology and Geology, followed by a Master in Sedimentology and Sedimentary Petrology (Geology) in 1996. He earned his PhD in Health Physics from Idaho State University in 2007. He has over 30 y of experience in health physics; his background in radiation protection is broad, diverse and international in scope. He began his career concentrating on the radiological monitoring of the environment, radio-

NORMs in Unconventional Oil and Gas Resources

Naturally occurring radioactive materials (NORMs) have always been a part of our environment. Petroleum starts its life with naturally occurring chemicals (organic materials) in the ocean with the presence of NORMs and other sediments. Eventually, after going through geological processes (diagenesis) which occurs over millions of years, these chemicals become expressed in source rocks as oil and gas. NORM radionuclides may become mobile or be deposited by migration of water or oil. Some of the organic complexes, such as humic acids, create mobile complexes of uranium. Uranium and its decay products and trace elements have chemical analysis, measurement and analysis of natural and man-made radionuclides in both terrestrial and marine environments. In the course of these years he has had the opportunity to work with a variety of state, federal, and international agencies and institutions and his experience has grown to include the following assignments:

- implementation and management of radiation protection programs for worker safety and public health;
- development of technical work plans, radiation protection standards, rules, regulations and codes of practice;
- radiation studies and radiochemical analysis for the evaluation of natural and artificial radionuclides in environmental samples;
- program implementation, surveillance, monitoring, and evaluation at high level natural radiation areas;
- expertise in nuclear counting techniques including; alpha spectroscopy, gamma spectroscopy, α / β proportional counting, liquid scintillation counting and emanation techniques;
- application of nuclear techniques in sedimentation rate (dating) under the auspices of the United Nations Development Program in the Persian Gulf;
- development and implementation of radiological monitoring programs for food supplies after Chernobyl accident 1986; and
- radiological monitoring of mines with emphasis on radon measurement.

He is a plenary member of the Health Physics Society, editorial member for the *Journal of Radiation Protection Dosimetry*, and has more than 30 publications in scientific journals and proceedings of national/international conferences. Additionally, he is adjunct associate professor at school of medicine at the University of Utah; affiliate faculty member at Idaho State University and adjunct professor at Alcorn State University, a historically black college where he also mentors young health physicists.

an affinity for crude oil; they are likely residues of consolidated organic and marine deposits. Petroleum is often assumed to have migrated to a position of minimum hydraulic potential in a reservoir rock, which may or may not be derived from the same source deposits as the petroleum. In conventional oil and natural gas fields, source rocks such as sandstone and carbonate are made of porous and permeable materials. In this situation, migration of hydrocarbons under the geological parameters such as hydrodynamic pressure will start from organic sources toward the impermeable reservoir cap rocks where they will be trapped with NORMs. However, in unconventional resources, hydrocarbons accumulations extend in a large area and are not significantly under the influence of geological pressure exerted by water; these types of source rocks are called “tight formations” (also known as “continuous formations”) and have a higher NORM concentration. For example, shales, which contain at least 35 % clay minerals and a significant amount of potassium, can readily adsorb the NORM series radionuclides. The radionuclides that are present may also be bound to organic matter in minor minerals or as precipitates in the cementing material that binds the rock. This presentation is a brief review of the geological origins of NORMs and understanding of the biological, chemical and geochemical parameters that may control the mobility and behavior of the NORM radionuclides in unconventional oil and gas resources.

1:55 pm

John R. Frazier

is a Certified Health Physicist with over 38 y of professional experience in radiation detection and measurement, radiological site characterization, environmental dose assessment, external and internal radiation dosimetry, and radiation risk assessment. Dr. Frazier holds BA, MS, and PhD degrees in physics and performed his dissertation research under an Atomic Energy Commission Fellowship in Health Physics at Oak Ridge National Laboratory. He has held Comprehensive Certification in health physics from the American Board of Health Physics since 1981. He served as instructor and coordinator of health physics courses at Oak Ridge Associated Universities (ORAU) from 1980 to 1986. He has also presented lectures on a wide-range of health physics topics at conferences, symposia and workshops over the past 30 y. Dr. Frazier is a Distinguished Emeritus member of NCRP and a Fellow and Past-President of the Health Physics Society. He has served as an advisor to numerous federal agencies and as a consultant to private companies on a wide range of radiation safety topics.

Dr. Frazier has over 30 y of experience as an advisor at sites having technologically-enhanced naturally-occurring radioactive material (TENORM). Those sites include (current and past) phosphate mining facilities, phosphogypsum storage/disposal sites, rare earth waste processing and disposal facilities, uranium/thorium processing facilities, and oil and gas exploration and production (E&P) sites. Over the past 21 y he has performed and directed radiological characterization surveys of hundreds of oil and gas E&P sites in Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, and Texas. Those survey sites included natural gas production and processing facilities, liquid petroleum gas processing

TENORM Issues in the Petroleum Industry

Nearly every substance on or in the Earth contains naturally occurring radioactive material (NORM) and the amounts of NORM vary with location and the type of substance. NORM was discovered in natural gas (methane) around the beginning of the 20th century – soon after the discovery of radium. About 40 y later NORM was found to be present in various fluids and in production equipment during petroleum exploration and production (E&P) operations. As NORM was brought to the ground surface from underground oil- and gas-bearing formations certain NORM radionuclides were inadvertently concentrated, leading to the name “technologically enhanced” NORM or TENORM. During those early years there was little concern for environmental impact from TENORM as the material was “naturally occurring” and NORM concentrations were generally considered to be inconsequential. Similarly, there was little concern for occupational health and safety from TENORM during petroleum E&P as the measured radiation levels from TENORM were at the very low end of the measurement range of available survey instruments. However, the presence of radon progeny (especially ^{210}Pb and ^{210}Po) in elevated concentrations on internal components of natural gas processing equipment was realized and investigated in the early 1970s, and radiation protection actions for natural gas processing operations were recommended at that time. Following the discovery in the mid-1980s of significant amounts of TENORM (^{226}Ra and ^{228}Ra) in some petroleum E&P sites, persons responsible for environmental safety and health (ES&H) within the petroleum industry implemented programs to determine where and how TENORM was being generated during their operations and, if so, whether workers, members of the public, and the environment were being adequately protected. Those actions sites, crude oil exploration and production sites, and pipe and equipment maintenance/testing and storage yards. He has been called upon to testify as an expert witness in litigation pertaining to scores of survey sites. Dr. Frazier's testimony has included descriptions of the nature and extent of TENORM in environmental media as well as assessments of radiation doses to workers and members of the public.

continue today but are generally developed and implemented without uniform guidance or standards for ES&H programs involving TENORM. In addition to current E&P operations, many sites having TENORM generated from previous E&P operations (often referred to as "legacy" sites) have been identified, characterized and, in many cases, remediated. These actions continue today, but as with current E&P operations, there is limited regulatory guidance for dealing with legacy sites. TENORM issues being faced by the petroleum industry today are associated with the details of ES&H activities at current and legacy E&P sites and with implementation of TENORM remediation/waste management programs at those sites.

2:20 pm

Jared W. Thompson

Council of Radiation Control Program Directors

received his Bachelor of Science degree in 1982 from the University of Central Arkansas. He has been with the Arkansas Department of Health since 1988 as Health Physicist in the x-ray and radioactive materials programs. Mr. Thompson has been Program Manager of the Radioactive Materials Program since 1995.

Mr. Thompson is currently on the Board of Directors of the Conference of Radiation Control Program Directors (CRCPD) serving as Chair-Elect. He served as Chair of the CRCPD E-42 Task Force – Review of TENORM in the Oil and Gas Industry.

Mr. Thompson is Past Chair of the Organization of Agreement States. In 2011, he was inducted into the Organization of Agreement States Hall of Fame.

In 1996, Mr. Thompson received the Food and Drug Administration Commissioner's Special Citation for collaboration and implementation of the Mammography Quality Standards Act of 1992.

Overview of State Activities to Regulate TENORM

State radiation control programs have been regulating radioactive contamination and waste management issues involved with technologically enhanced naturally occurring radioactive material (TENORM) for several decades. Since most of this material does not fall into the federal definition of source or byproduct material, the regulation of it is largely left to the states.

The Conference of Radiation Control Program Directors (CRCPD) has worked since the 1980s to develop model state regulations with applicable standards for TENORM in industries that had not come under the purview of radiation regulations previously. Since that time, several states have also addressed TENORM regulatory issues in their jurisdictions and CRCPD has modified the model state regulations. However, the standards remain inconsistent among the states that regulate TENORM. In addition, new pathways and changes in operations are directly affecting concentration of TENORM and environmental and worker impacts (*e.g.*, fracking). As a result, CRCPD is reviewing current issues to refine the regulatory standards and guidance for TENORM, and is making recommendations for future actions to address technical assessment issues, training needs, and action levels.

2:45 pm Panel Discussion

3:15 pm Break

Session 2: Potential Environmental Impacts (air, water, environment)

3:30 pm

Daniel F. Shank

Coats Rose Law, Houston

is a Director at Coats Rose with more than 35 y of experience in the practice of law. His practice is focused on complex litigation matters in the areas of commercial, personal injury, real estate, environmental, energy and insurance litigation. After receiving his degree from Georgetown University School of Law, he joined the firm of Butler & Binion. In 1985, he joined the firm of Cook, Davis & McFall and became that firm's first new partner in 1986. In 1990, Dan formed Davis & Shank and subsequently joined the Coats Rose team in 1999.During his career, Dan has successfully tried numerous cases involving a broad range of substantive areas of the law. He has prosecuted and defended cases involving substantial recoveries and significant exposures, and he has participated in a number of appellate matters on behalf of his clients. Dan has been selected to the Texas Super Lawyers in the area of commercial litigation for the years 2005 to 2015 and recognized by his peers for inclusion in The Best Lawyers in America© for the years 2010 to 2016. He is Board Certified for Civil Trial by the Texas Board of Legal Specialization. Dan has also served the Houston Bar and community, acting as the Chairman of the American Diabetes Association, Houston Chapter, participating on

TENORM Litigation Issues – Part 1

Several events have drawn attention to the potential health and environmental risks associated with naturally occurring radioactive material (NORM). In approximately 1981, the potential for NORM contamination was discovered in the North Sea. In 1986, investigators discovered significant levels of radioactivity in pipe scale at the oilfield pipe cleaning facility of Street, Inc. in Laurel, Mississippi. Following the discovery of NORM at the Street facility, significant quantities of scale involving NORM contamination were discovered in oil and gas as well as oilfield services industries. As a result, some states adopted regulations to deal with the NORM contamination phenomena as recognized by those industries. This lead to (1) cleanup activities to bring facilities to unrestricted or restricted use status; (2) landowner claims for damages due to remediation of NORM contaminated sites; (3) toxic tort claims for personal injury, wrongful death, medical monitoring, and fear of cancer; (4) allocation of environmental liabilities for NORM in mergers and acquisitions; (5) merger and acquisition breach of warranty claims involving NORM contamination; and (6) insurance coverage issues. This presentation will focus on some of the litigation related issues involving NORM that the presenter has experienced since 1995.

other charity boards, including the Christus Foundation and Mental Health America, chairing three HBA committees, volunteering as a member of one of the Texas Bar Association's grievance committees, and contributing as a director of the junior bar. Since approximately 1995, Dan has been involved with NORM contamination allocation issues from a merger and acquisition warranty claim perspective, NORM contamination property owner claims, personal injury claims involving NORM exposure (over 200 plaintiffs) and insurance coverage issues concerning NORM.

3:55 pm

Mauricio Escobar

Coats Rose Law, Houston

is an Associate in the Litigation section of Coats Rose. He received his J.D. from South Texas College of Law and was a Member and Assistant Note & Comment Editor of the South Texas Law Review. Prior to attending law school, Mauricio earned his Bachelor's degree in Music Theory from the University of Texas in 2000, where he was a member of the Dean's Honors List.

Mauricio's practice focuses on complex commercial litigation. He has represented individuals and corporations in matters involving contract claims, personal injury, wrongful death, fraud, and deceptive trade practices.

TENORM Litigation Issues – Part 2

4:20 pm

David Allard

Pennsylvania Department of Environmental Protection

is the Director of the Pennsylvania Department of Environment Protection (DEP) Bureau of Radiation Protection, and responsible for the: accelerator, x ray, environmental surveillance, nuclear safety, radiological emergency response, radioactive materials, decommissioning / site cleanup, low-level waste and radon programs within the Commonwealth. He is also the technical lead on technologically enhanced naturally occurring radioactive material issues in DEP. Mr. Allard is the Governor's official liaison to the U.S. Nuclear Regulatory Commission, and a Commissioner for the Appalachian States Low-level Radioactive Waste Compact Commission.

Mr. Allard received a bachelor of science degree in Environmental Sciences from SUNY Albany and a master of science degree in Radiological Sciences and Protection from the University of Massachusetts - Lowell. He is certified by the American Board of Health Physics, a Fellow of the Health Physics Society (HPS), and, has been the Conference of Radiation Control Program Directors' (CRCPD) official liaison to NCRP for over 10 y.

Prior to joining DEP in February 1999, he was a consultant to the U.S. Department of Energy on environmental and occupational radiation protection for 8 y. Mr. Allard has been involved in the various aspects of governmental, industrial, reactor, medical and academic radiation protection for over 38 y. He has been in leadership roles with the HPS and CRCPD, serves as a member or advisor on several national radiation protection committees, has authored numerous professional papers and reports, and frequently lectures on a wide variety of radiation protection topics and concerns.

The Pennsylvania Oil & Gas TENORM Study: Update & Impacts

The Pennsylvania Department of Environmental Protection (DEP) initiated a study to collect data relating to technologically enhanced naturally occurring radioactive material (TENORM) associated with oil and gas (O&G) operations in Pennsylvania. This "cradle to grave" study included the assessment of potential worker and public radiation exposure, TENORM waste disposal, and other potential environmental impacts. The study encompassed radiological surveys and sample media collected at: well sites, wastewater treatment plants, landfills, gas distribution and energy generation, and O&G brine-treated roads. Ambient gamma radiation field measurements were made at most sampling venues. The media sampled included solids, liquids, natural gas, ambient air, as well as fixed measurements and surface smears for radioactivity. We believe this may be one of the most comprehensive studies to date. Generally, the data show that there is limited potential for radiation exposure above the public dose limit of 1 mSv y^{-1} at these industrial sites and facilities where workers or the public may be exposed. Additionally, samples of natural gas collected for radon analysis at various well heads, distribution compressor stations and gas storage locations showed levels consistent with the results of others (*i.e.*, ~1.8 Bq L^{-1}). Subsequent calculations of the potential increase of indoor radon concentration with a typical residential scenario showed a minimal increase in radon contribution over that expected from local soils and rock. However, limited ambient gamma surveys of a gas processing facility indicated that additional surveys and investigation of ^{210}Po and ^{210}Pb contained in facility equipment and transmission systems are needed. Results for ^{226}Ra concentrations in O&G brines and flow-back hydro-fracture waste water show that O&G spill response protocols need to be updated to include radiological parameters. Further, a re-evaluation of solid waste containing TENORM generated in the treatment of O&G wastewater is warranted. The disequilibrium of ^{226}Ra and ^{222}Rn decay products in fresh solid waste sludges and sediments impedes accurate and timely assessment of ^{226}Ra concentrations. How this technical challenge relates to in-state disposal protocols at RCRA Subtitle D landfills is currently underway. Study results have also prompted the detailed assessment of facility and environmental contamination associated with O&G wastewater treatment and the need for safety controls when equipment is dismantled. The complete study report and supporting data are posted on the DEP website. A short summary of the current federal and state regulatory framework, study data for various media, along with observations and recommendations for future actions are presented.

4:45 pm Panel Discussion

Tuesday, February 2, 2016

Session 3: Who's Exposed? (scenario & pathway analysis)

8:30 am

Janet Johnson

Tetra Tech

is a Certified Health Physicist with over 50 y of experience in radiation protection including radiation worker training, uranium recovery facility environmental and occupational radiation protection, radiation safety for naturally occurring radioactive materials (NORM), radiation risk assessment; radon measurements and radon risk assessment and radiological site surveys. Dr. Johnson has evaluated radiation dose and risk from facilities with residual radioactive materials from both licensed activities and from NORM, with a primary focus for the last 20 y on uranium recovery facilities and mine remediation. She is currently the Radiation Safety Officer of record for two licensed uranium recovery facilities in decommissioning mode. Dr. Johnson was on the faculty at Colorado State University eventually managing their Environmental Health Services program. She has been a consultant in radiation protection for the past 20 y. She was a member of the U.S. Environmental Protection Agency Science Advisory Board from 1996 to 2003 and the Colorado Radiation Advisory Committee until 2013. Dr. Johnson served on NCRP Scientific Committee 64-22 updating the report on Environmental Surveillance (Report No. 169 published in 2012). She is a Fellow of the Health Physics Society and received the Society's Founder's Award in 2013.

Colorado TENORM Experience

Oil and gas exploration and production generate waste that may contain elevated concentrations of naturally occurring radioactive materials (NORM). The wastes must be disposed of properly to protect the environment and public health. Colorado is a major oil and gas producer ranking sixth in the nation of total production with approximately 1.6 trillion cubic feet of natural gas and 95 million barrels of oil produced in 2014. Disposal of technologically enhanced naturally occurring material (TENORM) waste is a critical issue for the state. At the present time, there is only one facility in Colorado licensed to accept oil and gas TENORM waste. The energy boom has engendered significant interest in providing alternative disposal options. Because there are no federal regulations for TENORM disposal, permitting disposal facilities is left to the state and local governments. The process for permitting a site to accept TENORM waste in Colorado requires extensive review by the county and a variety of state agencies including the Solid Waste and Radiation Control programs within the Colorado Department of Public Health and Environment (CDPHE) Hazardous Materials and Waste Management Division. The county where the proposed disposal facility will be located has final approval authority. Colorado is an Agreement State and regulates TENORM waste through its general authority to regulate radioactive materials even though there are no specific TENORM regulations. In accordance with a CDPHE draft guidance document, industrial landfills with specific permits are allowed to accept TENORM generated by the oil and gas industry with a combined $^{226/228}$Ra activity concentration up to 50 pC g^{-1}. Potential doses to workers and members of the public from TENORM disposal facilities are limited to 25 mrem y^{-1}. Radiation dose assessment is an integral part of the permit application process and involves identifying potentially exposed individuals, exposure pathways, estimating occupancy parameters. The RESRAD code is a generally accepted mechanism for assessing doses to workers and members of the public but it is dependent on realistic estimates of exposure parameter values. Several proposed alternate disposal sites are in various stages of the permitting process including dose and risk assessment.

8:55 am

Arthur S. Rood

K-Spar Inc.

has over 28 y experience in multimedia assessment of contaminants in the environment. He received a Masters Degree in Health Physics from Colorado State University and holds a Bachelor of Science Degree in Geology from Colorado Mesa University. His broad range of experience includes data collection and analysis, instrumentation, multimedia contaminant transport modeling, and dose and risk assessment. After receiving his Masters Degree in 1987, Mr. Rood began work at the Idaho National Laboratory (INL), and retired as an Advisory Scientist in 2013. Mr. Rood developed and implemented computer models for assessment of contaminant transport in the vadose zone and groundwater, and the radionuclide food chain transfer model implemented in the MELCOR Reactor Safety

Pathways of Exposure from TENORM Generated from Unconventional Oil and Gas Development and Production

Technologically enhanced naturally occurring radioactive material (TENORM) has long been an issue in conventional oil and gas production. Development of unconventional drilling and development methods such as horizontal drilling and hydraulic fracturing (termed "fracking") has introduced new waste streams and potential exposure pathways. This presentation examines potential TENORM exposure pathways from unconventional oil and gas development and production, which also include exposure pathways from conventional oil and gas production. Potential exposure can occur during the drilling, development and production phases of oil and gas wells. In most cases, exposures are limited to workers, but public exposure can occur in the event of improper well construction and inadconsequence code (MACCS). He led the technical analysis for three low-level radioactive waste performance assessments under U.S. Department of Energy Order 435.1, and performed numerous atmospheric modeling studies for facilities at the INL. In 1990, Mr. Rood conducted a field survey of naturally occurring radioactive materials (NORM) in oil and gas production equipment with the American Petroleum Institute, and served on the HPS/ANSI standards committee on NORM. Mr. Rood formed K-Spar Inc. in 1994 and has worked primarily as a consultant to Risk Assessments Corporation. His work has included multimedia contaminant transport modeling at former nuclear weapons plants including Rocky Flats, Hanford, and Los Alamos, and establishing soil clean up levels at the former Rocky Flats Plant. He also performed performance assessment for the U.S. Ecology Low-Level radioactive waste site near Richland Washington and served as an expert witness for the defense on litigation regarding exposure to past radioactive atmospheric releases from the Hanford facility, the former uranium mill at Uravan Colorado, and former uranium facility at Apollo Pennsylvania. Prior to his graduate studies, Mr. Rood worked as a uranium mine geologist and coordinated a gamma spectroscopy laboratory in support of the Uranium Mill Tailing Remedial Action project. Mr. Rood has been an author on over 70 papers, reports, and presentations, is a contributor to the graduate textbook, *Radiological Risk Assessment and Environmental Analysis*, and is currently a member of the International Commission on Radiation Protection Task Group 98. Mr. Rood was also an adjunct faculty member for the University of Idaho where he taught environmental modeling.

vertent release of production fluids and waste to the environment. In both conventional and unconventional oil and gas production, the magnitude of exposure is highly dependent on the local geology and the presence of naturally occurring radioactive materials (NORM) in the overlying formations, and more importantly in the producing formation. During the drilling phase, exposure pathways can include external exposure to recirculated drilling fluids, external exposure to drill cuttings, radon inhalation, and inhalation and inadvertent ingestion of drill cuttings and removable surface contamination on equipment. Exposures during this phase are similar for both conventional and unconventional drilling. However, if the producing formation contains elevated NORM, then unconventional horizontal drilling can produce higher exposures because more material from the producing formation is brought to the surface. The development phase includes hydraulic fracturing and installation of production equipment. Exposure pathways from unconventional oil and gas development and include external exposure to produce water and flowback fluids used during the fracking process. The production phase includes the treatment and disposal of liquid and solid wastes, maintenance of production and distribution equipment, and equipment refurbishing, including pipe scale removal. Exposure pathways during this phase include external exposure and radon inhalation during transport and treatment of produce water and accumulated tank sludge, radon and external exposure in gas pipeline equipment, and external, inhalation, and ingestion exposure during pipe scale cleaning operations. A recent study by the Pennsylvania Department of Environmental Protection found little potential for radiological exposure during the drilling and development phase, but a potential for environmental radiological impacts resulting from inadvertent release of production and fracking fluids. During the production phase potential radiological exposures could occur in wastewater treatment facilities receiving oil and gas production wastes, and in natural gas processing plants. Release of untreated produce water, drilling fluids, and fracking fluids to the environment, and improper well construction that results in leakage of NORM produce water to potable aquifers can result in radiological environmental impacts and potential exposures to the public.

9:20 am

Alan McArthur

ALMAC Environmental Services

identified naturally occurring radioactive material (NORM) in a North Sea oil well in 1981. He founded Aqua Dyne Europe the first Offshore Oilfield NORM Service in the United Kingdom in 1981. The same year he also founded the first Onshore Oilfield NORM Service Company called SAI Tubular Services. He gave his first U.S. presentation on NORM at the Conference of Radiation Control Program Directors (CRCPD) regulatory conference in 1987 in Boise, Idaho. He moved to the United States in 1988 and worked on both the API and CRCPD NORM committees developing draft NORM regulations and guidance bulletins. He co-wrote the first U.S. NORM license in 1989 for the State of Louisiana and obtained the first NORM license for NORMCO Amelia, Louisiana. Over the past 36 y he has managed professional services for major oil and gas companies in the United States and overseas as well as provided consulting services to many foreign governments that required specialist help with NORM regulatory issues. He is Chief Executive Officer of ALMAC and provides professional consulting and litigation support services to the oil, gas, pipeline, refining and processing industries in the United States, Canada, and many countries worldwide. His knowledge of NORM from oil and gas is unique.

TENORM Waste Issues

Mr. McArthur has been instrumental in the development of naturally occurring radioactive material (NORM) waste management practices from the North Sea to Alaska where he was responsible for the development and operation in 1991 of the first NORM waste processing and underground injection disposal. He has continued to evaluate the issue of NORM waste and its management in the Middle East and Africa as well as the United States and Canada. At present he is investigating the NORM wastes associated with gas production, transmission and processing in many countries around the world. NORM from natural operations is providing unique challenges to operators at a time when operational margins are already stretched and preemptive actions by early identification will be critical to operator NORM waste management cost minimizations.

9:45 am Panel Discussion

9:45 am Break

Session 4: TENORM Waste Disposal Options

10:15 am

Joseph J. Weismann

US Ecology, Inc.

is an Executive Manager and Certified Health Physicist with over 20 y experience in the areas of program management, radioactive waste management, environmental remediation, facility decommissioning, nondestructive assay, and applied radiation protection. He specializes in radioactive and hazardous waste management, treatment, and disposal. As Vice President of Radiological Programs for US Ecology, Joe is responsible for all aspects of the company's radiological programs; including waste treatment and disposal facility operations and compliance, budgeting, regulatory and public affairs, sales and marketing support, and supervision of both fixed facility and field support teams. He received his Bachelor of Nuclear Engineering from the Georgia Institute of Technology and MBA from Boise State University. Prior to joining US Ecology, Joe was the Health Physics Program Manager for Cabrera Services in Goshen, New York and began his career as a Radiological Engineer for Shonka Research Associates in Marietta, Georgia. Joe has served as technical and management lead on a variety of U.S. Environmental Protection Agency CERCLA/Superfund, U.S. Army Corps of Engineers, U.S. Department of Energy, and U.S. Nuclear Regulatory Commission licensed project sites in over 20 states. In this capacity, Joe provided project management, health physics, regulatory affairs, and field management support from initial site investigations through remediation and site closure. He also has advanced knowledge in the area of radiological instrumentation and is a Subject Matter Expert in Gamma Spectroscopy, with specific expertise in the area of in situ Non-Destructive Assay (NDA) techniques using Canberra Industries ISOCS® software. Joe was recently invited to participate in an International Low-Level Radioactive Waste Workshop at the International Atomic Energy Agency in Vienna, Austria designed as an information sharing forum where representatives from the United States and other developed countries shared radioactive waste best management practices with developing countries from all over the world.

TENORM Waste Issues – Waste Acceptance Criteria

Many issues regarding technologically enhanced naturally occurring radioactive material (TENORM) have been raised recently due to the increase in exploration, development and production of oil and gas resources in the United States. These activities have led to increased volumes of low-activity radioactive wastes that require safe handling, transportation, and disposal due to the presence of TENORM nuclides such as 226Ra and 210Pb. TENORM is not federally regulated by either the U.S. Nuclear Regulatory Commission or the U.S. Environmental Protection Agency, so regulation for purposes of licensing is delegated to the individual states. This regulatory environment poses a challenge to companies that generate TENORM wastes since it is incumbent upon them to stay abreast of rapidly changing regulatory environments in a variety of different locales. Just over the past few years, several states (including Pennsylvania, North Dakota, Michigan, and Montana) have investigated their TENORM disposal regulations to determine whether changes should be made to adapt to the evolving conditions inside (and outside) of their states. This presentation will focus on the radioactive waste management aspects of TENORM, specifically disposal options for these generated radioactive wastes. A summary of state TENORM disposal regulations will be discussed as well as an overview of available TENORM disposal facilities and their respective waste acceptance criteria for prominent TENORM nuclides.

10:35 am

Andrew J. Lombardo

PermaFix

has over 30 y of experience in radiation protection/health physics and the management of radioactive material sites including radiological engineering, hazardous and radiological waste characterization, project management, decontamination and decommissioning, and environmental remediation. Mr. Lombardo currently serves as the Senior Vice President and Manager of Nuclear Services for Perma-Fix. Mr. Lombardo is an industry expert in radioactive material assessment and the characterization and management of naturally occurring radioactive material (NORM) and technologically enhanced NORM (TENORM).

He received a BS in Natural Sciences in 1981 from Indiana University of Pennsylvania; an MS in Health Physics from the University of Pittsburgh in 1994; and is Certified in the Practice of Comprehensive Health Physics by the American Board of Health Physics since 1994.

Measuring and Modeling NORM

The regulatory release of sites and facilities (property) for restricted or unrestricted use has evolved beyond prescribed levels to model-derived dose and risk based limits. Dose models for deriving corresponding soil and structure radionuclide concentration guidelines are necessarily simplified representations of complex processes. A conceptual site model is often developed to present a reasonable and somewhat conservative representation of the physical and chemical properties of the impacted material. Dose modeling software is then used to estimate resulting dose and/or radionuclide specific acceptance criteria (activity concentrations). When the source term includes any or all of the uranium, thorium or actinium natural decay series radionuclides the interpretation of the relationship between the individual radionuclides of the series is critical to a technically correct and complete assessment of risk and/or derivation of radionuclide specific acceptance criteria. Unlike man-made radionuclides, modeling and measuring naturally occurring radioactive material (NORM) and technologically enhanced NORM (TENORM) source terms involves the interpretation of the relationship between the radionuclide present, *e.g.*, secular equilibrium, enrichment, depletion or transient equilibrium.

Isotopes of uranium, radium and thorium occur in all three natural decay series. Each of the three series also produces a radon gas isotope as one of its progeny. In nature, the radionuclides in the three natural decay series are in a state that is approaching or has achieved secular equilibrium, in which the activities of all radionuclides within each series are nearly equal. However, ores containing the three natural decay series may begin in approximate secular equilibrium, but after processing, equilibrium may be broken and certain elements (and the radioactive isotopes of that element) may be concentrated or removed. Where the original ore may have contained one long chain of natural decay series radionuclides, the resulting TENORM source term may contain several smaller decay chains, each headed by a different longer lived member of the original series. This presentation presents the anatomy of common TENORM source terms and the pitfalls of measuring, interpreting and modeling these source terms. Modeling TENORM with common software such as RESRAD is discussed.

11:00 am

Mel B. Hebert

Lotus, LLC

is an Environmental Health Physicist with over 30 y of experience in the Nuclear and Radiation Safety Industry. Mel has spent over 25 y of his career directly associated with the oil and gas naturally occurring radioactive material (NORM) industry. He received his BS and MS degrees in Nuclear Science/Radiation Protection from Louisiana State University in the early 1990s with an emphasis in NORM in the oil and gas industry. Mel is also a Marine Corps Veteran of the Persian Gulf War where he served as a platoon commander and Nuclear, Biological and Chemical warfare specialist. Mel possesses a comprehensive background in regulatory compliance and radiation safety derived from serving in state agencies, as a Corporate Radiation Safety Officer, Laboratory Manager, Technical Services Director, and a Health Physics Consultant managing multiple radioactive material licenses and permits for state and federal agencies. He currently serves as the Regulatory Affairs Manager for Lotus, LLC directing U.S. and international regulatory affairs in the Middle East.

Deep Well Injection

The oil and gas industry has successfully been commercially disposing of naturally occurring radioactive material (NORM) residues and waste by deep well injection for nearly 25 y. This presentation will focus on presenting the general characteristics and mechanisms of permanent NORM disposal by deep well injection. Description, concentrations and general waste characteristics will be discussed. Radiation safety practices in waste preparation and disposal of waste will also be discussed.

11:25 am Panel Discussion

11:50 am Summary

49th Midyear Meeting - Health Physics Society
Austin Texas
February 1, 2016
Plenary Session: Opening Remarks

NCRP / NORM / TENORM

John D. Boice, Jr.
National Council on Radiation Protection and Measurements

John.Boice@NCRPonline.org
http://NCRPonline.org

From the President

Nancy Kirner, CHP

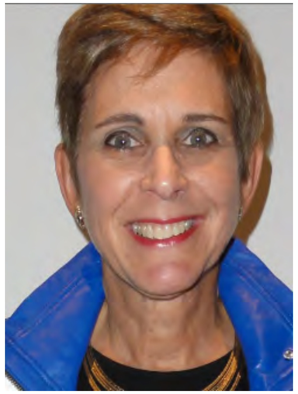
The WARP Report: Wow!

The most important item to find its way onto my desk this month is a copy of the National Council on Radiation Protection and Measurements (NCRP) Statement No. 12, 17 December 2015, *Where Are the Radiation Professionals (WARP)?* This long-awaited, four-page statement goes well beyond my personal concerns in its conclusions, the first one of which clearly states that ". . . the country is on the verge of a ***severe shortfall*** of radiation professionals such that ***urgent national needs will not*** [illegible] ." [Emphasis added.] If that statement doesn't hit you hard, then how about this one [illegible] mendations" portion of the statement? "Courses of action to preclude and [illegible] ***outcome*** of not having sufficient radiation professionals to handle the [illegible] eeds of the nation include: . . . " [Emphasis added.] The statement goe [illegible] ecommendations in the areas of education, research, training, joint [illegible], and continued monitoring and advocacy. This report does not mince [illegible] departure from most science-speak inside the Beltway!

A little back [illegible] y be in order here. In 2001 the Health Physics Society (HPS) recognized o [illegible] graying." HPS President Emeritus Kevin Nelson chaired a task force that publishe [illegible] te paper on the human capital crisis, issued in 2004. HPS Position Statement 015-01, "Human Capital Crisis in Radiation Safety," soon followed. Fast-forward to 2013, when the NCRP sponsored a workshop to study the decline in radiation professionals. There were presen-

INTERACTIVE PARTNERSHIP !

2016 Annual Meeting: April 11-12, 2016



Meeting the Needs of the Nation for Radiation Protection

Kathryn H. Pryor,
Richard E. Toohey, &
Judy L. Bader
Co-Chairs

See You There!

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

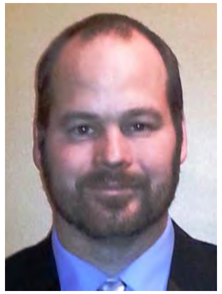
SC 5-2: Uniform Approach for Naturally Occurring Radioactive Material (NORM) & Technologically Enhanced NORM (TENORM) Waste Management and Disposal for Oil & Gas Industry

WE Kennedy, *Chair*
Dade Moeller & Associates

D Allard
Pennsylvania Department of Environmental Protection

M Barrie
Oak Ridge Associated Universities

P Egidi
US Environmental Protection Agency



G Forsee
Illinois Emergency Management Agency

R Johnson
Dade Moeller & Associates

A Lombardo
PermaFix

R McBurney
Conference of Radiation Control Program Directors

J Frazier,
Co-Chair
Staff Consultant

Funding: CDC for initial start up; CRCPD "in kind"; Seeking additional sources for Commentary/Report Guidance

NCRP NORM / TENORM Workshop

Monday, February 1, 2016 / Plenary	
8:20 am	NCRP Scientific Committee 5-2 on TENORM Waste, *William E. Kennedy*
Session 1: Logistics & Background (overview of states)	
1:30 pm	NORM in Unconventional Oil and Gas Resources, *Masoud Beitollahi*
1:55 pm	TENORM Issues in the Petroleum Industry *John R. Frazier*
2:20 pm	Overview of State Activities to Regulate TENORM, *Jared W. Thompson*
2:45 pm	Panel Discussion Break





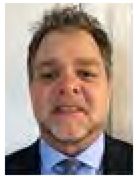


Session 2: Potential Environmental Impacts (air, water, environment)	
3:30 pm	TENORM Litigation Issues, *Daniel F. Shank & Mauricio Escobar*
4:20 pm	The Pennsylvania Oil & Gas TENORM Study: Update & Impacts, *David Allard*
4:45 pm	Panel Discussion

NCRP NORM / TENORM Workshop





Tuesday, February 2, 2016 / Session 3: **Who's Exposed**? (scenario & pathway analysis)	
8: 30 am	Colorado TENORM Experience, *Janet Johnson*
8:55 am	Pathways of Exposure from TENORM Generated from Unconventional Oil and Gas Development and Production, *Arthur S. Rood*
9:20 am	TENORM Waste Issues, *Alan McArthur*
9:45 am	Panel Discussion Break

Session 4: TENORM **Waste Disposal Options**	
10:15 am	TENORM Waste Issues – Waste Acceptance Criteria, *Joseph J. Weismann*
10:35 am	Measuring and Modeling NORM, *Andrew J. Lombardo*
11:00 am	Deep Well Injection, *Mel B. Hebert*
11:25 am	Panel Discussion
11: 50 am	Summary

Bill Kennedy
Dade Moeller & Assoc

8:20 AM MAM-A.1

NCRP Scientific Committee 5-2 on TENORM Waste

- BS and MS in Nuclear Engineering from Kansas State University
- HPS Elda E. Anderson Award, 1990
- HPS Board of Directors, 1998-2001
- HPS Fellow, 2002
- Chairs ANSI/HPS N13.12, Surface and volume Radioactivity Standards for Clearance
- Member of IAEA Advisory Groups such as on Waste Disposal
- NCRP Council, Chair Finance, SC 6-8 Tomodachi, Chair SC 5-2

Develops environmental pathway and radiation dosimetry models used to assess potential health and environmental impacts from releases of radionuclides to the environment.
He applies these models in environmental dose reconstruction, radioactive materials transport, radioactive waste disposal, and evaluation of nuclear facility operating practices.

49th HPS Midyear Meeting

National Council on Radiation Protection and Measurements: TENORM in the Petroleum Industry

W.E. Kennedy, Jr.
Dade Moeller & Associates

NCRP SC 5-2

- Purpose: To prepare a Commentary that provides *Recommendations for a Uniform Approach for Hydraulic Fracturing NORM/ TENORM Waste Disposal and lays the ground work for a more comprehensive Report…*
- Consistent with NCRP Mission: *to formulate and widely disseminate radiation protection recommendations*

SC 5-2 Membership

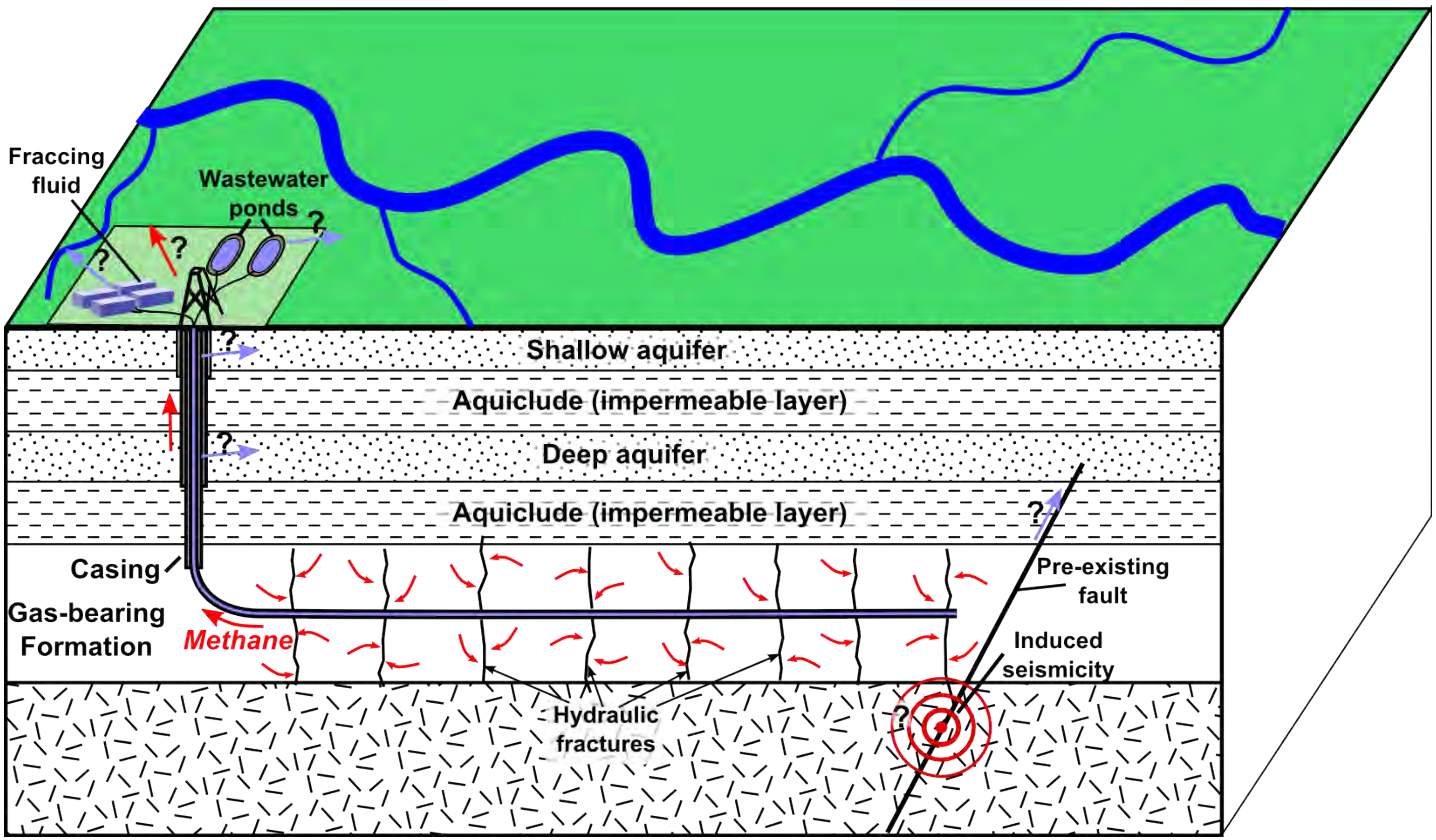
David Allard	PDEP	
Martin Barrie	ORAU	
Phil Egidi	U.S. EPA	
Gary Forsee	Illinois Environmental Compliance	
Raymond Johnson	Radiation Safety Counseling Inst.	
Andrew Lombardo	*PermaFix*	
Ruth McBurney	CRCPD	
John Frazier	Consultant	Co-Chair
W.E. Kennedy, Jr.	Dade Moeller & Assoc.	Co-Chair

- Workshop sessions this afternoon & tomorrow morning to help identify issues for Commentary

What is Fracking?

- Unconventional rock stimulation
- Injection of fluids (water), sand, and/or chemicals below ground to the host rock under high pressure
- Pressure fractures host rock to induce cracks – horizontal drilling a key!
- Sand/chemicals open cracks allowing oil, gas, and brine water to flow more freely

Fracking Schematic



From USGS

A Brief History of Fracking

- 1857 – Preston Barmore, Gunpowder
- 1865 – Col. Edward Roberts "superincumbent fluid-tamping" (damped explosions to amplify effects)
- Legacy lives on with the Tallini and Otto Cupler torpedo Company – still "shooting" wells today

A Brief History of Fracking

- 1930s – innovations using non-explosive liquids to increase production
- 1947 – Floyd Farris of Stanolind O&G studied the relationship between output and the quantity of pressurized treatment
- 1947 – Grant County, Kansas experiment – birth of modern day fracking
- Quickly commercialized in the 1960s in Kansas/Oklahoma/Texas

A Brief History of Fracking

- My experience in Kansas in the 1960s
- 1975 – President Ford promoted *development of shale oil resources as part of his overall energy plan (reduce imports)*
- 1990s – Modern day fracking, George P. Mitchell, combined fracking with horizontal drilling; greatly increased production
- New technologies – 3D Seismic mapping

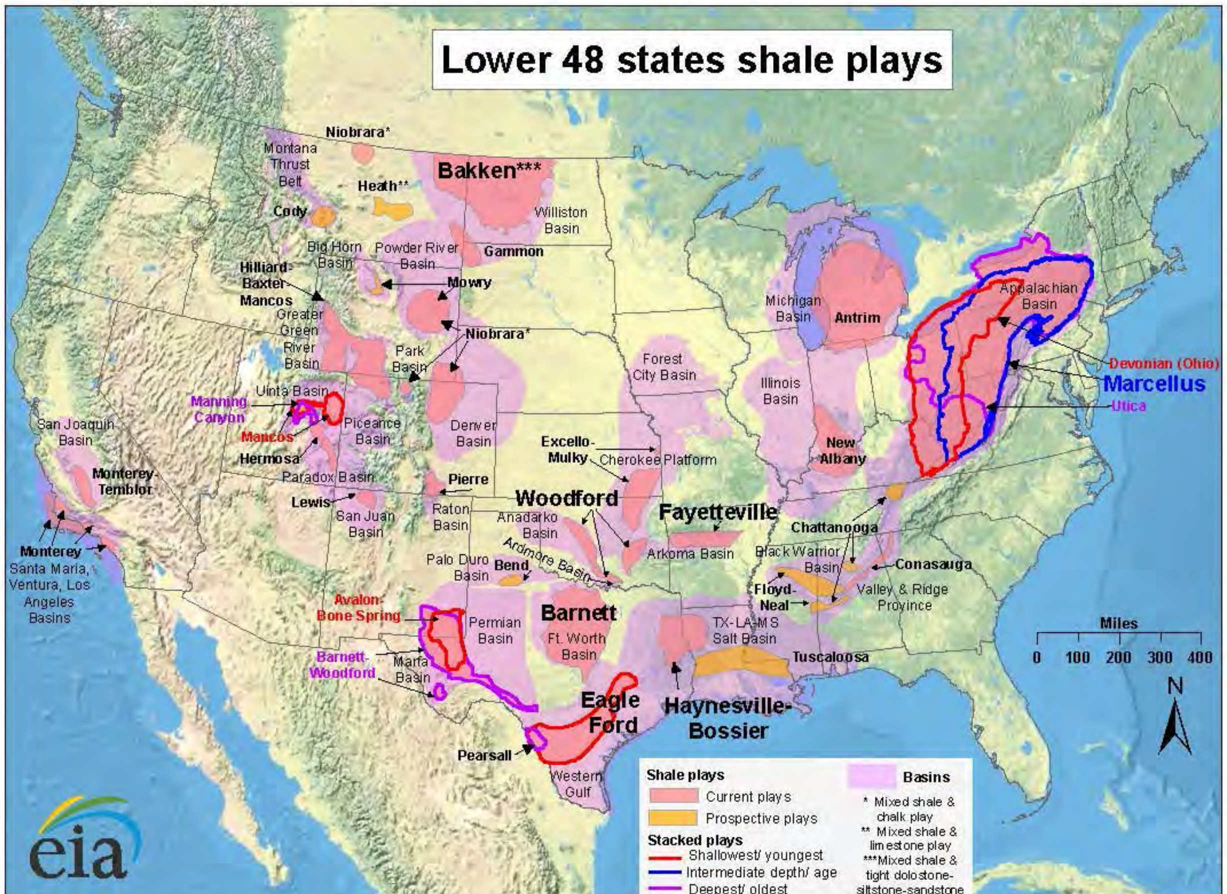
Fracking Equipment

From USGS

Drill Rig

From USGS

U.S. Shale Play Locations



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Shale Gas Fracking

- Typically involves five steps:
  - Develop well pad, drill to formation (> 1,000 m), horizontal drilling (may involve numerous directions)
  - Hydraulic fracturing
  - Capture/process gas
  - Storage, treatment, disposal of water/wastes
  - Decommissioning the well pad

Current U.S. O&G Surge

- Follow the money
  - 2000s; global production limited
  - Rising prices
  - Balance increased fracking costs after ~2005
- If not for higher prices, there would be no U.S. oil & gas surge
- Current low oil prices have reduced domestic exploration and production

Environmental Issues

- Water issues
  - Large quantities (15,000 m^3) used as part of fracturing fluids; depletion of water resources
  - Waste water; flow back water (injection fluids), production water (saline water liberated along with O&G)
- API estimates: 10 barrels of water recovered per barrel of oil; 18 billion barrels of waste fluid produced per year

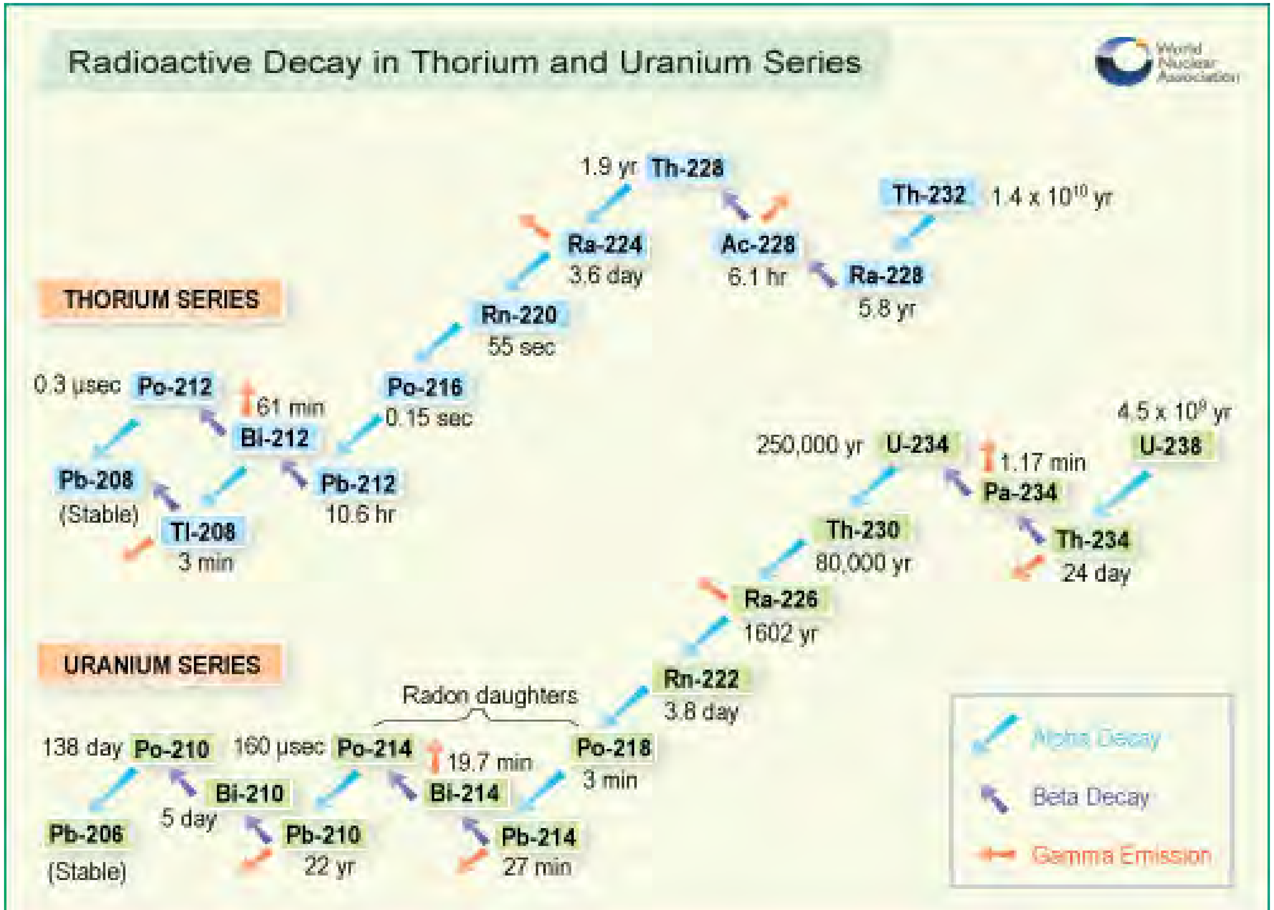
Fracking Waste Water

From USGS

TENORM Issues

- Uranium/Radium in geologic formations known and measured since ~1920
- 1980s – Radium pipe scale
  - Radium preferentially soluble in saline water
  - Precipitates with barium, calcium, and minerals as pipe scale or heavy sludge
  - Pipe recycling issues
  - Waste disposal issues

Thorium & Uranium Decay



Special Concerns

- Radiation exposures during operations
  - Emissions (air/water)
  - Radon
  - Contamination control
  - Lack of regulated disposal
- Public
  - Radon, transportation, waste management
- Legacy contamination after well decommissioning

ICRP Considerations

- Recommendations *to contribute to an appropriate level of protection … against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure.*
- Fundamental Principles: *Justification, Optimization (regardless of source), Dose Limitation*

ICRP Considerations

- Principles:
  - Exclusion – not amenable to control
  - Exemption – controls are unwarranted (effort to control is excessive compared to risk)
- Types of exposures: planned, emergency, and existing (including NORM)
- Dosimetric (not WL) approach to radon
- Judgement by regulatory authority on the *controllability* of source

ICRP Recommendations

- A graded approach to applying regulatory controls – important decisions?
- Optimization? *A balance of imposing regulatory control so that resources are not deflected away from more urgent health & safety needs*
- Reference levels for existing exposures (from 1-20 mSv/yr – feasibility of control?)
- ICRP Committee 4 Task Group (TG-76)

IAEA Activities

- NORM (mining/mineral + O&G) symposia
  - Amsterdam 1997
  - Krefeld, Germany 1998
  - Brussels 2001
  - Poland 2004
  - Seville Spain 2007
  - Marrakesh, Morocco 2011
  - Beijing, China 2013
  - Rio De Janeiro, Brazil 2016

IAEA Considerations

- Categorization of exposures – normal?
- Identify ranges of activity concentrations
- Identification of who is exposed
- Identification of pathways
- Use of reference levels (concentration & dose) whenever possible
- Are changes needed to the ICRP system to accommodate NORM? ICRP TG-76

IAEA Status

- New regulations for the control of exposure from NORM across EU member states
- Definition of scope of regulation remain controversial
- Global issue because of international mining and ore processing
- A uniform and harmonized regulatory scheme is still a hope for the future (USA)

IAEA Recommendations

- 1 Bq/g regulatory criterion for NORM
  - Principle; reflects normal range of environmental levels (1-10 Bq/g)
  - Regulation below 1 Bq/g is not “sensible”
  - Exception might be building materials (long term household exposures)
  - If >1 Bq/g; NORM to be regulated as a “practice,” as planned exposures subject to justification, optimization, & regulation

IAEA Conclusions

- IAEA dose assessment:
  - Member of the public (child) living 20 m from a 2Mt deposit at 1 Bq/g of each decay chain member; annual dose not likely >0.2 mSv
  - Supports IAEA recommendation that 1 mSv/y is appropriate for exemption from regulation
  - Supports current 1 Bq/g guidance
- But is exemption the optimum regulatory option for all NORM?

U.S. Regulatory Issues

- No Federal regulations – authority lies with the States
  - The scientific & technical basis for regulations not well established
  - TENORM ≠ uranium mill tailings
- States have little resources and are coping with emerging radiation protection issues on an *ad hoc* basis

CRCPD

- The Council of Radiation Control Program Directors (CRCPD) has been outlining needs and recommendations
  - 2015 E-25 Task Force report emphasized the need “for nationwide scientific consistency in a more standard regulatory framework to ensure public health and protection of the environment.”
  - TENORM waste management issues

Naturally Occurring Radioactive Materials in Unconventional Oil and Gas Resources

Masoud Beitollahi
University of Utah
Feb. 01, 2016

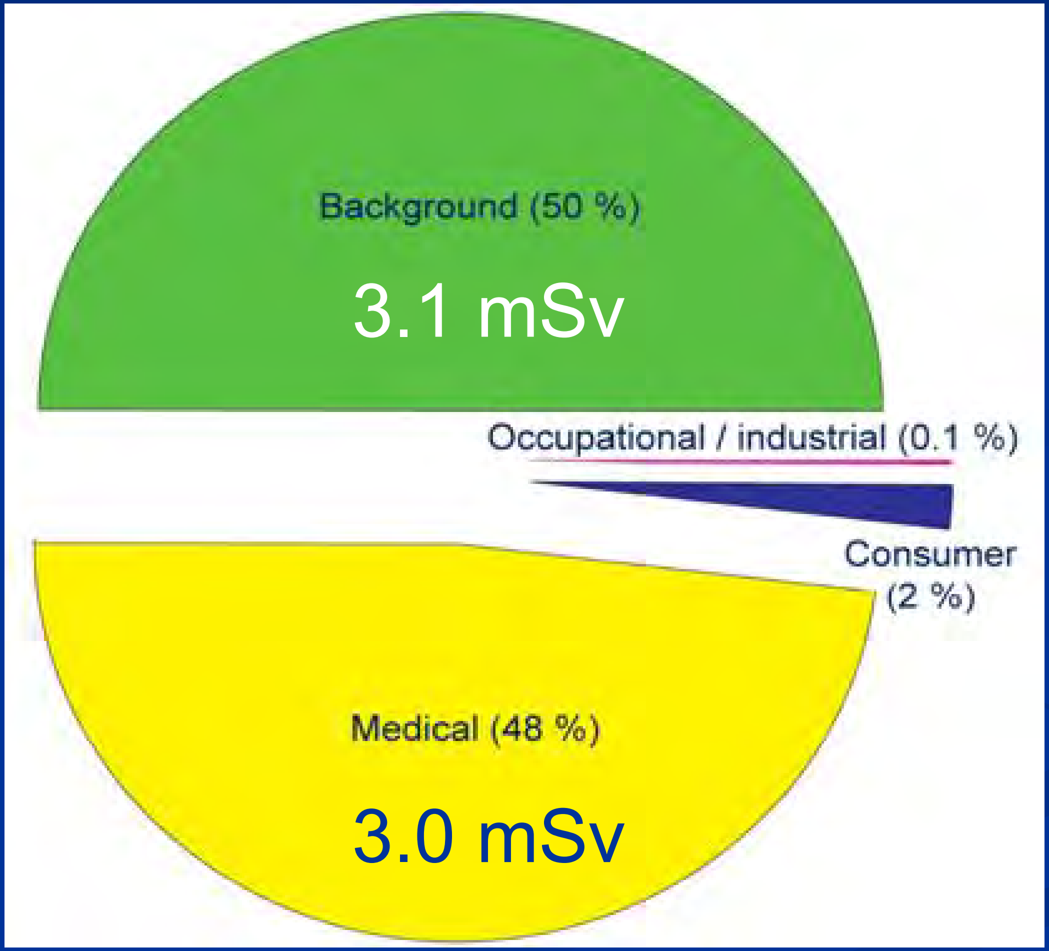
Purpose and Scope

- Brief review of the geological origins of NORM.
- Summary of the chemical, biological, geochemical, and other factors that may control the movement and behavior of NORM in oil and gas resources.
- Overview of the impact to ecosystems.
- Need for appropriate radiation protection measures and/or a regulatory approach.

Background & Significance

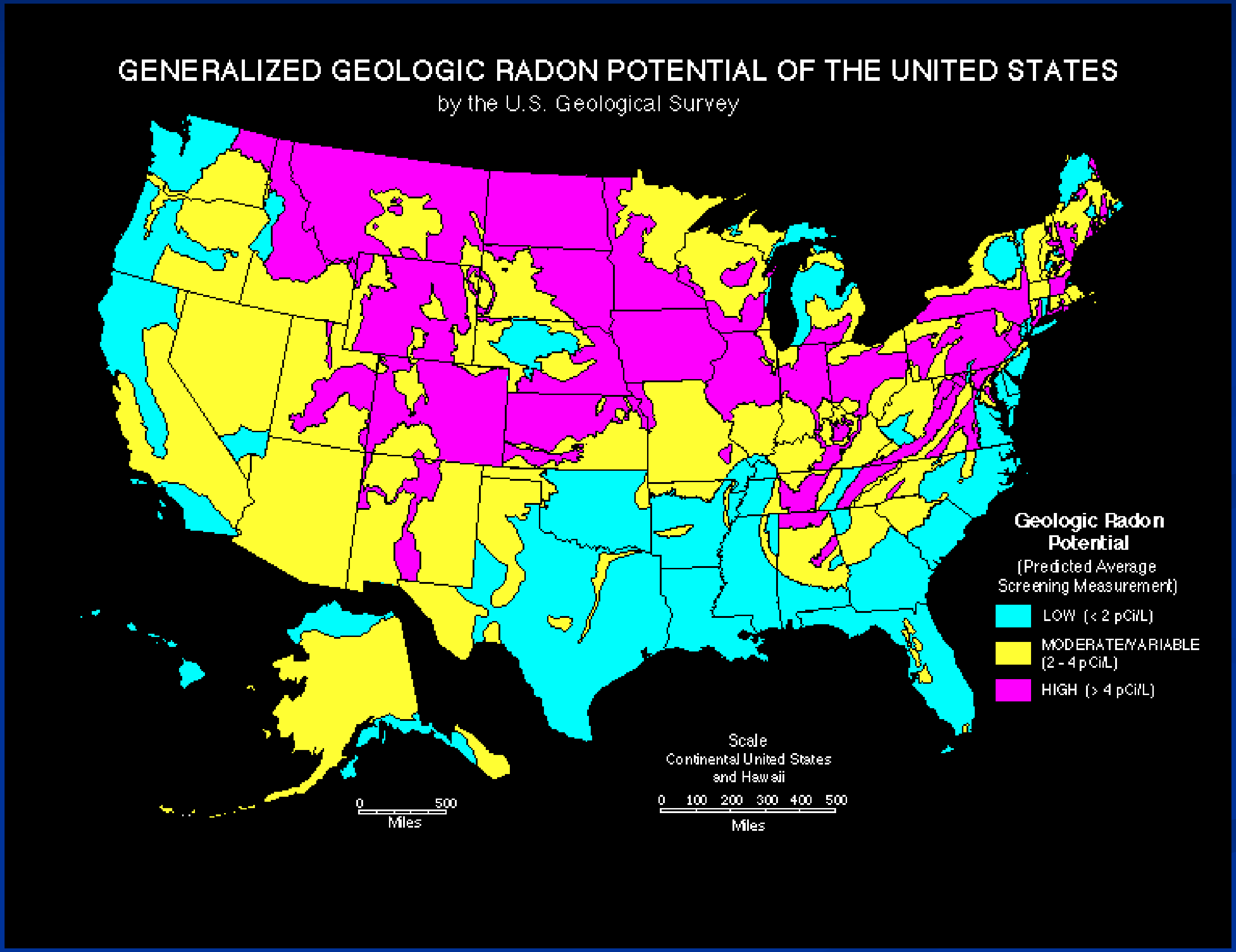
- Natural radionuclides are one the most significant contributors to human exposure.
- Long-lived radioactive elements such as uranium, thorium and potassium and any of their decay products, such as radium and radon are examples of NORM.
- A wide variety of industries use materials containing NORM include uranium ore, phosphate rock, baddeleyite, zircon and so on.

Annual per capita radiation exposure in the United States (NCRP, 2009)



0.1 mSv

Generalized Geologic Radon Potential of the United States



Natural Radionuclides

- Uranium (IV) compounds in the reduced environment are insoluble.
- In the oxidized environment the uranium has higher valence (VI), the complexes salts in this state are highly mobile and soluble.
- Oxidation and reduction properly refer to a change in oxidation number — the actual transfer of electrons may never occur.

Natural Radionuclides

- Uranium shows a strong affinity for oxygen-rich organic matter such as immature kerogen. During the early stages of thermal maturation in the source rock, oxygen is lost from kerogen resulting in the weakening of the uranium-organic association. This uranium is released to late-stage pore fluids to migrate from source to reservoir. Along the migration path, uranium is adsorbed onto clays and organic matter, leaving a trace of the migrating fluids.

Natural Radionuclides

- The occurrence of primary uranium minerals in igneous rocks is partially controlled by the oxidation state of this element in melted magma and by the fact that, as a large ion, uranium is most likely to remain in the molten rock as the magma begins to crystallize. The magma that crystallizes last is most likely to rise to the surface and contain the majority of the uranium from the original magma.

Natural Radionuclides

- Uranium is most likely to be found precipitated in rocks that formed under reducing (anoxic) conditions—these are the darkest sedimentary rocks (coal and black shale) and the lighter-colored igneous rocks.
- Among the decay products of ^{238}U some are outstanding due as much to their health and environmental effects as to their mobility in nature: ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po.

Natural Radionuclides

- Thorium occurs in several minerals, the most common being the rare-earth thorium phosphate mineral monazite, which may contain up to about 12% thorium oxide. Thorium containing monazite (cerium) occurs mainly in India, Brazil, and Australia.
- Ra-228, known as mesothorium with a half-life of 5.8 y. It emits beta particles to decay to ^{228}Th. ^{228}Ra frequently occurs in soil and water in about the same quantities as ^{226}Ra.

Natural Radionuclides

- Uranium and thorium are lithophilic (“rock-loving” elements that concentrate in the earth’s crust) actinides that commonly occur in sediments at low concentrations. Under reducing conditions their geochemical behavior is similar, and both are essentially immobile.
- Mobility of uranium relative to thorium, as shown by thorium–uranium ratios, indicates the passage of pore fluids enriched in uranium.

Sources of NORM

- NORM is widespread and diluted in many natural resources including rocks, soil, water, oil, gas and minerals.
- Elevated concentrations of these radionuclides are often seen in certain geological materials, namely igneous and sedimentary rocks and ore minerals.
- Human activities such as manufacturing, water treatment, or mining operations may increase the concentrations of these radionuclides.

Sources of NORM

- Abundances of NORM:
  - Rock types (composition and mineralogy),
  - Crystallization conditions,
  - Depositional environment,
  - Diagenetic processes,
  - Geologic structure,
  - Extent of weathering,
  - Alteration.

Sources of NORM

- Distribution, migration, and behavior of the NORM radionuclides:
  - Atomic structure,
  - Chemical bonding,
  - Molecular structure,
  - Hydrophobicity,
  - Concentration,
  - Presence of other chemicals,

Geology and NORM

- Sedimentary Rocks:
  - Sedimentary rocks make up a small fraction of the earth's crust but cover about 85% of the continental land area. Most of the surface soil is derived from sedimentary rock. Sedimentation processes naturally sort the products of weathering and develop several major sedimentary rock types with significantly different radionuclide concentrations.

Geology and NORM

- Sedimentary Rocks:
  - As with igneous rocks, thorium and uranium tend to be minor or disseminated. The radionuclides may become mobile or be deposited by migration of water or oil.
  - Some organic complexes, notably humic acids, create mobile complexes of uranium. Because of the geochemistry of uranium, it—and many other minor and trace elements—has an affinity for crude oil.

Geology and NORM

- Sedimentary Rocks:
  - Shales: The most abundant sedimentary rocks on earth; normally contain at least 35% clay minerals, and a significant fraction contains potassium as an essential constituent. Shales can also adsorb the series radionuclides because of their physical and chemical properties.

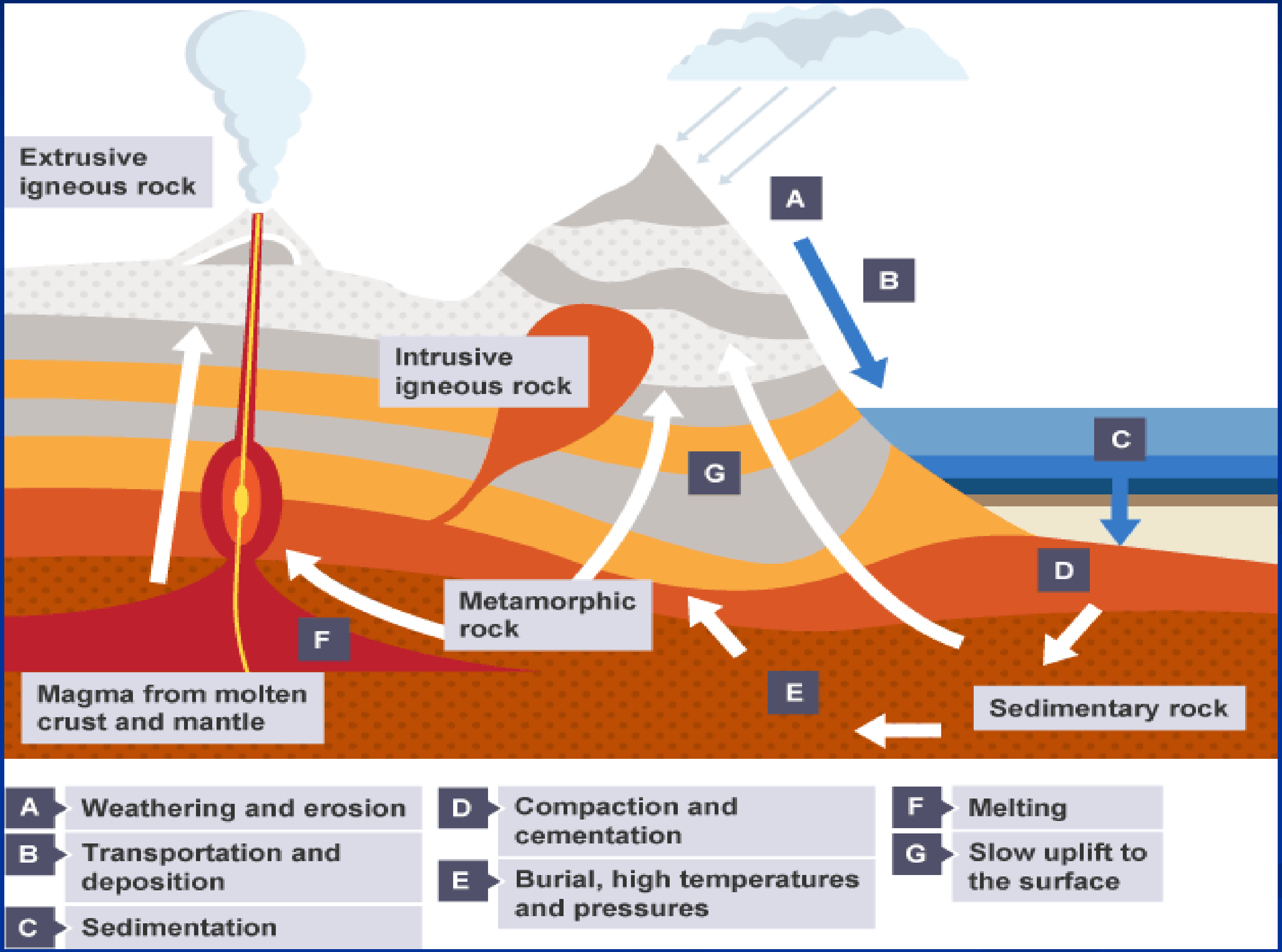
Geology and NORM

- Sedimentary Rocks:
  - Carbonate rocks such as limestone or dolomites are the result of chemical precipitation from water or the buildup of shells, bones, and teeth of organisms. Although the carbonate minerals themselves are relatively free of radionuclides, the intergranular spaces may contain elements found in the sea water from which they were deposited.

Geology and NORM

- Sedimentary Rocks:
  - On the whole, sandstones are low in both the series and non-series radionuclides. However, many deposits of uranium are found at the boundary of different layers of sandstones.
  - Potassium and thorium are usually of low concentrations in carbonate rocks, but uranium may be present because it may be fixed by reducing conditions in decaying organic matter where the rocks are deposited.

The Never Ending Rock Cycle



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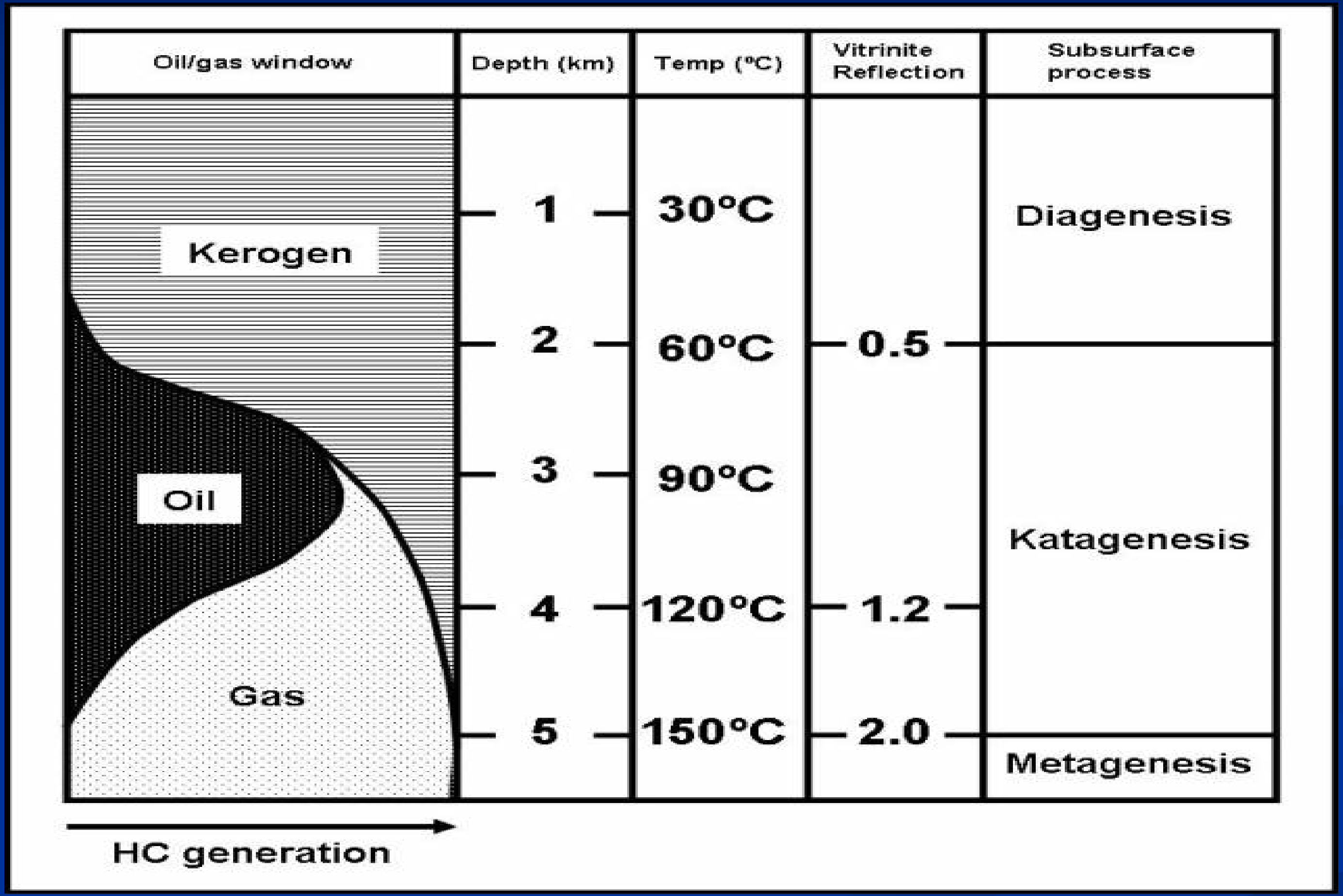
Generated Hydrocarbon

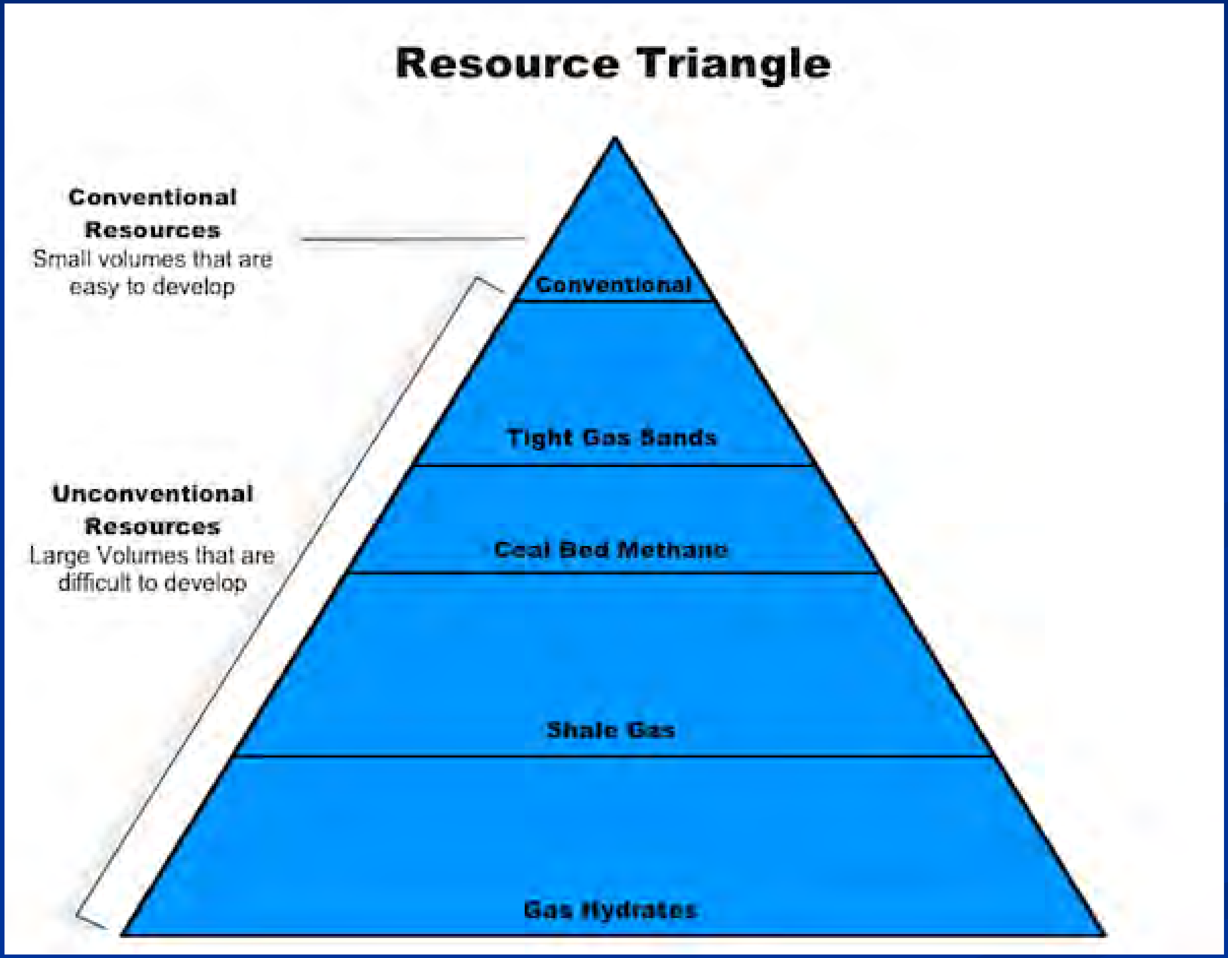


http://www.oilandgasgeology.com/oil_gas_window.jpg

Unconventional Resources

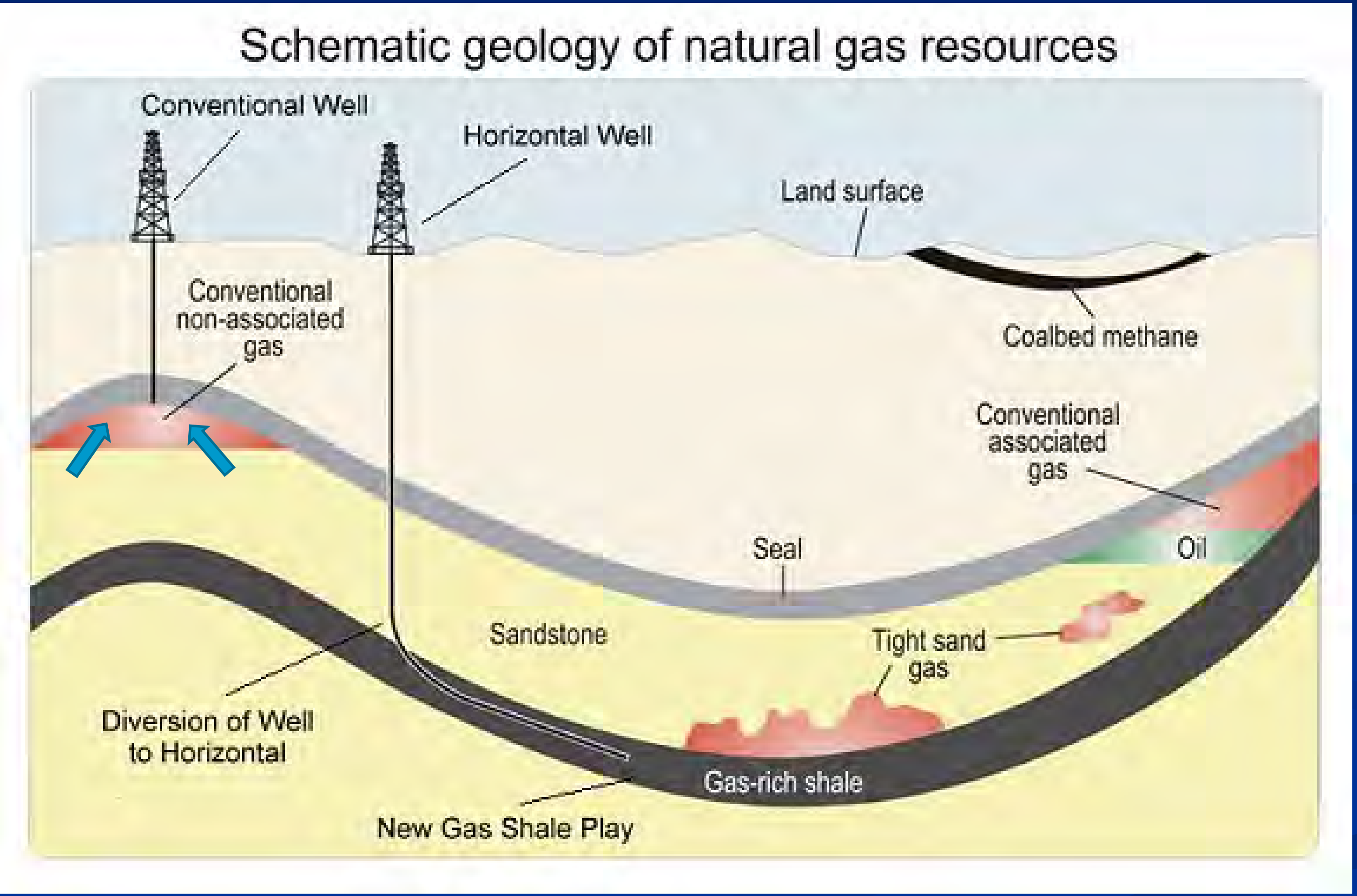
- Subsurface Hydrocarbon resources formations:
  - Tight (Using Hydraulic fracture methods, stimulation), no naturally commercial output.
  - Accumulation by diffusion.
  - Low-to-ultralow permeability < 0.1 mD & low-to-moderate porosity :
    - Tight gas sandstones
    - Shale gas, Shale oil
    - Coalbed methane; Tar sands, Heavy oil

Unconventional Resources



http://www.auxilliumenergy.com/wp-content/uploads/2013/03/rsrctringl.jpg

Conventional & Unconventional Resources

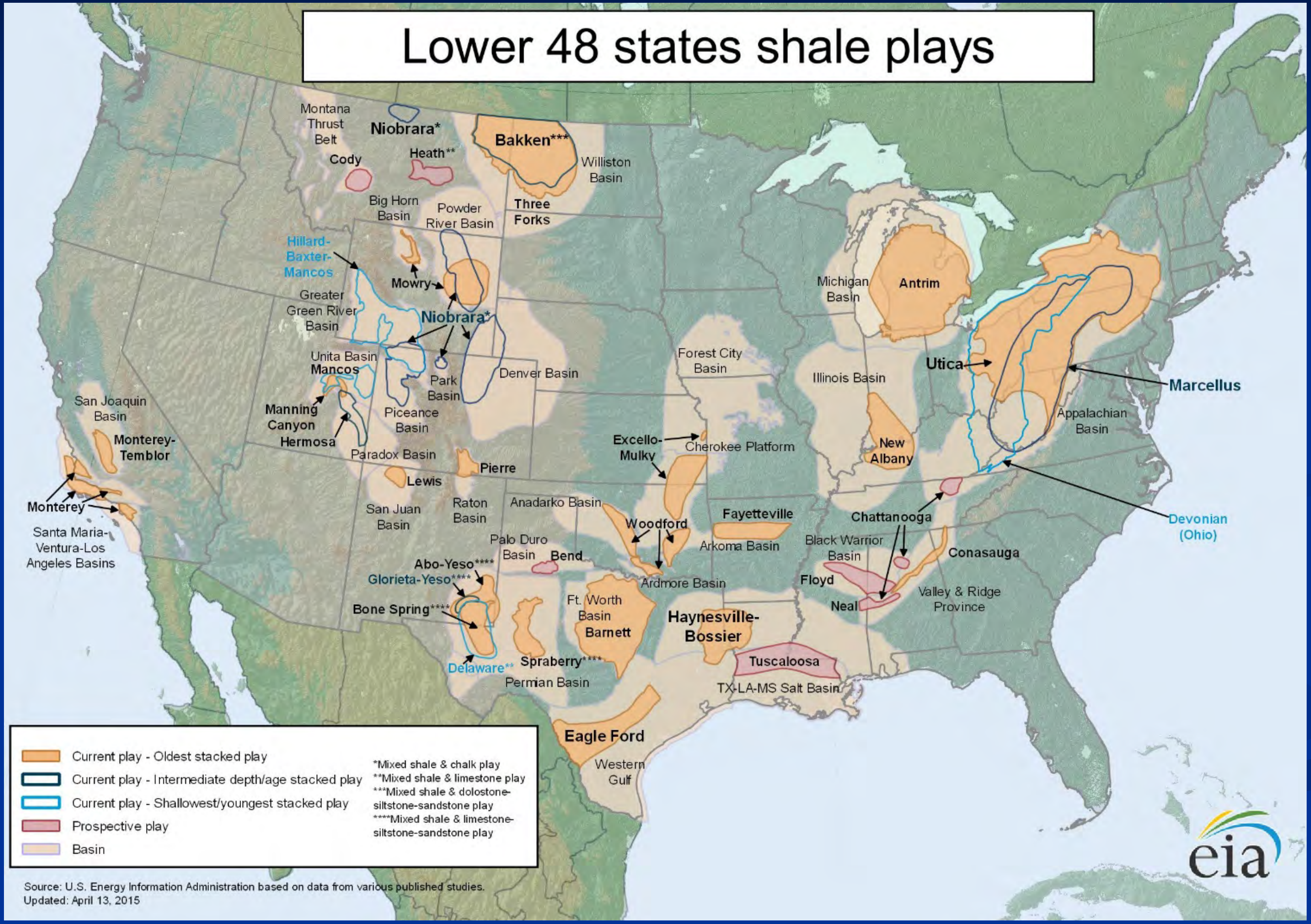


http://www.geomore.com/wp-content/uploads/2012/04/shale-gas-and-fracking-horizontal-drilling.jpg

Conventional Resources

- Accumulate in structural/stratigraphic traps.
- Porous and permeable formation, but sealed by cap rock (impermeable layer).
- Source rocks linked to the reservoir, no stimulation required for hydrocarbon production.
- In most conventional reservoirs Shales are considered as source rocks.

Shale Plays in the United States



Unconventional Resources- Shale Plays

- Barnett Shale -Texas, reservoir and not source
- Marcellus - marine sedimentary rock (Shale Gas): Black Shale is dominant, interbedded Limestone
- Niobrara - Chalk and Shale; Gas and Oil
- Bakken formations - siltstones sandwiched between upper and lower shales; Gas and Oil

Reservoir Quality

- TOC
- Thermal Maturity
- Organic mater
- Mineralogical Composition
- Lithology
- Effective Porosity
- Permeability
- Formation Pressure
- Natural Fractures

Environmental Impact

- Water management (water resources; chemicals; minerals; additives; waste water treatment; fluids flow-back; disposal of produced water;..)
- Residential area and impact of drilling
- Ground water contamination
- Increasing radon level and enhancing some radionuclides

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TENORM Issues in the Petroleum Industry

John R. Frazier, Ph.D.
Certified Health Physicist
February 1, 2016

Operations That Can Generate TENORM

- Purification of Drinking Water
- Production of Phosphate Fertilizer
- Extraction of Rare Earth Elements
- Elemental Phosphorous Production
- Natural Gas Production
- Crude Oil Exploration & Production (E&P)
- Numerous Other Examples

Introduction

- We live in a virtual "sea" of natural background radiation and we receive a radiation dose every second of our lives.
- Do oil and gas E&P activities increase our radiation dose?
- What is TENORM in the petroleum industry and where is it found?
- What are the issues regarding TENORM in the petroleum industry?

Issue 1 History of Knowledge of NORM and TENORM in Oil and Gas E&P

Knowledge followed the development of radiation detection instruments.

- Gas-filled detectors (simple ionization chambers) – Radon in natural gas
- Geiger-Mueller (G-M) detectors – Surveys around wells, flowlines, and tank batteries
- NaI (Tl) scintillation detectors – Highly sensitive to measure variations in natural background levels

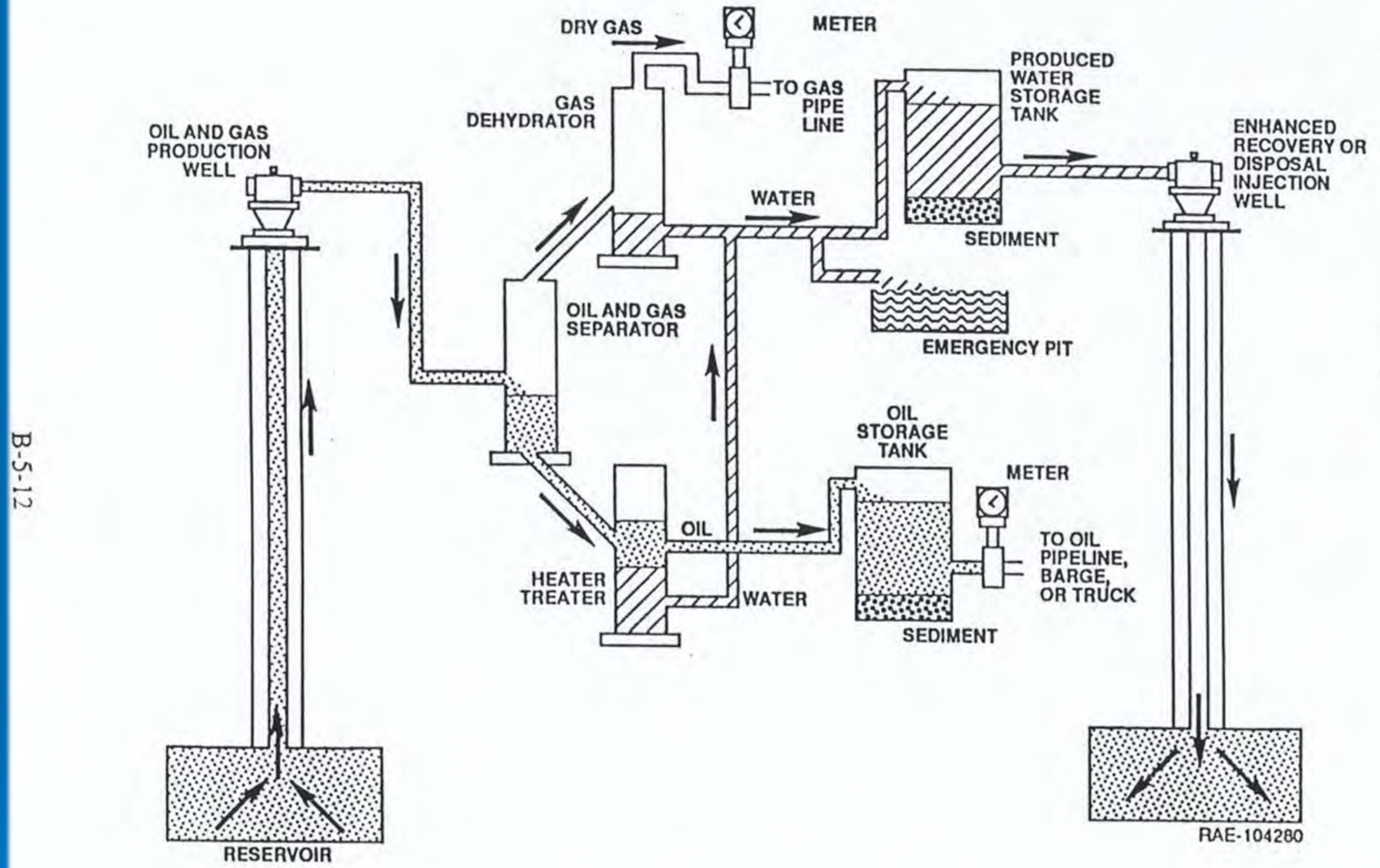

Figure B.5-1. Typical production operation, showing separation of oil, gas and water.

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Key Point No. 1

Knowledge of the presence of TENORM is not the same as knowledge that there may be significant doses from TENORM.

Key Point No. 2

There was recognition in the early 1970's that there might be potential above-background doses from TENORM in natural gas and LPG processing sites. Specific actions by industry were recommended.

Key Point No. 3

Following recognition in the early 1980's that there might be potential above-background doses from oil field TENORM, state regulators, CRCPD, API, and petroleum companies responded to assess the TENORM sources and potential doses.

Issue 2 Characteristics of TENORM at Oil and Gas E&P Sites

Two categories of E&P sites:

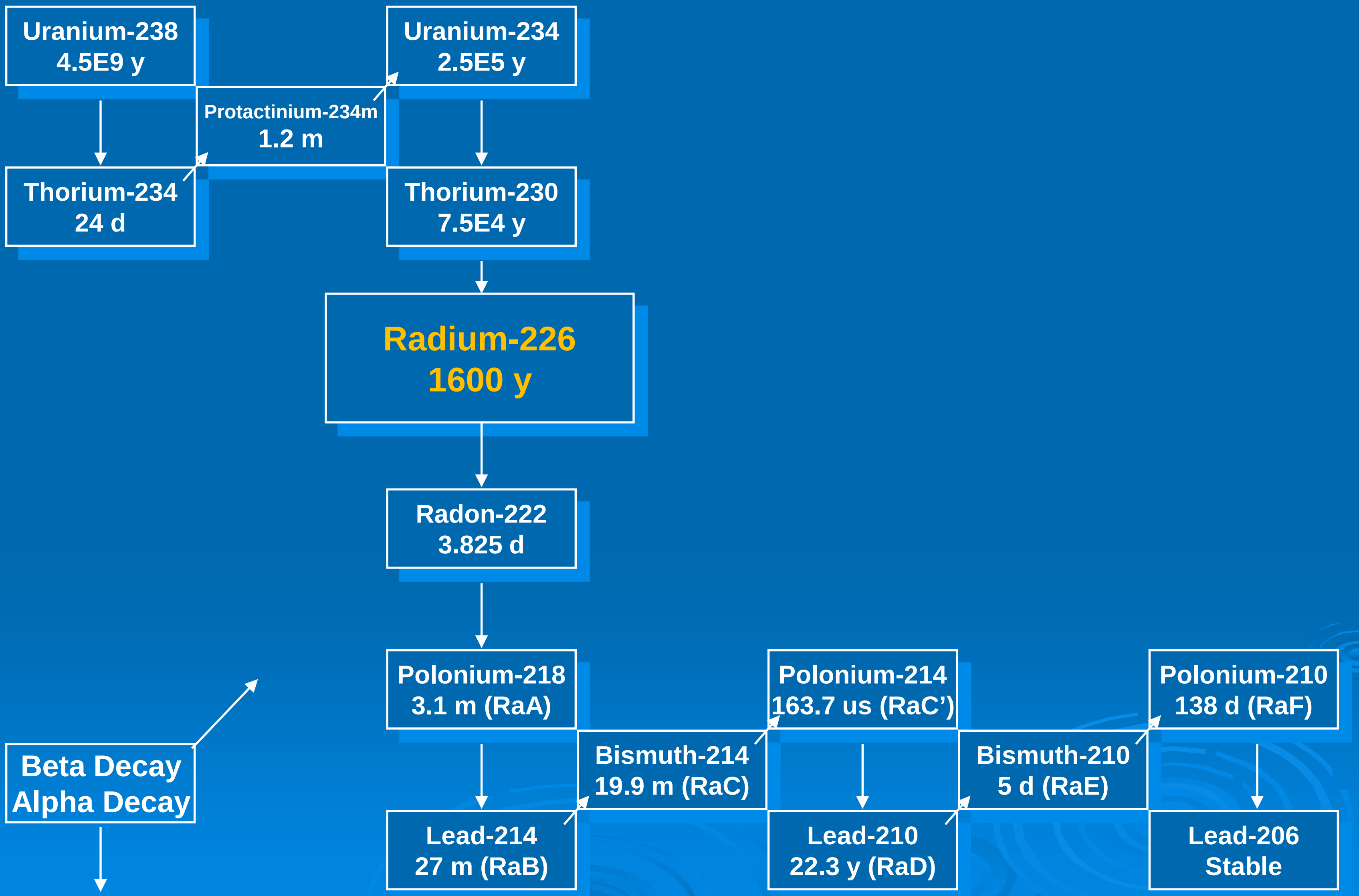
active sites and "legacy" sites

- Where does this radioactive material come from?
- What are the radionuclides in TENORM?
- Where is TENORM located/concentrated?
- What are the concentrations of those radionuclides?
- What are the chemical and physical forms of TENORM?

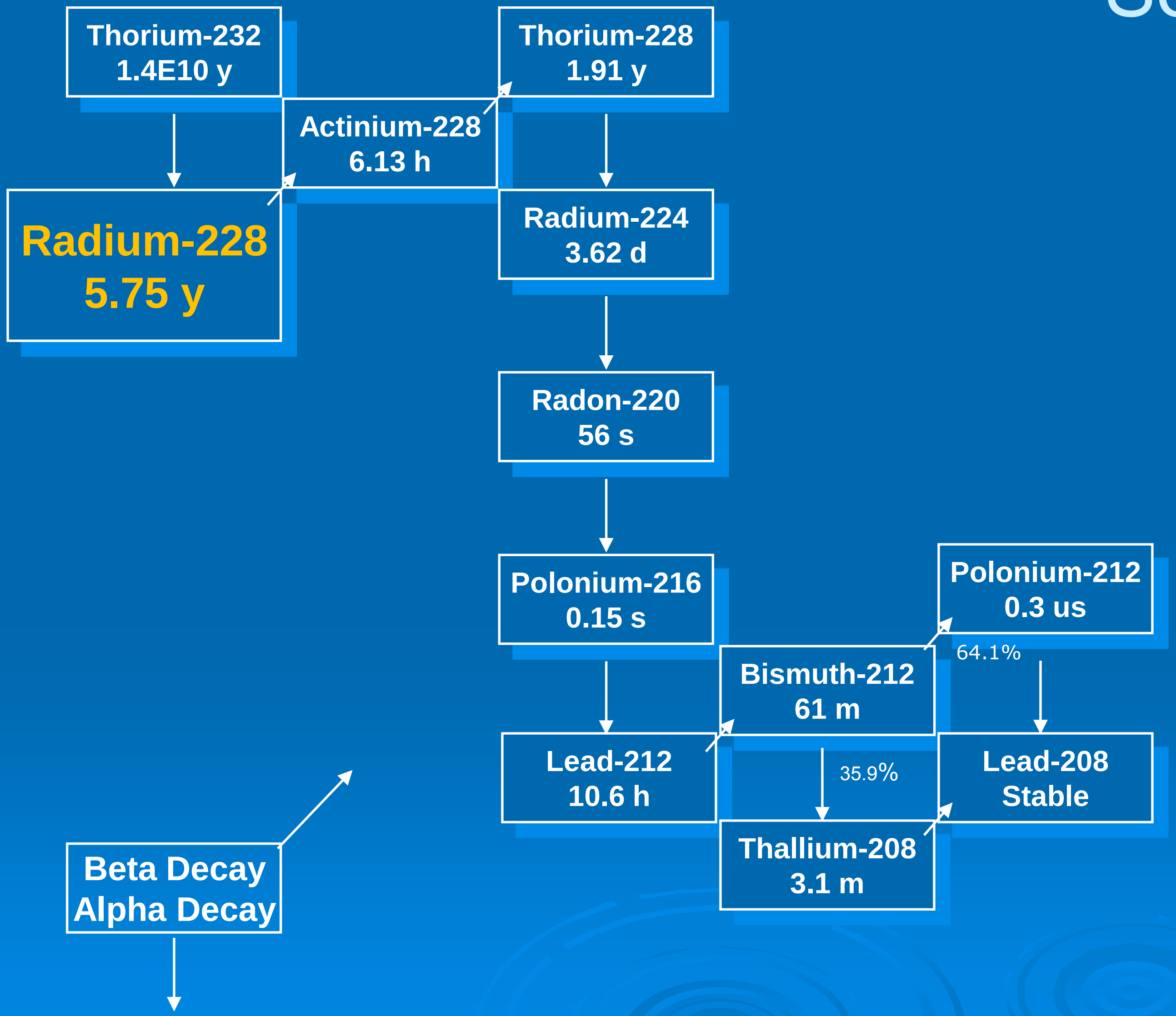
Source of TENORM in Crude Oil E&P Activities

- Natural uranium and thorium in formation rock.
- Water at high temperature and high chloride content in contact with the formation rock.
- Some radium from the U and Th series goes into solution as RaCl in the water. [accompanies Ba]
- Water ("produced water") accompanies oil from the well and carries the radium to the ground surface.
- The radium is unintentionally concentrated in scale and sludge at or near the ground surface.

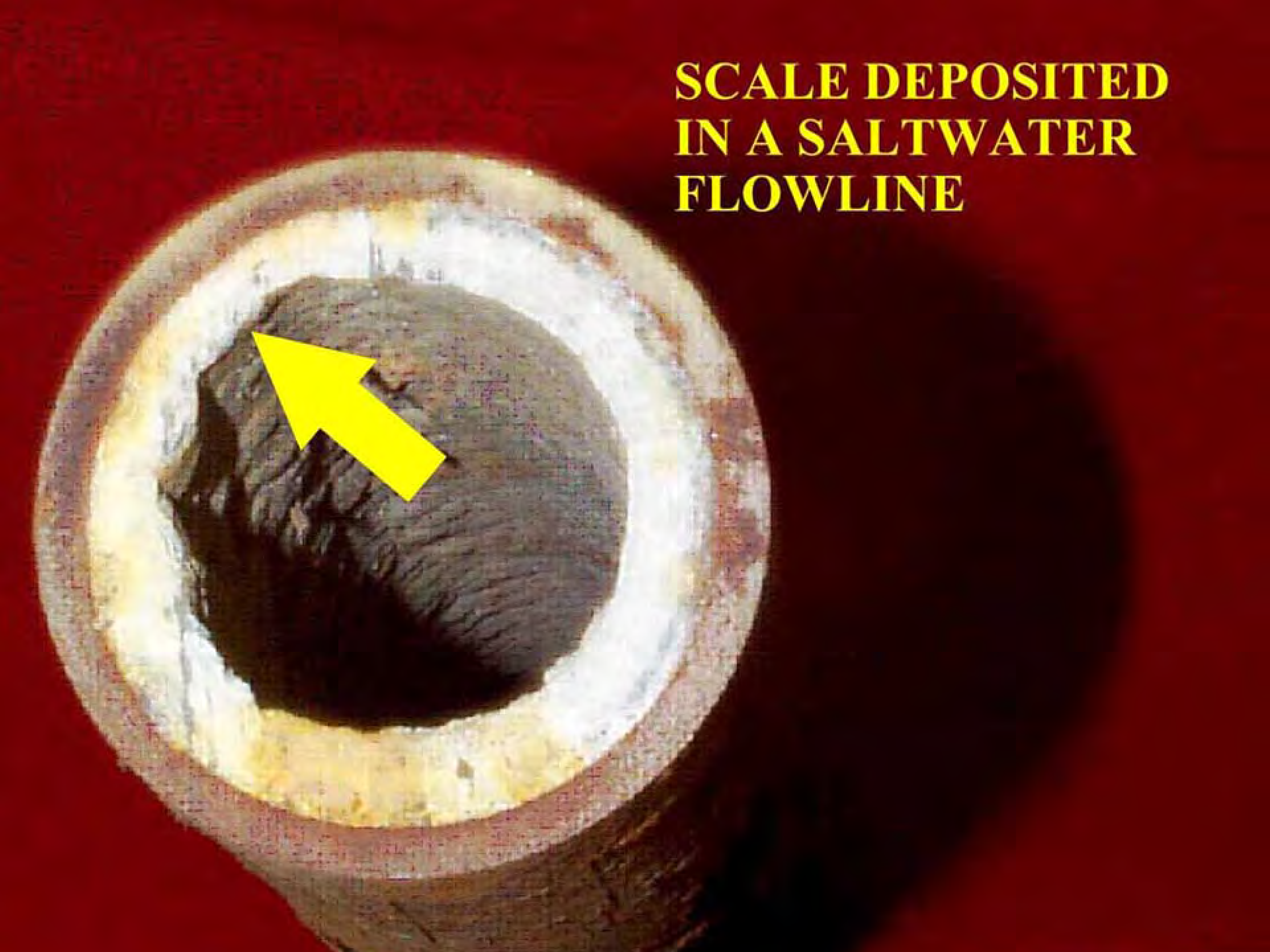
Uranium Decay Series



Thorium Decay Series



Scale Inside Used (Previously Downhole) Pipes


SCALE DEPOSITED
IN A SALTWATER
FLOWLINE

Scale

- Forms on inner surfaces of tubing, flowlines, and other equipment (e.g., heater treaters), and on pump (“sucker”) rods.
- Is usually composed of barium sulfate (barite), a highly insoluble compound.
- Has a radon emanation fraction (from radium in scale) that is very low compared to soil, U-mill tailings, etc.

Sludge

- Occurs inside heater treaters, separators, and in tank bottoms.
- Appears to include barite as coatings on grains of sand and other precipitates during oil production.
- Usually contains petroleum residues.

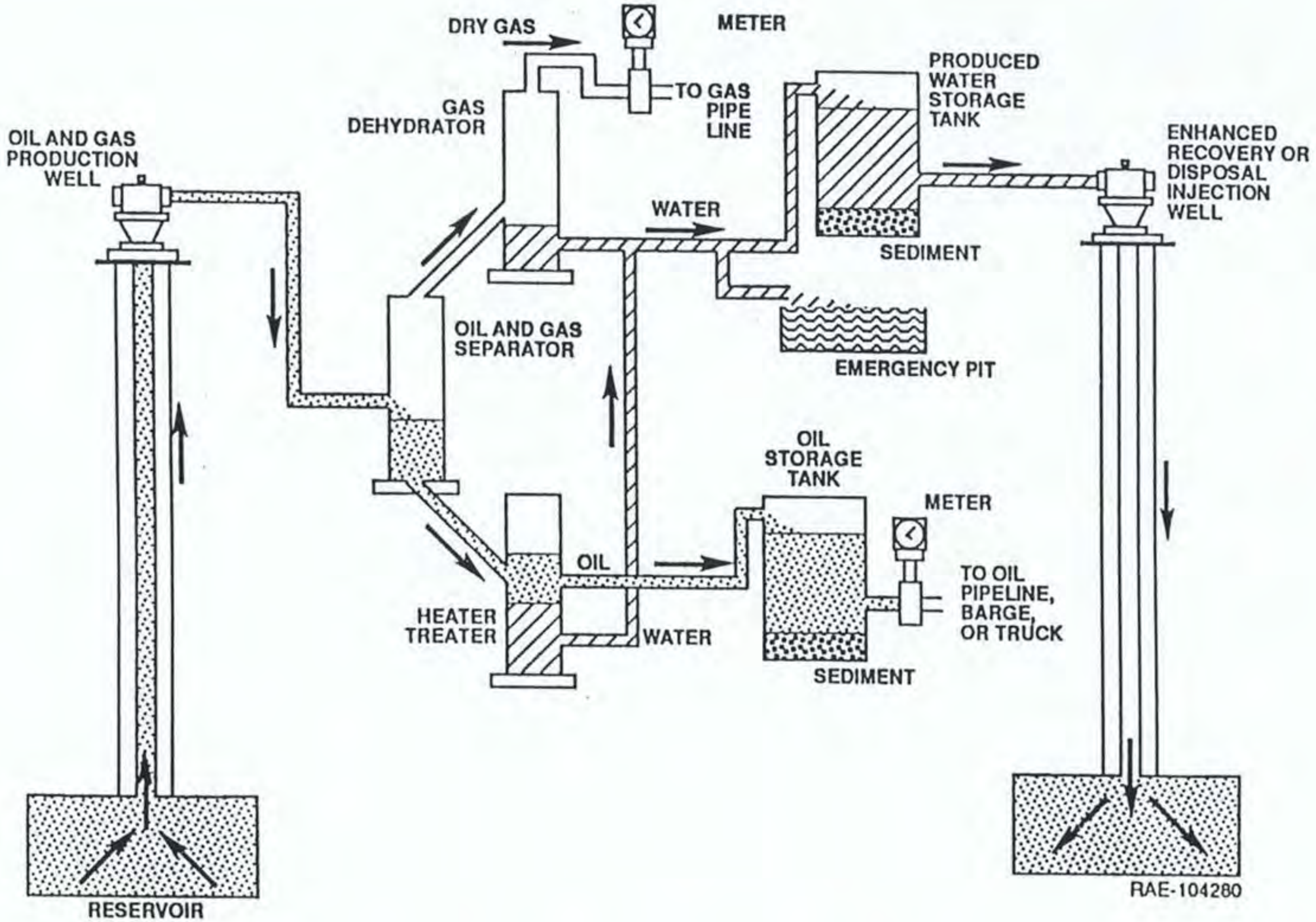
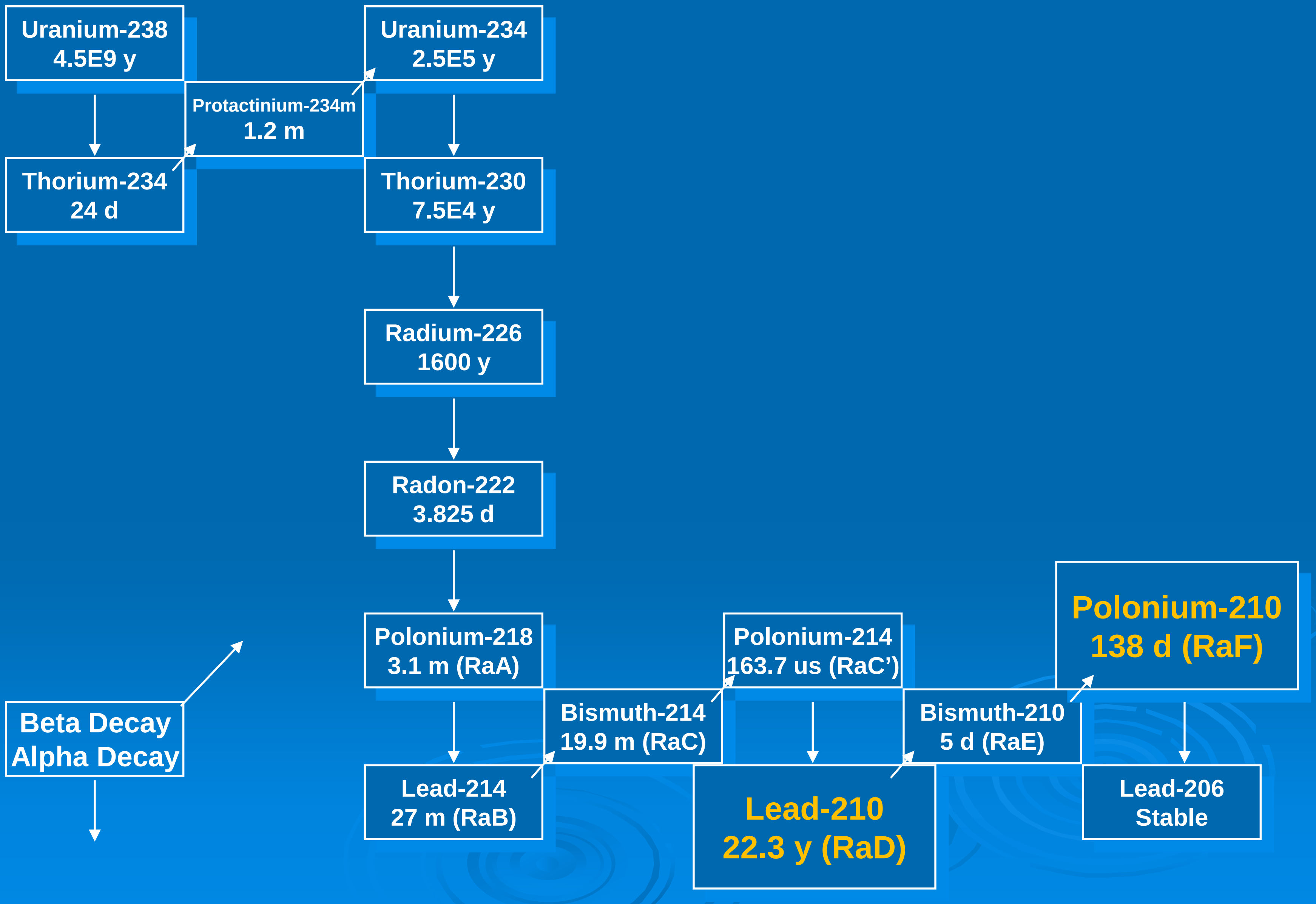


Figure B.5-1. Typical production operation, showing separation of oil, gas and water.

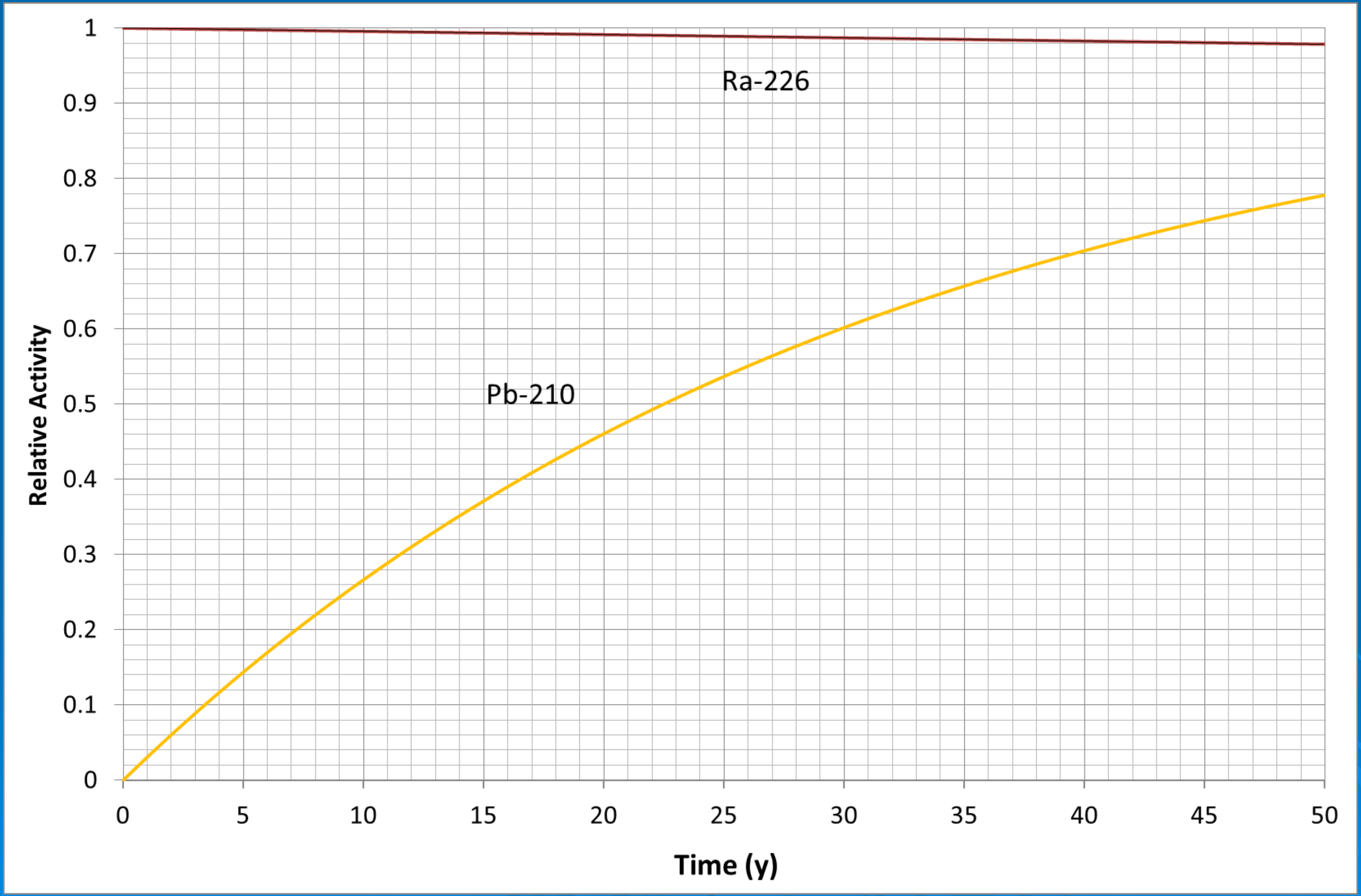
Radionuclides in Oil Field TENORM

- Ra-226 and Ra-228 Initially
- Decreasing Activities of Ra-228 (relative to Ra-226)
- Ingrowth of Progeny
  - Rn-222
  - Pb-210 (and Po-210)
  - Th-228

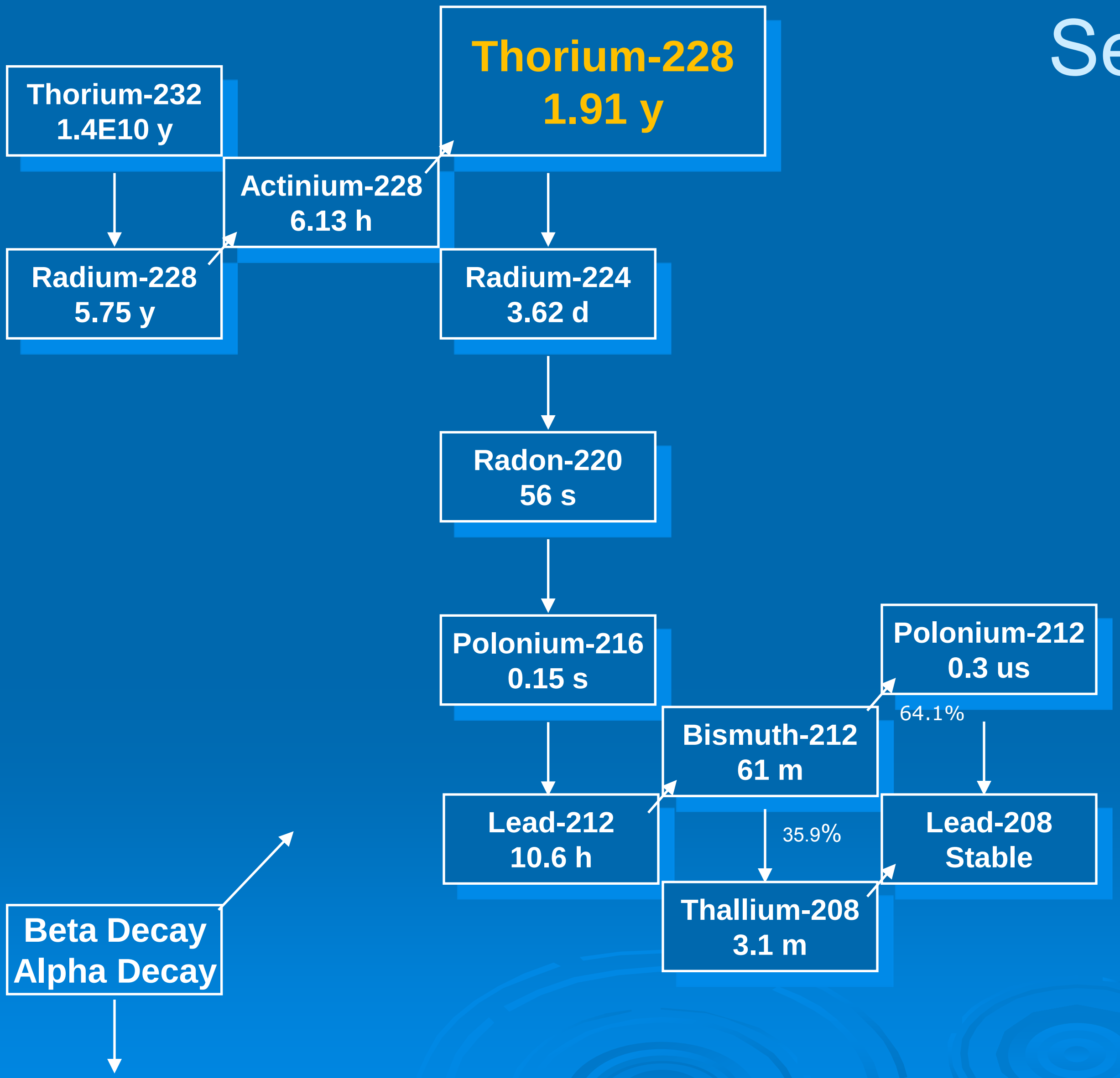
Uranium Decay Series



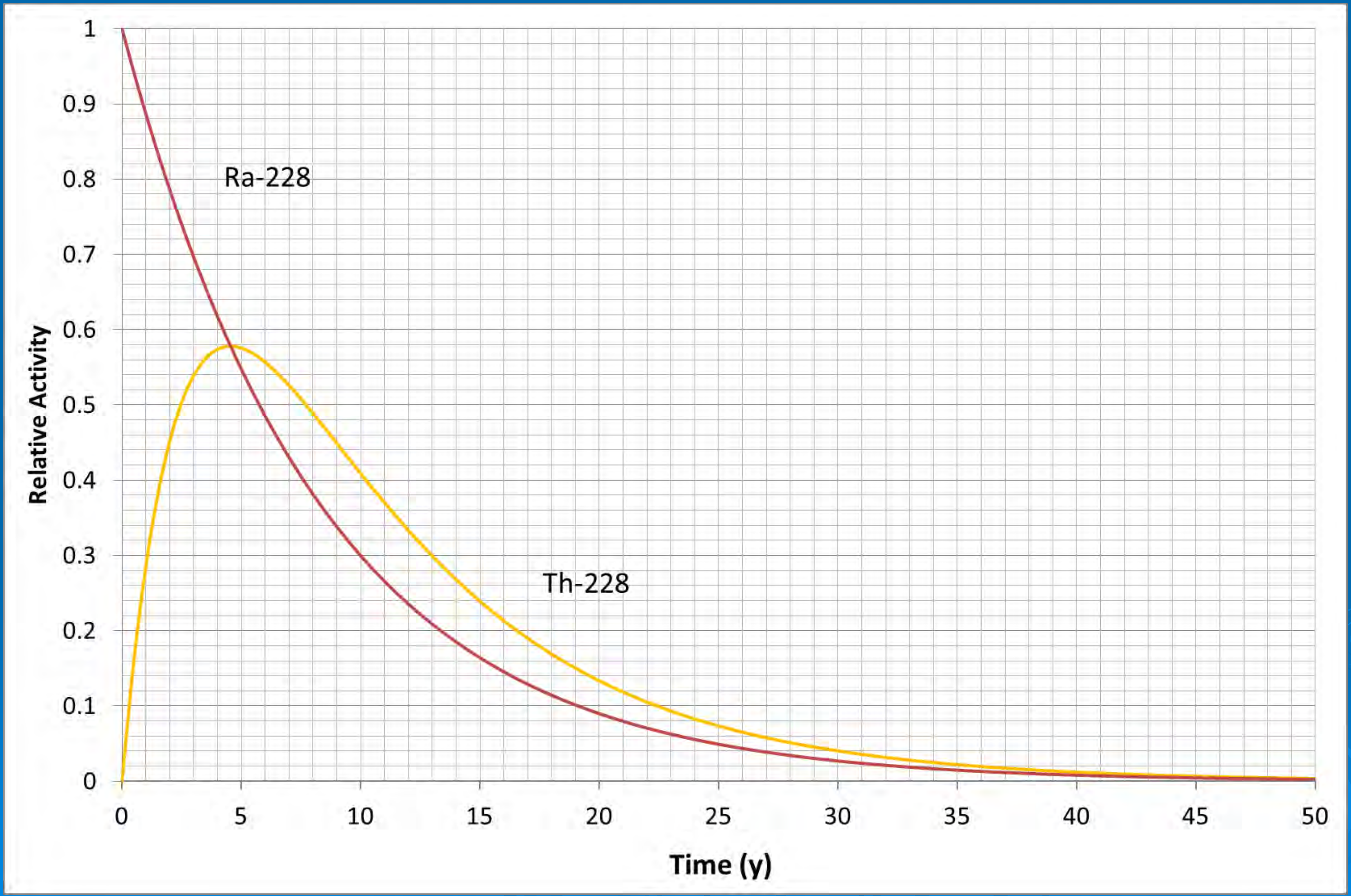
Pb-210 Ingrowth



Thorium Decay Series



Th-228 Ingrowth



NORM in Groundwater

- All groundwater contains naturally-occurring radioactive materials, including radium-226 and radium-228.

- The concentrations of radium-226 and radium-228 in natural groundwater vary, but the ratio of radium-226 to radium-228 is often approximately 1:1 (unless the water is near U or Th ores).

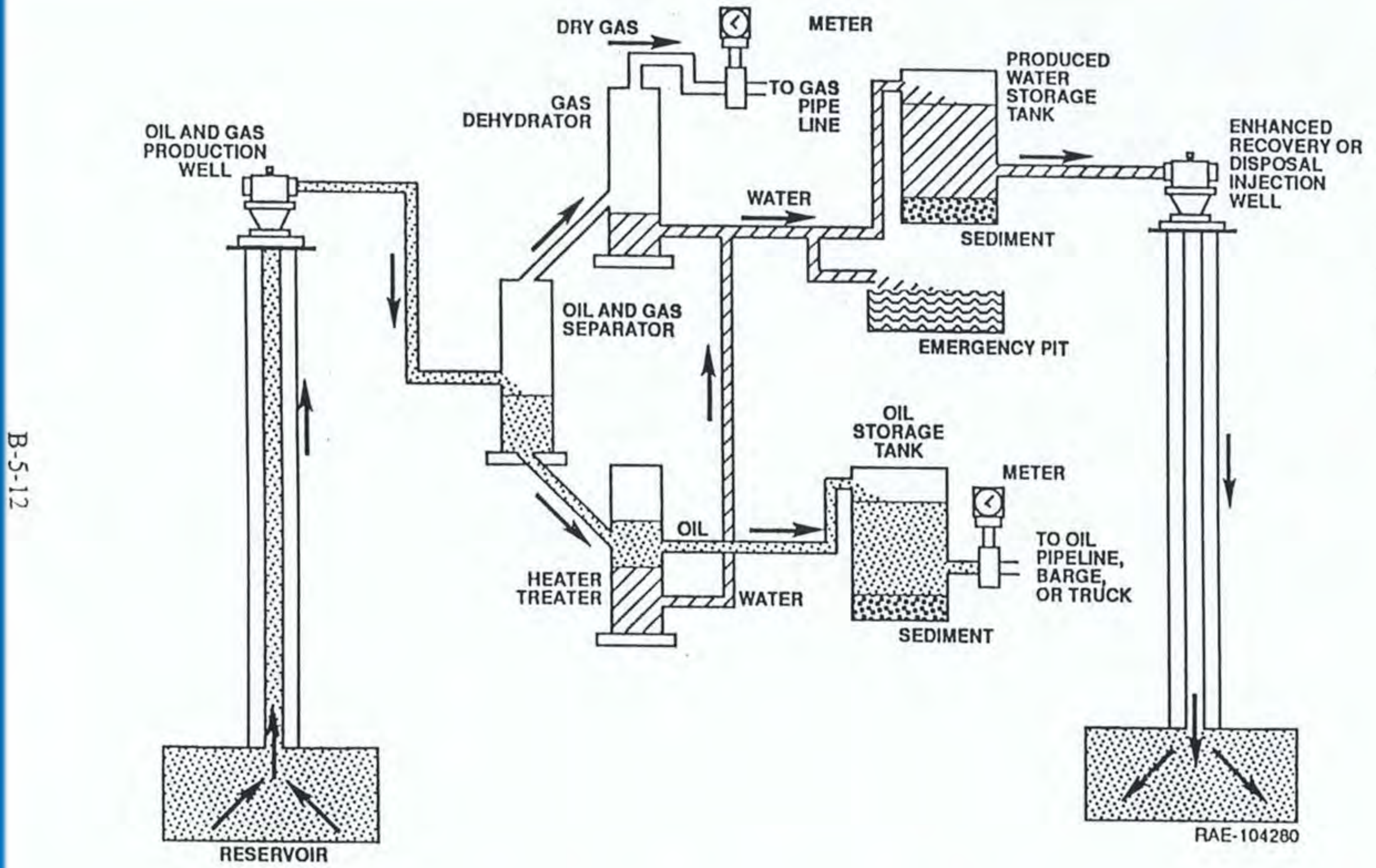


Figure B.5-1. Typical production operation, showing separation of oil, gas and water.

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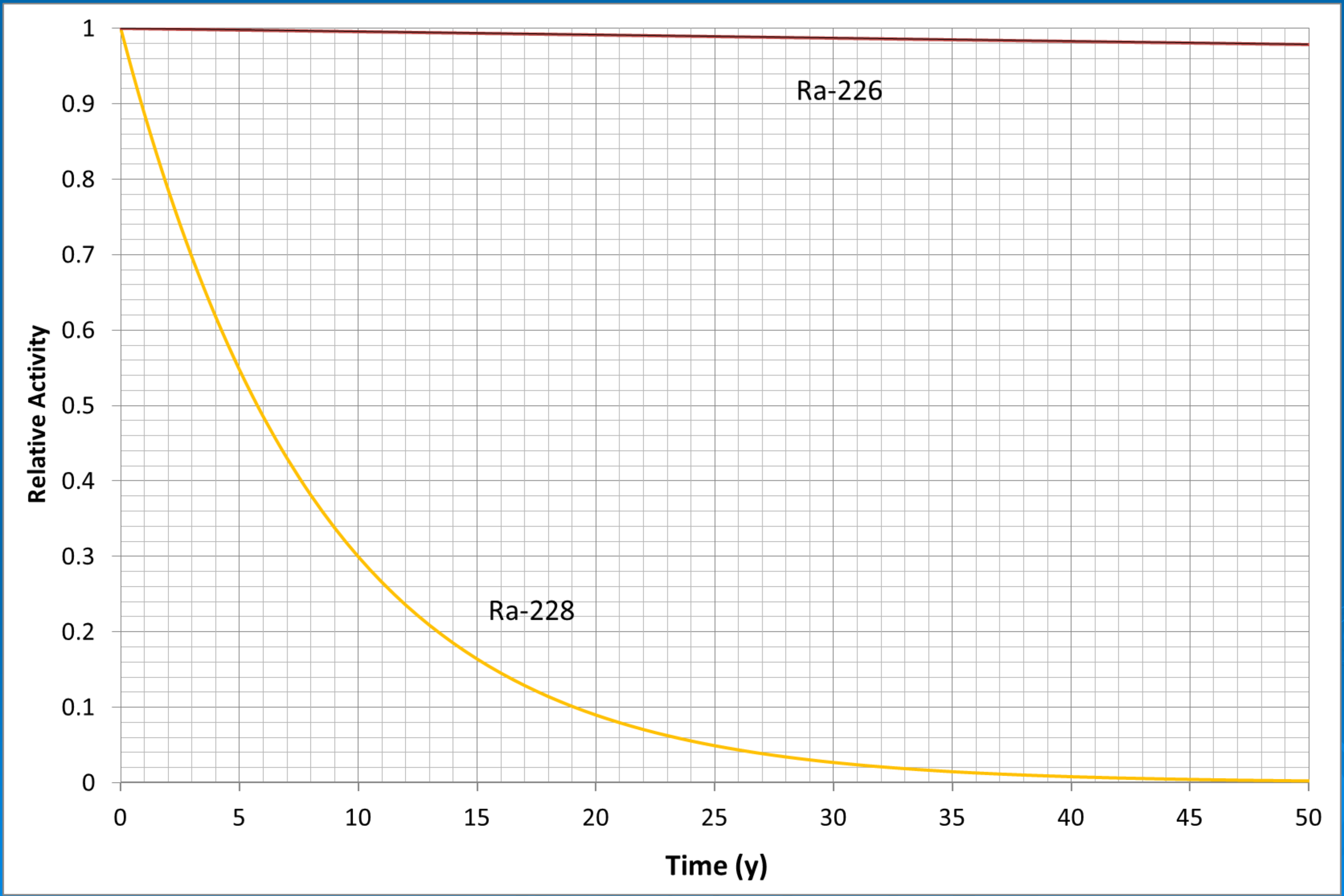
NORM in Produced Water

- Concentrations of NORM radionuclides in new produced water vary, but the ratio of radium-226 to radium-228 is often approximately 1:1.
- After produced water comes from the formation the Ra-226 and Ra-228 are no longer with the other radionuclides in the series.
- The activity of each then decays according to its half-life in the produced water and in the scale formed from that produced water.

Ra-228 Decay Relative to Ra-226



Key Point No. 4

TENORM Radionuclides for Consideration:

- Natural Gas – Rn-222 and its progeny
- LPG Processing (Propane Fraction)
  - Pb-214 and Bi-214 during processing
  - Pb-210 and Po-210 in propane fraction
- Crude Oil E&P
  - Ra-226 and Ra-228 initially
  - Ra-226 progeny and Ra-228 progeny

Key Point No. 5

The concentrations of Ra-226 and Ra-228 reported for scale samples from oil E&P sites are almost always biased high because the samples are almost always selected based on elevated gamma readings.

The distribution of radium concentrations in scale is seldom, if ever, measured and reported.

Contamination with Oil Field TENORM

- Because oil field TENORM is highly insoluble, it is nearly impossible to contaminate your clothing, shoes, or skin with it.
- Sludge can adhere to surfaces but it usually contains much lower concentrations of TENORM than scale.

Oil Field TENORM in Soil

- Scale or sludge can be dropped onto the ground during oil production activities.
- The radium in the scale or sludge will remain where it falls on the soil unless it is removed.
- Oil field TENORM scale won't spread over or deeper into the ground.
- Mechanical processes are necessary to transport and/or disperse TENORM-impacted soil.

Issue 3 Exposure Scenarios, Pathways, Parameters and Potential Radiation Doses

- What are reasonable human exposure scenarios for oil field TENORM?
- What are potential exposure pathways?
- What are realistic values for each dose calculation parameter?

Typical Scenarios

Active E&P Site

- On-site Worker
- Member of the Public as a Sort-Term Visitor

Legacy Site

- Member of the Public as Short-Term Visitor
- On-Site Resident

Potential Exposure Pathways

- External exposure
- Internal exposure
  - Inhalation of particulates
  - Inhalation of radon and radon progeny
  - Ingestion

Major Considerations for TENORM Dose Assessments

- External Exposure Pathway
  - Areal extent of locations having above-background exposure rates
  - Realistic durations of exposure at those locations
- Ingestion Exposure Pathway
  - Radionuclides
  - Site-specific concentrations of each radionuclide
  - Realistic values for ingestion rates
  - Ingestion dose coefficients for the chemical/physical form of each radionuclide

Major Considerations for TENORM Dose Assessments (cont'd.)

- Inhalation of Particulates
  - Radionuclides
  - Site-specific concentrations of each radionuclide
  - Realistic values for air concentrations of respirable particulates
  - Realistic values for inhalation rates
  - Realistic durations of inhalation exposure
  - Inhalation dose coefficients for the chemical/physical form of each radionuclide

Radiation Doses at Active E&P Sites

- Above-background external dose rates are limited to relatively small areas.
- Exposure durations at a specific location are usually very low.
- External doses are much more likely than internal doses.
- TENORM radiation doses assessed for E&P workers are nearly always less than the doses from natural background radiation.

Key Point No. 6

TENORM dose assessments should be based on reasonable, site-specific scenarios, pathways, and parameter values.

(not based on default values)

Key Point No. 7

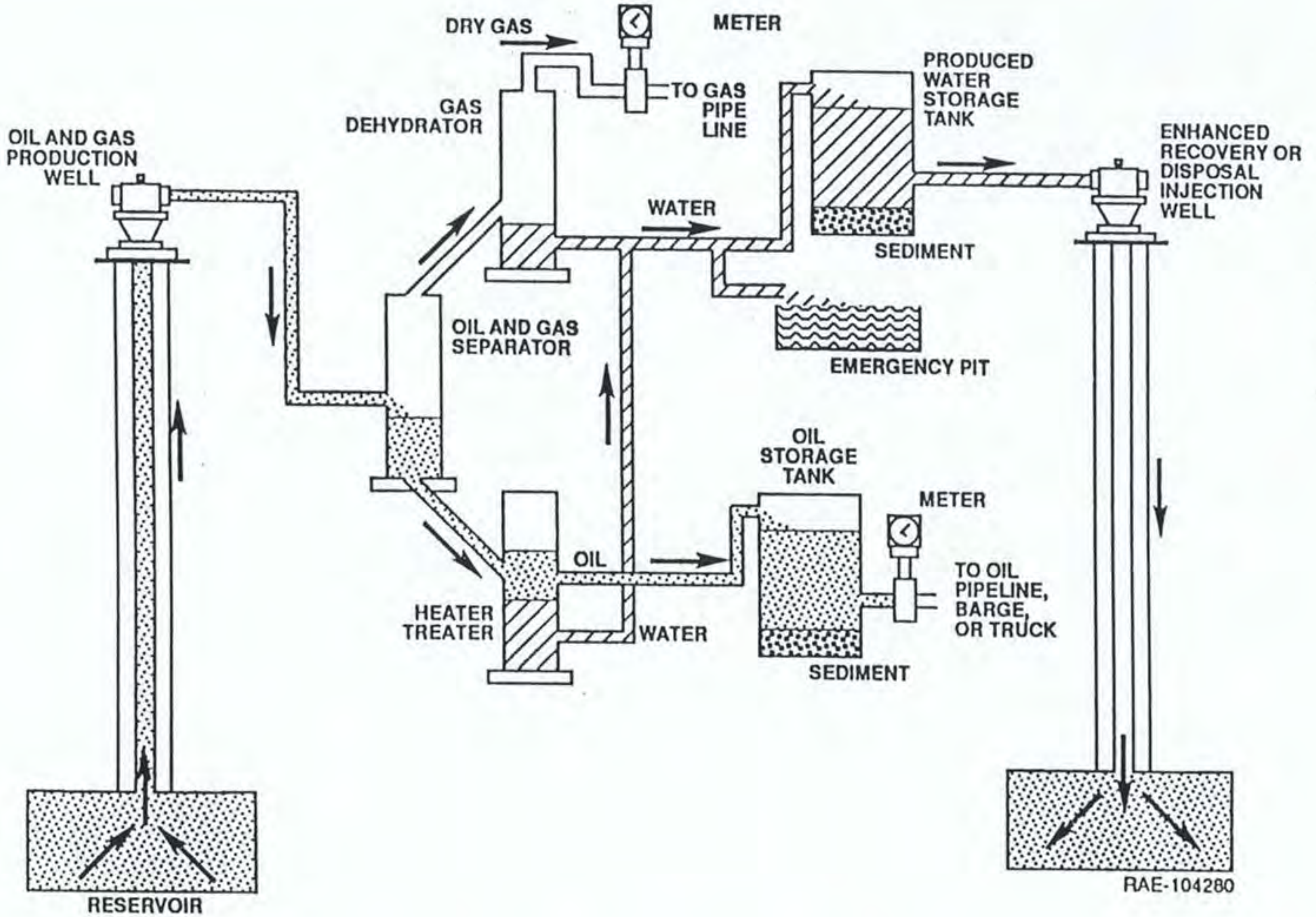
Ordinarily, there are no realistic exposure scenarios whereby people can receive significant radiation doses from oil field TENORM.

Key Point No. 8

With few exceptions, external radiation exposure is the potential exposure pathway that gives the greatest dose from oil field TENORM.

Issue 4 Assessment and Remediation of TENORM at Legacy E&P Sites

- Abandoned Pipe and Equipment
- Surface Soil
- Groundwater



B-5-12

Figure B.5-1. Typical production operation, showing separation of oil, gas and water.

Key Point No. 9

Oil field TENORM in soil at legacy sites is usually limited to the top 15-30 cm in relatively small areas of land and is not transported via normal wind or water.

Key Point No. 10

Detectable oil field TENORM in groundwater at legacy sites is nearly always limited to pits that previously received millions of barrels of produced water that had elevated concentrations of radium.

Categories of Issues

- Issue 1 History of Knowledge of TENORM in Oil and Gas E&P
- Issue 2 Characteristics of TENORM at Oil and Gas E&P Sites
- Issue 3 Exposure Scenarios, Pathways, Parameters and Potential Radiation Doses
- Issue 4 Assessment and Remediation of Legacy E&P Sites

Take Away Thought

The radiological impacts from TENORM must be assessed for the specific radionuclides that are actually present – taking into account their locations, concentrations, and chemical/physical forms.

OVERVIEW OF STATES' ACTIVITIES TO REGULATE TENORM

JARED W. THOMPSON CHAIR-ELECT

CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS

Acknowledgements

CRCPD Task Force to Review the TENORM Aspects of the Oil and Gas Industry

- **Gary Forsee**, Chair- SSR Part N

  Illinois Emergency Management Agency

  Environmental Compliance

- **Ruth McBurney**, CHP

  CRCPD Office of the Executive Director

  Executive Director

Background

- Awareness in state radiation control programs of technologically enhanced naturally occurring radioactive material (TENORM) for over 40 years

- Primary isotopes of concern: Radium and daughters
  Lead-210 & Polonium-210

- Need for uniform regulatory position
  - Use
  - Decontamination
  - Disposal of wastes

Types of Processes Enhancing NORM

- Oil and Gas Production
  - *Scales*
  - *Sludge*
- Phosphate fertilizer production and phosphogypsum
  - *Tailings*
  - *Filters*
- Water treatment facilities
  - *Filters and resin beds*

Pipe Scale

Early concerns from:

- ➢ Contaminated pipe in scrap yards and for recycling into other uses
- ➢ Contaminated soil in pipe cleaning and storage yards

Concentrations

Average: 3.7 kBq/g

Upward range to: 3.7 MBq/g

Contaminated Oil Production Equipment

Worker awareness and protection issues involved in cleaning and maintenance

Phosphogypsum

Large areas of diffuse material
Average concentration of radium:
1.1 Bq/g (30 pCi/g)

Water Treatment Systems

- Filtration systems concentrate radionuclides from drinking water
- Example: Average Illinois municipal sludge concentration: Approx. 1kBq/kg combined radium
  (50% Ra-226, 50% Ra-228)
- Average 56,000 tons per year

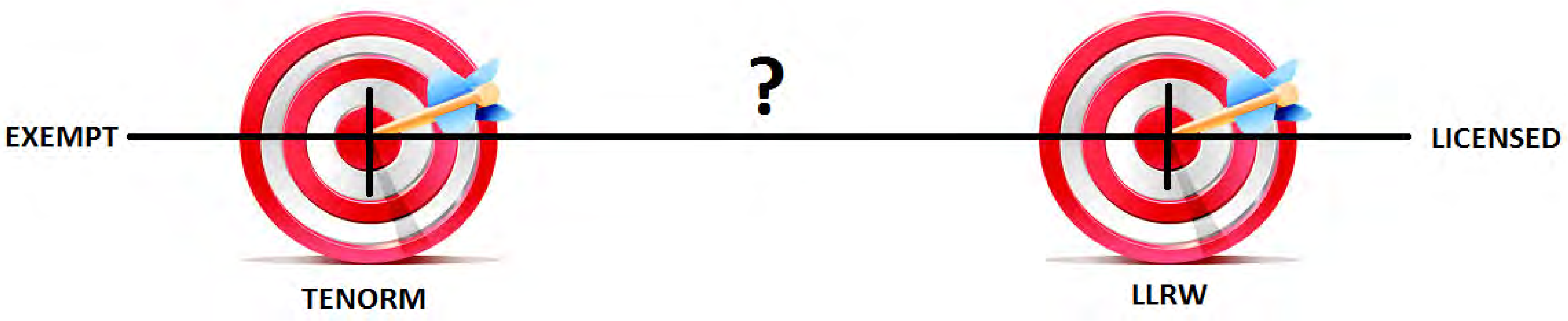
Other Sources of TENORM

Additional Industries:
- Chemical production facilities
- Geothermal wastes
- Paper/pulp industry
- Rare earth mining

Other Waste Forms:
- Flowback/Formation Waters
- NPDES Outfalls (liquid discharges)
- Radon from landfill gas systems
- Pb-210/Po-210 airborne particulates

Varying State Limits:
- Fly Ash
- Municipal wastewater sludges
- Drill cuttings
- Refractory material

Moving Targets



- CRCPD has developed the Model TENORM Regulations
- Regulatory oversight of these wastes vary by state
- Not only does the lower level at which TENORM is differentiated from exempt material vary, the upper level at which TENORM is considered low level radioactive waste is a moving target.
- As a consequence, wastes that may be completely unregulated in one state may require licensure and handling/disposal as low level radioactive waste in another.

Consistent Regulatory Framework Needed

Inconsistencies in handling TENORM and varying thresholds at which TENORM becomes LLRW

- Unclear regulatory picture for industry
- No clear disposal guidance for state SW and RAM decision makers
- Inconsistent protective standards for the environment and the public
- Worker protection standards range from non-existent to licensed personnel
- Differences in waste acceptance criteria drive these wastes across states and compact commissions.

Current SSR Part-N

- Ongoing push since mid 1990’s (and before) for a nationally consistent TENORM regulatory framework.
- Product of decades of CRCPD work
- 1982-1990’s Multiple drafts circulated and commented on by states, industry, and public

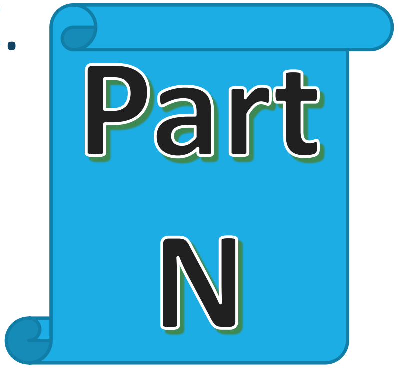
  - 1985 – SR-5 Committee Draft 2
  - 1987 – Draft 5
  - 1988 – Draft 6
  - 1991 – Proposed Part N
  - 1993 – “Final Part N” – Distributed to States
  - 1997 – NORM Commission Draft
  - 1998 – Substantial Rewrite
  - 2003 – Implementation Guidance
  - 2004 – Revised Draft

Features of Model Regulations for NORM

- Scope limited to TENORM (as defined)
- Dose-based exemptions
- Basic radiation protection standards applied
  - *Occupational limit of 0.05 Sv*
  - *Public limit of 1 mSv*
  - *Decommissioning criteria of 0.25 mSv*
- Licensing Provisions
  - *General license*
  - *Specific license*
- Disposal Options
- Land application up to 370 Bq/kg
- 50 μR/hr release limit for scrap & contaminated equipment
- Focus on radium

Definition of TENORM in Current Part N

Naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils. TENORM does not include "source material" and "byproduct material" as both are defined in the Atomic Energy Act of 1954, as amended (AEA 42 USC §2011 et seq.) and relevant regulations implemented by the NRC.



Implementation Guidance

- Environmental exposure pathways and scenarios
- Suggested computer assessment programs
- Appropriate instrumentation for radiation measurements
- Appropriate methodology for conducting, documenting and analyzing measurements
- Provides action items for future review…

CRCPD E-42 TASKFORCE

- CRCPD Executive Board formed the E-42 Task Force in May 2012.
- Charge:

  Publish a "White Paper" that examines and reviews the TENORM radiological, environmental, regulatory and health and safety issues observed since the publication of the CRCPD E-4 report (1994) and the E-36 Implementation Guidance (2003).

CRCPD E-42 TASKFORCE

The "White Paper" was to summarize at least the following TENORM issues:

- Provide assessment and propose recommendations for the following:
  - **TENORM Radiation Exposure Issues-** Occupational/ Public exposures included but not limited to regulatory impacts and health and safety.
  - **TENORM Environmental Impacts** from technologies included but not limited to, disposal options for various types of TENORM waste
- Assess and evaluate TENORM Worker Awareness Training and general Public Awareness Information.

TASK FORCE ACTIVITIES

- Over a 2.5 year time period, the “White Paper” evolved and became a 119-page report
- Report provides a limited summary of the TENORM issues since 2003
- International and national data and literature on TENORM reviewed
- Additional issues of concern arose during report development
- Common disposal scenarios for TENORM materials containing the estimated source term were modeled using RESRAD to produce dose estimates

TASK FORCE ACTIVITIES

Diverse E-42 Task Force

Members/Advisors:

- (12) State Members
- (3) TENORM Industry Consultants
- (2) Federal Government Reps (EPA & NRC)

A Peer Review was performed on the Task Force Report by (5) individuals, including Bill Kennedy, HPS/NCRP.

CRCPD Task Force Report

The emphasis of this report is on the need for **nationwide scientific consistency in a more standard regulatory framework** to ensure public health and protection of the environment.

Report completed in June 2015

Task Force Recommendations

1. Establish a more consistent definition of TENORM
2. Review the acceptance criteria in SSR Part N for adequacy, using a consistent dose and regulatory approach
3. Partner with NCRP on the criteria development for trigger levels
4. Further evaluate the extent and quantification of Lead-210 (Pb-210) and Polonium-210 (Po-210) contamination and exposure to radon for radiation protection of oil and gas workers
5. Incorporate TENORM assessment in the early phases of oil and gas permitting

Task Force Recommendations

6. Amend existing regulatory programs, including SSR Part N, to include an assessment of TENORM.
7. Collect and maintain a compendium of state regulations and guidelines pertaining to the management and disposition of TENORM.
8. Compile and maintain a database of the concentrations volumes and radiation fields associated with the oil and gas operations and activities.

CRCPD BOARD ACTIONS

The CRCPD Board has recently taken the following actions regarding the Recommendations made by the Task Force:

1. CRCPD Executive Director has prepared a letter to the National Council on Radiation Protection (NCRP) requesting to work jointly on TENORM issues related to Acceptance Criteria (Trigger levels, i.e., 5 pCi/kg) and the Quantification/Clarification of Pb-210 and Po-210 as described in the E-42 Task Force Report – Review of TENORM in the Oil and Gas Industry. **CRCPD is seeking scientific and technical assistance in the development of these two recommendations from the Task Force.**

CRCPD BOARD ACTIONS

2. Establish the E-45 Committee on ***ALL SOURCES OF TENORM*** which is a continuous Committee that will report to the Board at least annually.

   The primary charges are:

   To review and provide a report to the CRCPD Board on the following recommendations from the *E-42 Task Force Report Review of TENORM in Oil and Gas Industry:*

   a. Assess and determine if the definition of TENORM as identified SR-N should be revised or changed as discussed in the Task Force Report. This will be completed within one year after Committee activities begin.

   b. Review the training recommendations identified in the Task Force Report and identify training components to be implemented by SR-N.

CRCPD BOARD ACTIONS

c. Prepare a consolidated guidance document for the non-licensing nature for TENORM facilities. This guidance should be in the format of the USNRC NUREG-1556 series.

d. Evaluate the feasibility of CRCPD maintaining a compendium of state regulations and guidelines pertaining to the regulatory management of TENORM.

- The discussions and reports related to these charges will not be limited to just the oil and gas industry, but will also evaluate other TENORM source production processes.
- Industry stakeholders, consultants and representatives of other professional organizations will be included in the completion of this charge.
- This Committee will consult, comment and make appropriate recommendations concerning TENORM issues and regulatory revisions to the SR-N Committee.

CRCPD BOARD ACTIONS

SSR-N working group issued a revised charge in September 2015:

- Phase I – Perform Data Scoping *(currently underway)*
- Phase II – Review of SSR-N
  - Incorporate Board-approved E-42 Recommendations
  - Incorporate technical solutions from E-45
  - *(Tentatively)* Work with the NCRP and incorporate resulting work
  - Provide recommendations for revision to the CRCPD Board

Why Revisit Part N?

- Continual process to ensure Part N is responsive to changes in industry and adequately addresses recent technological developments
- Address published guidance from other standard setting bodies
- Capture regulatory changes and ensure compatibility with Federal rulemakings
- Low adoption of Part N and various alternative disposal limits
- Additional hazards not encompassed in Part N
- Ensure Part N is effective in meeting the most up to date protective standards for the environment and the public.

Why Revisit Part N?

Issues Identified in the 2003 Implementation Guidance

- Review the definition of TENORM
  - *ANSI & US EPA vs. Current CRCPD*
  - *Industry stakeholders are wanting consistent definition*
- Solid Waste Release Criteria
  - *Recent studies (Pennsylvania, North Dakota, EPA)*
- Differing Site Release Criteria *(13 vs 25 mrem/year)*
- Dose Based Surface Contamination Values
- Exemption criteria for other radionuclides
- RSO Requirements and Radiation Safety Training for TENORM Workers

Why Revisit Part N?

Issues Identified in the 2003 Implementation Guidance (continued)

- Assessing the groundwater pathway *(4 mrem/yr)*
  - *EPA is addressing TENORM industry by industry*
  - *Will likely vary by industry/waste form*

- Implementation guidance offers items for future consideration
  - *Assessments of operations on page 9*
  - *Trigger levels that would move a general licensee to a specific licensee are present (operations that give rise to a dose in excess of 10% the occupational limit)*

Why Revisit Part N?

Issues Identified by the E-42 Working Group

- Radon – Use in models, worker protection standards, and dose to the public
- A need to formalize the notification to states for intent to be covered by a TENORM license
- A need to formalize the "assessment" for dose-based exemptions
- Address inconsistencies in worker training

Why Revisit Part N?

- Analysis of the 5 pCi/g exemption in light of disposal pathway
  - *Clarification that Part N doesn't prohibit RCRA landfill disposal*

- Land application does not account for site buildup of radium

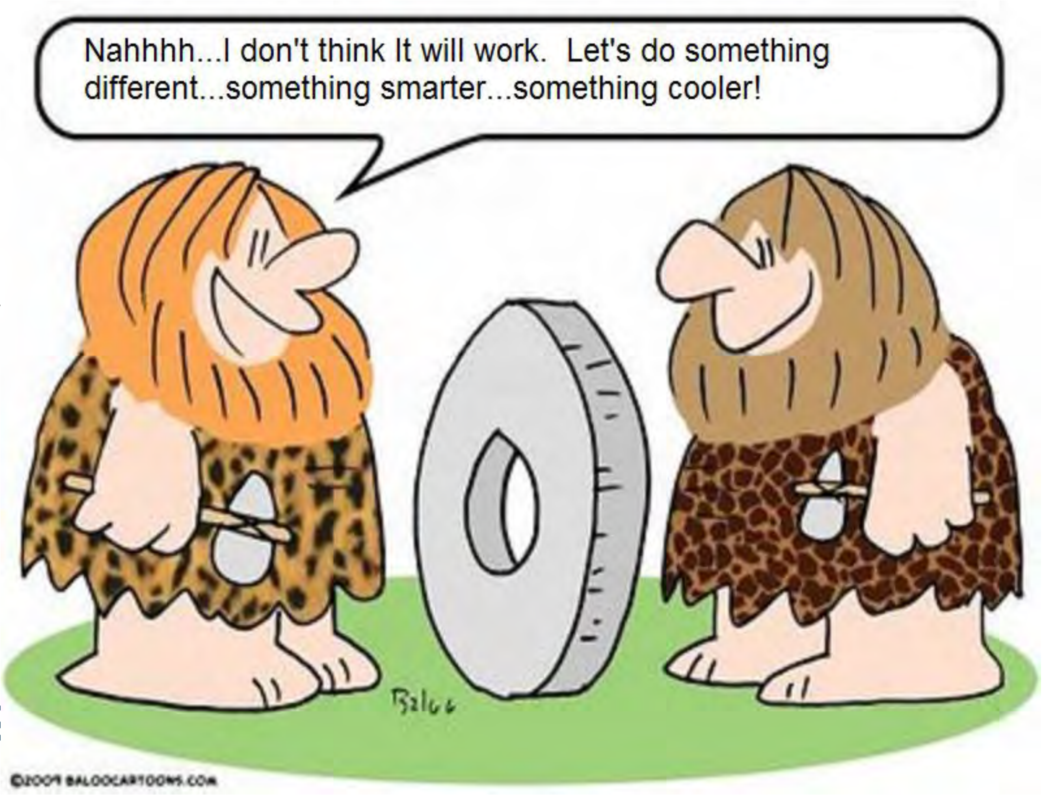
- Desire for radiation protection programs and training that is commensurate with the duties/hazards present. (I.e., a "graded approach")

Developments since Part N and Possible Implications

- ANSI N.53-2009
- Drinking Water Regulations and increased radium removal
- High Volume Hydraulic Fracturing Operations
- Harmonization with US DOT and International Shipping Regulations
  - (*special permits, X10 NORM exemption*)

Expectations

- Multiyear effort with E-45 input
- The RCRA *vs* NRC site release
  - *likely won't be resolved soon.*
- The EPA *vs* NRC allowable public dos
  - *constraints won't be resolved soon.*
- Introduce proposals to formalize the notification to the state of coverage under a license



Expectations

- Introduce proposals to formalize the dose assessment process
- Include the groundwater pathway in models
- Examine the utility and science behind 5 pCi/g. Is the exemption appropriate and defensible across multiple industries and all exposure scenarios?
- Examine alternative field-screening methods that allow the regulated community to quickly determine compliance and allowable disposal options. These need to be tied to both a dose and a disposal pathway.

Expectations

- Revise the language that delineates the lower levels of TENORM that do not warrant regulatory oversight.
- Scope of TENORM will continue to grow
- Changing definitions places an emphasis on the dose assessment process
- Industry-specific guidance *(“NUREG 1556-ish”)*
- Examine “permitting”, “exemptions”, and the AEA Licensing structure as it applies to TENORM.

Problems

- Permitting doesn't address contaminated legacy sites
- Permitting requires multi-agency coordination
- Who reviews / approves proposed dose assessments
- "Trigger levels" are desired by industry. However, these are dependent upon the disposal pathway in play
- Training desired for all TENORM workers. I.e., prior to licensing space. No regulatory framework outside of AEA licensing..

Other Organizations Looking at TENORM

- National Council on Radiation Protection, SC 5-2 Working Group
  - *Recommendations for Uniform Approach to TENORM Management and Disposal*
- EPA: Concentrated on fracking issues
- Interstate Oil & Gas Compact Commission and American Petroleum Institute
  - *Establishment of working relationship with CRCPD on TENORM issues*.
- Association of State and Territorial Solid Waste Management Officials (ASTSWMO):
  - *Awareness amongst industry, disposal guidance for solid waste with TENORM.*

Conclusion

CRCPD will continue to work on the regulatory issues involved with TENORM

- New E-45 committee to be a clearinghouse for emerging technical issues
- Revision of Part N of the Suggested State Regulations for Control of Radiation
- Coordinate with other organizations to create a more consistent approach to regulatory and non-regulatory control of TENORM

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NORM

Legal Issues On Roller Skates

ATTORNEY SOLICITATIONS

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Introduction

- In approximately 1981 NORM contamination was discovered in the North Sea
- In 1986 investigators discovered significant levels of radioactivity in pipe scale at Street facility in Laurel, MS
- Following that discovery, significant quantities of scale involving NORM contamination were discovered in the oil & gas as well as oilfield services industries
- As a result, some states adopted regulations to deal with the NORM contamination phenomena as recognized by those industries
- This lead to (1) cleanup activities to bring facilities to unrestricted or restricted use status (2) landowner claims for damages due to remediation of NORM contaminated sites (3) toxic tort claims for personal injury wrongful death, medical monitoring and fear of cancer (4) allocation of environmental liabilities for norm in mergers and acquisitions (5) merger and acquisition breach of warranty claims involving NORM contamination and (6) insurance coverage issues

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Timeline

- 1981
- Radioactive scale found on Piper Alpha rig platform in North Sea 200 miles Northeast of Aberdeen, Scotland
- Had Geiger counter on platform to check radioactive sources for logging tools
- Went off at separator

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Timeline

- 1986
- Radioactive scale discovered at oilfield pipe cleaning facility of Street, Inc. in Laurel, MS
- Street had been in business of removing scale from salvaged oilfield equipment
- Suit was filed by Street, Inc. and its employees for personal injury and property damages

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In NORM Litigation

- Primary targets – oil company defendants
- Secondary targets
  - Oilfield services companies which cleaned inspected or coated pipe
  - Pipe yards
  - Trucking companies

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Street, Inc. et al sued for $35 million and settled for an undisclosed amount

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Grefer v. Alpha Technical, et al

- Jury verdict in favor of landowners against Exxon Mobil Corp. (“Exxon”) and Intracoastal Tubular Industries (“ITCO”)
- Sought compensatory and punitive damages as a result of defendants alleged contamination of real property with radioactive material (pipe scale aggregated on land)

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Grefer v. Alpha Technical, et al

- Focus was radium 226 and 228 precipitated into scale in tubing
- Debate over historical knowledge of Exxon
- Plaintiffs claimed NORM was really technologically enhanced radioactive material (TERM)
- Claimed Defendants knew about TERM
- Causes of action for:
  - Negligence
  - Strict liability
  - Absolute liability
  - Nuisance
  - Fraud

Grefer v. Alpha Technical, et al

- Compensatory damages for loss of use and remediation of property
- Punitive damages

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Grefer v. Alpha Technical, et al

- 5 week trial
- Jury verdict:
- Compensatory damages $56,145,000 ($145,000 general damages & $56,000,000 in restoration costs
- Exemplary damages $1,000,000,000
- Exxon 85% at fault; ITCO 5% at fault; Alpha Technical 5% at fault OFS (3rd party defendant) 5% at fault

GREFER V. ALPHA TECHNICAL, ET AL

Court denied Exxon’s prescription exception (i.e. statute of limitations) based on Louisiana’s discovery rule (*contra non valentum*)

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Grefer v. Alpha Technical, et al

- Restoration damage issues:
- Level of remediation required

- Measure of damages: restoration costs (greater than fair market value of property) versus value of the property before and after the injury

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Grefer v. Alpha Technical, et al

- Jury verdict upheld except exemplary damages reduced to $112,290,000
- Vacated by U.S. Supreme court
- U.S. Supreme Court remanded to Louisiana Supreme Court under punitive damages standards promulgated by the U.S Supreme Court in Phillip Morris U.S.A., Inc. v. Williams which affirmed award again

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After Street and Grefer, Plaintiff lawyers, particularly in Louisiana, signed up and filed 1000s of claims

Claims

- Cancer
- Leukemia
- Damage to bone tissue
- Fear of cancer
- Increased risk of cancer
- Medical monitoring

Typical Claims
(From Actual Petition)

- Defendants are strictly liable for conducting activities on pipe yards and continue to cause damage to petitioners who are neighbors to other pipe yards as a result of the presence of radioactive, hazardous and/or toxic materials on the other pipe yards from those activities

- Defendants failed to fence off the pipe yards or otherwise restrict access causing an attractive nuisance for young children

- Defendants maintained an attractive nuisance on the pipe yards which lured young children onto it

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- Defendants failed to timely and properly clean up or remediate the pipe yards to remove the radioactive, hazardous and/or toxic materials from it

- Defendants failed to timely warn petitioners that there were and are radioactive and/or toxic materials on the pipe yards

- Defendants failed to prevent the petitioners from using the pipe yards for recreation, farming and other uses while knowing that other pipe yards were and are contaminated

- The pipe yard owners owed a duty to the petitioners to use the pipe yards in a way that did not cause harm or injury to the petitioner or petitioner's property

- The acts and omissions of the pipe yard owners were a substantial contributing cause of the petitioners injuries and damages

- The pipe yard owners are jointly and severally liable to petitioners for all general, special, and equitable relief to which petitioners are entitled by law

Liability of Pipe Cleaning Contractors

- Failure to conduct safe pipe-cleaning operations
- Failure to properly dispose of radioactive waste
- Failure to clean up contaminated soil and water
- Failure to properly test pipe for radiation

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- Failure to warn petitioners of the damages from radioactive materials being discharged and emitted from pipe-cleaning operations

- Pipe-cleaning contractors are strictly liable for having *garde* as a contaminated drilling pipe

- Pipe-cleaning contractors are strictly liable for conducting operations at the pipeyards that caused damages and injuries to petitioners

- Pipe-cleaning contractors owed a duty to petitioners to conduct operations at the pipe yards in a way that did not cause harm or injury to petitioners or petitioner's property and the pipe-cleaning contractors breached that duty

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- The acts and/or omissions of the pipe-cleaning contractors were a substantial contributing cause of petitioners' injuries and damages and a direct cause of the injuries, damages and special losses suffered by petitioners

- As a result, the pipe-cleaning contractors are jointly and severally liable for all general, special and equitable relief to which petitioners are entitled by law

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- Because of long latency periods extreme difficulties in reconstructing work histories and exposure

- Louisiana Prescription vs. Peremption vs. Texas and other Common Law States Statute of Limitations (SOL)

- SOL tort – Texas is generally 2 years, Louisiana is 1 year

- Discovery rule in Texas - inherently undiscoverable – objectively verifiable

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- Fraudulent concealment – defendant willfully conceals its wrongdoing
- Example: Texas – wrongful death and survival claims accrue on date of death without tolling
- Louisiana – accrues with actual or constructive knowledge of torts which entitle Plaintiff to bring suit

- Most plaintiffs or survivors deny knowledge about NORM/TERM

- Most first learned of it when signed up by a plaintiff’s attorney or local newspaper article about a verdict or a friend who had filed suit

- *Contra non valentum* – Louisiana’s discovery rule

- Prescription (discovery rule) vs. Peremption (no discovery rule): distinction no longer applicable to survival claims – prescription applies to wrongful death, survival and personal injury claims

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Contra non valentum, a judicially created doctrine suspends prescription “where the cause of action is not known or reasonably knowable by the plaintiff, even though his ignorance is not induced by the defendant”. This jurisprudence “discovery” exception was originally limited to the situations where the plaintiff was prevented from filing suit because of a legal bar, physical impossibility or the defendant’s fraud, but courts have expanded the doctrine to apply when the plaintiff was unaware of the facts giving rise to the cause of action. Accordingly, *contra non valentum* has the practical effect of extending the amount of time permitted for the exercise of a right of action.

Alleged Exposure Pathways

Plaintiffs generally allege that they cleaned and/or handled tubulars and/or were working in the vicinity of those pipe-cleaning operations, or lived nearby those operations. Plaintiffs allege they inhaled and ingested the scale dust when it was airborne during the process when tubulars containing scale contaminated with NORM was cleaned or handled.

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Plaintiffs also allege they were exposed to NORM/TERM in the scale that accumulated on the ground where the cleaning process occurred, and from handling the used pipe that contained the contaminated pipe scale.

The plaintiffs in these cases have sued virtually every major and medium sized oil company having a presence in the Gulf Coast area in Louisiana.

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The plaintiffs contend that the oil companies have known for several decades about the phenomenon of naturally occurring radioactive material in the scale which forms in oilfield tubulars during the production period for a well, even dating back to the 1950s.

Plaintiffs contend that the oil companies failed to take action to warn the companies who employed the workers who worked at the pipeyards cleaning, handling and inspecting the used tubulars that the oil companies sent to those pipe-cleaning service companies.

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Plaintiffs also allege that oil company defendants had knowledge of the NORM phenomenon prior to the late-1980s when regulations were promulgated in the oil and gas production industry concerning potential hazards associated with NORM in oilfield production tubulars and equipment and failed to disclose what they knew.

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A significant threshold time period for these cases appears to be 1981-1986. Plaintiff attorneys claim they discovered from Chevron, Shell and Exxon Mobil historical records that, in 1981, the existence of radiation in pipe scale from produced water was discovered in tubulars pulled from north sea wells.

As a result, plaintiff attorneys have alleged and argued successfully that, by 1981, the oil companies knew or should have known of radiation contamination in the scale found in used oilfield tubulars from wells in the Gulf Coast area.

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Beginning in 1987, certain oil companies sent out advisory letters to oilfield service vendors warning of the NORM phenomenon.

Between 1987and 1989, the NORM phenomenon was studied by the oil and gas industry and by the State of Louisiana and other states. Rules and regulations were promulgated by 1989 by the State of Louisiana Department of Environmental Quality (LDEQ) regulating the handling and disposal of used oilfield tubulars/equipment and the radioactive scale from those tubulars.

Likewise, oilfield service companies adopted their own company policies and procedures for handling used tubulars and other used oilfield equipment.

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Other Defenses

- Most states employees have workers' compensation exclusions remedy for employees.

Louisiana intentional act or intentional tort exception

- Consciously desires the physical result of his act, whatever the likelihood of that result happening from his conduct; or
- Knows the result is substantially certain to follow from his conduct, what his desire may be as to that result;
- i.e. Inevitable or certain

- Very high burden not sustainable in context of typical NORM/TERM tort claims

- Such claims against oilfield service companies strategically undercuts claims against oil company defendants

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Texas

Only "gross negligence" exception for claims for exemplary, not compensatory, damages

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Fear of Cancer – Elements

- Fear of cancer and increased risk of cancer on a showing of negligent infliction of emotional distress.
- Plaintiff must show a “special likelihood of genuine and serious distress, arising from special circumstances, which serves as a guarantee that the claim is not spurious”.

- Under La. Civ. Code article 2315, such damages are available only when there is a manifest physical or mental injury or disease. The basis for finding fear of cancer or an increased risk of cancer at a minimum depends on the dose of cancer causing Alpha or Beta particles to impact the plaintiffs' bodies

Medical Monitoring

In *Bourgeois v. Ap Green Industries, Inc.,* 716 So. 2d 335 (LA. 7/8/98) the Louisiana Supreme Court held, for the first time, that the reasonable cost of medical monitoring is a compensable item of damage under Louisiana C.C. Article 2315, providing that the plaintiff satisfies a seven-prong test set forth in the court's opinion.

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The court held:

The reasonable cost of medical monitoring is a compensable item of damage under Civil Code, Article 2315 provided that plaintiff satisfies the following criteria:

1. Significant exposure to a previous hazardous substance;
2. As a result of his exposure, plaintiff suffers a significantly increased risk of contracting a serious latent disease;

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3. Plaintiff's risk of contracting this serious latent disease is greater than (a) the risk of contracting the same disease had he or she not been exposed and (b) the chances of members of the public at large of developing the disease;
4. A monitoring procedure exists that makes early detection of the disease possible;

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5. The monitoring procedure has been prescribed by a qualified physician and is reasonably necessary according to contemporary scientific principles;
6. The prescribed monitoring regime is different from that normally recommended in absence of the exposure; and
7. There is some demonstrated clinical value in the early detection of the diagnosis of the disease.

Subsequently, the legislature amended La. C.C. Article 2315 to eliminate medical monitoring as a compensable item of damage in the absence of a manifest physical or mental injury. *See* La. Acts 1999, No. 989. Specifically effective July 9, 1999, the legislature added the final language to Article 2315.

Damages do not include costs for future medical treatment, services, surveillance, procedures of any kind unless such treatment, services, surveillance, or procedures are directly related to a manifest physical or mental injury or disease.

Additionally, Section 2 of the Act provided:

The provisions of this act are interpretive of civil code article 2315 and are intended to explain the original intent notwithstanding the interpretation given in *Bourgeois v. Ap Green Industries, Inc.,* 97-3188 (La. 7/8/98, 716 So. 2d 355) and all cases consistent therewith.

Furthermore, Section 3 of the Act stated:

The provisions of this act shall be applicable to all claims existing or actions pending on its effective date and all claims arising or actions filed on or after its effective date.

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In order to maintain a cause of action seeking medical monitoring, the seven factors forming a *Bourgeois I* cause of action must have converged prior to July 9, 1999. See *e.g. Crooks v. Metropolitan Life In. Co.,* 20001 04 (la. 5/25/01), 785 So. 2d 810.

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Alternatively, for post-1999 medical monitoring claims that did not “converge” prior to 1999, plaintiffs are required to demonstrate a manifest physical injury or mental injury.

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Expert Theories

1. Unreasonable reconstruction models which overstate dose overexposure
2. Because of forum shopping with the C.D.C in New Orleans, La, application of Daubert standards generally weaker than other states

3. Daubert factors include but are not limited to:

- The extent to which the theory has been or can be tested;
- The extent to which the technique relies upon the subjective interpretation of the expert;
- Whether the theory has been subjected to peer review and/or publication;

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- The technique's potential rate of error;
- Whether the underlying theory or technique has been generally accepted as valid by the relevant scientific community; and
- The non-judicial uses which have been made of the theory or technique.

4. Discretion of trial court/ reviewable for abuse of discretion.

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Property Owner Claims

- Clean-up, restitution and loss of use damages
- Recourse to negligence theories
- Environmental indemnities in leases
- CERCLA– no fault liability as potentially responsible party at super fund site
- Negligence
- Negligence per se
- Strict liability
- Abnormally dangerous activity

- Failure to act as a reasonable prudent oil & gas operator
- Nuisance
- Trespass
- Fraud and fraudulent concealment
- Gross negligence/malice to recover exemplary damages

Property Damages

- Some states look at before and after approach to Fair Market Value property damages
- Other states look to restoration or cost to cure approach to property damage
- Some states limit restoration or cost to cure damages to fair market value or diminishment of fair market value of property allegedly damaged

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Allocating Environmental Indemnities in Acquisition

Federal and state laws require landowners to remediate contamination to acceptable levels

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Contractual Allocation of Environmental Liabilities

1. Asset purchase versus merger
2. "Mere contamination" exception
3. "As is, where is" contracts
4. Environmental representations and warranties
5. Definitional coverage/stake on the ground
6. Indemnities
7. Warranty and indemnity survival terms
8. Escrow/financial viability of seller
9. Involve environmental attorneys
10. Phase I-IV environmental site assessments
11. Due diligence inquiries/NORM surveys

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Merger and Acquisition Indemnity and Warranty Claims

1. Breach of environmental warranty or representation
2. Indemnification claim (express negligence rule/unambiguous indemnity)
3. Within specified time limit
4. Minimum threshold/maximum cap
5. Contract ambiguity issues
6. Demand/timing
7. Arbitration/judge trial (waive jury/jury trial)

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Factors to Consider Concerning Trial versus Arbitration:

1. Complexity – need for special expertise of situation versus judge versus jury
2. Cost
3. Confidentiality
4. Administration versus non-administration
5. Reviewability/appeals
6. Rules of civil procedure/discovery
7. Number of arbitrators – single v. three

8. Party appointed/true neutral/AAA panel (Strike Method)
9. Ability to obtain summary judgment v. unlikely summary disposition in arbitration
10. Arbitration – less formal/relaxed evidentiary rules
11. Arbitrators do not have to follow the law – more latitude and discretion
12. Arbitration award if not honored requires court confirmation
13. Party may knowingly waive a right to trial by jury and submit dispute to judge trial or arbitration

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Insurance Coverage Issues

1. Absolute pollution exclusion
- NORM/TERM as "pollutant"

2. Sudden & accidental pollution exclusion
- Long term latent exposure claims are arguably not "sudden & accidental"

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Bureau of Radiation Protection

PA TENORM Study, Environmental Impact & U.S. Regulatory Framework

David J. Allard, CHP

HPS Mid-year Meeting

February 2, 2016

Tom Wolf, Governor

John Quigley, Secretary

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The author has no conflicts of interest.

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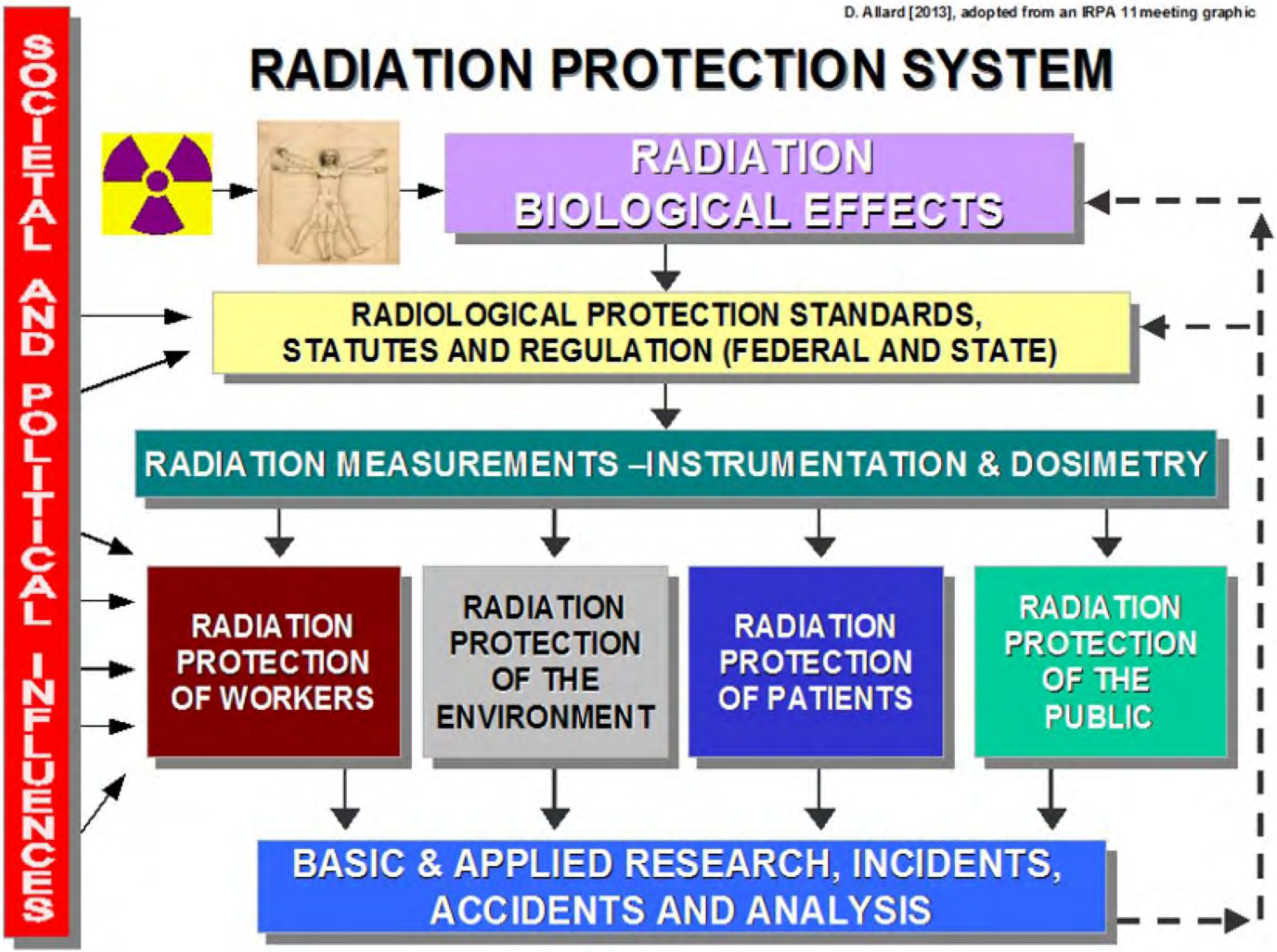
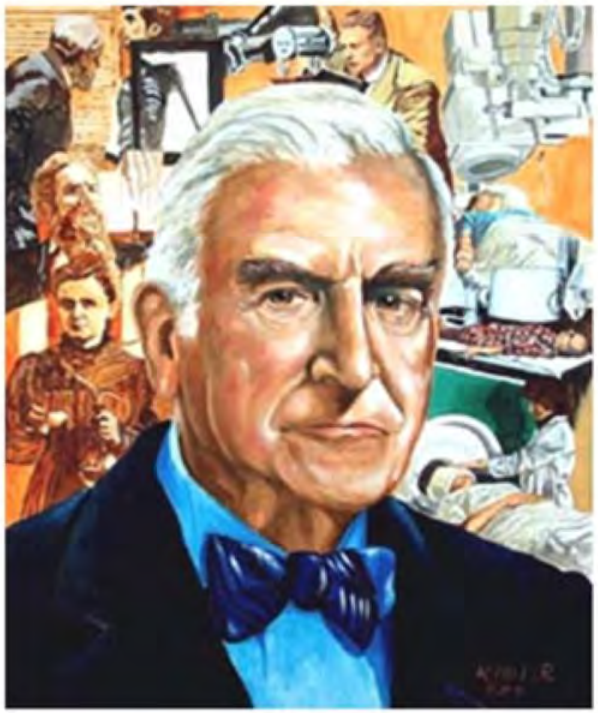

D. Allard [2013], adopted from an IRPA 11 meeting graphic
RADIATION PROTECTION SYSTEM
SOCIETAL AND POLITICAL INFLUENCES
RADIATION BIOLOGICAL EFFECTS
RADIOLOGICAL PROTECTION STANDARDS, STATUTES AND REGULATION (FEDERAL AND STATE)
RADIATION MEASUREMENTS –INSTRUMENTATION & DOSIMETRY
RADIATION PROTECTION 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 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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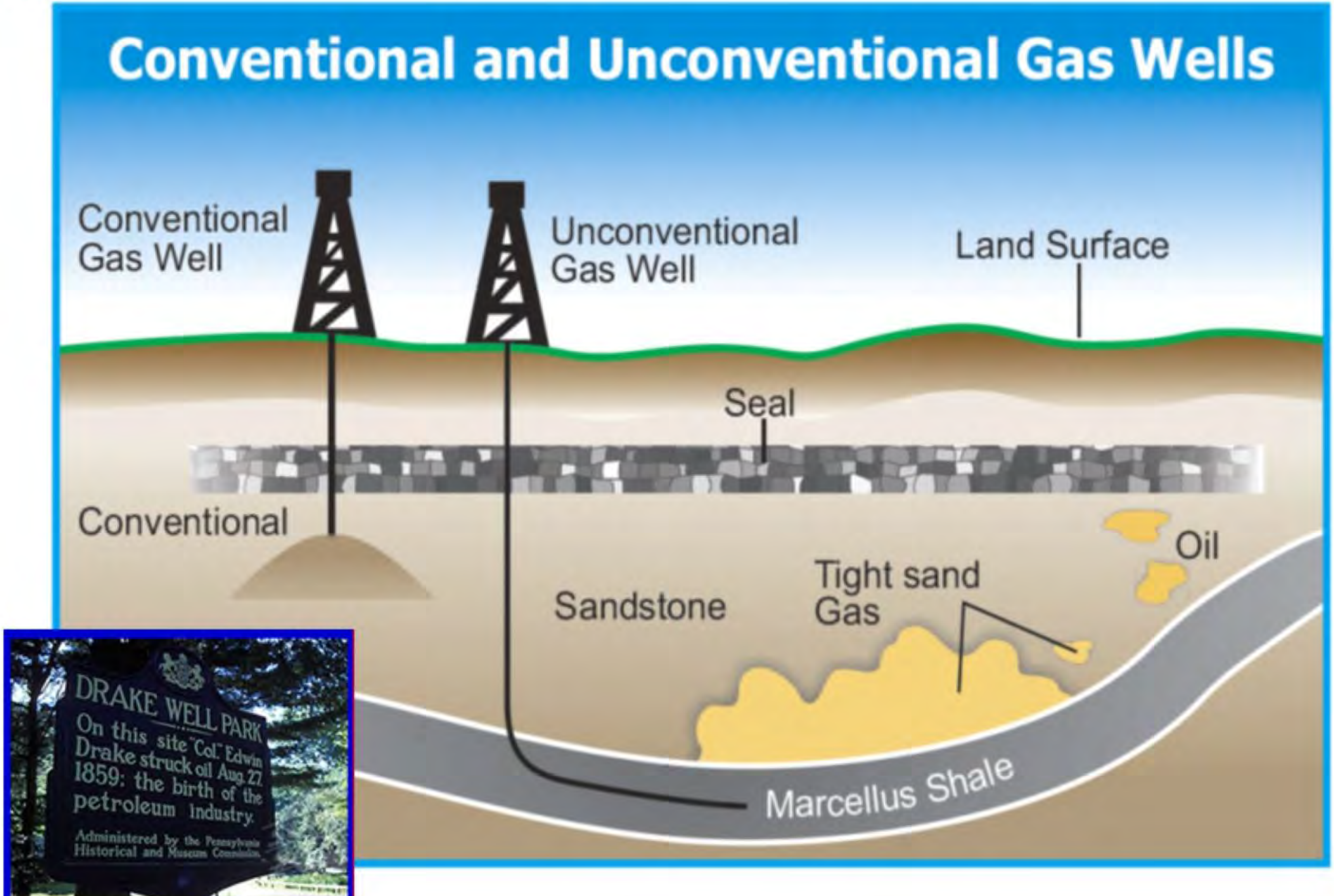
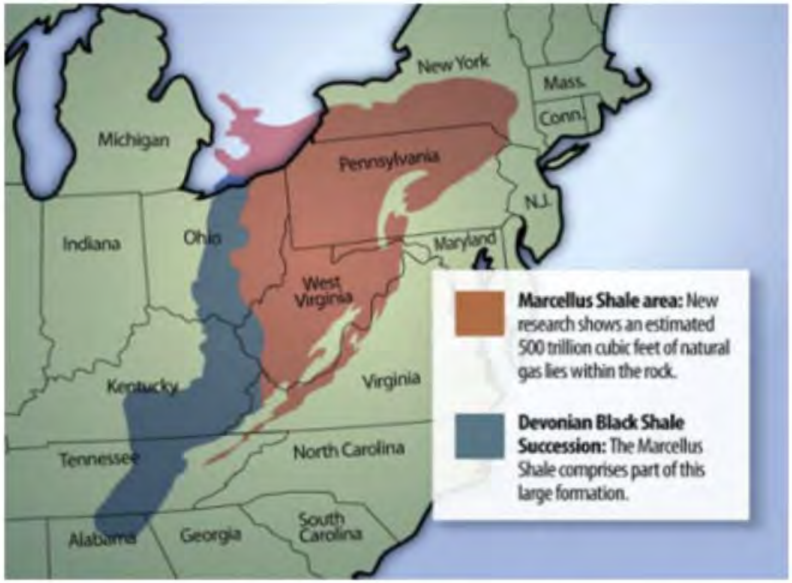
O&G Well Types

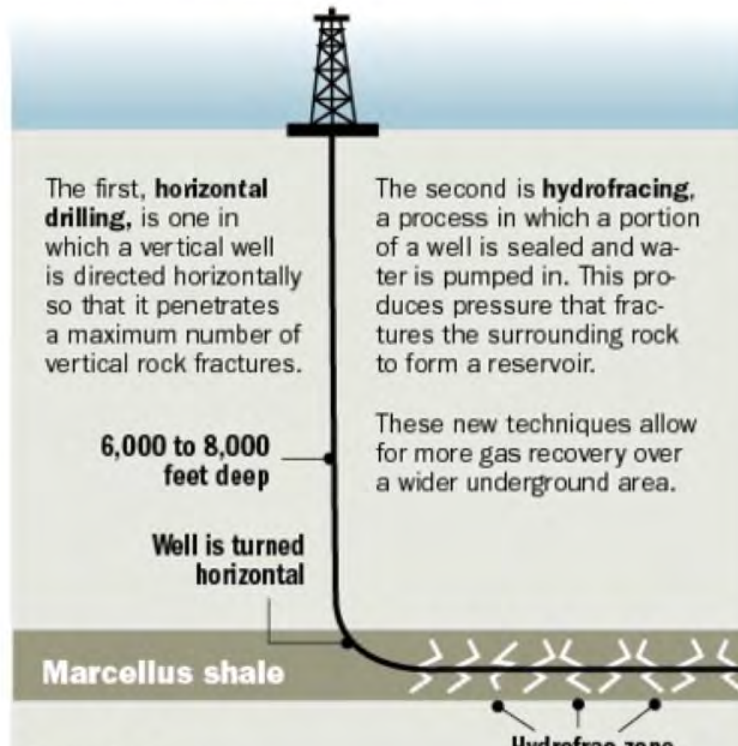


Marcellus Shale Drilling & Fracturing



New techniques, better recovery

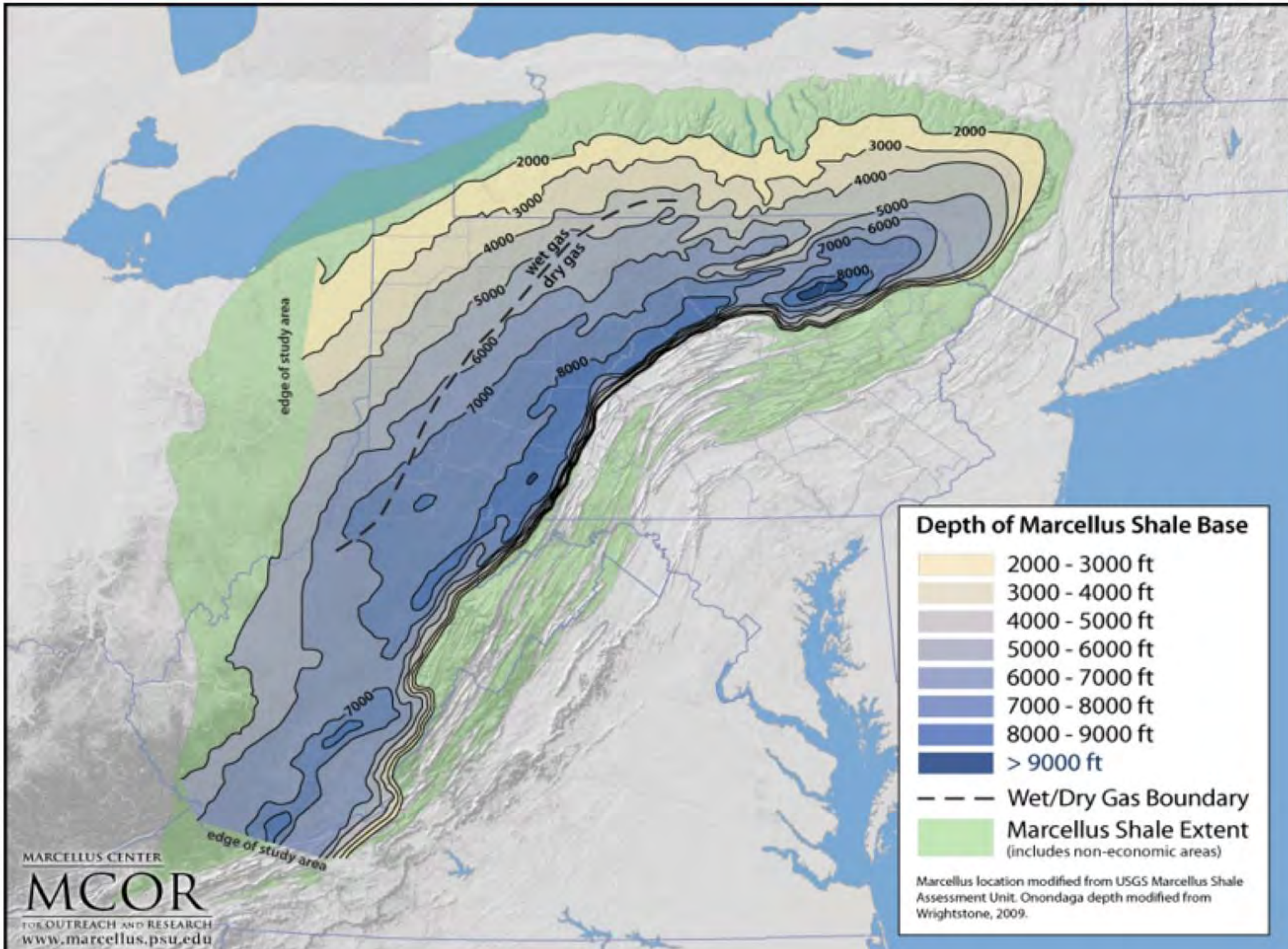
Two technologies relatively new to the Appalachian Basin are employed in wells drilled into the Marcellus formation.



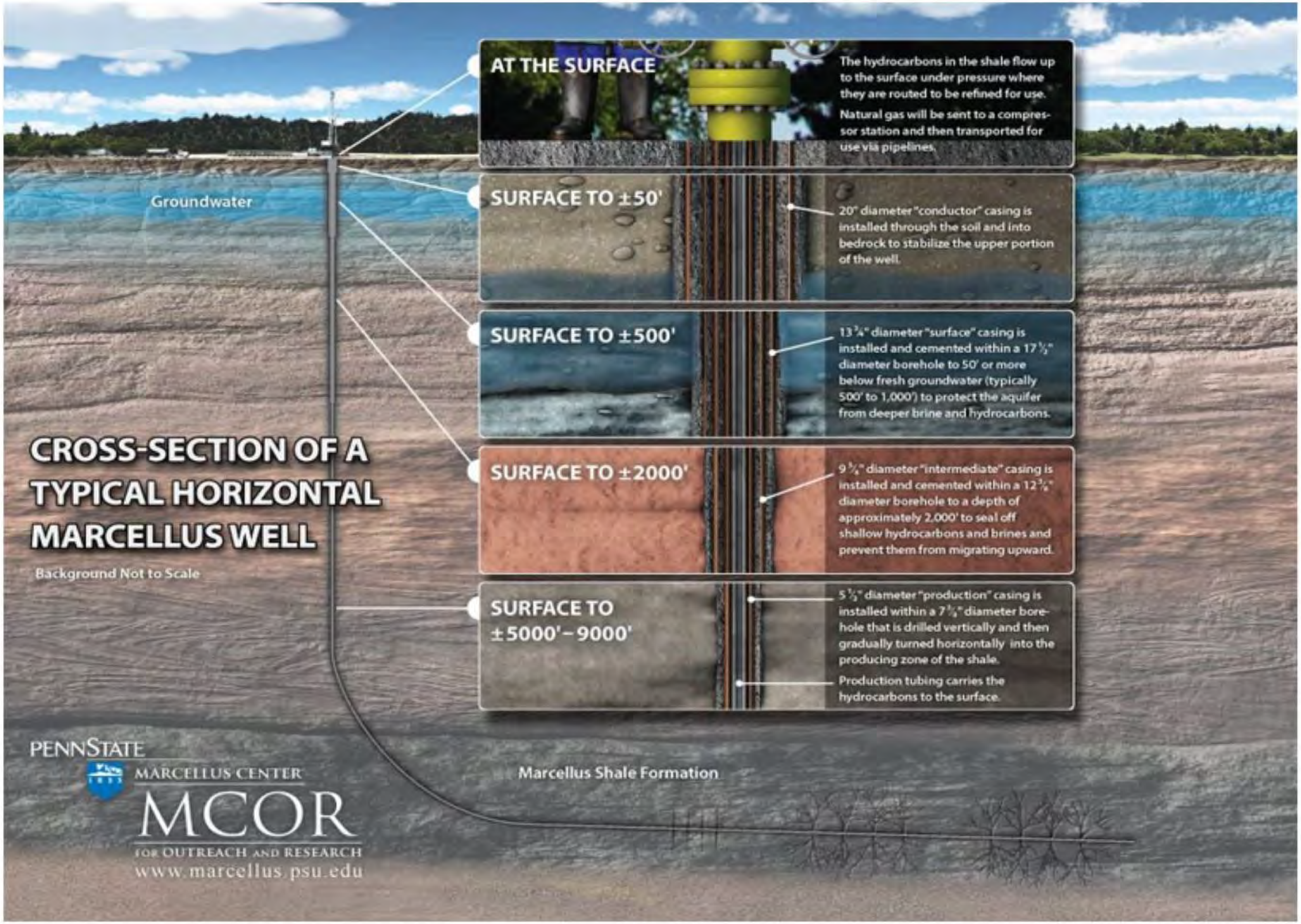
Source: Geology.com, Catskillmountainkeeper.org

Post-Gazette

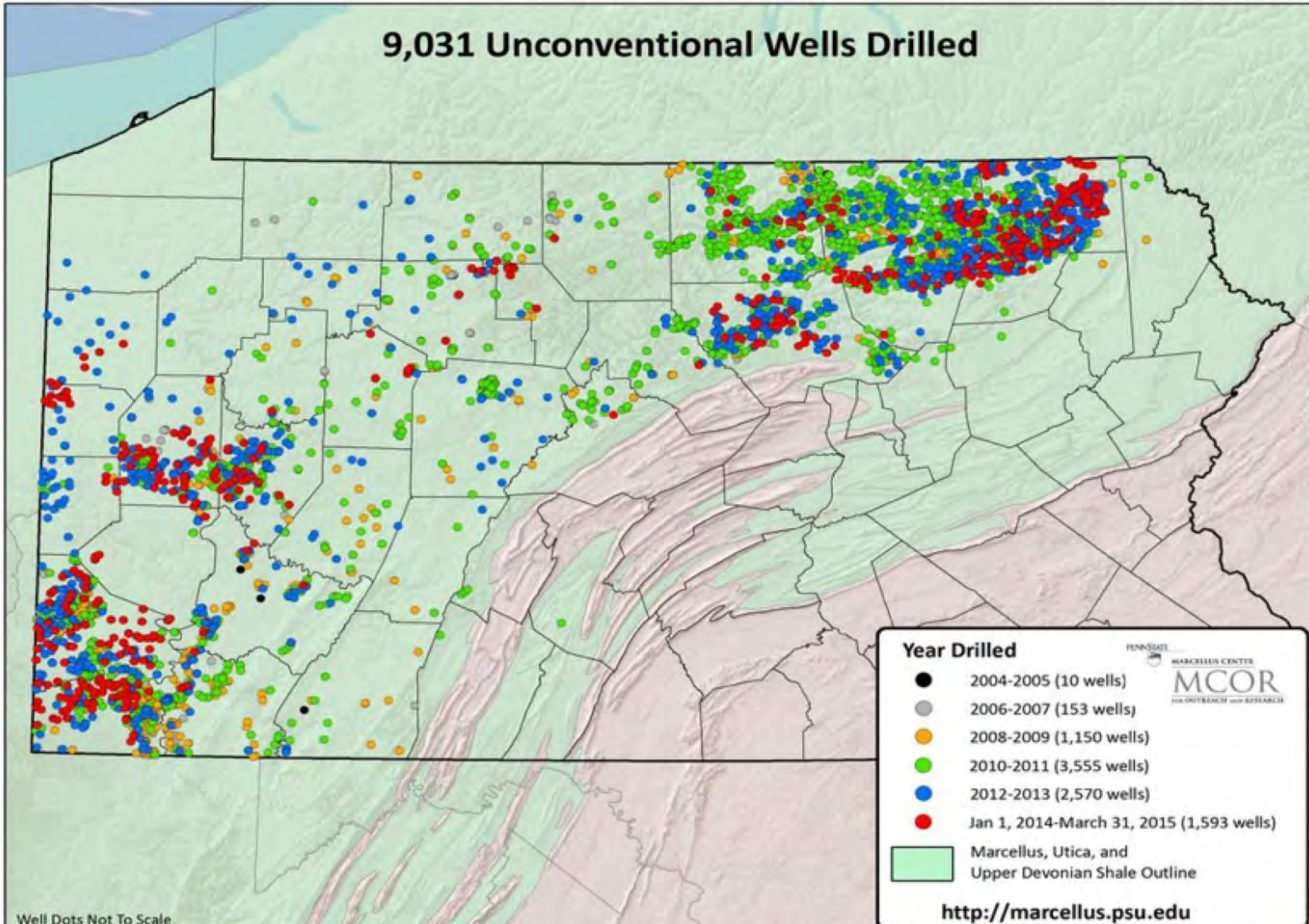
MS - Wet vs. Dry Gas



O&G Well Design



MS Gas Wells Thru 2015



Marcellus Shale

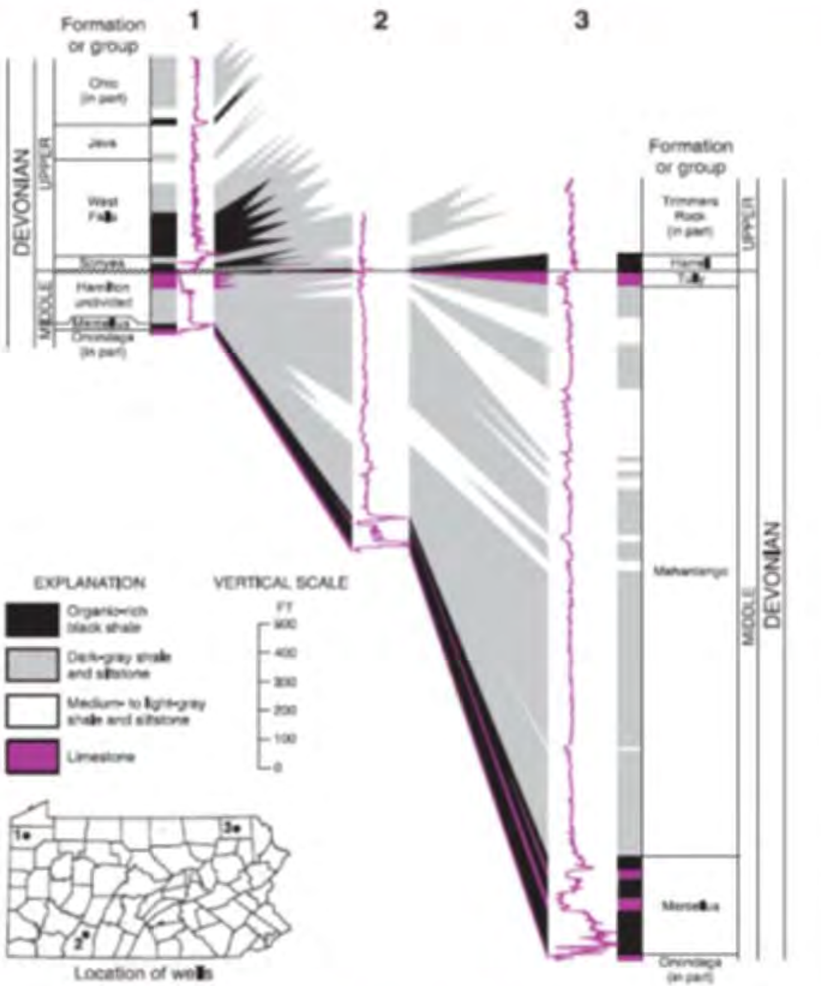


Figure 2. Correlation of Middle and Upper Devonian organic-rich shale facies and interbedded strata in three wells in Pennsylvania, based on gamma-ray log signatures (the jagged purple lines) and descriptions of well cuttings. Note that the black shales correspond in large part to higher-than-normal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

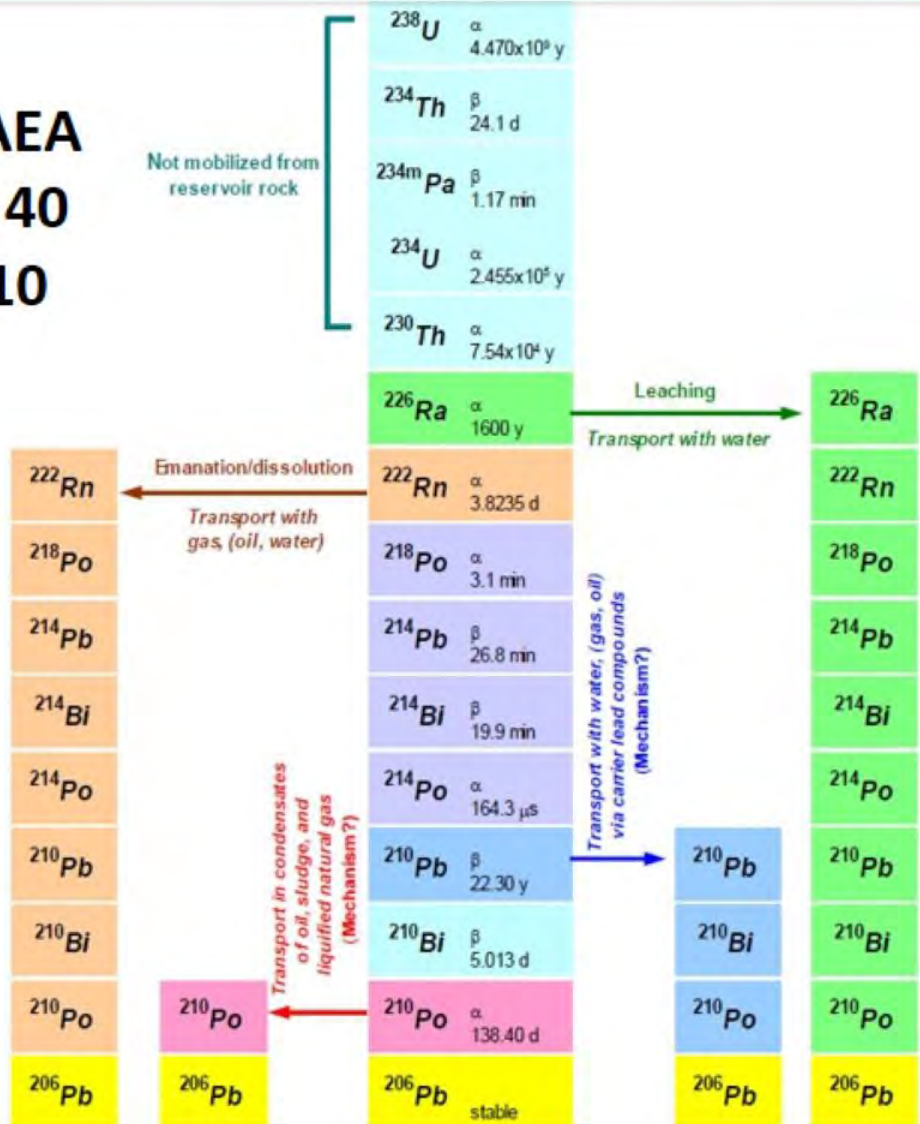
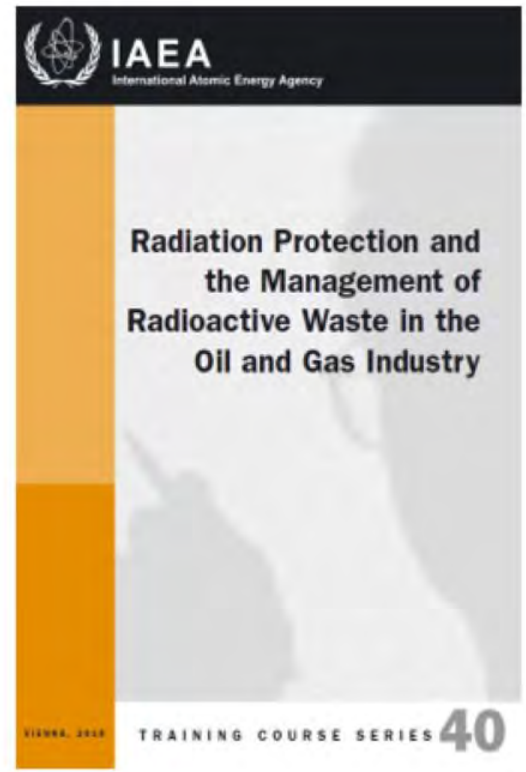


FIG. 41. Transport of ^{238}U progeny in oil and gas production



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

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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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 reviewed
- Rev 1 of report to be posted shortly

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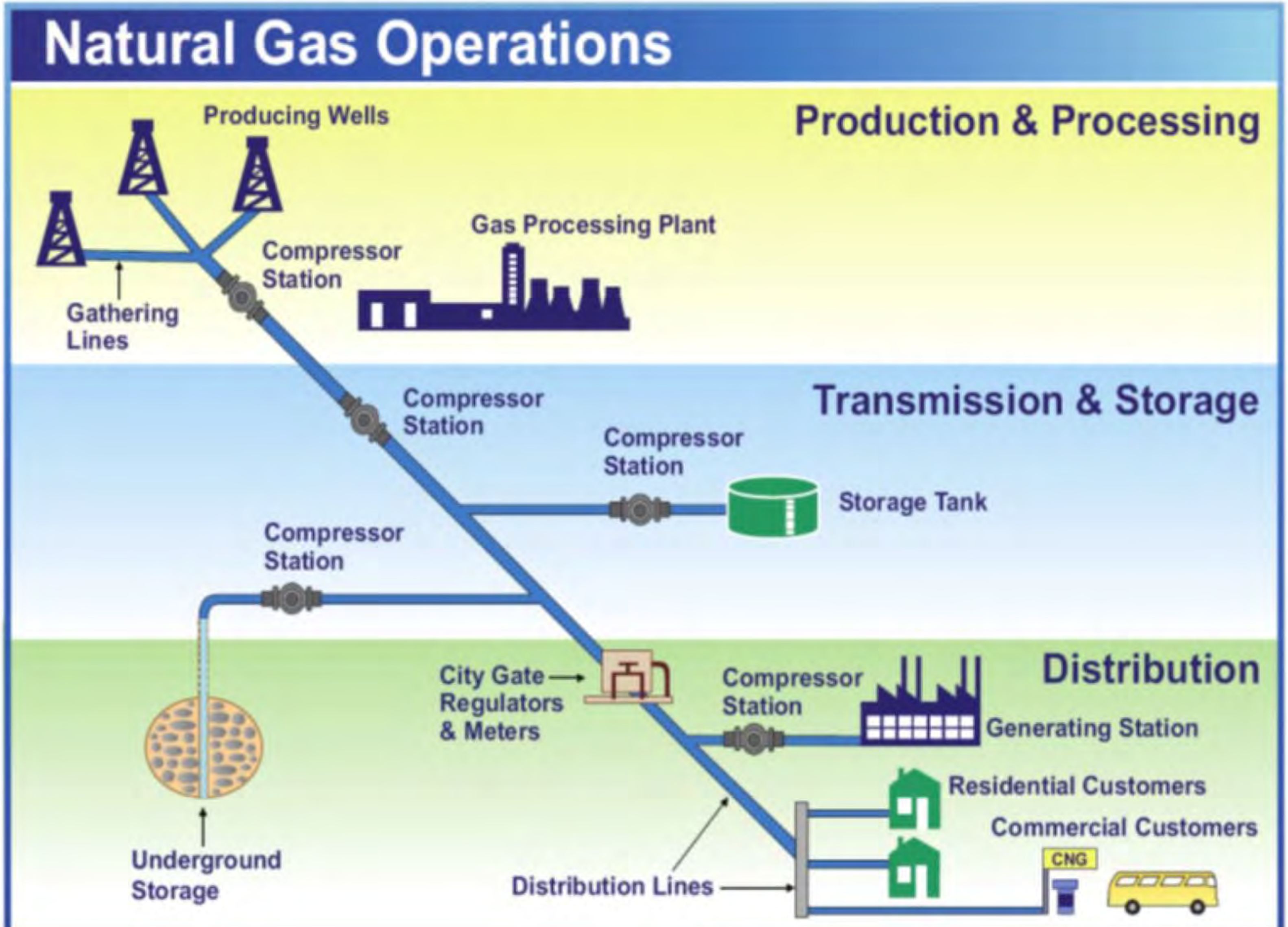
Natural Gas Production & Use



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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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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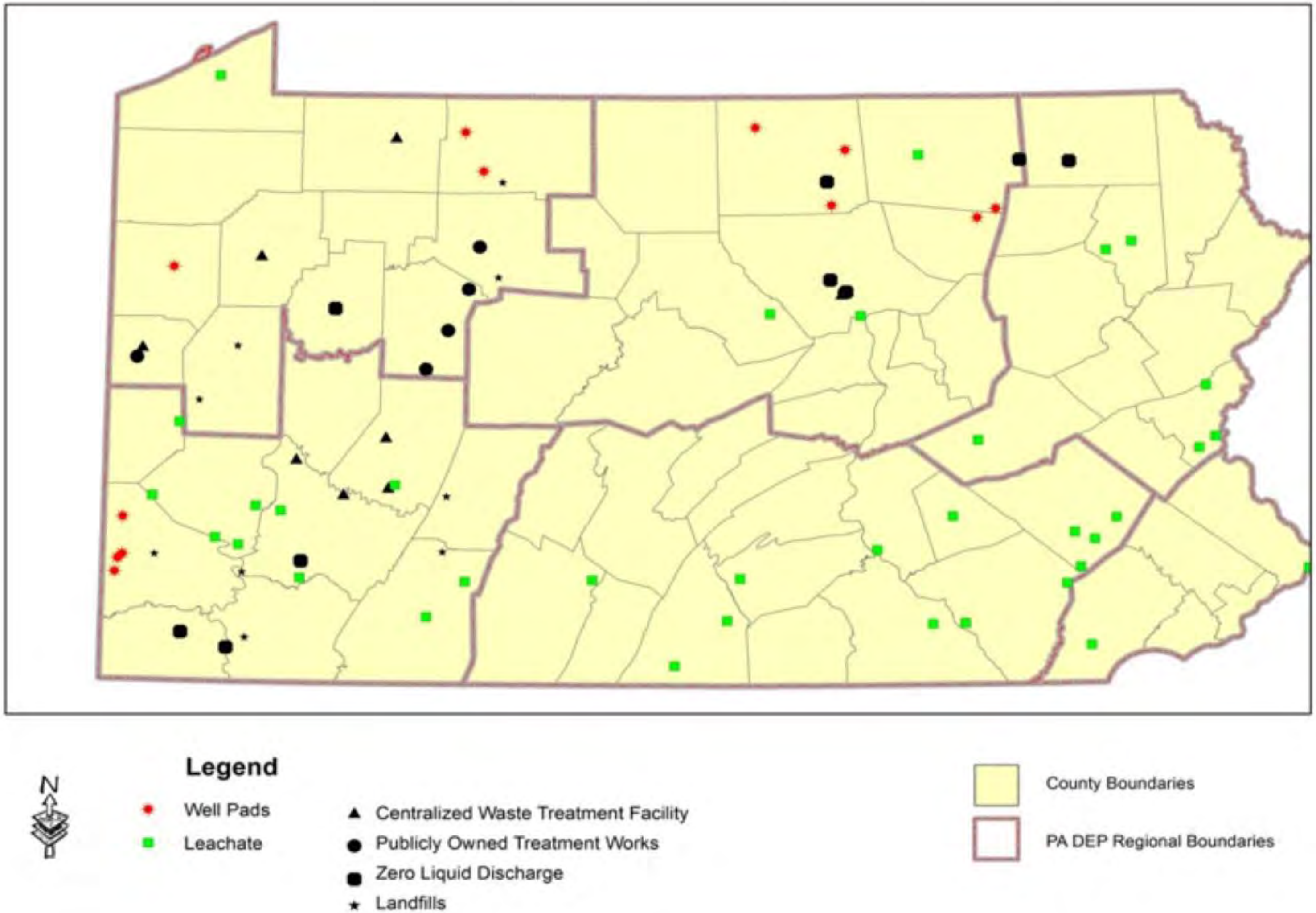
Field Work - Locations



Field Work

MS Well pad [Patriot News photo]

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

Rn testing at unconventional well in production

Field Work

Radon testing at a gas storage and electrical generator facilities

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Field Work

Conventional well pad survey

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Field Work

Pipe recycle

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Field Work

Surveys at gas processing facility

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Field Work

Beneficial Use of brine on roads

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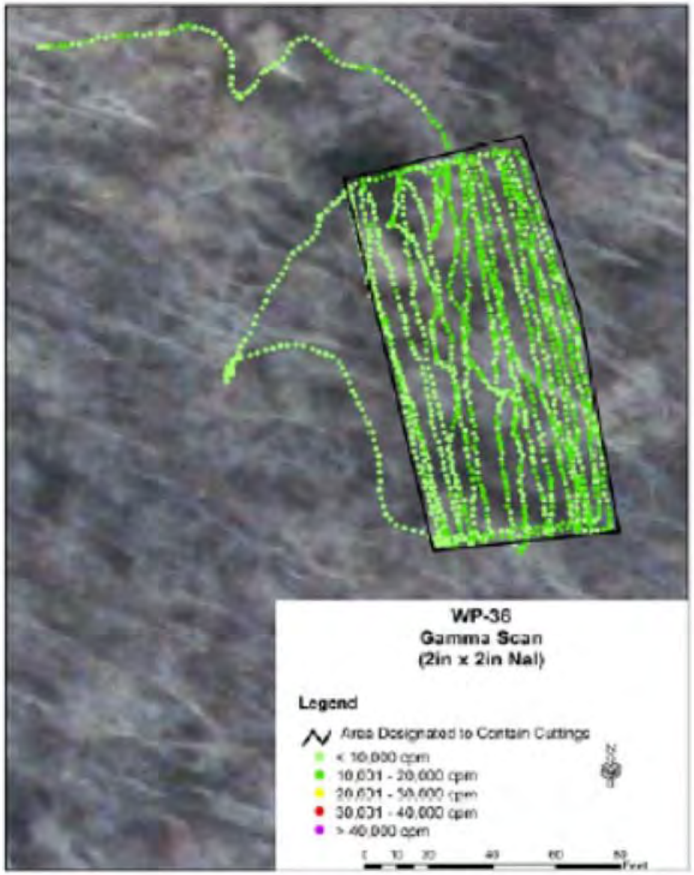
Field Work



Well Pads

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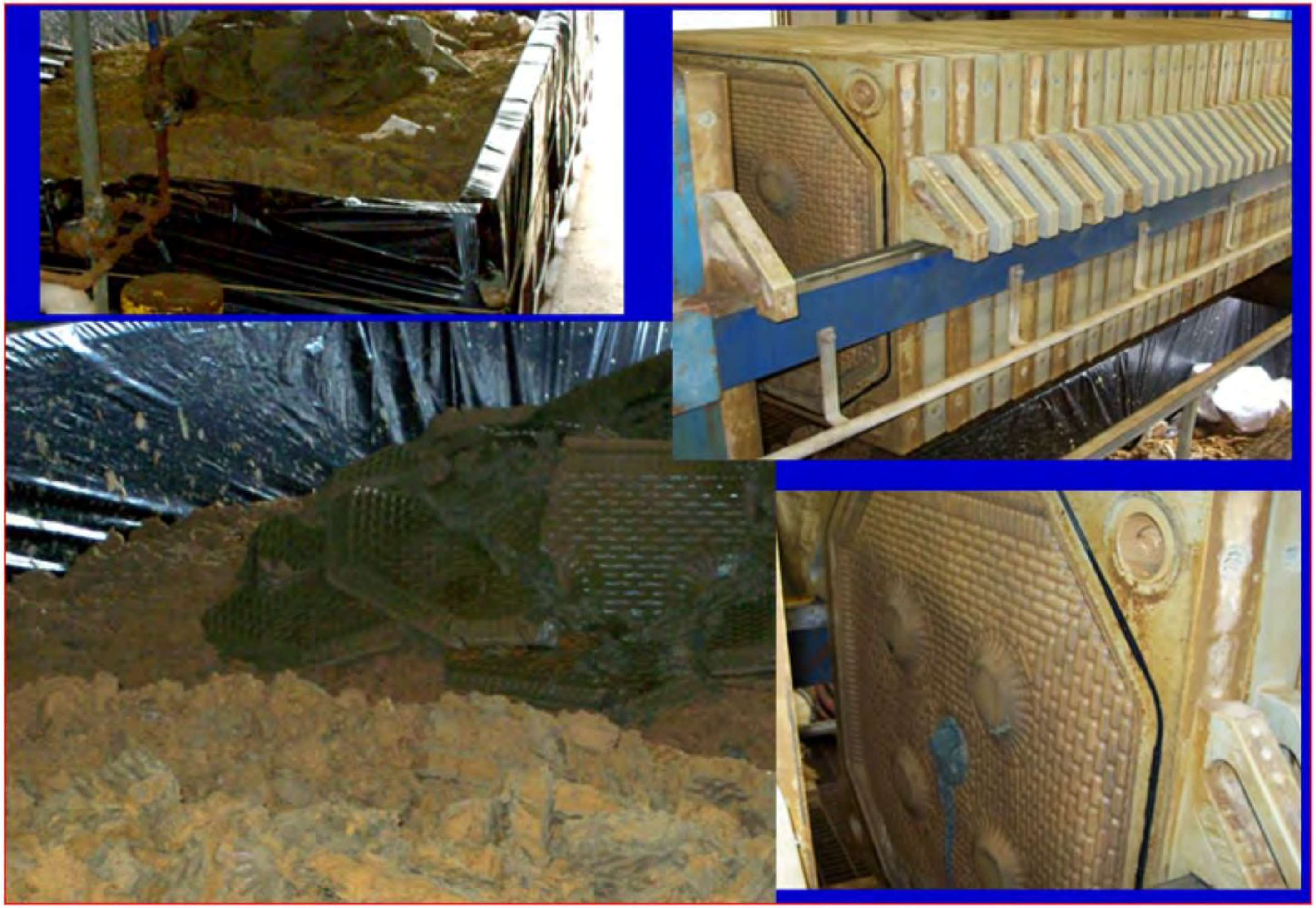
Field Work

Wastewater Treatment

Field Work

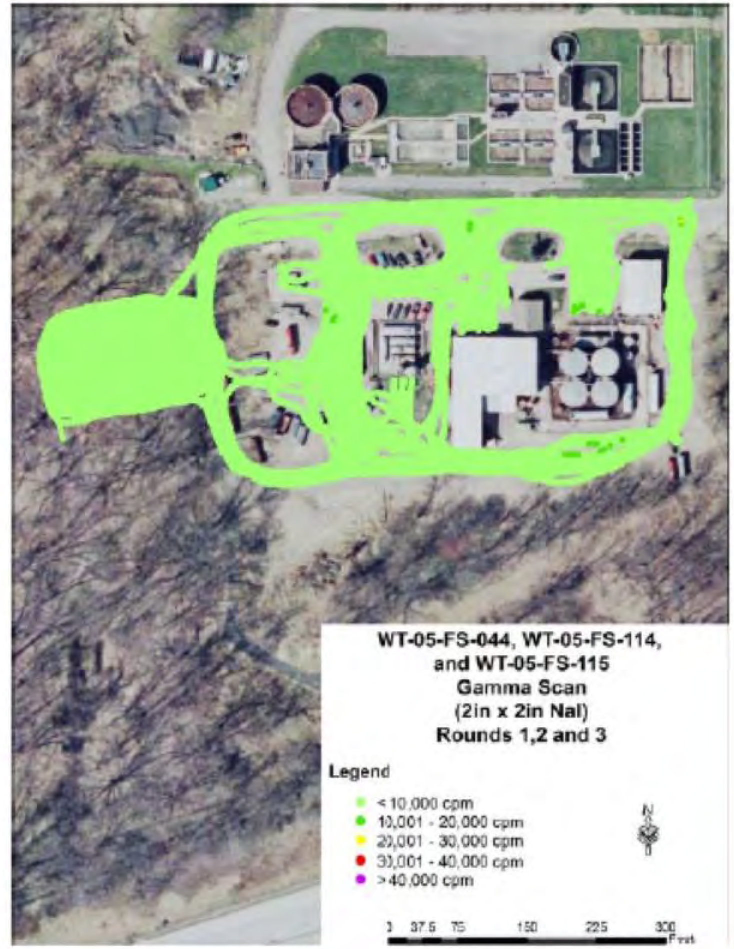
Wastewater Treatment

Field Work



Wastewater Treatment

Field Work



Wastewater Treatment Facilities

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Field Work

PA RCRA D landfill

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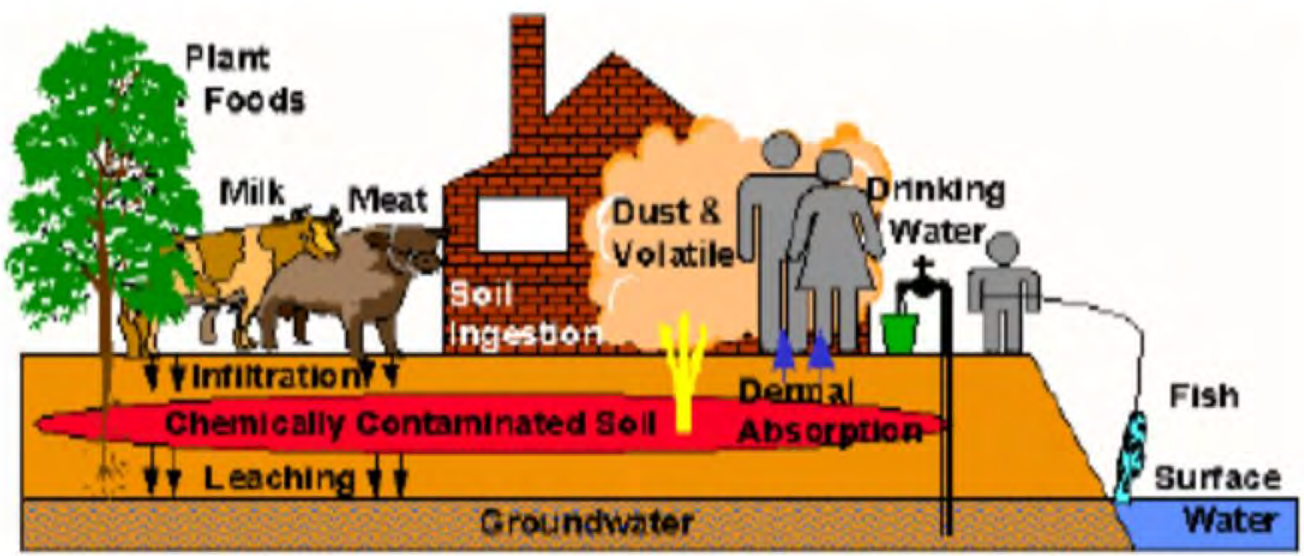
TENORM Waste Disposal

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.



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 c2004 MicroShield® calculations assumed Ra-226 / Rn-222 decay product equilibrium for μR/h
- PA TENORM Study data has informed DEP for the need to update our approach for TENORM disposal

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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]

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’

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

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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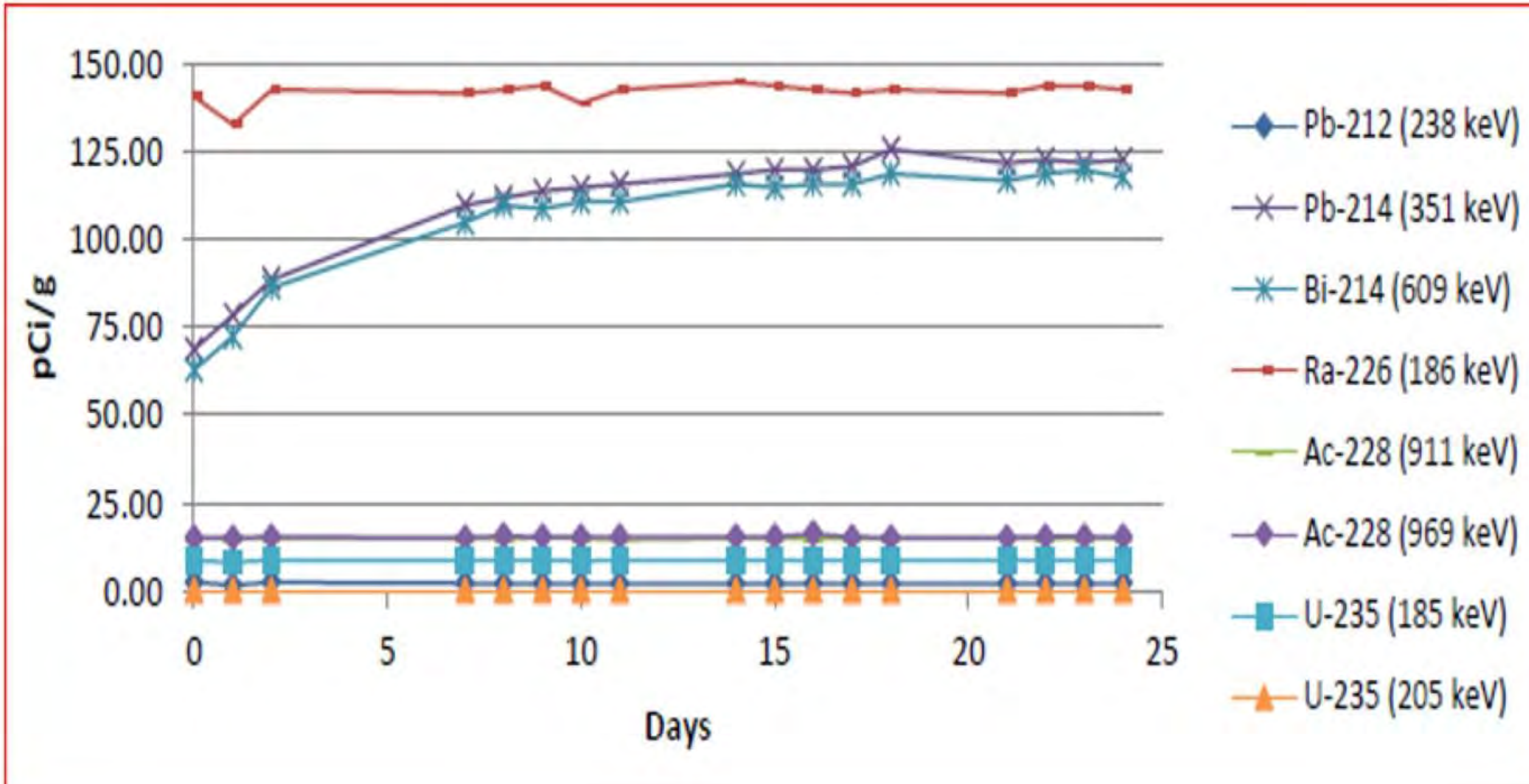
Study Results

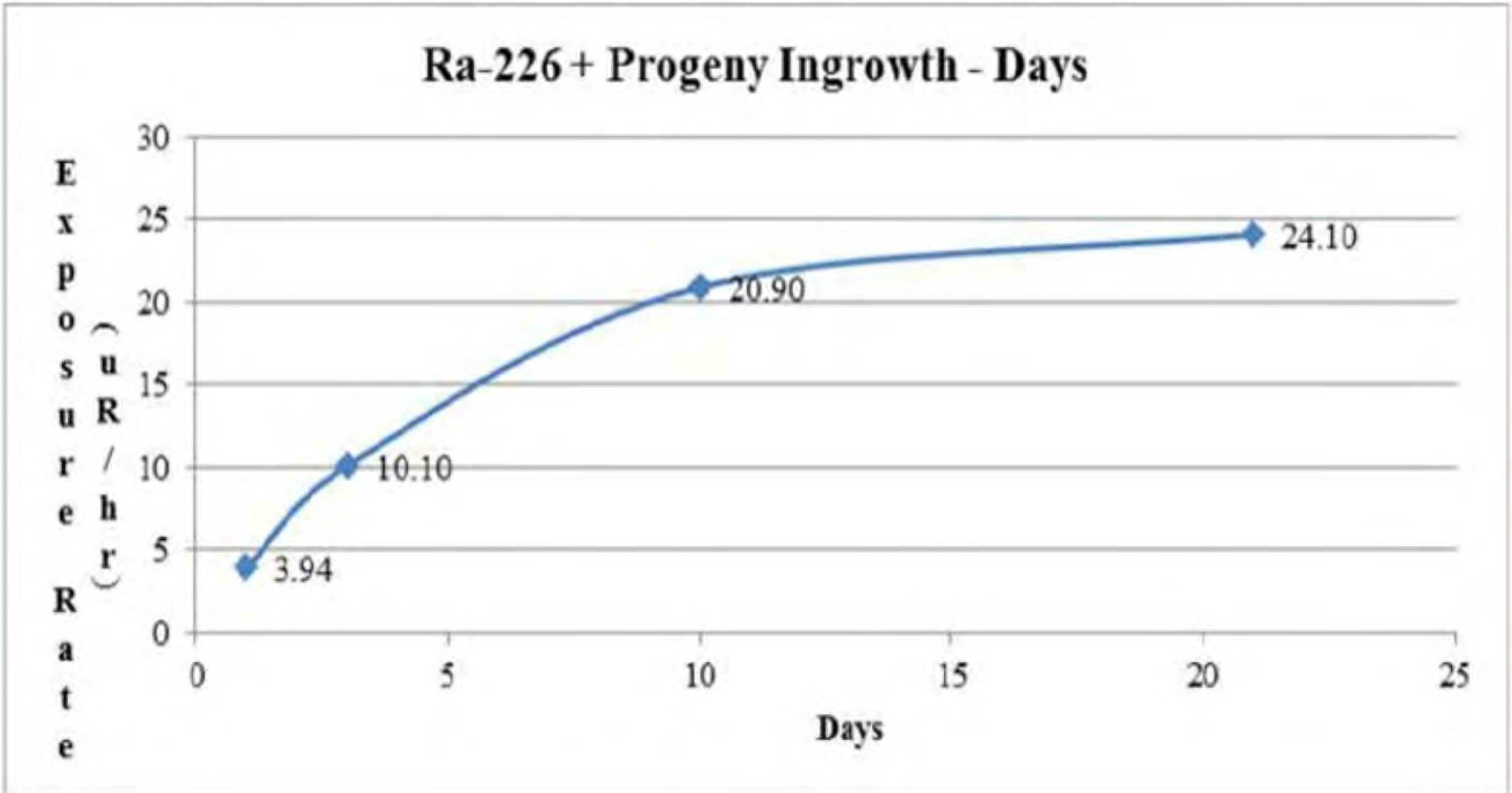
Radiochem of Filter Cake vs. Time



Study Results

Rn-222 [+d] Ingrowth vs. μR/h

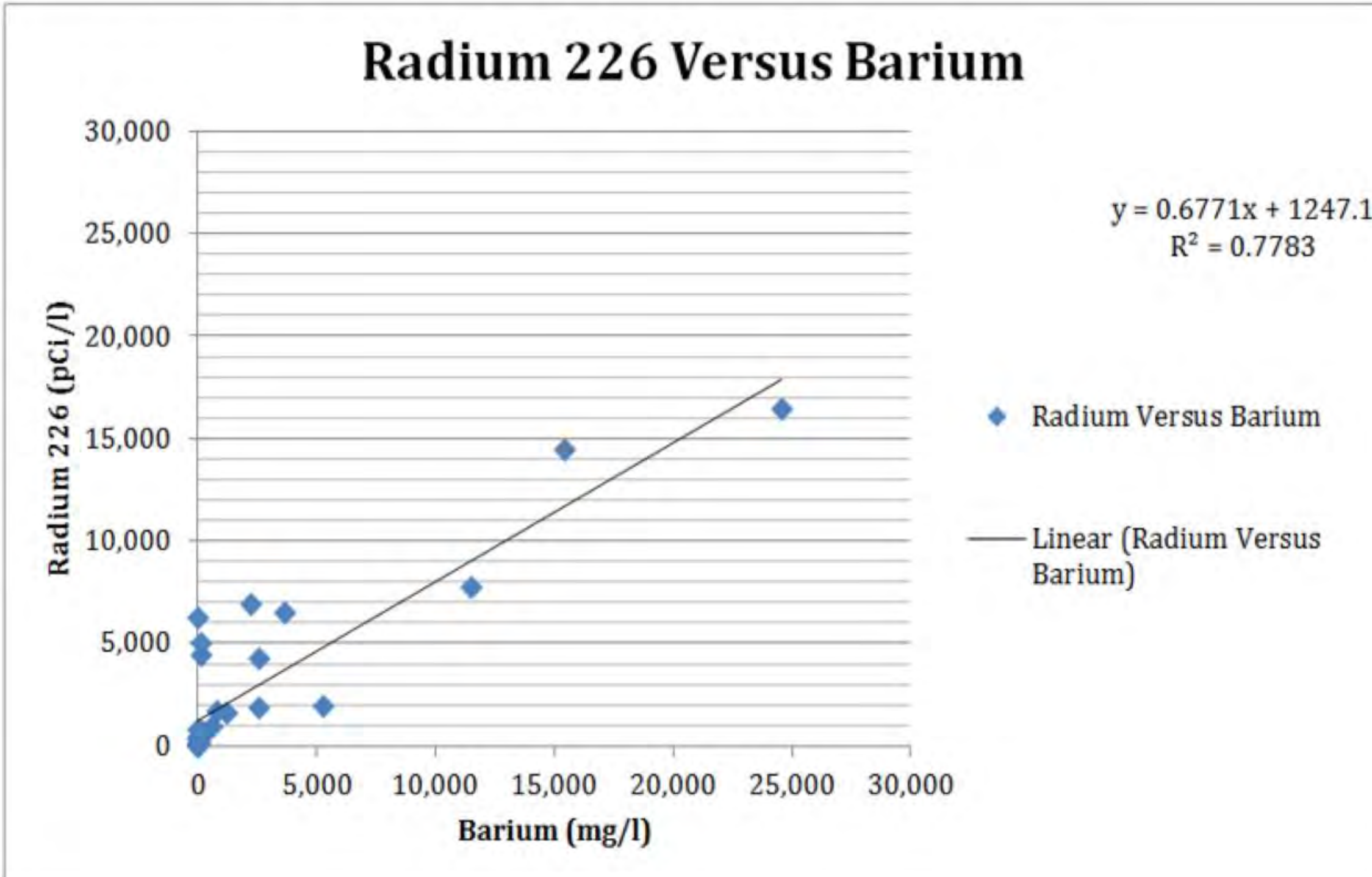
Figure 5-1. Ra-226 Progeny Ingrowth (Days Post Removal) versus Exposure Rate from 13.34 pCi/g Ra-226



Study Results

Non-Rad Chem. Data on Flow-back H2O

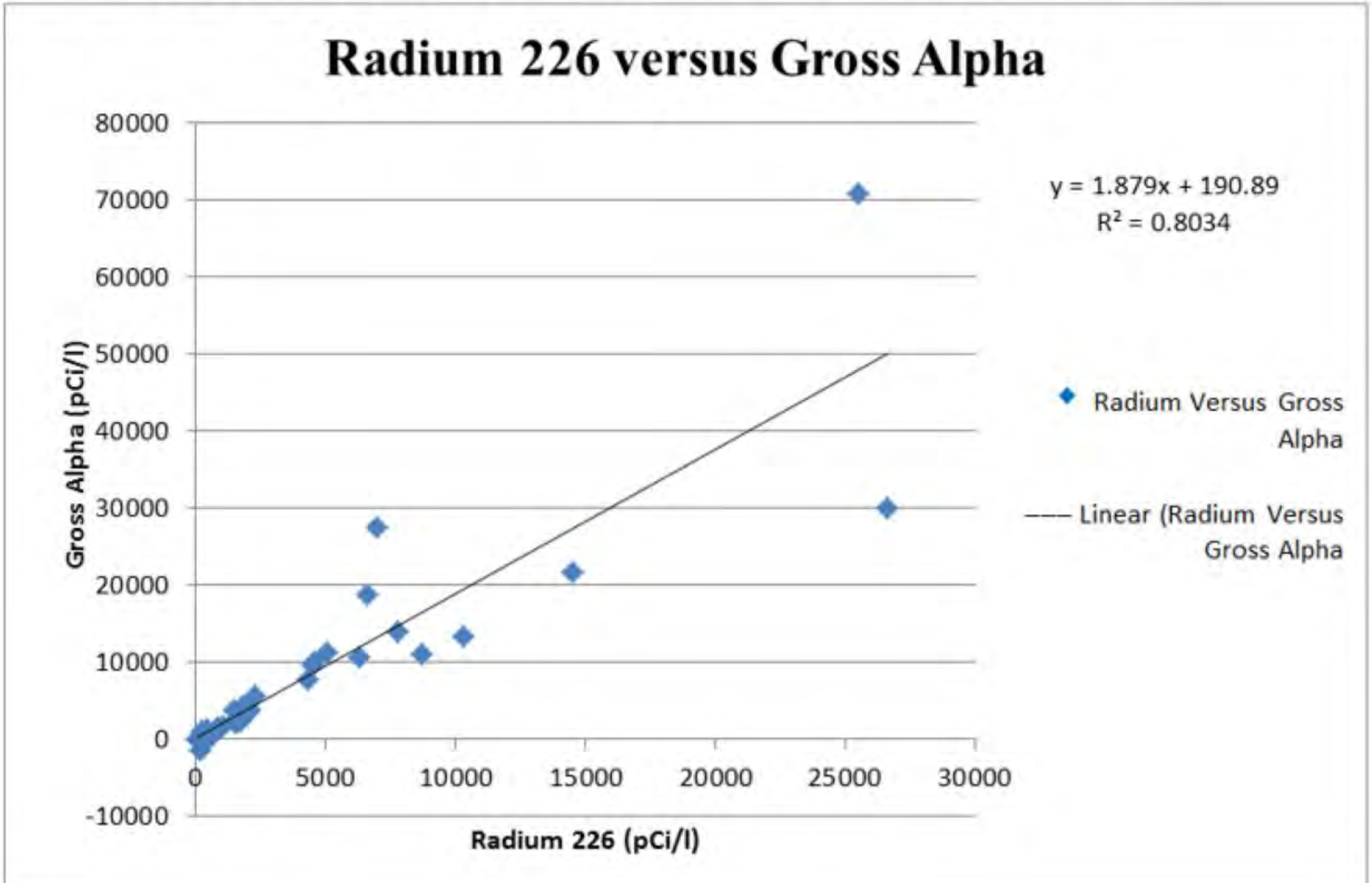
Figure M-11. Ra-226 X-Y Scatter Plot versus Barium – Outlier Removed



Study Results

Non-Rad Chem. Data on Flow-back H2O

Figure M-19. Ra-226 X-Y Scatter Plot versus Gross Alpha – Outlier Removed



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

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
- O&G industry data on samples taken during DEP study in-line with our data
- 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

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Pipeline 'Pigging' Operations

In Situ **Rn-222 Decay…**

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

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

TENORM RP Regulatory Framework

Regulate under RP or Solid Waste laws?

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, accurate TENORM [Ra-226] measurements!

State Regs TENORM Disposal

New 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

Health Physics Society & TENORM

ANSI/HPS N13.53-2009

Approved: March 2009

ANSI American National Standards Institute

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

HPS Position Statement

Adopted January 1992

The Health Physics Society believes the current regulatory framework for establishing and enforcing regulatory radiation safety standards results in inconsistent, inefficient, and unnecessarily expensive public health protection policies regarding radiation safety. Therefore, the Society advocates the establishment of a regulatory framework with the following requirements:

1. A single, independent U.S. federal agency (herein called the Agency) shall have the responsibility and authority to establish all ionizing radiation safety standards for all controllable sources[1] of occupational and public exposures.

HPS

Health Physics Society
Specialists in Radiation Safety

HEALTH PHYSICS SOCIETY

COMPATIBILITY IN RADIATION SAFETY REGULATIONS

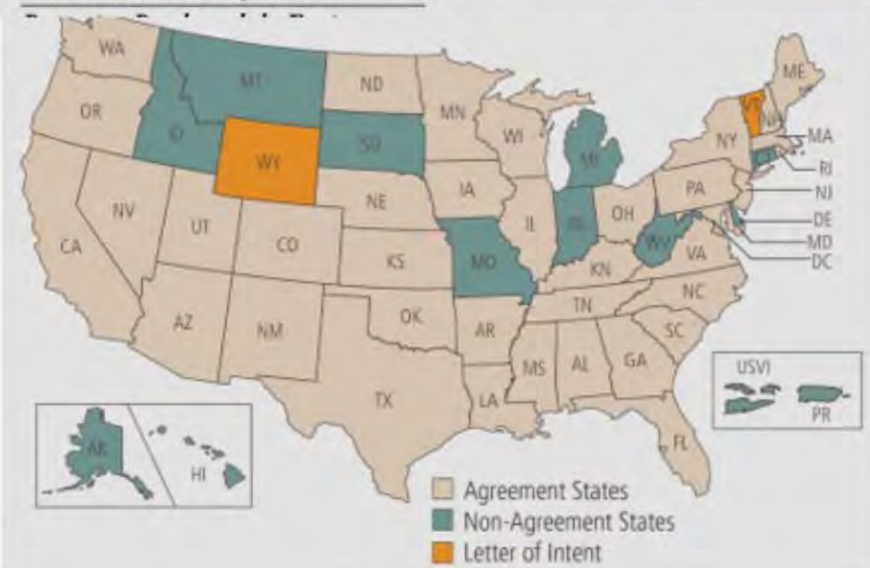
POSITION STATEMENT OF THE HEALTH PHYSICS SOCIETY*

Adopted: January 1992
Revised: August 2000
Reaffirmed: July 2007

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)

TENORM RP Regulatory Framework

Current USA regs are fragmented !!

SCIENTIFIC AUTHORITY SINCE 1929 • CONGRESSIONALLY CHARTERED •
NCRP

**But we're hopeful…
a new NCRP Scientific Committee has been stood-up to review TENORM waste disposal.**

SC 5-2 Working Group on TENORM

Acknowledgements

DEP Staff -

Dan Husted (FOs)

Bob Lewis (Radon Div.)

CO & RO BRP Staff

Taru, Janelle & Tom, et al. (BoLs)

Ken, Sharon & Ali (Dep. Sec's Office)

PermaFix Staff -

Andy Lombardo, Jason, Allan, Tony, Anita, et al.

GEL Lab Staff -

Bob Seyer, et al.

O&G Firms' Staff

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TENORM DISPOSAL
THE COLORADO EXPERIENCE

NCRP Workshop
February 2, 2016

Jan Johnson
Tetra Tech

Technologically Enhanced Naturally Occurring Radioactive Material

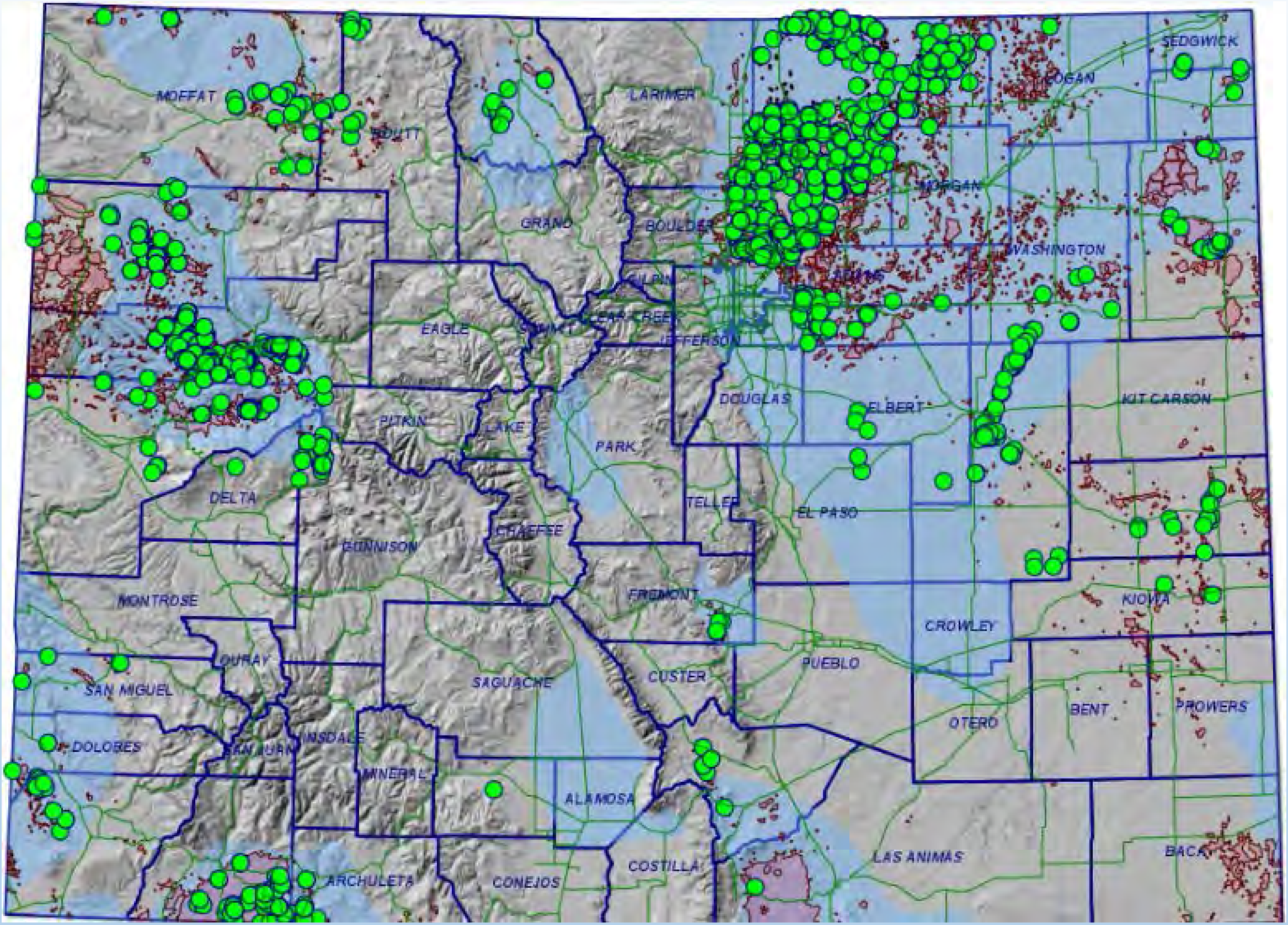
- Naturally occurring radioactive material (NORM) that has been concentrated or made more accessible by human activities – uranium, thorium, and potassium
  - Mine wastes
  - Water treatment residuals
- How does it relate to oil and gas Exploration and Production (E&P) wastes
  - Drilling fluids and produced water
  - Drill cuttings and other soils
  - Filter socks
  - Pipe scale

Oil and Gas Exploration and Production (E&P) Wastes

- Well Drilling and Completion
  - Drilling fluids (drilling muds)
  - Cuttings
  - Flowback water
- Well Stimulation (hydraulic fracturing)
  - Fracturing fluid returns
  - Flowback water
- Production
  - Produced waters
  - Treatment sludges
  - Filter cake
  - Tank bottoms

Radiological Impacts of E&P TENORM Disposal

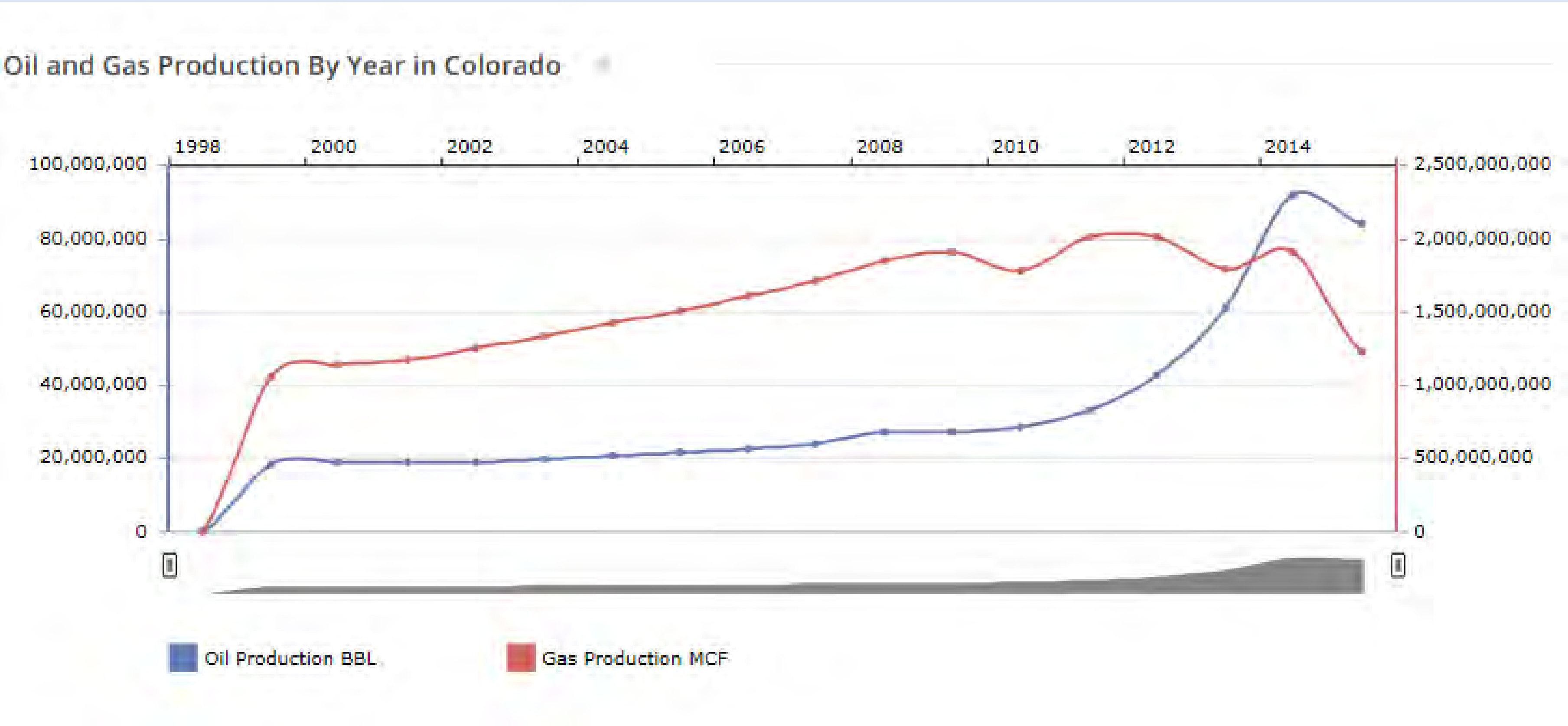
- Pathways of Exposure
  - Direct radiation – for close contact – i.e., landfill worker
  - Inhalation of airborne dust and radon decay products
  - Ingestion of radionuclides in soil, water and food
- Control of Exposure
  - Passive – location, control of land use
  - Active
    - Waste Acceptance – pre-screening and waste analysis
    - Cover – Interim cover to prevent re-suspension and provide shielding
    - Lined disposal area to prevent infiltration into ground water
    - Fencing to prevent intrusion
    - Monitoring for early detection of potential problems
    - Proper site closure – adequate cover over TENORM



Map from COGCC (dnrwebmapgdev.state.co.us/mg2012app

Colorado Oil and Gas Production

(from Drilling Edge, http://www.drillingedge.com/colorado)



Monthly Oil and Gas Production by County
July 2015

(Drilling Edge – www.drillingedge.com/Colorado)

Oil

County	BBL (barrels)
Weld	9,161,457
Rio Blanco	355,534
Arapahoe	129,443
Garfield	98,036
Cheyenne	91,895

Gas

County	MCF (thousand cubic feet)
Weld	43,709,893
Garfield	41,045,494
La Plata	26,679,121
Las Animas	6,693,216
Rio Blanco	6,199,935

Weld County Eastern Plains

- Photo from Weld County Building Department

- Photo from Greeley Tribune

Garfield County – Colorado Plateau

(Photo from Colorado Public Radio)

GLENWOOD SPRINGS

POST INDEPENDENT

Your free community newspaper | postindependent.com | Volume 124, Number 10 | Sunday, January 10, 2016

GarCo at epicenter of O&G industry in 2014

CU report: Industry generated nearly $32B, more than 38,000 jobs

Ryan Hoffman
rhoffman@citizentelegram.com

Garfield County was one of two counties at the epicenter of a Colorado's robust oil and gas industry that contributed $31.7 billion in total output to the state's economy in 2014 while accounting for approximately 38,650 direct jobs, according to a report.

The report — conducted by the Leeds School of Business at the University of Colorado Boulder — was commissioned by the Colorado Oil and Gas Association, which is the state's leading trade group. It analyzed the industry's economic impact throughout Colorado in 2014.

Aside from the nearly $32 billion in total economic impact and more than 38,000 jobs, the industry supported an additional 64,000 jobs and $403.5 million in property taxes across the state, according to the report.

While a total of 34 counties produced oil and 38 counties recorded production of natural gas in 2014, Garfield and Weld counties saw the bulk of new activity in Colorado.

According to the report, 80 percent of drilling permits in 2014 came from those two counties. Garfield and Weld also were the only two counties in both the top five counties for production and the top five counties for employment in 2014.

In Garfield County, 2,325 people were employed by the industry in 2014. The average salary was $80,888, which accounted for total wages of $188.1 million. Weld, Denver and Mesa counties were the only other ones in Colorado with more people employed by the oil and gas industry than in Garfield County in 2014.

The findings in the report show some growth compared with the number in a similar study conducted in 2014 for 2013. The message in that report was the oil and gas industry continued to rebound and expand

O&G, A2

Not a word about TENORM waste disposal

Interesting Factoid
Plowshare Program

Purpose: stimulate the flow of naturally low permeability formations

Garfield County - 1969

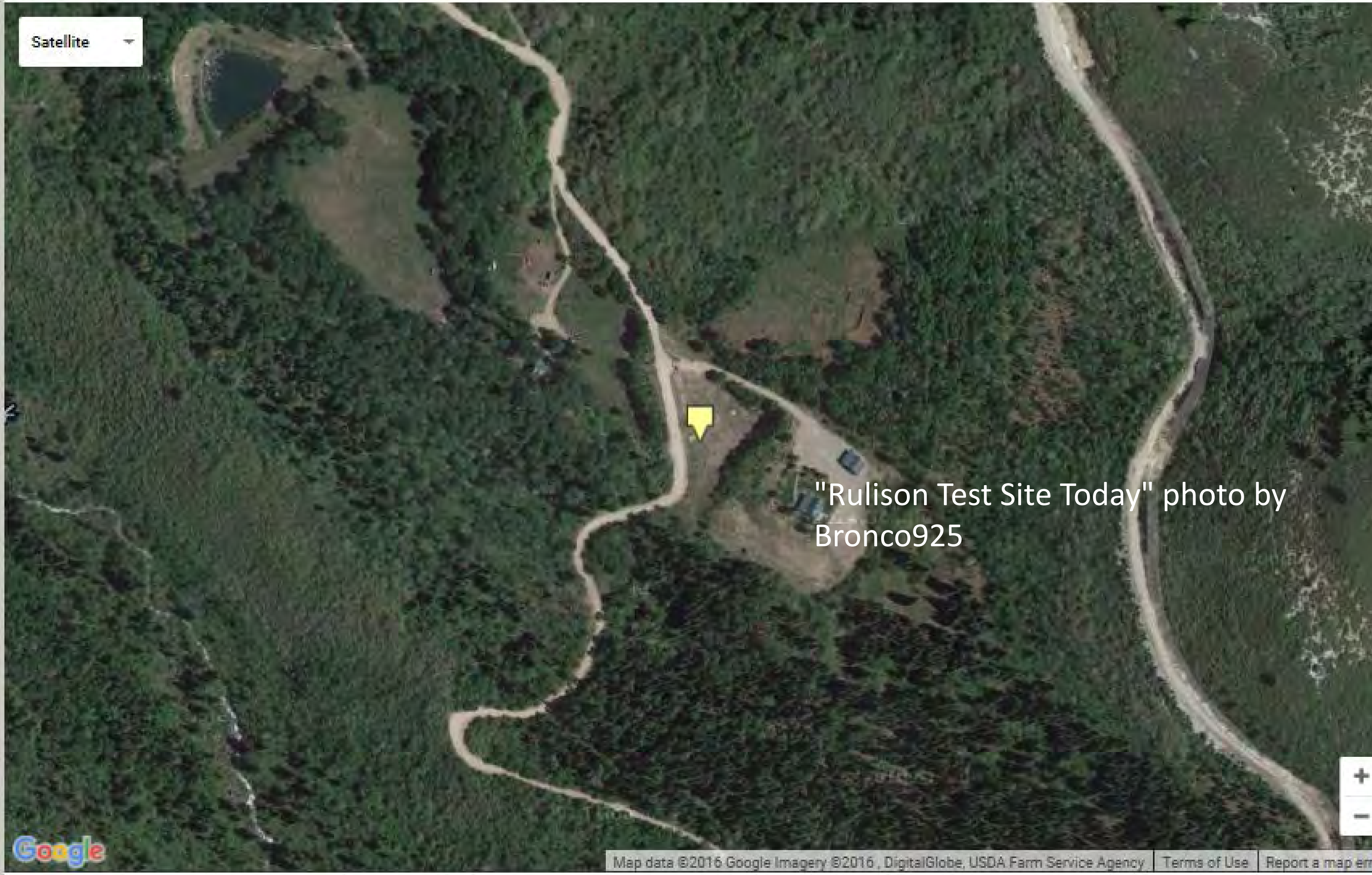
- Rulison
- 43 kT device

Rio Blanco County - 1973

- Three 30 kT devices
- Marginally successful – blast sealed fractures
- Gas too radioactive to be sold commercially
  - Tritium, C-14
  - Kr-85

RIO BLANCO NUCLEAR TEST SITE

RULISON NUCLEAR TEST SITE



"Rulison Test Site Today" photo by Bronco925

Representative TENORM Concentrations

- Cuttings
  - Colorado data from COGCC for Weld County – radionuclide concentrations consistent with background
  - Other analyses have found a difference between vertical and horizontal cuttings – higher concentrations in horizontal cuttings
- Other solids
  - Approximately 8 to 30 pCi/g Ra-226/228
  - U-nat less than 3 pCi/g
  - USGS (1999) – 54% less than 30 pCi/g
- Produced waters – USGS (1999)
  - 48% less than 100 pCi/l;
  - 76% less than 300 pCi/l;
  - 90% less than 1000 pCi/l
- Filter socks – generally higher concentrations

COGCC (Colorado Oil and Gas Conservation Commission)

USGS. 1999. Naturally Occurring Radioactive Materials (NORM) in Produced Water and Oil-Field Equipment – An Issue for the Energy Industry. USGS fact Sheet FS-142-99. September.

COLORADO OIL AND GAS TENORM WASTE
Where does it go now?

- Solid Waste
  - Licensed Low Level Radioactive Waste Site - Clean Harbors (Deer Trail)
    - TENORM limit – 2,000 pCi/g; 400 pCi/g radium
      - U-238, U-235, Th-230 decay series
    - Most TENORM <50 pCi/g radium
  - Municipal Landfills
  - Out of state?
- Produced Waters
  - Deep well injection
  - Evaporation ponds

How is disposal of TENORM regulated?

- Local authorities – e.g. County government
- State of Colorado – Regulation under SWDA and Rad Control Act
  - Only very low levels allowed in municipal landfills (40 pCi/g total alpha above background) without special permit from the Colorado Department of Public Health and Environment (CDPHE)
  - Limits to the amount of radioactivity that can be disposed of in industrial landfills
  - Requirements for control
  - Monitoring

Colorado authority to regulate TENORM

- Under the Colorado Radiation Control Act, “The department shall develop and conduct programs for evaluation and control of hazards associated with the use of any and all radioactive materials and other sources of ionizing radiation…”
- The State Board of Health may adopt regulations concerning the disposal of NORM at any time <u>after</u> the promulgation by the EPA or its Successor of rules for the disposal of NORM…
- Under the Radiation Control Act, Colorado has authority over all forms of radioactivity, including NORM and TENORM.
- **Colorado exercises discretion on regulating materials that do not pose a health or environmental risk**

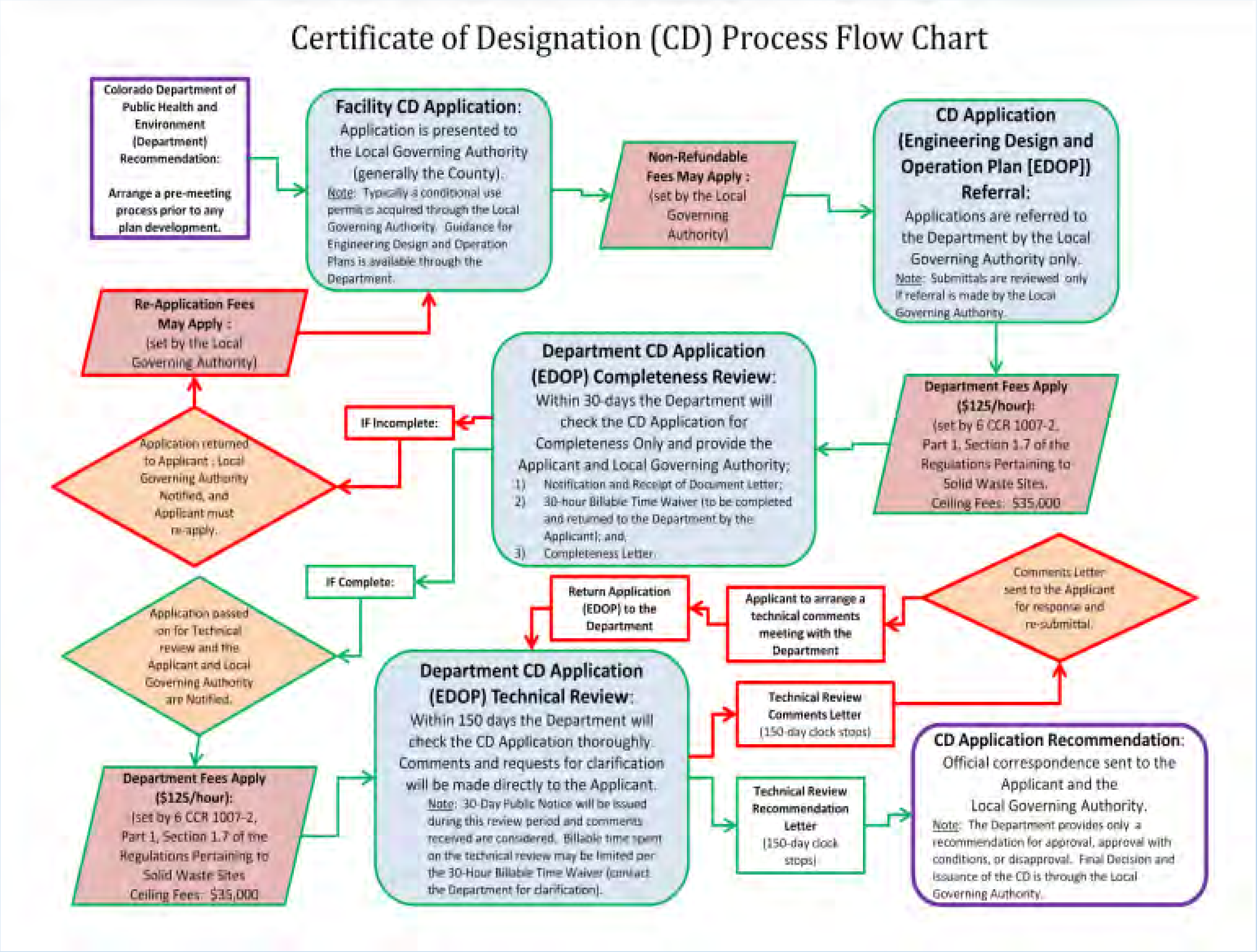
Colorado TENORM Guidance

- Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado – Rev 2.1, February 2007 (Revision in process – 2013, 2014 responses to comments)
  - Establishes policies for TENORM
  - Sets concentration limits for TENORM disposal
  - Requires consultation with the Radiation Control Division for NORM greater than 40 pCi/g gross alpha or uranium greater than 30 pCi/g above background

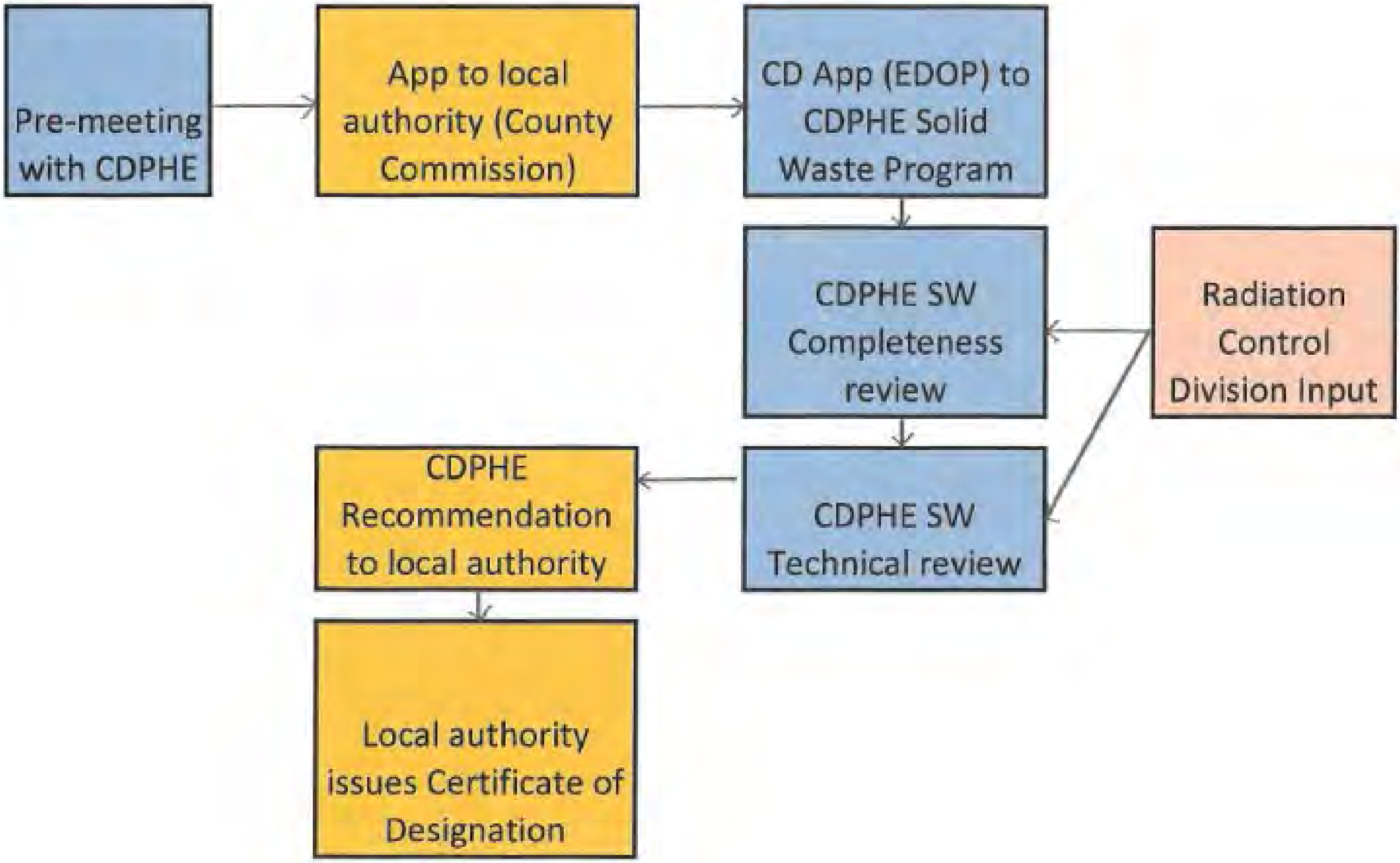
Colorado Limits for TENORM Disposal (February 2007 Guidance)

- Municipal landfills
  - 10 pCi/g Ra-226/228 above background
  - 100 pCi/g U-nat above background
  - No more than 1 – 10% TENORM
- Industrial landfills
  - 50 pCi/g Ra-226/228
  - 300 pCi/g U-nat
- Variance – the policy allows any facility to apply to CDPHE for a variance from the limits if the applicant can demonstrate disposal will not jeopardize public health or the environment - less than 25 mrem per year dose to workers and members of the public

Landfill Approval Flow Chart



CERTIFICATE OF DESIGNATION APPROVAL PROCESS



Alternative Disposal Site Projects Pending

- Municipal Landfills applying for TENORM disposal permits from CDPHE
- Northeast Colorado Landfill for TENORM
  - Solid waste only – cuttings, muds, sludges, etc.
  - Proposed limited average radionuclide activities
  - Maximum allowable Ra-226 concentration in any load – 50 pCi/g
- Mesa County – (Adjacent to Garfield and Rio Blanco Counties)
  - Conditional Use Permit amended in 2013 to accept TENORM
  - 2014 construction approval from CDPHE for produced water disposal ponds
  - Current status - unknown

Mesa County – *ALANCO* Energy Services

Deer Creek existing disposal facility for produced waters

Indian Mesa – proposed solid waste – 160 acres adjacent to DOE U mill taillings disposal site (Cheney site)

RESRAD Dose Analyses

- Worker Dose – Pathways
  - Direct gamma radiation
  - Inhalation of particulates
  - Inhalation of radon decay products
  - Soil ingestion
  - No veg, meat, milk, fish ingestion
- Public Dose Post Closure – Pathways – resident farmer scenario
  - Direct gamma
  - Inhalation of particulates
  - Soil ingestion
  - Water pathways
    - Direct ingestion
  - Veg, meat, milk ingestion
  - Radon decay product dose "subtracted" with institutional controls
    - e.g., radon resistant construction and environmental covenants

Exposure Factors Used for Industrial Landfill

- Worker
  - 1000 hrs/y on bare waste at average Ra-226 concentration
  - 1000 hrs on covered waste
  - 25% shielding (reduction) factor for heavy equipment
  - Incidental soil ingestion – 100 mg/day
  - Dust inhalation and radon decay product inhalation – RESRAD default
  - No food or water ingestion
  - Dose for covered and bare waste calculated separately then summed.
- Resident Farmer-Post Closure
  - Site-specific hydrologic, weather, soil characteristics.
  - 25% outdoor occupancy; 50% indoor occupancy
  - 50% of veg diet from on-site
  - 100% of meat and milk from on-site
  - 100 mg/day soil ingestion
  - RESRAD default values

RESRAD Dose Distribution by Pathway

Depends on average radionuclide concentrations and specific landfill conditions

- Worker (during active disposal operations)
  - Nearly all of the dose from direct gamma radiation – 99%
  - Radon negligible
  - Soil ingestion – 1%
  - Particulate inhalation – negligible
- Resident Farmer (on closed, covered landfill at 1,000 years)
  - Direct gamma – negligible
  - Soil ingestion - negligible
  - Veg ingestion – 32%
  - Water ingestion – 64%
  - Meat, milk – 4%
  - Radon not included in dose

Key Issue – Ensuring that maximum Ra-226 Concentration is less than 50 pCi/g

- Generator Waste Acceptance Process
  - Waste must be characterized before acceptance
  - Operator samples a fraction of the loads to verify generator data
  - Operator maintains a running tally to ensure that the average concentration in the landfill meets permit limits
- Portal/hand held monitors
  - Sensitivity of the monitors
    - Large area plastic detectors
    - NaI or HPGe detectors
    - False positives
  - Time since separation of the Ra-226
    - Freshly separated Ra-226 low gamma emissions
    - Exposure rate increases as Rn-222 decay products build in

Interstate Disposal of TENORM
(Rocky Mountain Low-Level Waste Compact)

- Regulates import and export of TENORM in and out of the compact
- Facilities wishing to import or export NORM/TENORM waste must obtain authorization from the RMLLWC.
- Is there a limit?
- Rationale?

- *Nevada does not actually abut Colorado – Utah gets in the way*

Exposure Pathways from TENORM in Unconventional Oil and Gas Production

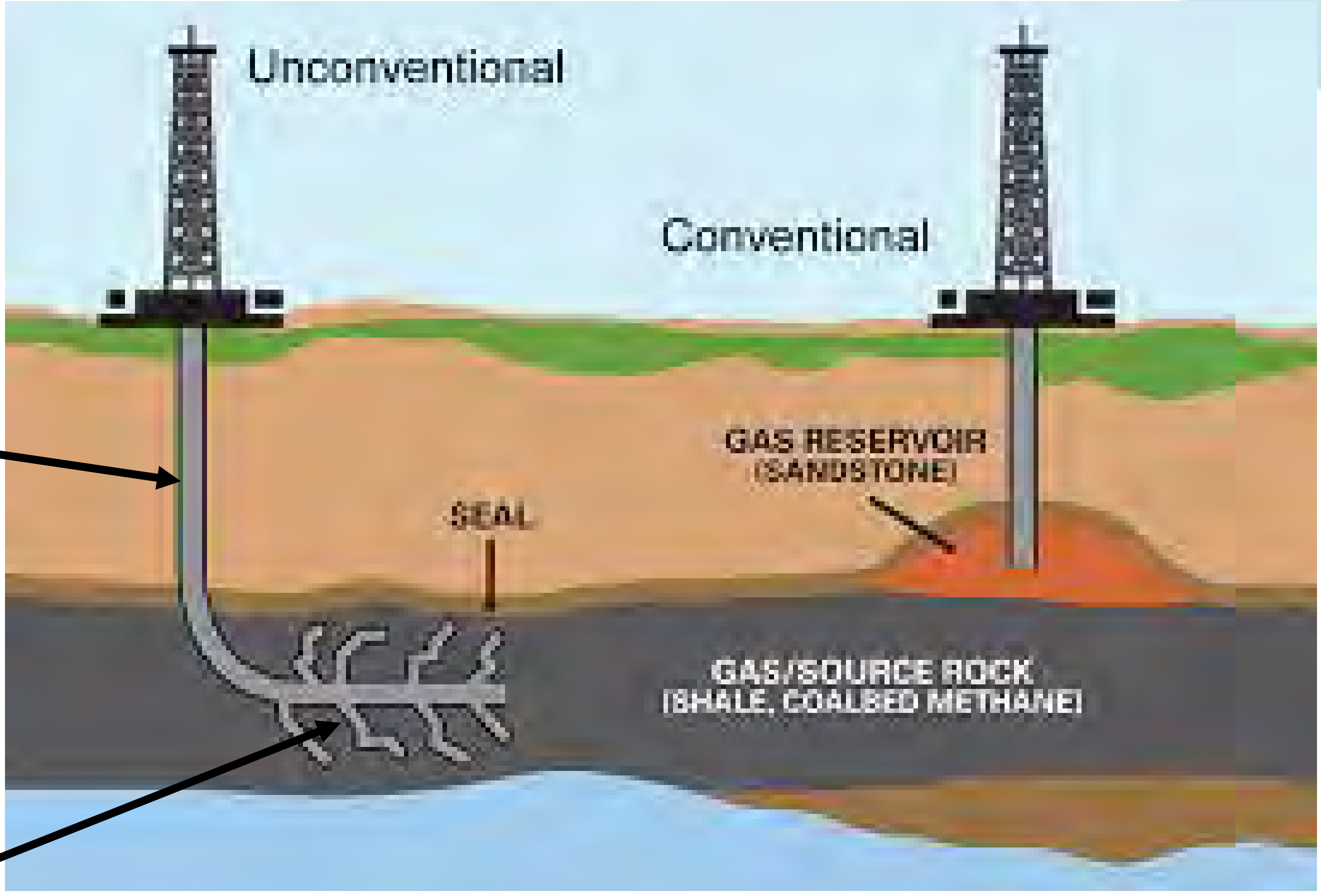
Arthur S. Rood
February 2, 2016
NCRP TENORM Workshop
Austin, Texas

Outline

- Unconventional Oil and Gas Production – what makes it different from conventional production?
- Production Phases
- TENORM Source Terms
- Exposure Pathways by Production Phase

Unconventional Oil Gas Development

directional drilling and well development



Horizontal drilling and hydraulic fracturing through a producing formation containing elevated NORM has the potential to bring greater quantities of radionuclides to the surface and in contact with humans

Oil and Gas Production Phases for Exposure Assessment

- **Drilling**
  - vertical and horizontal
- **Development**
  - Fracking, installation of production tubing, and equipment

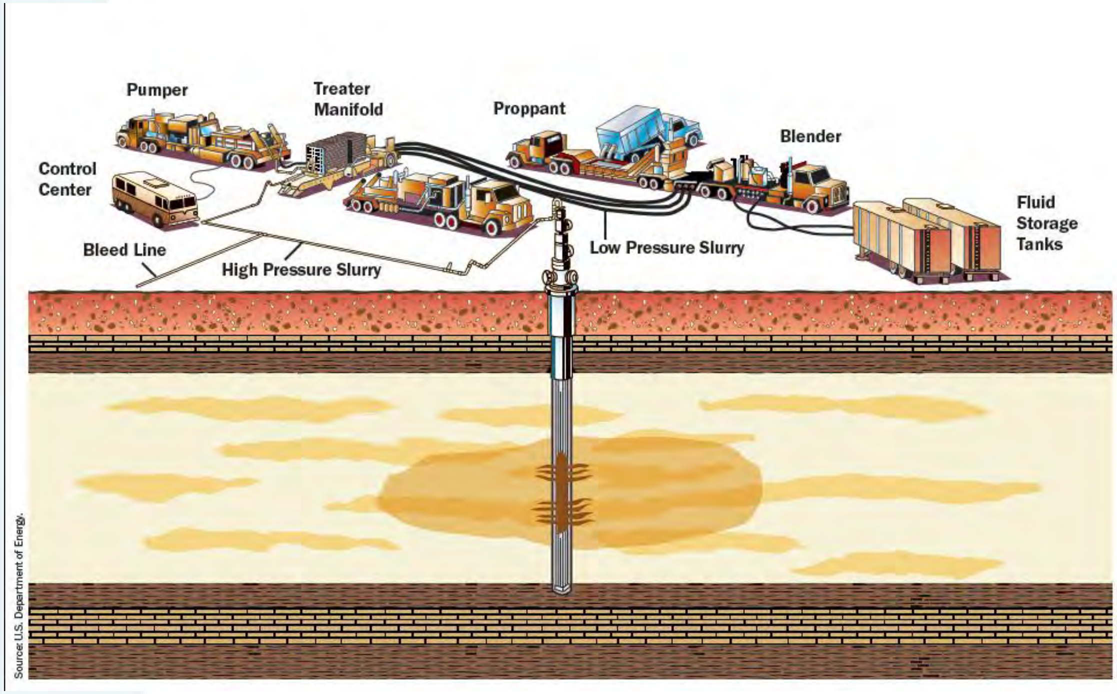
- **Production**
  - TENORM accumulation in production equipment, Maintenance, and waste disposal

TENORM Source Terms

- **TENORM in conventional oil and gas production include radionuclides (primarily $^{226/228}Ra$) in barium pipe scale, sludge, drilling fluids and cuttings, and produce waters.**

TENORM Source Terms

- **TENORM generated from unconventional oil and gas can include**
  - conventional sources (barium pipe scale, sludge, drilling fluids and cuttings, produce waters)
  - radionuclides in flow-back water



Flow-back water:

fluid pumped down the well to fracture the formation and then returned to the surface

TENORM Source Terms - Unconventional

- The inventory of U and Th series is controlled by the local geology of the producing formation
- Temperature, pressure, and chemical composition of fracking fluids may enhance TENORM formation in oil and gas equipment over that of conventional production

Typical TENORM Concentrations[a]

	Mean (range)[b]	
Media	**^{226}Ra (Bq g^{-1})**	**^{228}Ra (Bq g^{-1})**
Pipe Scale	52 (0.2 – 273)	68.5 (0.037 – 159)
Sludge and other waste	8.8 (0.0 – 58)	2.4 (0.0 – 16.4)
Soil near production facilities	3 (0.0 – 26)	2.4 (0.0 – 1.1)

a. From Rood and White, 1999
b. Soil guidelines for U mill tailings: 0.19 Bq g^{-1} 0-15 cm, 0.55 Bq g^{-1} >15 cm

TENORM Concentrations in Marcellus Shale Flow-back Water[a]

- **^{226}Ra 75.1 Bq L^{-1} (<0.01 - 630)**
- **^{228}Ra 75.1 Bq L^{-1} (<0.01 - 630)**
  - $^{226+228}$Ra Drinking water standard 0.19 Bq L^{-1} (5 pCi L^{-1})
- **^{234}U 0.3 Bq L^{-1} (<0.01 – 0.93)**
- **^{235}U 0.39 Bq L^{-1} (<0.01 – 1.5)**
- **^{238}U 0.7 Bq L^{-1} (<0.01 – 5.5)**

a. From Abualfaraj et al., 2014

Radon Emanation from TENORM Materials

- **Radon emanation from pipe scale is known to be lower than uranium mill tailings**
  - Pipe scale - 0.04 (0.02 to 0.06)[a]
  - Uranium Mill Tailings – 0.2 (0.1 to 0.3)[b]

a. Rood and White, 1999
b. Rogers et al., 1984

Exposure Pathways – Drilling Phase

- External exposure to re-circulation drilling fluids
- External exposure to drill cuttings in mud pits
- Radon inhalation
- Inhalation and ingestion of drill cutting

Exposure Pathways – Drilling Phase (continued)

- External exposure at well sites in PA ranged from background to 38 $\mu R\ hr^{-1}$ with the highest average rate during all drilling activities of 18 $\mu R\ hr^{-1}$
- Radon concentrations in ambient air were around background (7.4 to 26 Bq m^{-3}, [0.2-0.7 pC L^{-1}])
- Minimal alpha and beta surface activity

Exposure Pathways - Drilling (continued)

- Exposure potential to workers or public during this phase were considered small (PDEP 2015)
- Potential environmental contamination and public exposure from spills and improper disposal of wastes

Exposure Pathways – Development Phase

- **Unconventional oil and gas development poses potential exposure pathways through external exposure to flow-back fluids during fracking**
- **Some flow-back fluids in PA (PDEP 2015) had Ra-226 concentrations ranging from 2.4 to 777 Bq L^{-1} (64-21,000 pCi L^{-1})**

Exposure Pathways – Development Phase (continued)

- External doses from flow-back fluids was deemed low by PDEP
- Spilling and improper disposal of fracking fluids poses a risk of environmental contamination and public exposure

Exposure Pathways –Production Phase

- Natural gas processing plants and compressor stations
- Waste water treatment plants receiving TENORM waste
- Landfills receiving TENORM solid waste
- Pipe scale removal operations

Natural Gas Processing (NGP) and Compressor Stations (PDEP results)

- **Radon concentrations in gas entering NGP (~1.9 Bq m^{-3}) are similar to well concentrations and are lower in the outflow.**
- **^{210}Pb from the decay of ^{222}Rn builds up within pipe and filter housing**
- **External exposure in NGP plants ranged from background to 75 µR hr^{-1}, but some were as high as 900 µR hr^{-1}**

NGP Exposures (continued)

- **These exposure rates could result in public exposure limits being exceeded for NGP workers**
- **^{210}Pb concentrations in propenizer (a distillation column) filter equipment were as high as 132 Bq g^{-1} (3580 pCi g^{-1})**
  - Gross alpha and beta removable activity exceeded Reg Guide 1.86 limits
- **Potential for internal (inhalation and ingestion) exposure**

Waste Water Treatment Plants

- Waste water treatment plants receiving oil-production waste showed $^{226+228}Ra$ concentrations greater than background
- Radium accumulates in filter cake
- Estimated doses were highest for external exposure and but less than 1 $mSv\ yr^{-1}$ (PDEP 2015)

Pipe Scale Cleaning

- **External, inhalation, radon, and ingestion**
- **External exposure most important**
- **Hamilton et al. 2004 estimated doses**
  - External from pipeshine : 4.1 mSv
  - External from groundshine (i.e., scale on ground): 0.28 mSv
  - Inhalation: 0.45 mSv
  - Radon: 0.11 mSv
  - Ingestion: 0.097 mSv

Landfill Disposal Oil Field Wastes

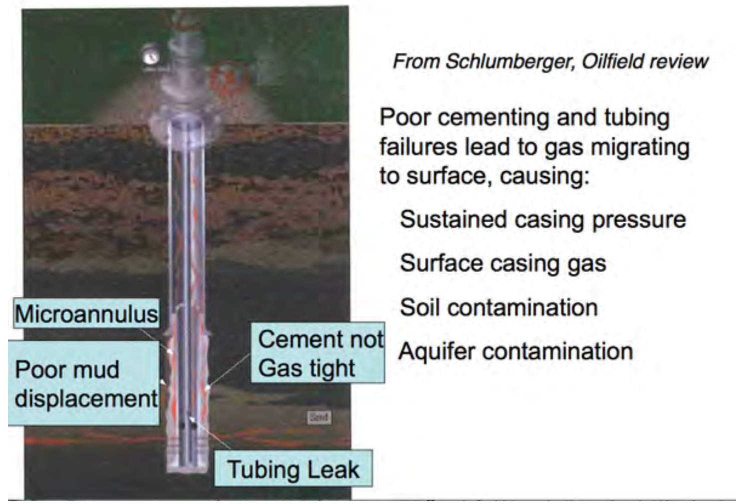
- **Potential pathways of exposure similar to mill tailings**
- **Long-term leaching and transport to groundwater**
- **^{210}Pb build-up in overburden**
- **Long-term impacts depend on TENORM waste inventory in the landfill**
  - Can be assessed using methods for shallow land burial of radioactive waste

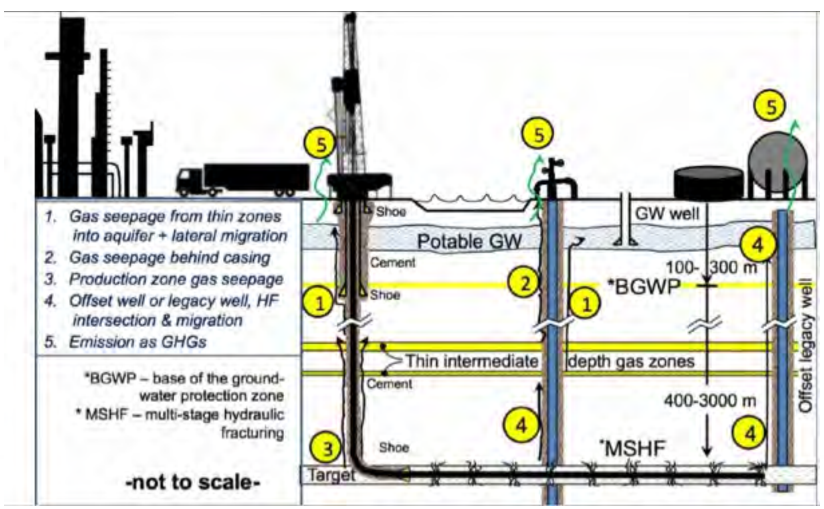
Environmental Contamination – Pathways of Exposure to the Public

- **Land surface spills**
  - Similar to residual radioactivity in soil (i.e., RESRAD assessment)
  - External exposure and radon expected to be the primary pathways
- **Discharges to water bodies**
  - Accumulation in sediment
  - Bioaccumulation in aquatic species

Environmental Contamination – Pathways of Exposure to the Public (continued)

- **Faulty well construction can result in contamination of potable aquifers during fracking and production phases**
- **Public water ingestion pathway**





Conclusions

- Use and disposal of fracking fluids presents an additional pathway of exposure from unconventional oil and gas extraction
- External exposure to gamma-emitting radionuclides appears to be the most important exposure pathway during the drilling, development, and production phase

Conclusions

- **External exposure primary pathway in NGP equipment**
  - Inhalation and ingestion may be important in some NGP equipment
- **Spills, inadvertent releases, improper disposal of TENORM materials, and faulty well construction can result in environmental contamination and potential exposures to the public**

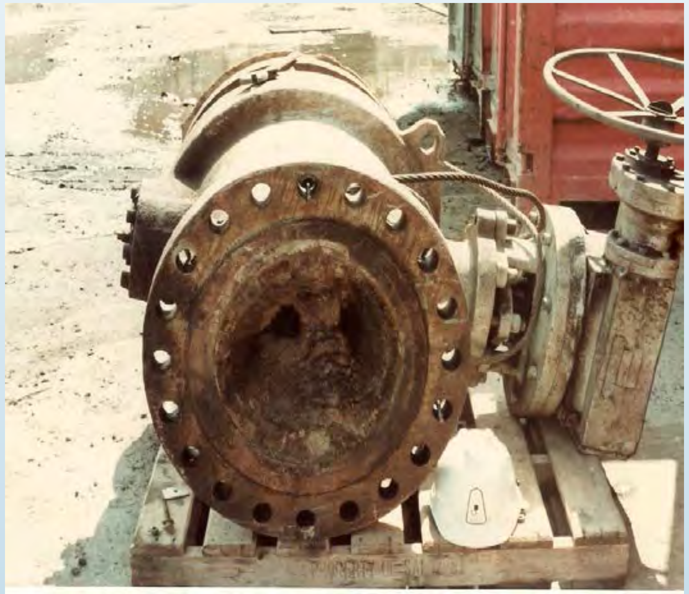
International Review TENORM Wastes in Oil and Gas

Presented at the Health Physics Society Mid Year Meeting
NCRP TENORM 2 February 2016 Austin Texas

Presenter: Alan McArthur P.Eng.

UK TENORM 1981 through present

- TENORM identified UKOOA LSA Safe Work Procedures
- Massive Regulatory TENORM inspection problem
- Regulations require Radiation Protection Advisors
- TENORM Solids Disposal by onshore burial



NORWAY 1985

- FPSO Gas Well Test First Gas TENORM issue
- Pb, Bi and Po-210 formed in ID surface cracks
- Massive **Regulatory** TENORM inspection problem
- **TENORM solids disposal Underground storage onshore**

Holland 1985

- TENORM Pb in gas processing
- Wide spread TENORM in gas processing
- TENORM waste containerized and stored onshore

EGYPT 1985

- **TENORM blocked water lines and pipelines**
- **TENORM Management follows UKOOA LSA Safe Work Procedures**
- **TENORM waste disposal by onshore storage in concrete cells.**

Libya1986

- TENORM in Unlined Produced water lakes
- Operating Oil Company and follow UKOOA LSA practices
- TENORM waste disposal unresolved

Thailand 1996

- TENORM surveys of Offshore platforms and gas processing plants
- TENORM indications showed only a minor issue at that time.
- Production was gas and gas condensate focused on water treatment.
- International Oil companies voluntary TENORM programs from home country. (US API or EC)

Venezuela 2003

- TENORM in Onshore Oil and Gas Fields, Pipelines and Upgrader
- Heavy Oil batch pipeline sludge BRC.
- Regulatory API TENORM with IAEA in discussion

Angola 2010 to present

- **TENORM in Offshore Oil and Gas Production Platforms and FPSO's**
- **2 FPSO's cleaned of TENORM decommissioned by end of 2014**
- **TENORM regulations in effect 2010 IAEA using Radiation Protection Advisors**
- **TENORM returned to Angola onshore and stored**

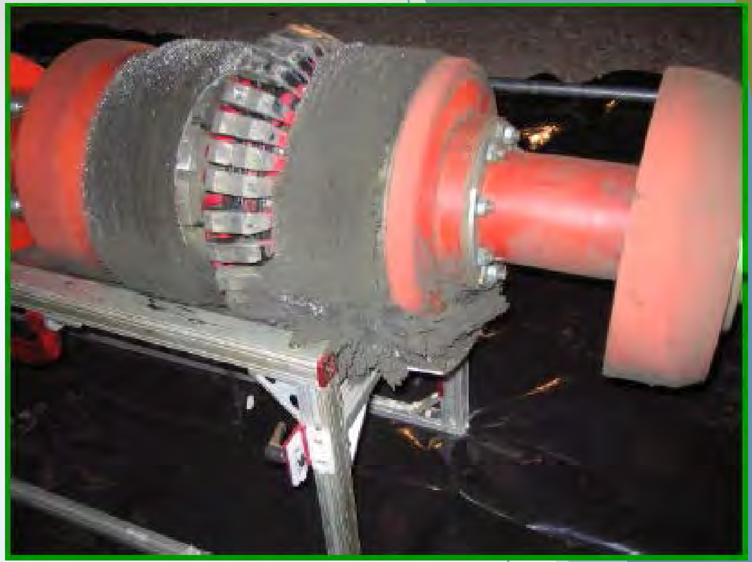
USA 1988 to Present
Alaska to Gulf of Mexico

Shale Gas TENORM issues

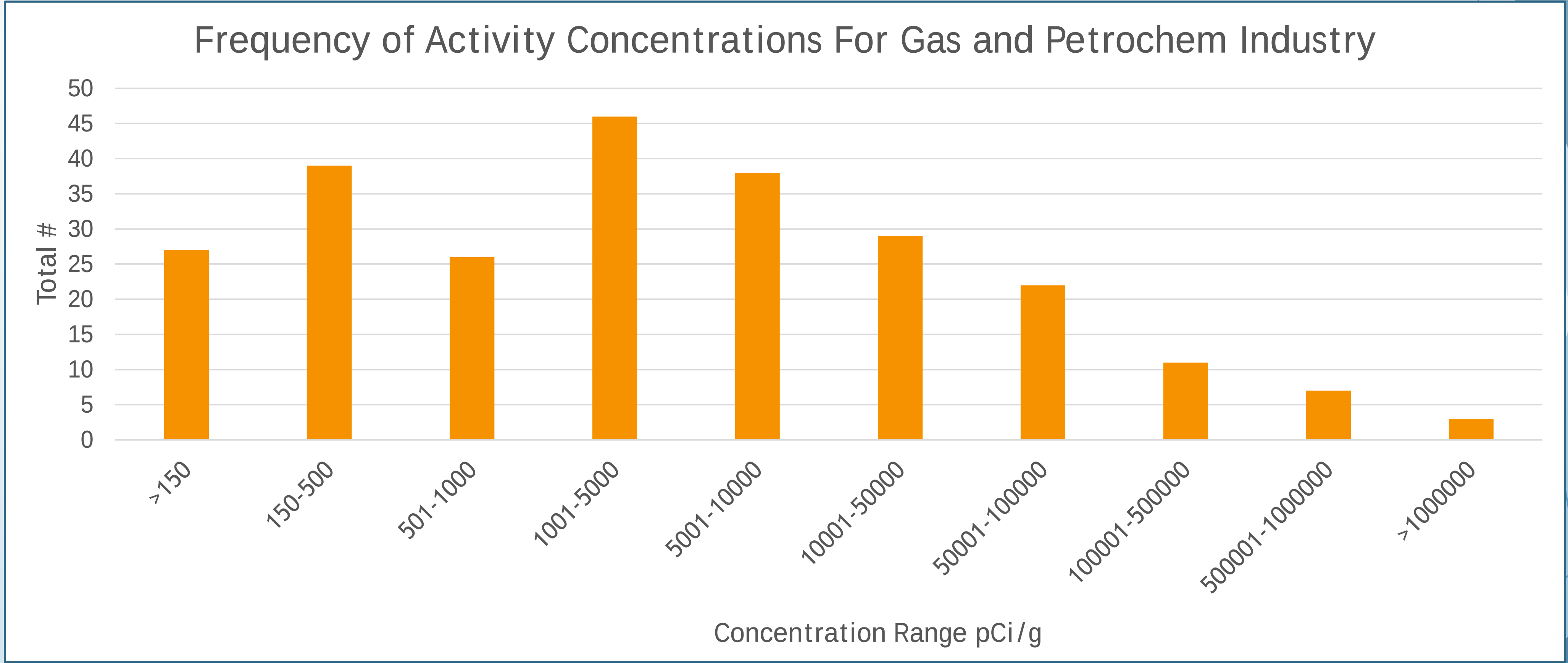
- Radon gas at production wellhead 8 Bq/cu m (200 pCi/cum)
- Pb, Bi, Po-210, 37-110 MBq/g . (1 to 3 mCi/gram) HIGH CONCENTRATIONS
- Gas pipeline filter pot 20,000-500,000 dpm/100 cm^2
- Respiratory Air Monitoring exceeded 10% of Occupational DAC

TENORM in pipeline pigs/traps

- Radon measurable in produced gas
- Lead 210 22 year half life
- Polonium 210 5.3 Mev alpha particle
- Polonium IS electro static
- Respiration fraction minute
- Accumulated in pigs / traps
- Elemental Polonium dust attaches to rust
- Real risk from Po dust inhalation

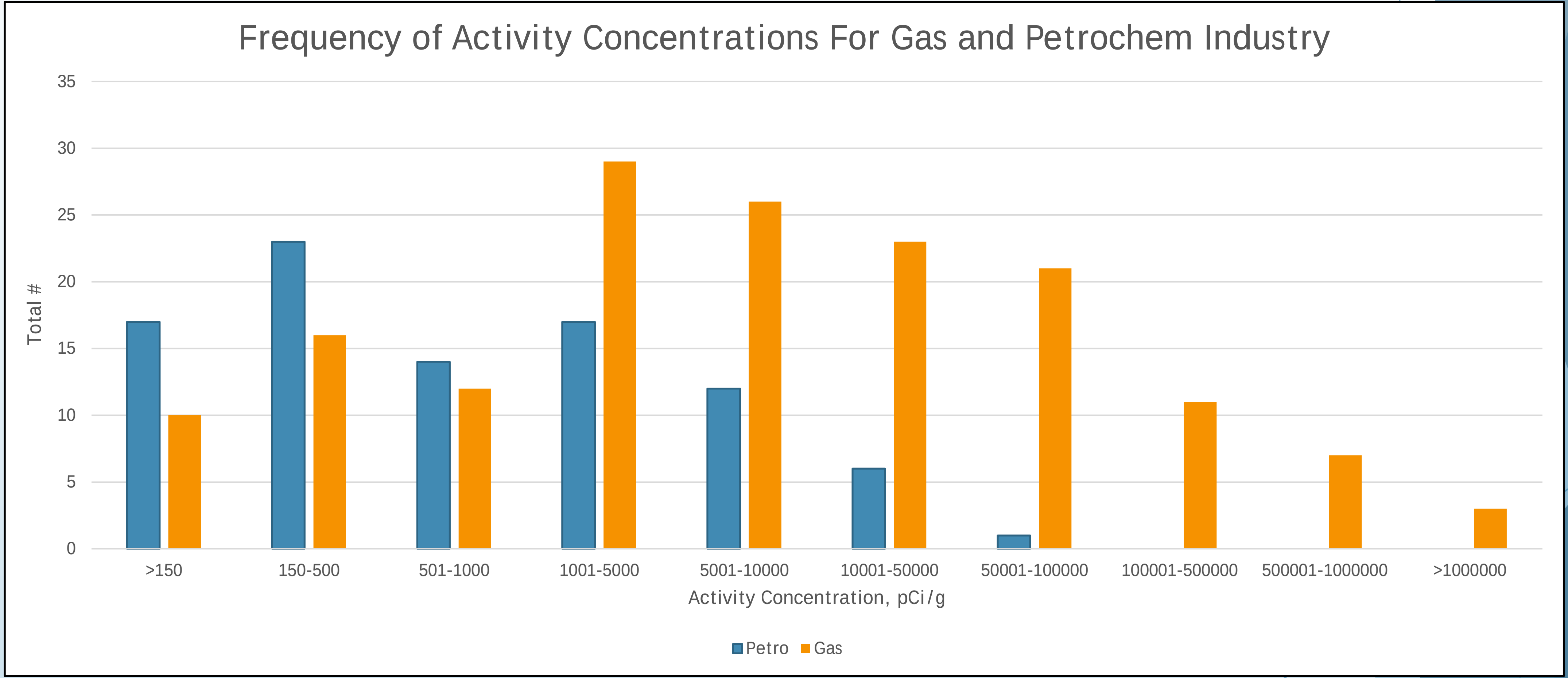


TENORM GAS Waste Sample Analysis



Based on waste analytical reports for filter sediment, scale, and sludge from production lines, filter stations and petrochemical equipment associated with propane, ethane, propylene and ethylene.

TENORM GAS Waste concentrations



Petrochemical waste is primarily exchanger and compressor scale and process-line sludge.
Gas waste is primarily filter trap sediment and pigging sludge.

TENORM in Gas Processing

- Gas processing, radon follows propane and compression leads to higher radon concentrations
- Produced water frequently TENORM contaminated
- Compressing/liquefying gas increases radon concentration
- Most surface contamination data is from gas pipeline filters fractionation plants and petrochemical plants
- Data indicates GAS TENORM in Propane/Propylene exchangers and equipment present in gas storage and processing in South Texas and Oklahoma

TENORM further data required

- TENORM more sample analysis reporting/sharing
- Samples from all shale gas producing areas
- TEDE/Air Monitoring and reporting
- General License Compliance Reporting
- Harmonize TENORM Waste options

GAS TENORM Recommendations

- Require **respiratory air monitoring and reporting** by ALL Licensees
- Require **TEDE reporting** for GAS maintenance workers
- Require **HP/RPA review/approval** of TENORM Management programs
- Require TENORM **Surveyor License**
- TEDE requires air monitoring using trained personnel

Alan McArthur, P.Eng. **Bill Lemons BS, MS**

ALMAC LLC

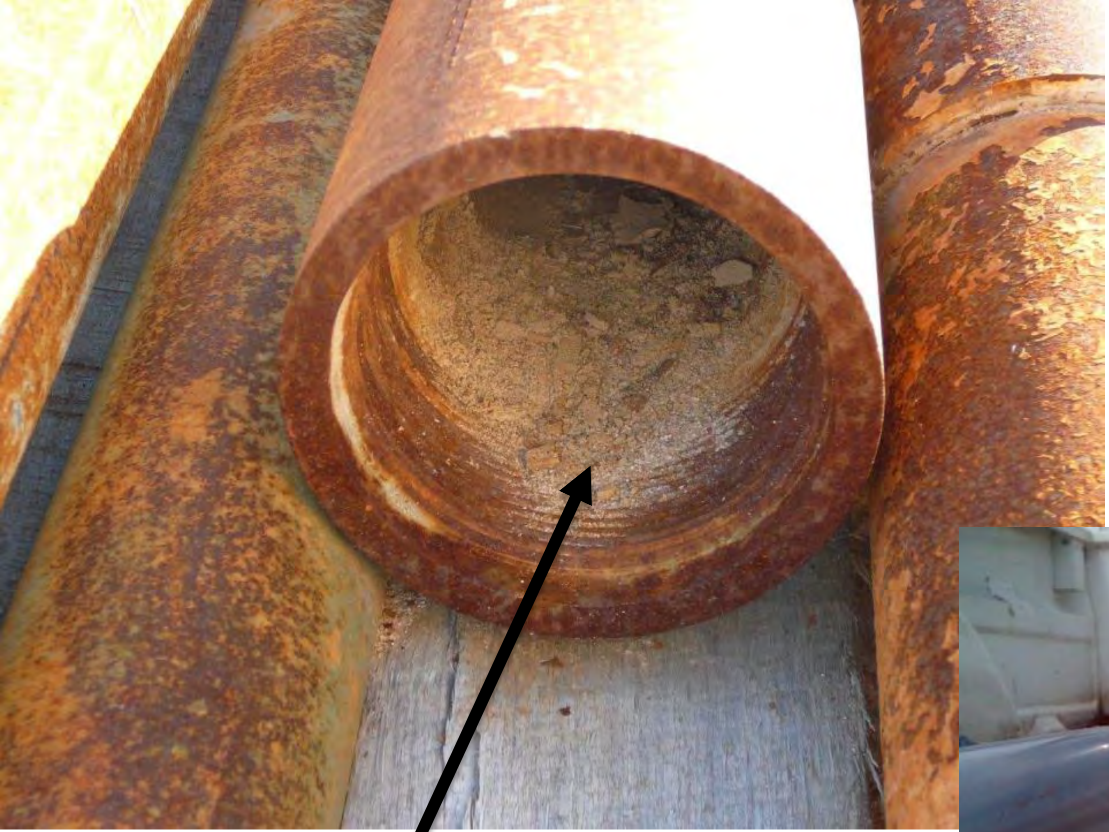
809 Balmoral Ct. Friendswood, Texas 77546

Tel: 281-948-0995 email: almac@almaces.com

TENORM Waste Issues
Waste Acceptance Criteria

HPS Mid-Year / NCRP TENORM Workshop
Austin, TX

February 1-2, 2016



Pipe Scale

Gas Pipeline Pigging Waste

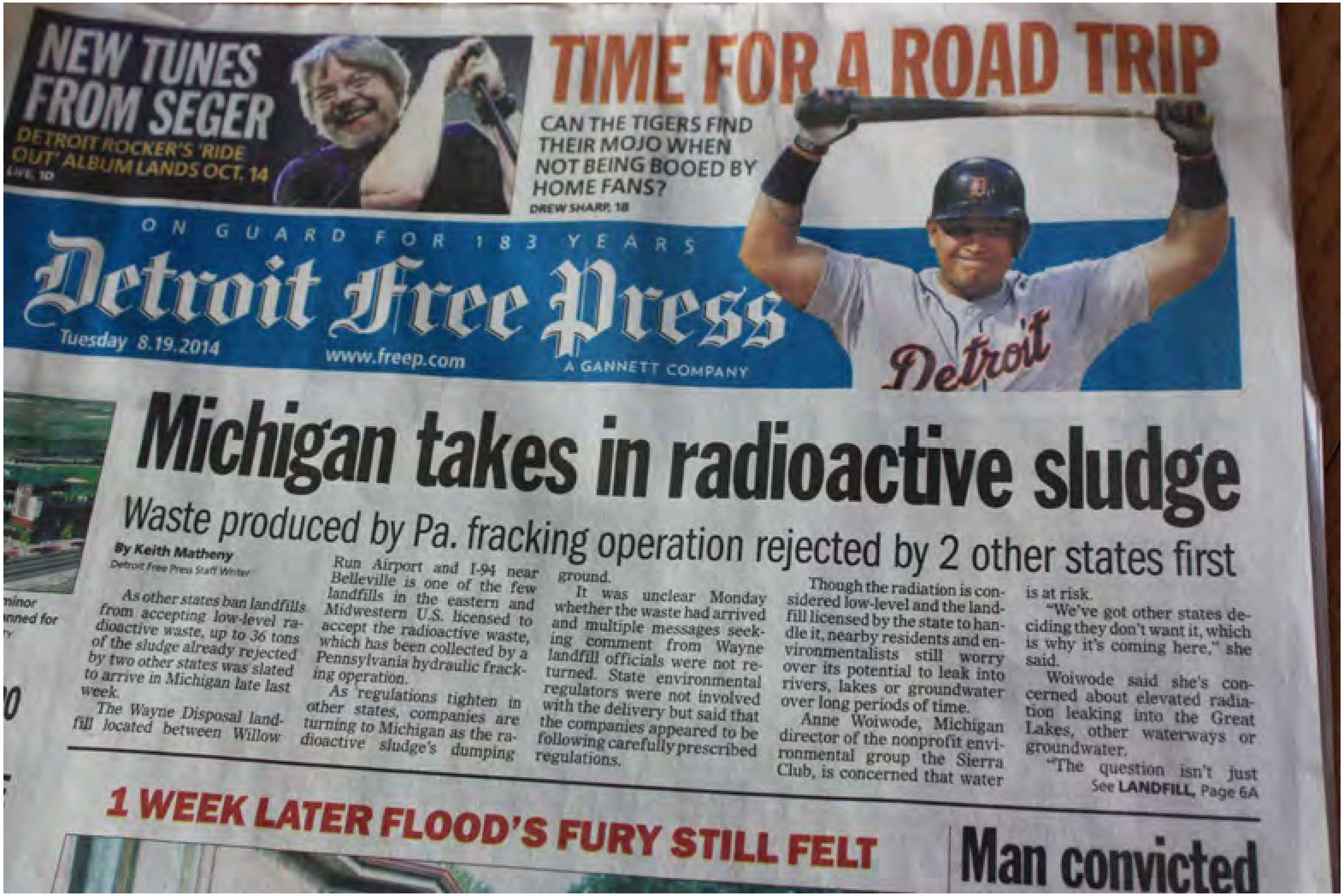
TENORM Disposal Challenges

- Not federally regulated
- Up to States to regulate licensing & disposal
- Rapidly changing regulatory environment
- Complex environment for generators
- Politics!!

State TENORM Disposal Limits

State	Ra-226 (pCi/g)	Notes / Basis
Oklahoma	0*	No ‘measurable’ rad accepted
Ohio	5	Via State Licensing Exemption
Nevada	5	Via State Licensing Exemption
Texas	30	Via State Licensing Exemption
Montana	15-50	Based on MDEQ 11/2015 Update
North Dakota	50	Disposal in ‘Special Waste’ landfills
Michigan	50	Disposal Only as per MDEQ approval
Pennsylvania	270*	Subject to dose rate and volume limits
Colorado	Variable	From 3-400 based on facility type
Idaho	1,500	At RCRA Subtitle-C landfills only

August 19, 2014



NEW TUNES FROM SEGER

DETROIT ROCKER'S 'RIDE OUT' ALBUM LANDS OCT. 14

LIFE, 1D

TIME FOR A ROAD TRIP

CAN THE TIGERS FIND THEIR MOJO WHEN NOT BEING BOOED BY HOME FANS?

DREW SHARP, 1B

ON GUARD FOR 183 YEARS

Detroit Free Press

Tuesday 8.19.2014

www.freep.com

A GANNETT COMPANY

Michigan takes in radioactive sludge

Waste produced by Pa. fracking operation rejected by 2 other states first

By Keith Matheny

Detroit Free Press Staff Writer

As other states ban landfills from accepting low-level radioactive waste, up to 36 tons of the sludge already rejected by two other states was slated to arrive in Michigan late last week.

The Wayne Disposal landfill located between Willow Run Airport and I-94 near Belleville is one of the few landfills in the eastern and Midwestern U.S. licensed to accept the radioactive waste, which has been collected by a Pennsylvania hydraulic fracking operation.

As regulations tighten in other states, companies are turning to Michigan as the radioactive sludge's dumping ground.

It was unclear Monday whether the waste had arrived and multiple messages seeking comment from Wayne landfill officials were not returned. State environmental regulators were not involved with the delivery but said that the companies appeared to be following carefully prescribed regulations.

Though the radiation is considered low-level and the landfill licensed by the state to handle it, nearby residents and environmentalists still worry over its potential to leak into rivers, lakes or groundwater over long periods of time.

Anne Woiwode, Michigan director of the nonprofit environmental group the Sierra Club, is concerned that water is at risk.

"We've got other states deciding they don't want it, which is why it's coming here," she said.

Woiwode said she's concerned about elevated radiation leaking into the Great Lakes, other waterways or groundwater.

"The question isn't just

See LANDFILL, Page 6A

1 WEEK LATER FLOOD'S FURY STILL FELT

Man convicted

Michigan Aftermath

- USE temporarily suspended fracking waste
- Gov. Snyder establishes multi-disciplinary TENORM Advisory Panel (incl MDEQ)
- Panel deliberated Sept 2014 – Feb 2015
- Published White Paper affirming 50 pCi/g Ra-226 disposal limit (link below)

https://www.michigan.gov/documents/deq/deq-RMG-TENORM_Disposal_Advisory_Panel_White_Paper_-_FINAL_481404_7.pdf

US Ecology Overview

- Based in Boise, Idaho
- Founded in 1952
- Publicly traded company (NASDAQ – Ticker: ECOL)
- Acquired EQ – The Environmental Quality Company in June 2014 for $465 million
  - Six (6) hazardous, PCB, and radioactive materials disposal facilities
  - Thirteen (13) hazardous materials treatment centers
  - 1,500 employees in Canada and the United States
  - $615 million revenue & $120 million EBITDA (combined 2014 pro-forma)

Safety and Compliance

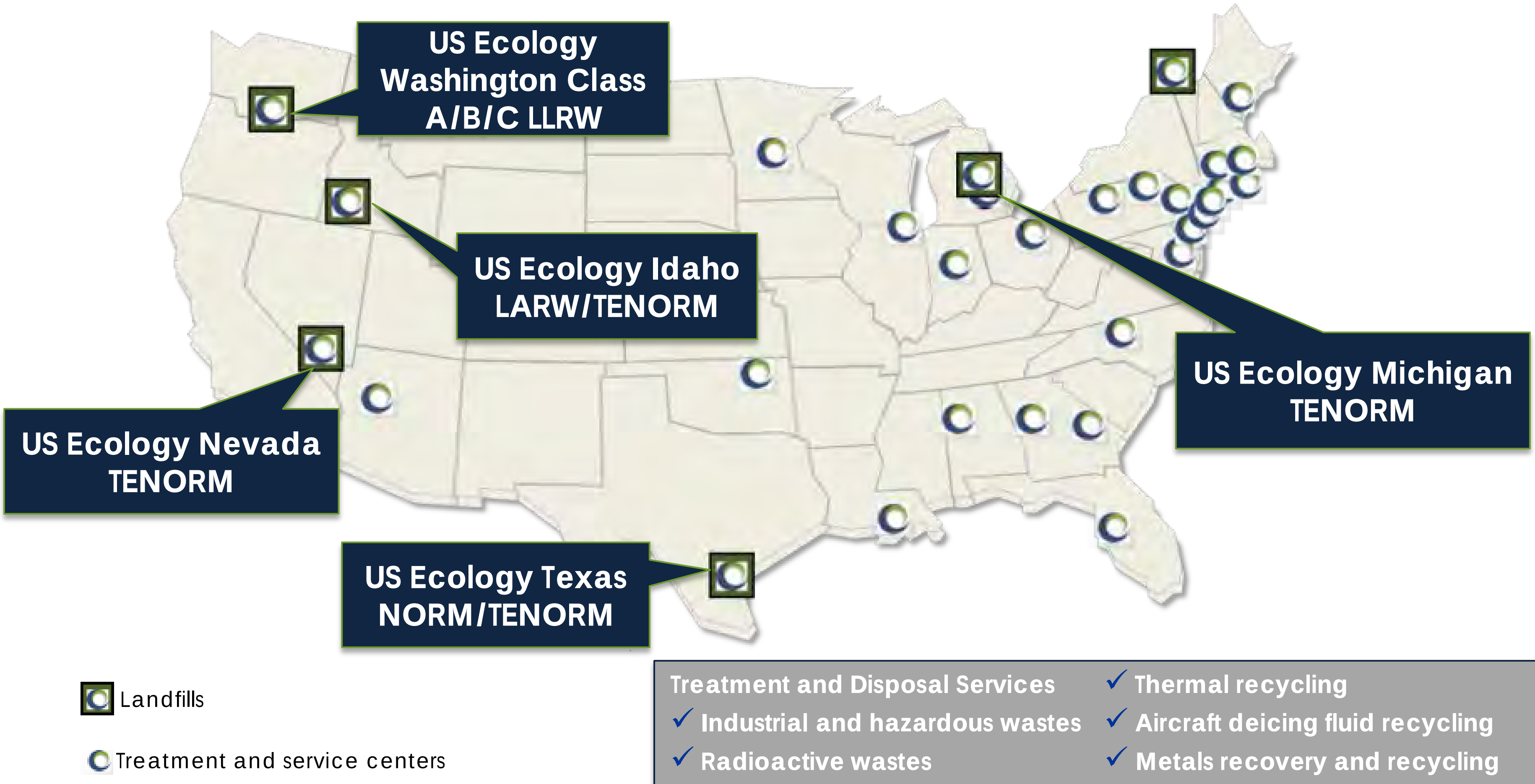
- Safe and Compliant Operations
  - **This is our top priority, period!**
- VPP Star Status at 3 Sites
- Very strong compliance record companywide
- Transparent and cooperative relations with state and federal agencies and local community

STAR WORKSITE

VPP

Partners in Safety and Health
OSHA – Management – Labor

Radioactive Disposal Network



Treatment and Disposal Services

- ✓ Industrial and hazardous wastes
- ✓ Radioactive wastes
- ✓ Mobile solvent recycling
- ✓ Organic chemical recycling
- ✓ Thermal recycling
- ✓ Aircraft deicing fluid recycling
- ✓ Metals recovery and recycling

US Ecology WAC Levels

WAC Parameter	USE Nevada (RCRA-C)	USE Texas (RCRA-C)	USE Michigan (RCRA-C)	USE Idaho (RCRA-C)	USE Washington (NRC LLRW)
Ra-226	5 pCi/g	30 pCi/g	50 pCi/g	500 pCi/g (bulk) 1,500 pCi/g (IP-1)	10,000 pCi/g or <1.2 Ci
Pb-210	None	150 pCi/g	260 pCi/g	1,500 pCi/g	Unlimited
K-40	TBD	818 pCi/g(1)	818 pCi/g(1)	818 pCi/g(1)	No Limit
Other TENORM	None	Tubulars (<50 uR/hr)	MDI Downblending(2)	Ra-228 1,500 pCi/g	Radium Sources, etc.
Source Material (10CFR 40 or State)	< 500 ppm bulk + Exempt Items	< 500 ppm bulk + Exempt Items	< 500 ppm bulk + Exempt Items	< 500 ppm bulk + Exempt Items	Class A/B/C LLRW
Byproduct Material (10 CFR 30 or State)	Exempt Items	Exempt Items	Exempt Items	Exempt Items, <3,000 pCi/g*(3)	Class A/B/C LLRW
SNM (10CFR 70)	None	None	None	<3,000 pCi/g*(3)	Class A/B/C LLRW

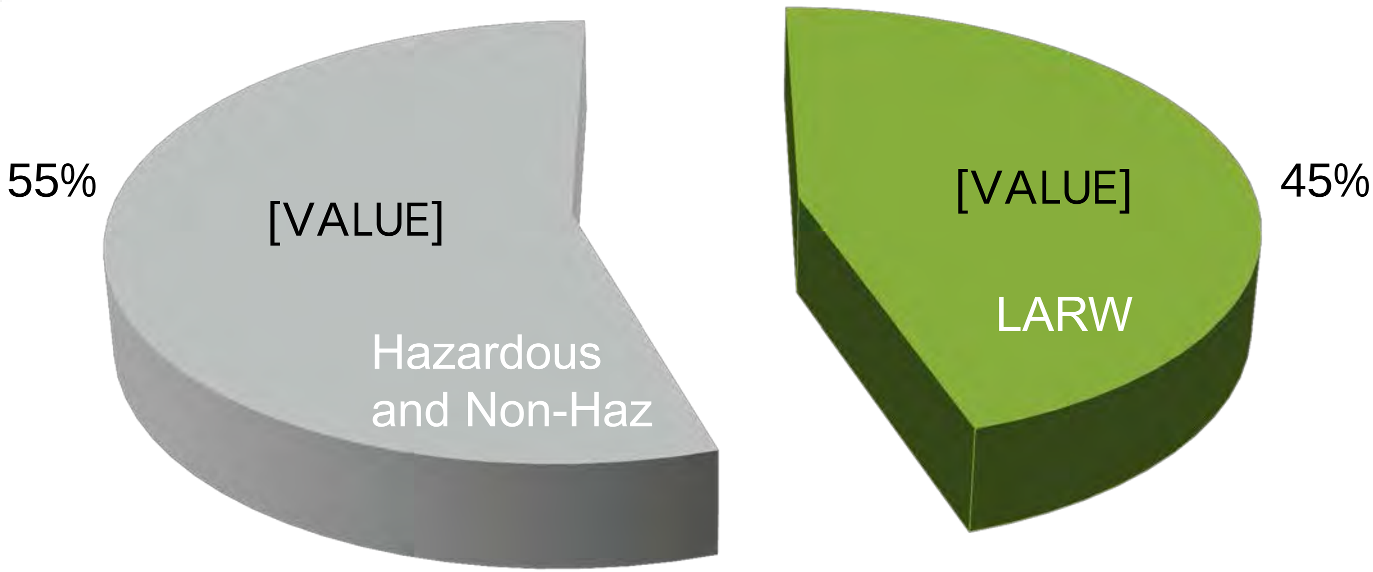
1. Natural amount of K-40 in elemental potassium
2. Consult USEM for more information
3. Requires Exemption, License Termination, or Release from Regulation

US Ecology Idaho

US Ecology Idaho Overview

- ‘Hybrid’ Low-Activity Radioactive Waste (LARW) Disposal Facility
- RP Program based on Washington LLRW program
  - Environmental Monitoring
  - Personnel and Environmental Dosimetry
  - Contamination Monitoring
  - RSO and Customer Audits

USEI 8 Million Tons Disposed (2000-2014)



Summary

- If you don't like TENORM regulations, check back in 10 minutes…
- Ample TENORM disposal capacity in the marketplace
- Need to understand the disposal landscape and where your waste fits

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MEASURING AND MODELING NORM

February 2, 2016

TENORM IN UNCONVENTIONAL OIL & GAS PRODUCTION WORKSHOP
sponsored by the
National Council on Radiation Protection and Measurements

Presented by: Andrew Lombardo, CHP
Senior Vice President & Manager of Nuclear Services
Perma-Fix Environmental Services, Inc.
Pittsburgh, PA
alombardo@perma-fix.com

MEASURING AND MODELING NORM

Presentation Focus:

1. Why is modeling NORM unique?
2. Developing the appropriate Source Term
3. Evaluating data used in the Source Term
4. Interpreting RESRAD results when NORM is in the Source Term

Measuring and Modeling NORM

NORM – Naturally Occurring Radioactive Material

We have sufficiently defined and discussed NORM.

Measuring and Modeling – To measure/model, i.e. perform a dose assessment, with NORM as a source term, an additional level of complexity associated with natural decay series and equilibrium (or not) must be addressed.

Measuring and Modeling NORM

What is a "Dose Assessment"?

An estimate of the potential future dose that could be caused by the residual radioactivity remaining on a site derived from site specific data, default values and a mathematical model to approximate the environment.

The mathematical model most likely used is the software code RESRAD.

Measuring and Modeling NORM – Simple Assessment

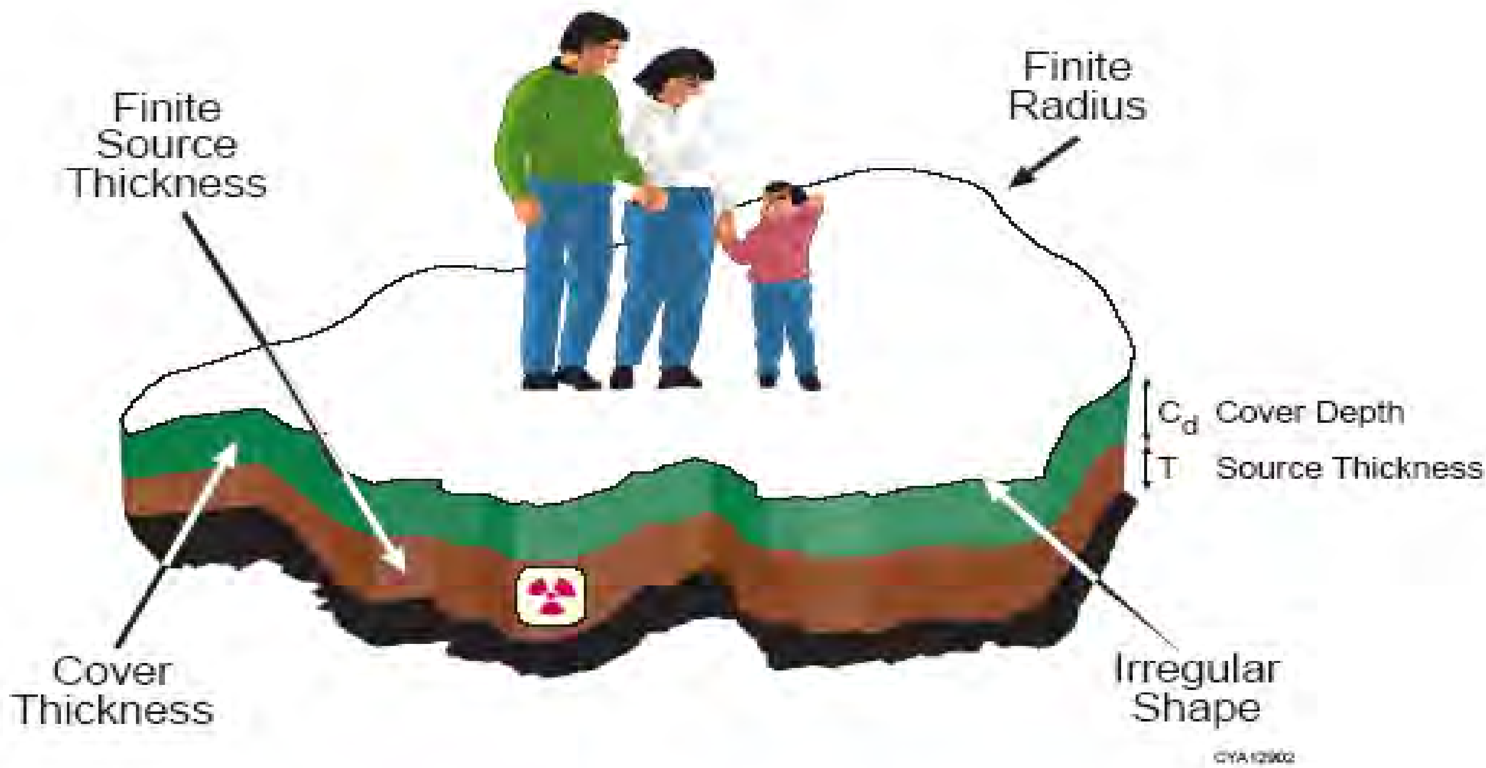

FIGURE 2.1 Geometry of Contaminated Zone

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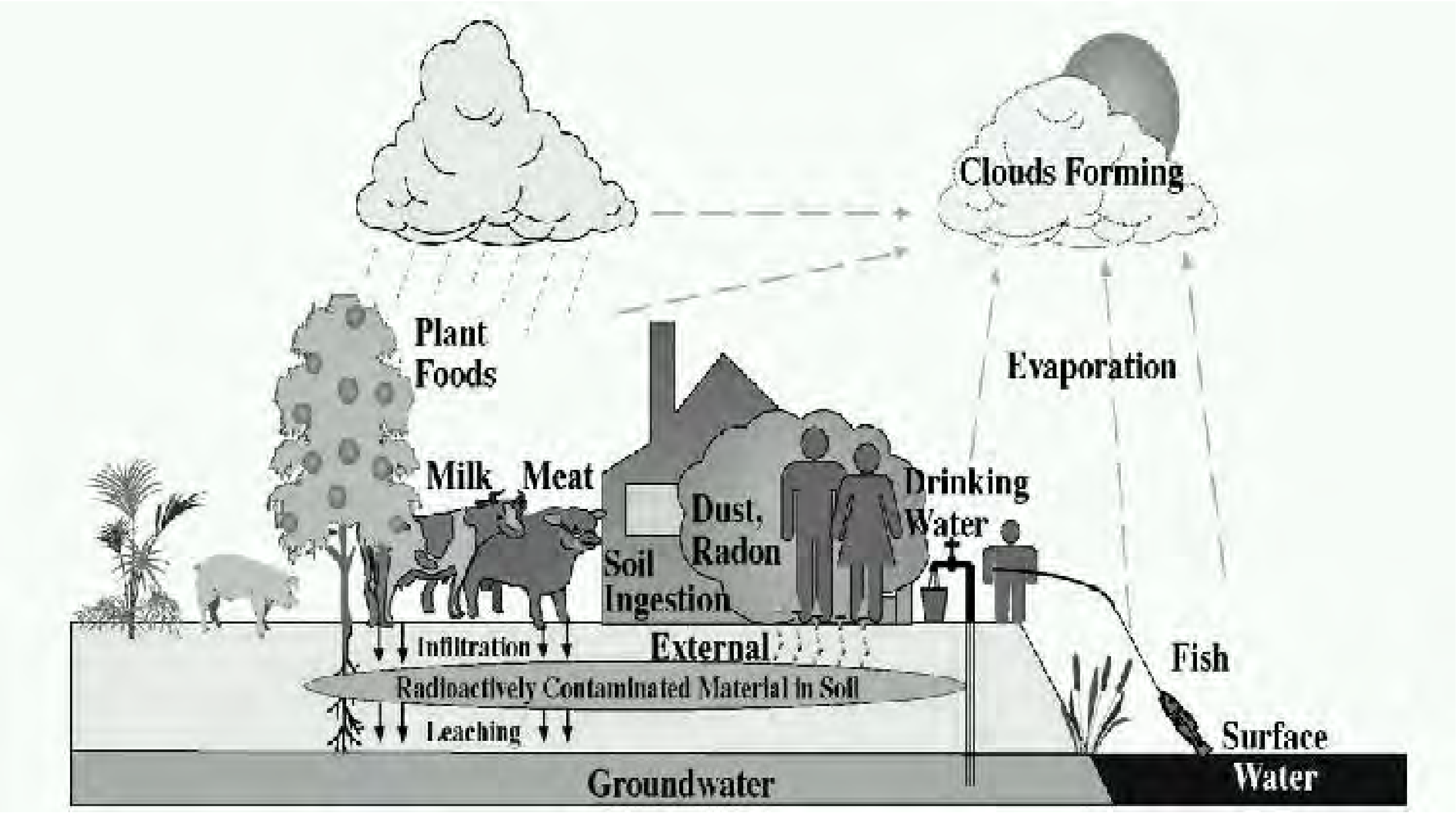
Measuring and Modeling NORM

Simple Assessment – one nuclide, one pathway, clearly defined geometry, one point in time, little uncertainty

- I could do this assessment with a good dose rate meter! And nail it.

- RESRAD helps us make sense of the complex process by which residual radioactivity delivers dose over time.

Measuring and Modeling NORM



Measuring and Modeling NORM

RESRAD is a pathway analysis computer code used to assess RESidual RADioactivity in the environment.

Hydrogeological, meteorological, geochemical, geometrical (size, area, depth), and material-related (soil, waste materials) parameters are used in the RESRAD code.

A total of 92 parameters are specified in RESRAD requiring user input via ten input screens.

Measuring and Modeling NORM

A dose assessment (pathway analysis) to determine dose or concentration corresponding to dose has four parts:

(1) **source analysis** – developing the source term,
(2) environmental transport analysis,
(3) dose/exposure analysis, and
(4) scenario analysis.

Measuring and Modeling NORM

Assessments can be complex.

Modeling NORM increases the complexity, mainly because of the complexity in source term development when NORM is present.

This presentation will focus on source term.

Measuring and Modeling NORM – Source Analysis

Source analysis, deriving the source term, ultimately determines the rate at which residual radioactivity is released into the environment. Rate determined by:

(a) the geometry of the contaminated zone,
(b) the radionuclides present and the concentrations of the radionuclides present, e.g. equilibrium?
(c) the in-growth and decay rates of the radionuclides, and
(d) the removal rate by erosion and leaching.

Measuring and Modeling NORM – Source Analysis

(a) the geometry of the contaminated zone

Size (volume) matters. Especially with NORM source terms where the activity concentration is relatively low but when combined with high volume still delivers enough radioactivity to pathways to result in appreciable dose.

For assessments of landfills determining the appropriate source term size can make a significant difference in results.

Measuring and Modeling NORM – Source Analysis

(b) the concentrations of the radionuclides present

For a large contaminated zone, such as a landfill, the actual activity concentration of each radionuclide is dependent on the activity concentration of the NORM waste and the fraction of the total waste that is not radioactive, i.e. dilution

If a landfill were filled with “exempt” radium and nothing else, would likely exceed nominal dose standard.

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Measuring and Modeling NORM – Source Analysis

2-10

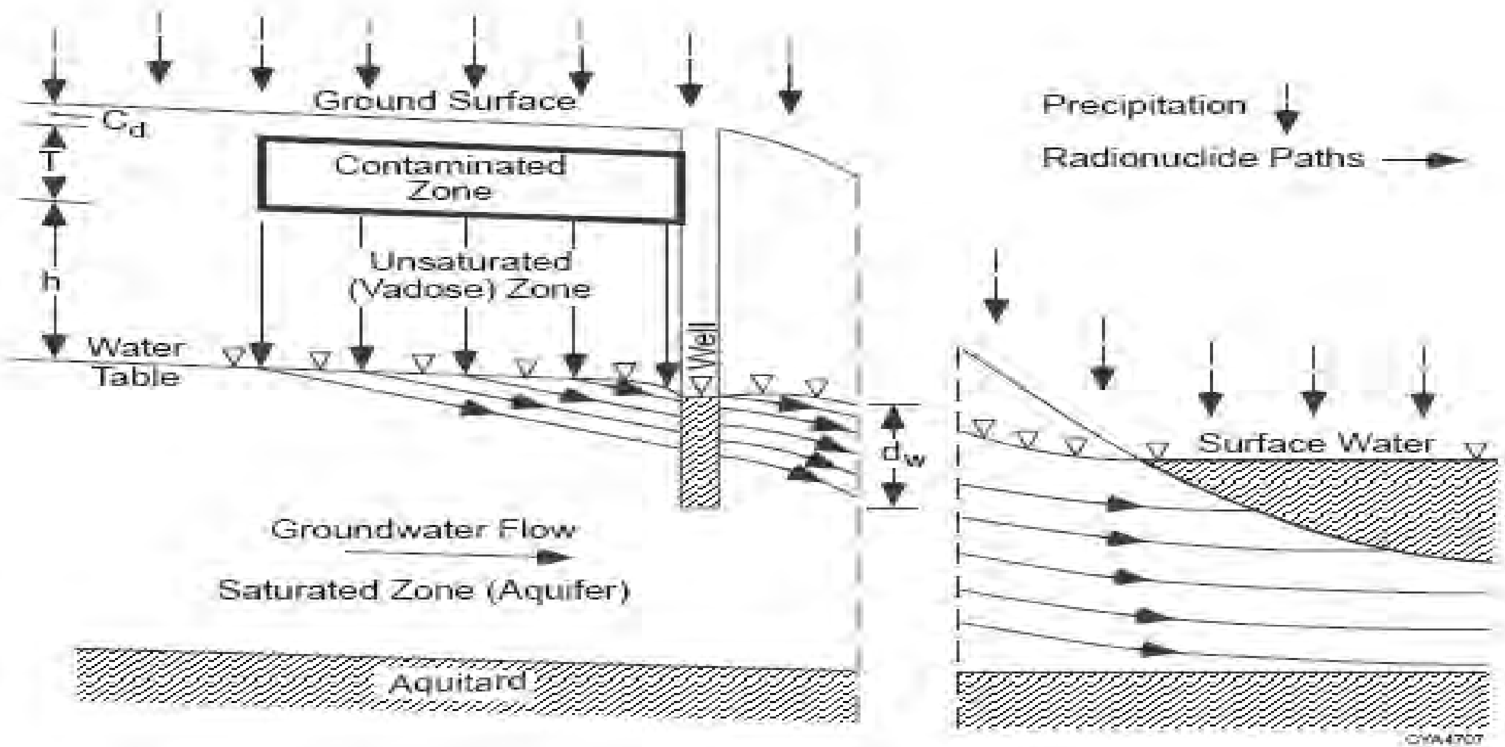

FIGURE 2.3 Schematic Representation of the Water Pathway Segments

Measuring and Modeling NORM – Source Analysis

(c) the in-growth and decay rates of the radionuclides

Input of actual state of equilibrium concentrations. Sample and analysis to determine a NORM source term is complicated:

- Not all key members of decay series can be determined by standard gamma spec analysis
- Determining which decay series are present
- Determining the state of equilibrium of members of the series present, or subseries present.

Measuring and Modeling NORM – Source Analysis

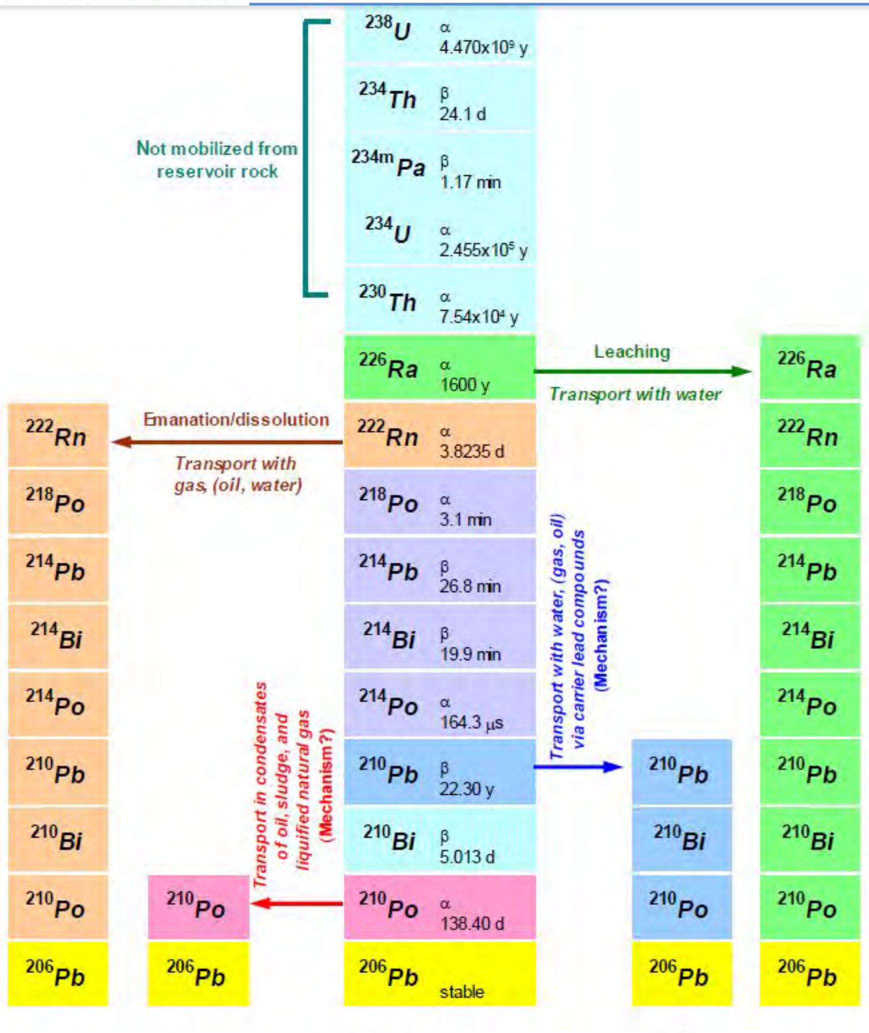

FIG. 41. Transport of ^{238}U progeny in oil and gas production

Not understanding the status of equilibrium of progeny may lead to an incorrect source term.

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Measuring and Modeling NORM – Source Analysis

(c) the in-growth and decay rates of the radionuclides continued…

Input only the long lived progeny present, in appropriate status of equilibrium. Interpretation of the assessment results includes the contribution of the short-lived progeny:

Uranium Series

1. U-238 (long lived)
Th-234, Pa-234m
2. U-234 (long lived)
3. Th-230 (long lived)
4. Ra-226 (long lived)
Rn-222, Po-218, Pb-214, Bi-214, Po-214

*5. Pb-210 (long lived)*Bi-210, Po-210

Thorium Series

1. *Th-232 (long lived)*
2. *Ra-228 (long lived)*
Ac-228
3. Th-228 (long lived)
Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Th-208

Actinium Series

1. *U-235 (long lived)*
Th-231
2. *Pr-231 (long lived)*
3. Ac-227 (long lived)
Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Th-207

Measuring and Modeling NORM – Source Analysis

(d) the removal rate by erosion and leaching

Each assessment has several key input parameters that drive the result and the time at which the max dose occurs:

- Erosion of the cover
- Erosion of the contaminated zone
- Leaching of radioactive material – both groundwater and radon pathways
- Kd values – determine rate of migration to groundwater

Measuring and Modeling NORM – Assessment Results

The RESRAD output is used to answer questions:

Is the total dose acceptable?

Which pathways are providing the majority of the dose?

Which radionuclides are providing the majority of the dose?

Do the results make sense?

Measuring and Modeling NORM – Assessment Results

Is the total dose acceptable?

- Dose the result meet the standard selected, e.g. 25 mrem/yr TEDE, for 1,000 years or 100 mrem TEDE?
- Is the result representative of the majority of the population or of the “maximum potential” population?
- Is a probabilistic assessment appropriate to determine a range of possible dose results?

Measuring and Modeling NORM – Assessment Results

Which pathways are providing the majority of the dose?

- For NORM source terms including radium the radon pathway may be limiting?
- Is the radon pathway included in the assessments? Many states and federal organizations preclude the use of the radon pathway.
- Groundwater pathways may be limiting in the future once the residual radioactivity has migrated and built up in groundwater.

Measuring and Modeling NORM – Assessment Results

Which radionuclides are providing the majority of the dose?

- Usually dependent on what pathway is providing the majority of dose:
  - Radon pathway – radium
  - External shine – thorium and progeny
  - Groundwater pathways – uranium and radium
- May be a function of relative activity concentration at onset of assessment

Measuring and Modeling NORM – Assessment Results

Do the results make sense?

- The RESRAD model is not perfect. Especially in regards to the complex natural of decay series ingrowth and decay
- The maximum dose may occur at a time beyond the scope of the assessment, e.g. > 1,000 years post onset
- Timing is critical. Not all of the pathways “peak” at the same time. Review the output graphs over time.

Measuring and Modeling NORM – Assessment Results

A review of the initial assessment results should be used to develop additional iterations of the assessment and a sensitivity analysis of key input parameters.

A proper assessment is actually the culmination of multiple RESRAD "runs" and evaluation of the results.

QUESTIONS?

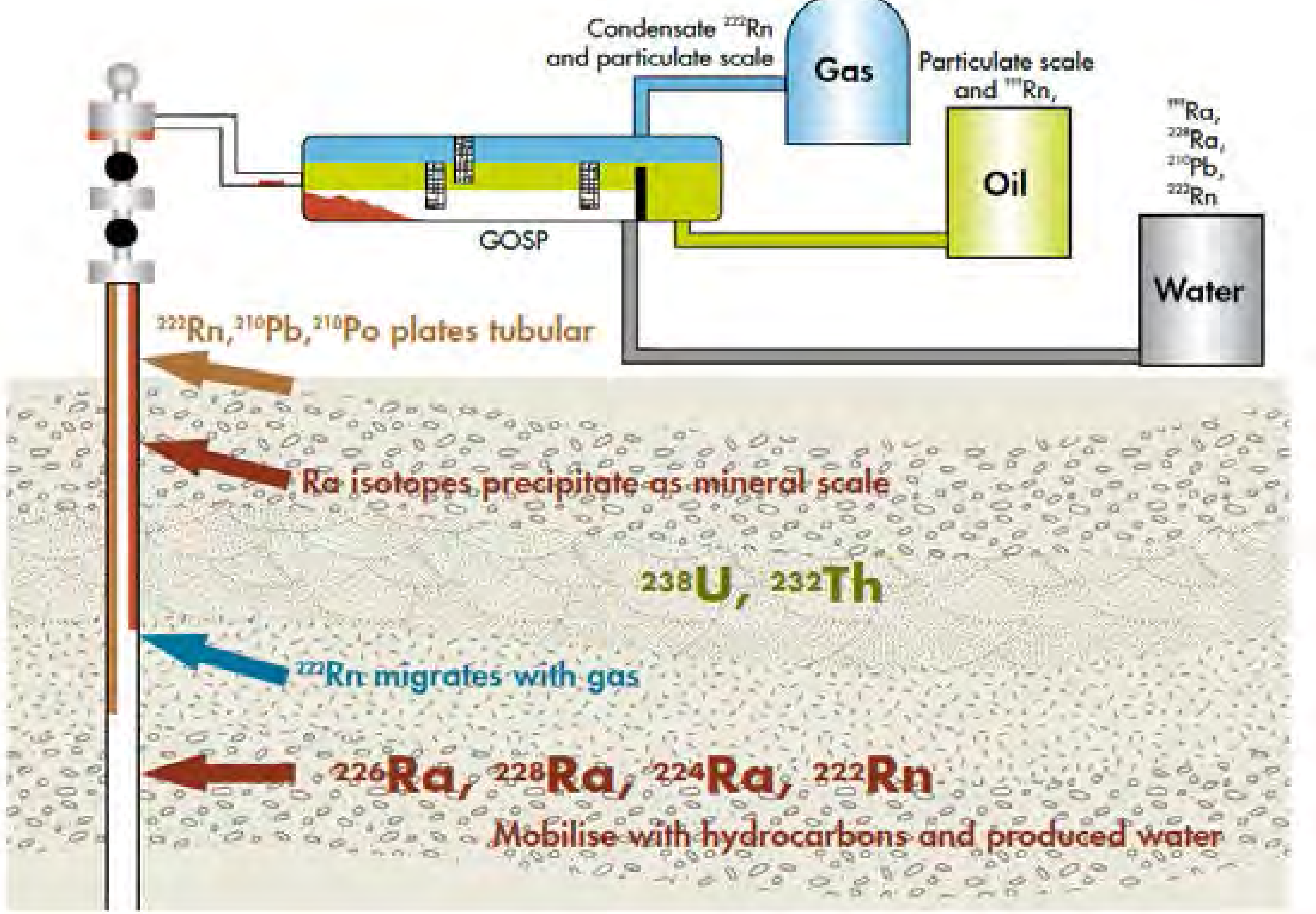
Deep Well Injection of Oil & Gas NORM Waste

NCRP SC-2 Scientific Committee on TENORM in Oil & Gas
HPS 2016 Midyear Meeting, Austin, TX – Feb 2, 2016

Presented by: Mel Hebert
Lotus, LLC

Production of Oil & Gas NORM Waste

Typically on the Production Side of Exploration & Production (E&P) Facilities – Especially Older Operations



Condensate ^{222}Rn
and particulate scale
Gas
Particulate scale
and Rn,
Oil
Ra,
Ra,
^{210}Pb,
^{222}Rn
Water
GOSP
^{222}Rn, ^{210}Pb, ^{210}Po plates tubular
Ra isotopes precipitate as mineral scale
^{238}U, ^{232}Th
^{222}Rn migrates with gas
^{226}Ra, ^{228}Ra, ^{224}Ra, ^{222}Rn
Mobilise with hydrocarbons and produced water

Production Tubing & Flow Line

Surface Equipment

Tank Bottoms

Pipeline Pigging Operations

Spills/Poor Practices

Oil & Gas NORM Disposal Options

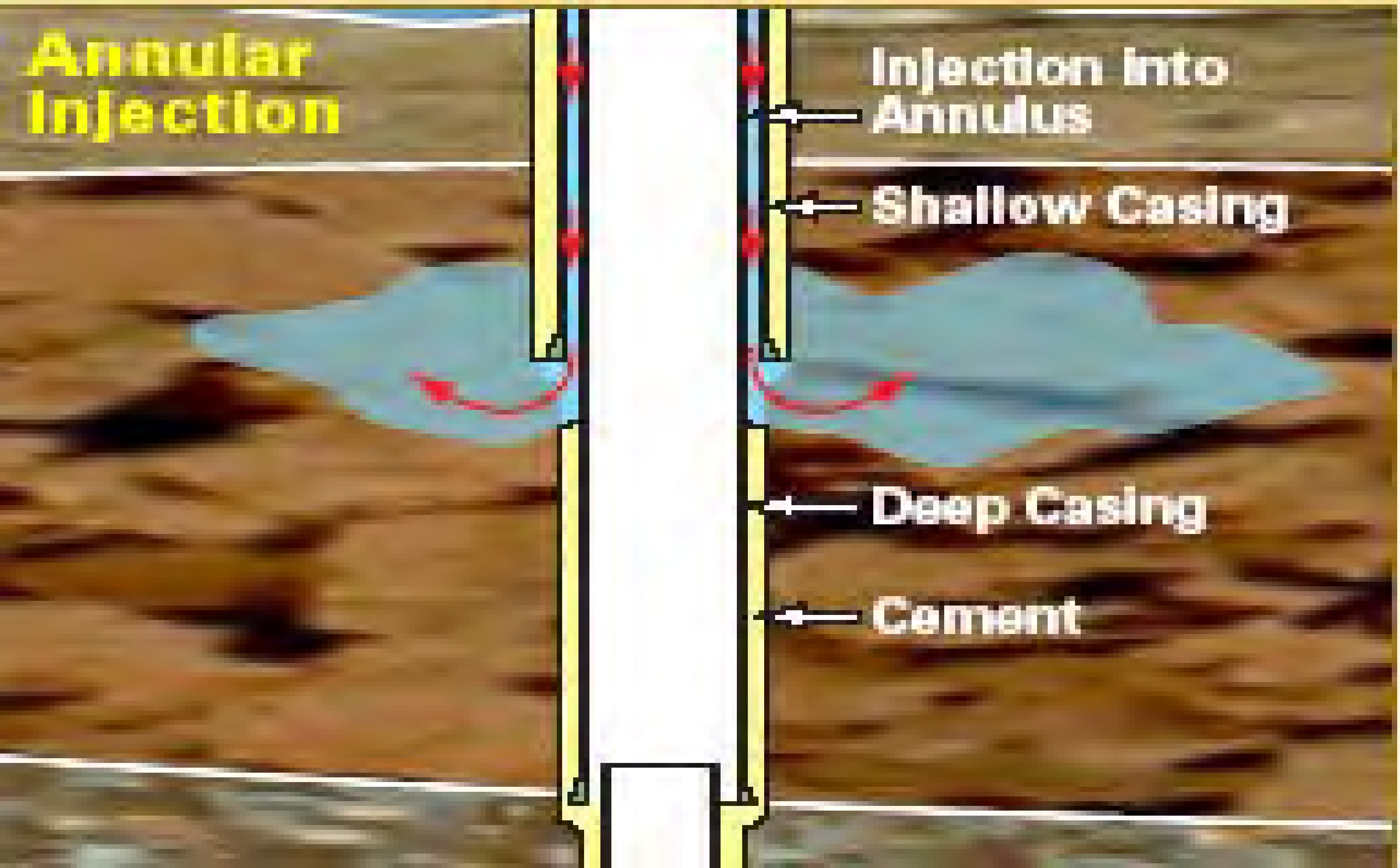
1. Shallow Land Burial
2. Treatment/Dilution to Non-hazourdous Oilfield Waste (NOW)
3. Encapsulation in Plugged & Abandoned (P&A) Wells
4. Landspreading with Dilution On Site
5. Deep Well Injection

Deep Well NORM Injection

1. Annular Injection
2. Slurry (Hydraulic) Fracture Injection
3. Cap-Rock/Sub-Fracture Injection
4. Cavern Well Injection

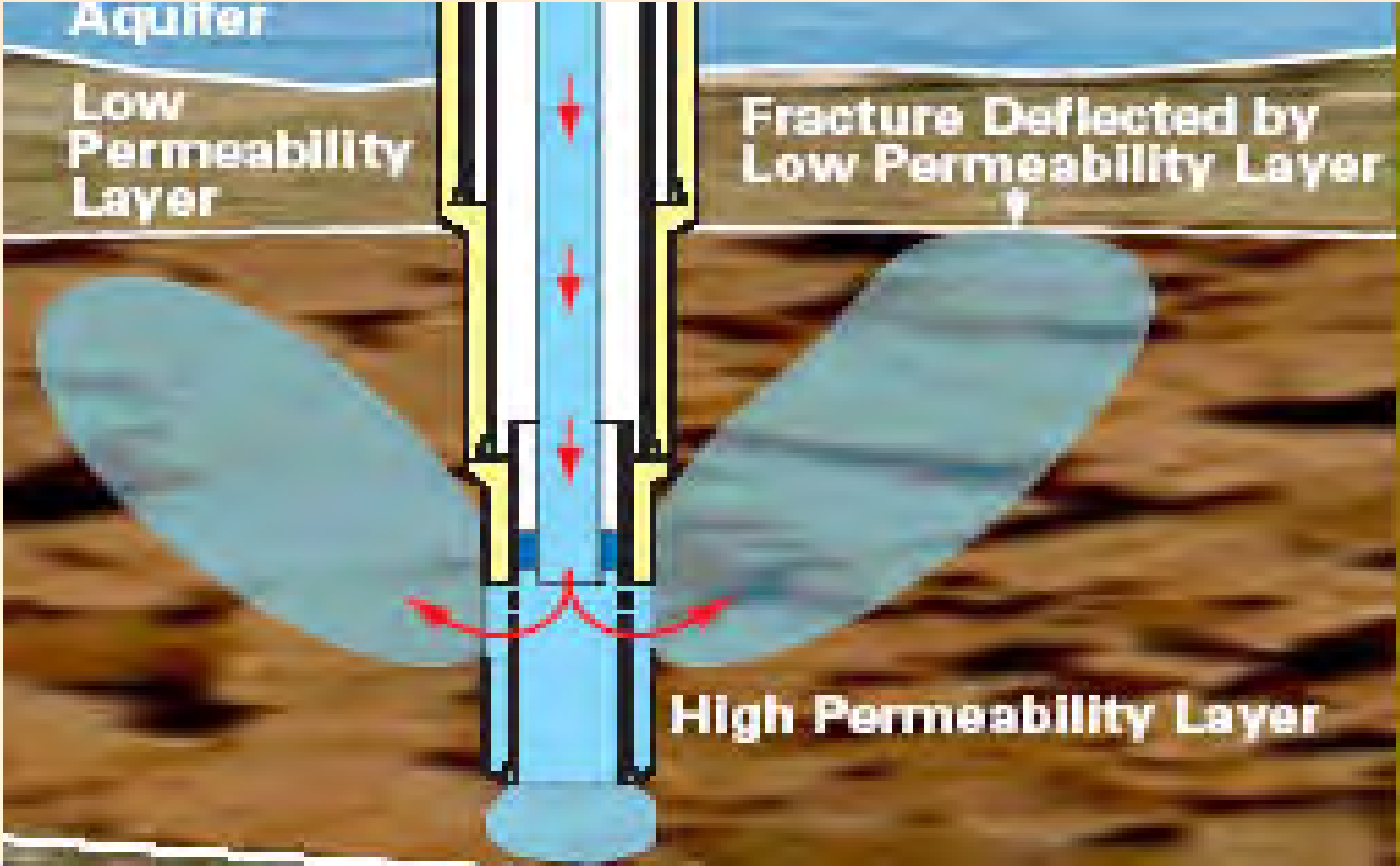
Annular Injection

1. Slurry Injection through the Space between 2 Casing Strings
2. Suspended Solids are Injected Under High Pressure
3. Completed on Existing Wells typically during P&A, or in Old Injection Wells.


Annular Injection
Injection Into Annulus
Shallow Casing
Deep Casing
Cement

Slurry (Hydraulic) Fracture Injection

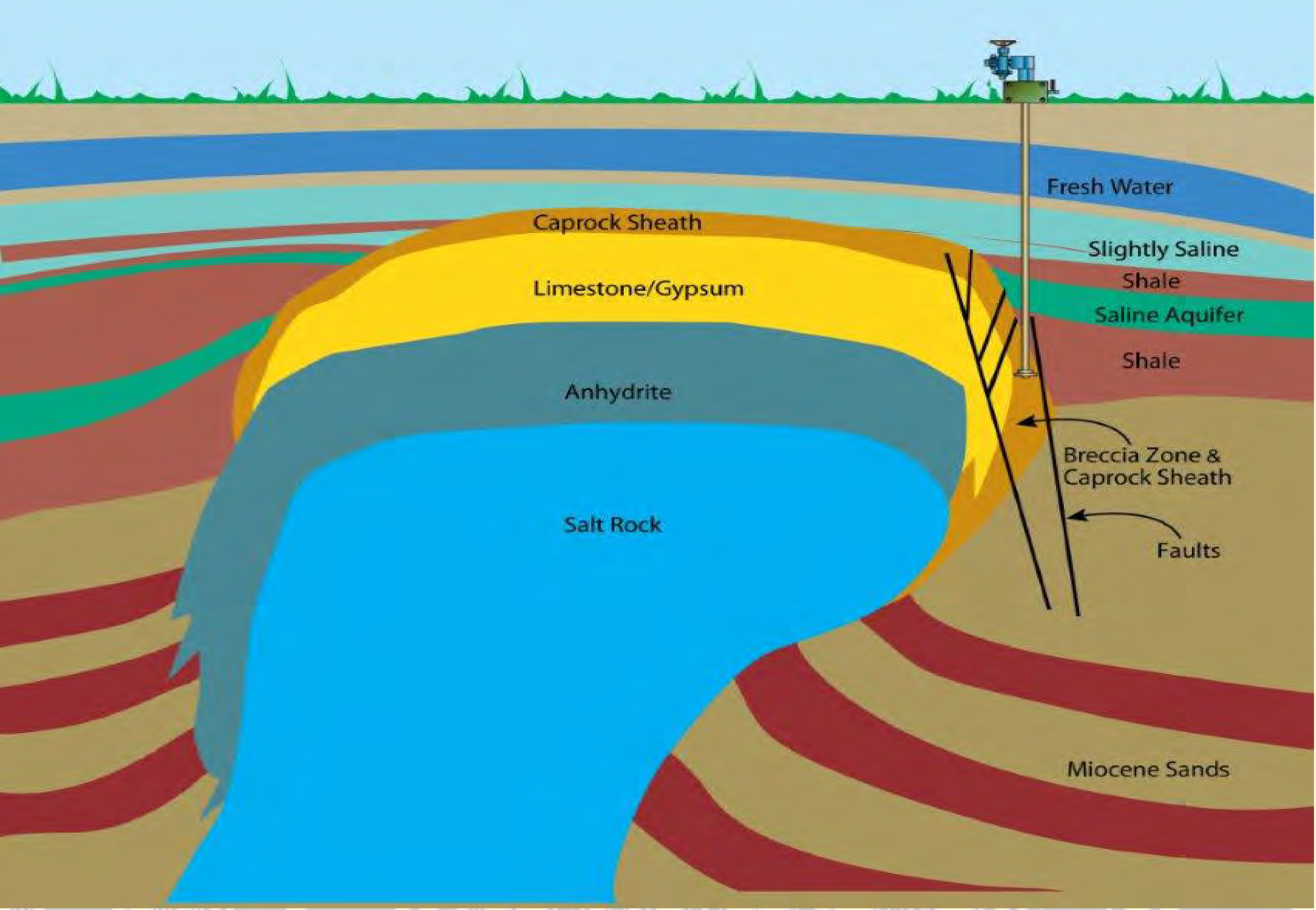
1. **Waste is injected by Fracturing Formations**
2. **Suspended solids are Injected Under High Pressure (Fracturing Pressure)**



Aquifer
Low
Permeability
Layer
Fracture Deflected by
Low Permeability Layer
High Permeability Layer

Cap-Rock/Sub-Fracture Injection

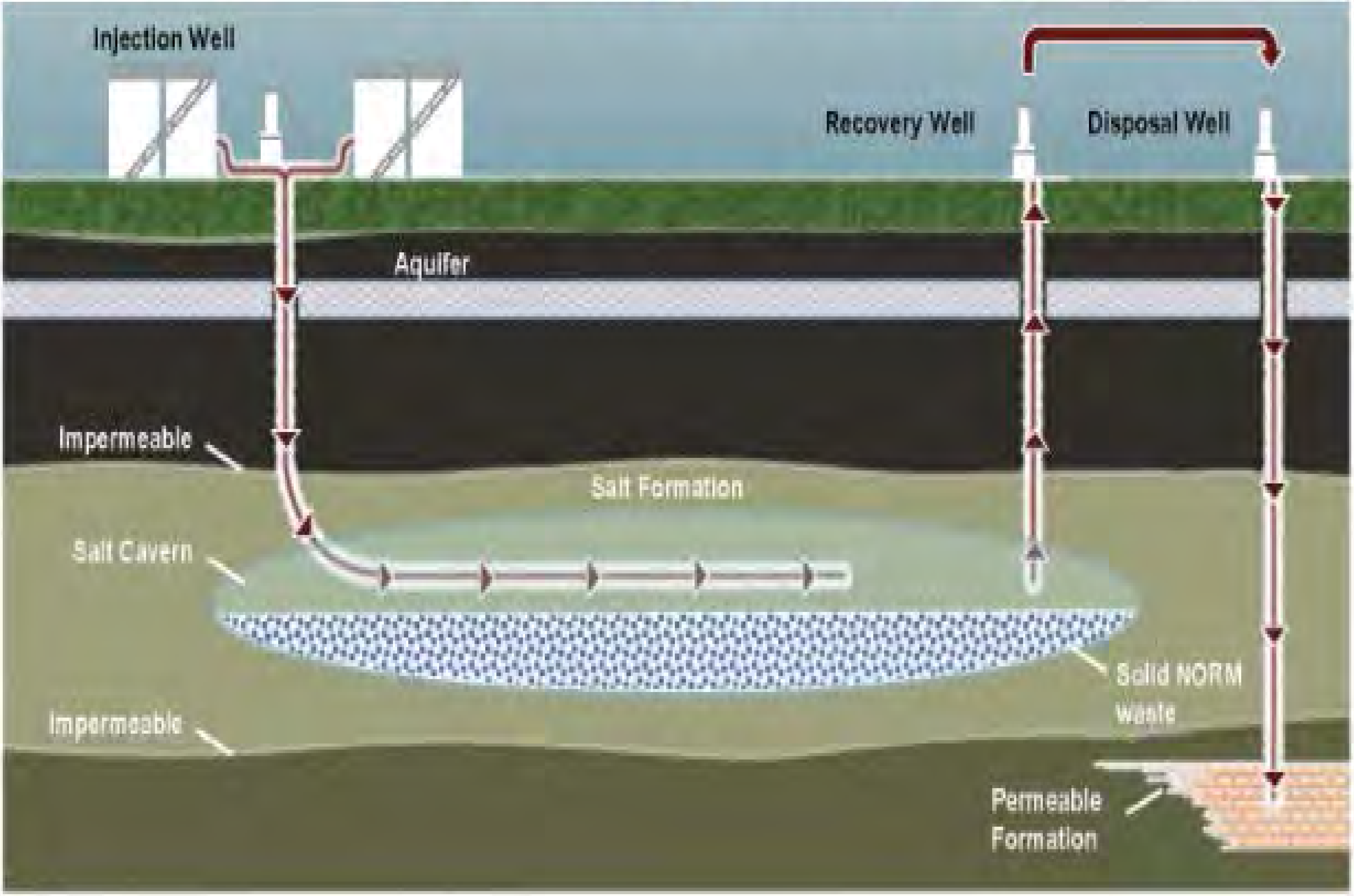
1. **Waste is Injected into Loss Circulation Zones under Moderate Pressure.**
2. **Processing and Injecting Waste into the Cap Rock of an Isolated Salt Zone**


Fresh Water
Caprock Sheath
Slightly Saline
Shale
Limestone/Gypsum
Saline Aquifer
Shale
Anhydrite
Breccia Zone &
Caprock Sheath
Salt Rock
Faults
Miocene Sands

Cavern Well Injection

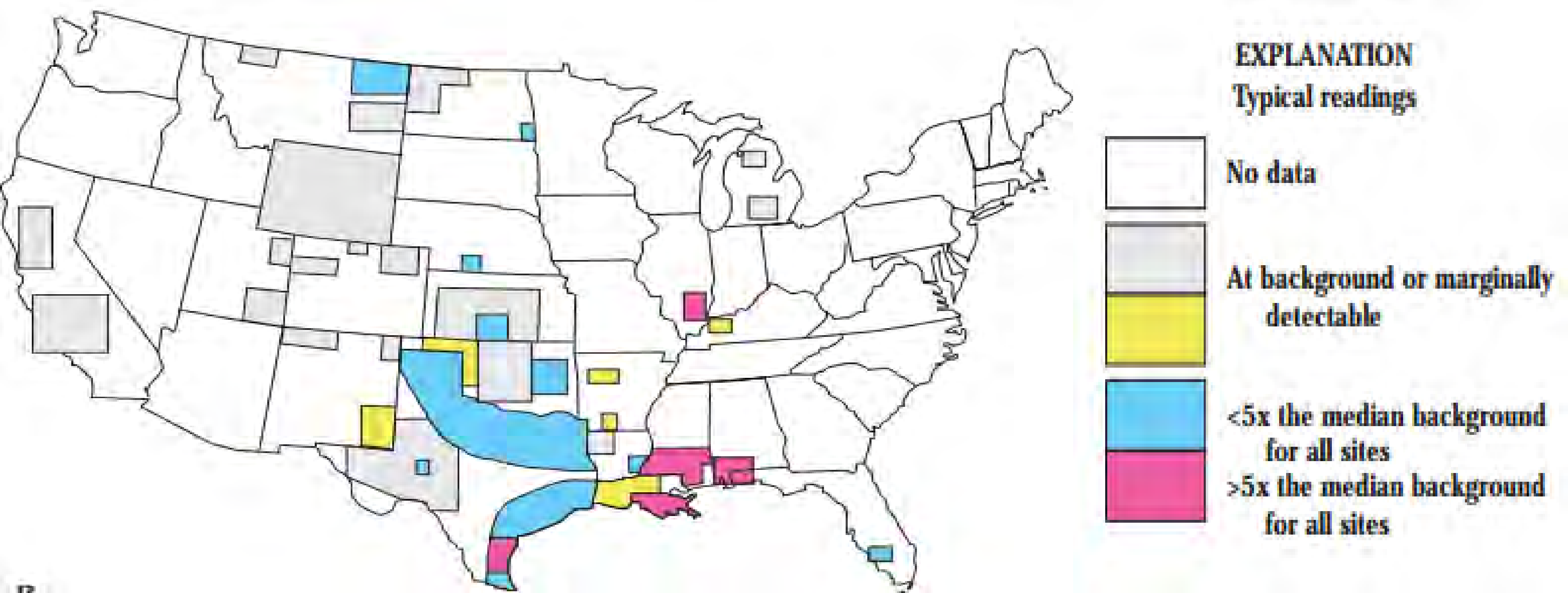
1. Deep Bedded or Domal Salt Formation
2. Caverns Act Like Giant Oil/Water/Solids Separators
3. Processed from Solids, Liquids and/or Mixtures
4. Technically Feasible & Economical
5. Poses a Very Low Human Health Risk

Lotus Patented Process for NORM Disposal



How much NORM is out there?

1. 1995 Argonne National Lab Study: Estimated 10,000,000 BBLS of NORM Produced
2. Up to 30% of surface equipment showed levels at or above background levels



API Drilling Waste Volume Estimates

API Survey (Drilling Waste)	1985 Study (BBLS/YR)	1995 Study (BBLS/YR)
Generated Liquids	324,000,000	109,000,000
Generated Solids	38,000,000	39,000,000
Estimated NORM (1% of Solids)	400,000	400,000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TEXAS
NEW MEXICO
OKLAHOMA
ARKANSAS
LOUISIANA
ARIZONA
MISSOURI
MEXICO
SANTA FE
Albuquerque
Amarillo
Plainview
Lubbock
Wichita Falls
Abilene
Odessa
El Paso
San Angelo
Ft. Worth
Dallas
Paris
Tyler
Longview
Shreveport
Naco
Waco
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Corpus Christi
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Brownsville
MONTERREY
CHIHUAHUA
OKLAHOMA CITY
Tulsa
LITTLE ROCK
Gulf of Mexico
Padre Island
0 km 75 150 125 km
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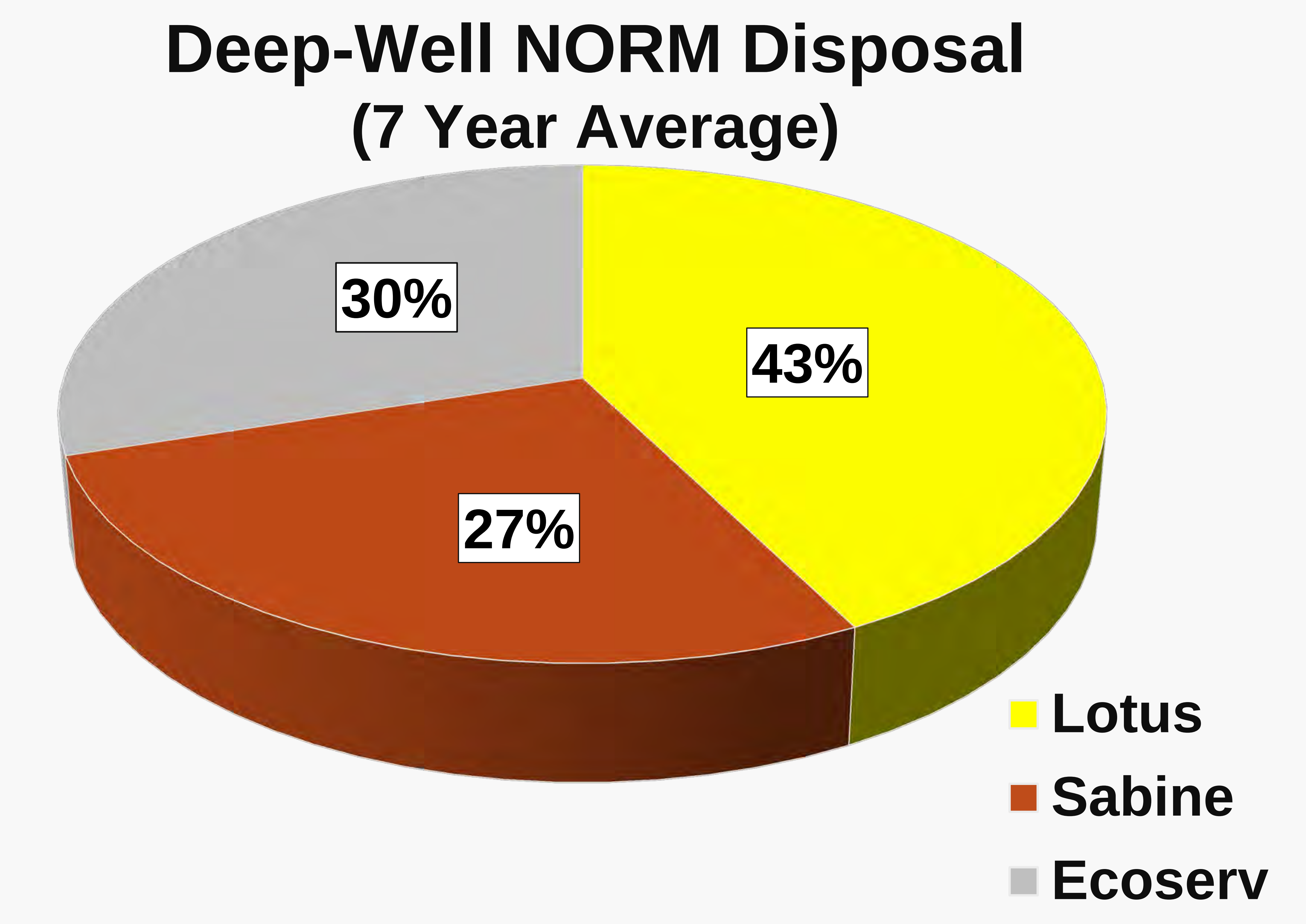
Deep-Well NORM Disposal
(7 Year Average)
30%
43%
27%
Lotus
Sabine
Ecoserv

Texas Commercial Deep Well Disposal

NORM Incoming Receipts	Average Annual NORM Receipts	Total NORM Receipts
7 Years (2009 – 2015)	58,000 BBLS (10 Million Liters)	403,000 BBLS (64 Million Liters)
Since Inception (All Commercial TX Wells) (1994 – 2015)	46,000 BBLS (7 Million Liters)	1,000,000 BBLS (161 Million Liters)