Michigan TENORM Disposal Advisory Panel White Paper

2014-2015

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EXECUTIVE SUMMARY

On August 25, 2014, Governor Rick Snyder directed the Michigan Department of Environmental Quality (MDEQ) to assemble a panel of experts to review Michigan's standards for disposing low-activity radioactive materials. He charged the group with providing a technical review of Michigan's current disposal guidelines for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) to assess if these guidelines sufficiently protect public health and the environment.

Michigan's current TENORM disposal guidelines are 50 picoCuries per gram (pCi/g) of Radium-226, provided in "*EQC - 1602 – Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226 (Ra-226).*" It was established in 1996 and subsequently studied in 1999 by the U.S. Department of Energy's (DOE) Argonne National Laboratory (ANL). Their review, "*An Assessment of the Disposal of Petroleum Industry NORM in Nonhazardous Landfills*," concluded that up to 50 pCi/g of Radium-226 can be safely disposed in any Type I (i.e., hazardous waste) or Type II (i.e., municipal solid waste) landfill in Michigan without adverse impact to human health or the environment.

The TENORM Disposal Advisory Panel (TDAP) investigated current federal and state regulatory standards, changes to risk assessment methodology since the 1990s, the nature of TENORM and how it decays over time, methods of mathematical modeling dose assessment to workers and members of the public, and the design and operation of modern landfills. In keeping with its charge and by unanimous agreement of the TDAP, the effects of disposal of TENORM were evaluated independent of the origin of the materials.

The TDAP also thoroughly reviewed the 1999 ANL study and is in agreement with its conclusions that the current MDEQ disposal guideline of 50 pCi/g is safe for public health and the environment. However, as a result of the TDAP's thorough investigation into this study as well as others recently performed for other states, notably North Dakota and Pennsylvania, the TDAP developed specific recommendations for MDEQ:

1. **Consider clarifying the applicability of Michigan's TENORM disposal regulation - *EQC 1602, Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226*.** The current document includes both cleanup criteria for contaminated sites as well as disposal of Radium-226 in landfills. The TDAP recommends splitting EQC-1602 into two documents to clarify the guidance.

2. **Consider requiring all landfills that accept TENORM waste to restrict its placement.** Restricting placement such that the TENORM remains at least 10 feet below the bottom of the landfill cap, in keeping with the ALARA principle, reduces the radon exposure to negligible levels.

3. **Consider requiring all landfills that accept TENORM waste to restrict the total volume of TENORM waste placed annually.** The primary factor affecting worker dose is the amount of waste being handled annually. Restricting the total volume of TENORM waste helps to limit worker exposure.

4. **Consider requiring all landfills that accept TENORM waste to monitor leachate and ground water monitoring wells for Radium-226.** Landfills currently have leachate collection systems and ground water monitoring wells which are routinely tested. Adding a Radium-226 test to the testing protocol provides additional assurance.

5. **Consider modifying regulatory guidelines to clearly identify that different limits should apply between Type I and Type II landfills.** The MDEQ disposal guidelines do not differentiate between Type I and Type II landfills, and the TDAP discovered significant differences in levels of protection between them that could allow a great activity concentration of Radium-226 in Type I landfills.

6. **Consider developing regulatory guidelines for the safe handling of TENORM contaminated with Lead-210.** Currently only Radium-226 is considered in the MDEQ disposal guidelines. Due to its short half-life, the TDAP does not consider Lead-210 to pose a long term disposal risk; however, Lead-210 may pose a health risk to workers, particularly in the gas and pipeline cleaning industries.

The TDAP also documented several other 'Areas for Future Consideration' discovered during the panel's deliberations but determined to be outside the Governor's primary charge.

The composition of the TDAP was similar to the science and industry panel that originally established Michigan's standards in 1996, with representatives from the MDEQ, the University of Michigan, the Health Physics Society, the Michigan Environmental Council, the Hospital/Medical Physics community, the environmental consulting community, the oil and gas industry, the waste management industry, and a member of the general public.

I. Overview of TENORM Disposal Advisory Panel

On August 25, 2014, Governor Rick Snyder directed the MDEQ to assemble a panel of experts to review Michigan's standards for disposing low-activity radioactive materials. Specifically, he asked the panel to address recent questions concerning landfilling of oil and gas wastes containing low levels of TENORM. Additionally, he asked the TDAP to determine if Michigan's current landfill disposal standard (EQC - 1602 – *Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226*) sufficiently protects public health and the environment.

The composition of the group was similar to the science and industry panel that originally established Michigan's standards in 1996. Subsequent review of those standards by the U.S. DOE suggested Michigan could even raise its disposal standard substantially at some landfills.

Appointees to the TDAP were:

- **Duane DeMore**, CHP, Chesapeake Nuclear Services, Novi, representing the Health Physics Society
- **Cheryl Culver Schultz**, Medical Nuclear Physicist, Beaumont Health Systems, Royal Oak, representing the medical community
- **Kimberlee J. Kearfott**, ScD, CHP, Professor of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, representing academia

- **Nicholas Occhipinti**, West Michigan Environmental Action Council, Grand Rapids, representing the Michigan Environmental Council
- **Donald J. Carpenter**, PG, CPG, Senior Vice President and Chief Geochemist, ARCADIS, Inc., Brighton, representing environmental consultants
- **Joseph J. Weismann**, CHP, US Ecology, Inc., Boise, ID, representing the waste disposal industry
- **Bill Myler, Jr**., Muskegon Development Company, representing the oil and gas industry
- **Ken Yale**, MDEQ Radiological Protection Section
- **Dave Minnaar**, Middleville, representing the public

The TDAP held its first meeting September 22, 2014. A total of 7 meetings and one conference call were held. This white paper serves as the TDAP's final report to MDEQ Director Dan Wyant.

Throughout the report, two documents are referenced frequently. For consistency and clarity, the following will be used:

1. The term "MDEQ disposal guidelines" refers to the 1996 MDEQ document: EQC – 1602 *Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226 (Rev. 03/ 2007).*

2. The term "1999 ANL study" refers to the report issued by the DOE's ANL in September 1999, titled: *"An Assessment of the Disposal of Petroleum Industry NORM in Nonhazardous Landfills."*

II. Summary of Current TENORM Disposal Practices in Michigan

In 1996, the MDEQ issued EQC - 1602 – *Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226.* The revision in use today is Rev. 03/2007. The revisions only reflect changes in administration and organization. The standards set in the original 1996 version are the same as those in the current revision. The MDEQ disposal guidelines state:

"1. For disposal of radium-226 contaminated materials in the form of bulk waste, such as contaminated soil or contaminated debris, materials containing a radium-226 concentration not exceeding 50 pCi/g, averaged over any single shipment, can be accepted without regard to radioactivity in a Type I or Type II solid waste landfill, as defined in Parts 111 and 115 of 1994 PA 451, as amended. Prior to shipment, the generator must provide the following information to the MDEQ's Waste and Hazardous Materials Division *[now the Office of Waste Management and Radiological Protection],* Radiological Protection Section:

a. Verification of radium-226 concentrations based upon representative sampling.
b. The name and address of the proposed Type I or Type II landfill recipient.
c. The proposed date of transfer and estimate of the total volume and radioactivity content of the waste.

Proposed shipments are subject to independent confirmation testing by the MDEQ.

2. For disposal of radium-226 contaminated waste materials at concentrations above 50 pCi/g, the contaminated wastes should be transferred to a licensed radioactive waste disposal facility. *There are no licensed radioactive waste disposal facilities in Michigan.*

3. In addition, any naturally occurring radioactive material wastes containing radium-226 at any concentration generated during plugging and abandonment operations of mineral wells or oil and gas wells in Michigan may be disposed down-hole, subject to any additional applicable requirements of the MDEQ, as specified or authorized under Parts 615 and 625 of 1994 PA 451.

   Applicable portions of Michigan's Ionizing Radiation Rules containing related requirements and authorizing these guidelines are contained in Rule 123(3)(e); Rule 237(1), (2), and (3); Rule 253; and Rule 272."

(Note: the term "concentration" is used in EQC – 1602 to mean "activity concentration" as used throughout this document)

These guidelines are used today by the MDEQ to evaluate each proposed disposal into a Type I or Type II landfill (a detailed discussion of Type I and Type II landfills is found in Section III F of this document). On a case-by-case basis, and after a thorough review, the MDEQ may authorize a facility to accept bulk waste with Radium-226 activity concentrations above 50 pCi/g and mix it with other material to reduce the activity concentration to below 50 pCi/g prior to final placement in a Type I or Type II landfill. When applying the MDEQ disposal guidelines, the source of the material is not a consideration. The source of the Radium-226 could be from oil and gas production, water treatment, or something else.

During 2014, MDEQ approved three shipments to the Type I landfill and 85 shipments to Type II landfills. For the Type I landfill, the three shipments accounted for less than 1 percent of the total waste placed. For the Type II landfills, TENORM accounted for less than 1 percent of the total material placed in any given landfill. All shipments were tested and the lab analysis was reviewed by the MDEQ to confirm they were below the 50 pCi/g of Radium-226 when placed in the landfill.

III. Areas Addressed

The TDAP approached the TENORM disposal issue from a number of perspectives. The panel examined changes to the risk assessment methodology since the 1990s, reviewed the typical isotopic mix and how it changes over time, evaluated the primary public and worker exposure pathways, considered federal and state standards, and investigated landfill design considerations. Each of these areas is addressed in greater detail below. In keeping with its charges and by unanimous agreement, the TDAP evaluated the effects of placing TENORM in a Type I or Type II landfill independent of the origin of the materials.

A. Changes to Methodology since 1990s

The risk assessment for the disposal of radioactive materials relies heavily on computer models. The TDAP examined changes to these models since the early 1990s and how those changes impacted risk assessments. The TDAP focused on three areas where changes were known to have occurred: changes to the models used, changes to dose conversion factors, and changes to how regulations are interrupted.

To begin, the TDAP carefully reviewed the 1999 ANL study, paying particular attention to the models used and the assumptions made. The 1999 ANL study used two types of models: transport models to estimate how the Radium would move in landfills after placement and dose models to estimate the risk to workers and members of the public. The TDAP found the assumptions made resulted in a reasonable assessment of exposure.

Transport Models

The transport modeling relied on a series of calculations to arrive at the Naturally Occurring Radioactive Material (NORM) activity concentrations at down-gradient receptors. The process began with the Hydrologic Evaluation of Landfill Performance (HELP) model, which uses precipitation and landfill construction as inputs and predicts infiltration through the cap and leakage through the bottom. The output from the HELP model is combined with the NORM source term (activity concentration and location) in an analytical process that provides the NORM activity concentration at the landfill liner.

A dilution calculation is then applied to the NORM activity concentration at the liner to yield the NORM activity concentration in leachate after mixing with uncontaminated leachate from the landfill. It is this diluted NORM activity concentration in the leachate that is used in some of the worker dose calculations.

The diluted NORM activity concentration in the leachate is also one of the inputs used by the SWIFT II model, which is the final step in the process. The SWIFT II model uses the NORM activity concentration in the leachate, infiltration through the cap, leakage through the bottom, geologic parameters (soil types, precipitation, and groundwater gradient), and receptor locations as inputs to model the NORM activity concentrations at the down-gradient receptor locations. It is this final output that is used in the Groundwater Receptor dose calculations.

The TDAP concluded that the methodology used in the transport calculations was still valid, and the assumptions used were typically very conservative.

Dose Assessment Models

The 1999 ANL study used several dose assessment models. It used TSD-DOSE to model the dose to the workers and off-site residents during the operational phase of the landfill. Second, it used RESRAD version 5.782 to model the future use scenarios of on-site residents, on-site industrial workers, and recreational visitors. Finally, it used the transport methodology described above to model groundwater ingestion by an off-site resident.

The TDAP agreed that professional judgment resulted in reasonable assumptions used in the 1999 ANL study and are still appropriate today. However, the TDAP used RESRAD version 7.0 to model the same scenarios modelled on RESRAD version 5.782 in the 1999 ANL study. The panel duplicated the model runs as closely as possible to determine if using a current version of RESRAD would change the conclusions reached. There was no significant difference between dose projections of the two versions of RESRAD, reaffirming the 1999 ANL study conclusions.

One of the critical factors to consider with dose modeling software is the dose conversion factors used. The dose conversion factors are used to determine how a certain exposure would impact the body or specific organs. The 1999 ANL study used the 1990 Recommendations of the International Commission on Radiological Protection (ICRP-60) dose conversion factors. The most recent update by the ICRP came in 2007 with the release of ICRP-103. The dose conversion factors in ICRP-103 have not changed a great deal, and in many cases have decreased and would show a lower dose impact for the same level of exposure. The TDAP agreed that the ICRP-60 values, while not the latest, are still valid and provide a sufficient level of conservatism.

One of the most significant changes since the 1990s is the recognition that the doses from medical procedures have become a significant part of what would be considered average annual dose. When determining relative risk in the 1999 ANL study, background radiation was assumed to contribute to an annual dose of roughly 300 millirem per year (mrem/year). By applying the ICRP risk factor for the public, the risk of a fatal cancer over a lifetime from background radiation is 2 x 10^-4/year. The National Council on Radiation Protection & Measurements (NCRP) Report No. 160 indicates that the annual dose for a person in the U.S. from all sources is about 620 mrem/year. This total dose includes the 300 mrem/year from background exposure and an average per person dose from medical procedures of 320 mrem/year.

Since the 1990s, the As Low As Reasonable Achievable (ALARA) principle has been used to encourage facilities to view the public dose limit of 100 mrem/year above background as being from all sources, and that no single source should exceed the license termination standard of 25 mrem/year public dose. This change effectively reduces the maximum allowable dose, which in turn puts an upper bound on the activity concentration. The 1999 ANL study estimated a maximally exposed member of the public (future use on-site resident) to receive a dose of 7 mrem/year, which is still well below the 25 mrem/year license termination limit.

B. Isotopic Mix and How it Changes Over Time

Radioactive Decay Processes and TENORM Formation

The naturally occurring radionuclides of interest discussed here, enhanced through often unintentional human-made technological processes, stem from the radioactive decay of uranium and thorium isotopes present during the earth's formation nominally 4.52 billon years ago. Specifically, the well-established modes and rates of radioactive decay of Uranium-238 and Thorium-232 and the subsequent decay processes affecting their respective progeny radionuclides and the geochemical behavior of each specific radioelement allow for a proper assessment of the human health-related impacts of TENORM upon disposal within engineered facilities.

Figure 1 depicts the radioactive decay chain associated with precursor Uranium-238, leading to a stable Lead-206 progeny. Incorporated within this figure is the measured half-life of each radionuclide. Half-life is the period of time required for decay of one-half of the radioactive atoms initially present. Similarly, Figure 2 depicts the decay chain associated with precursor Thorium-232 leading to a stable Lead-208 progeny. Examination of the order of the radioactive progeny formation, their associated rate of subsequent decay, and their specific geochemical behavior provides critical insight into assessing their potential human health impacts from specific forms of TENORM.

Figure 1 – Radioactive Decay Chain of Uranium-238

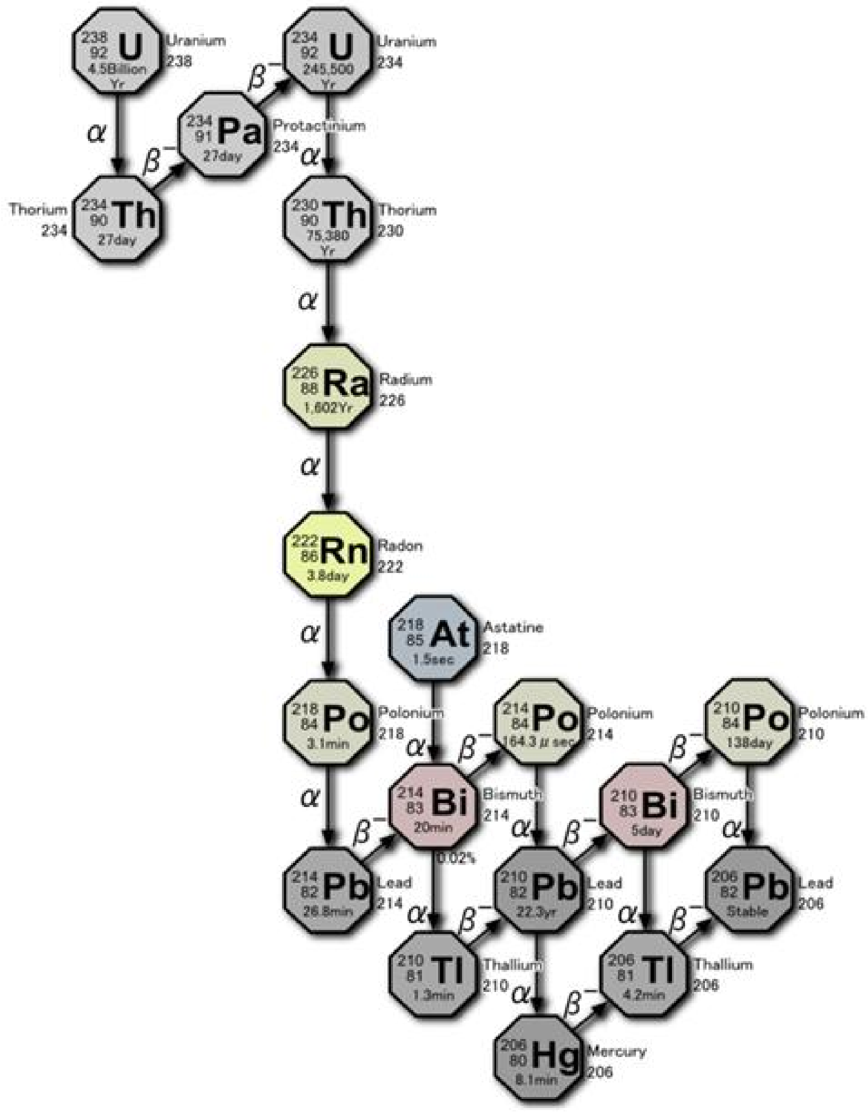
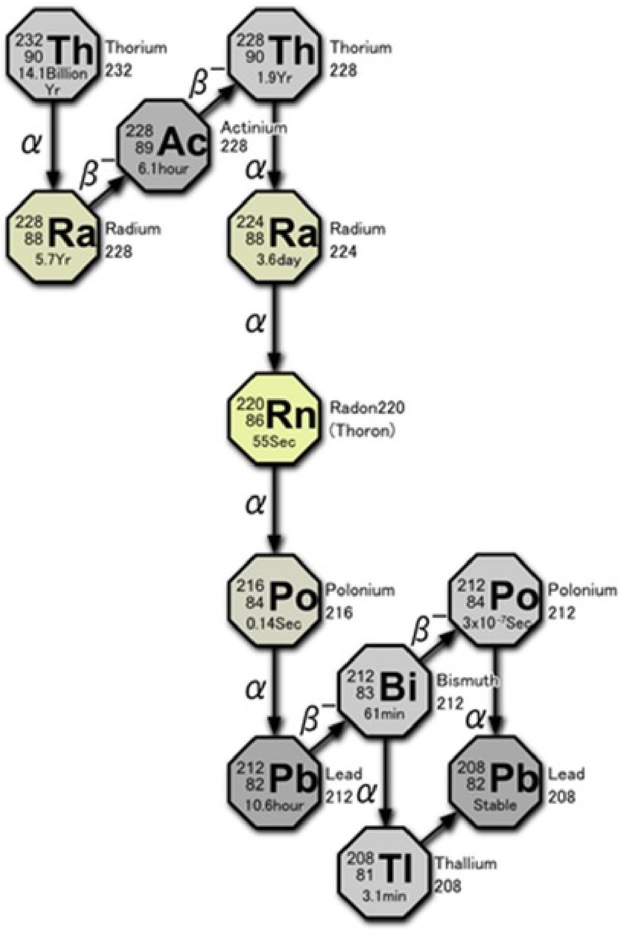


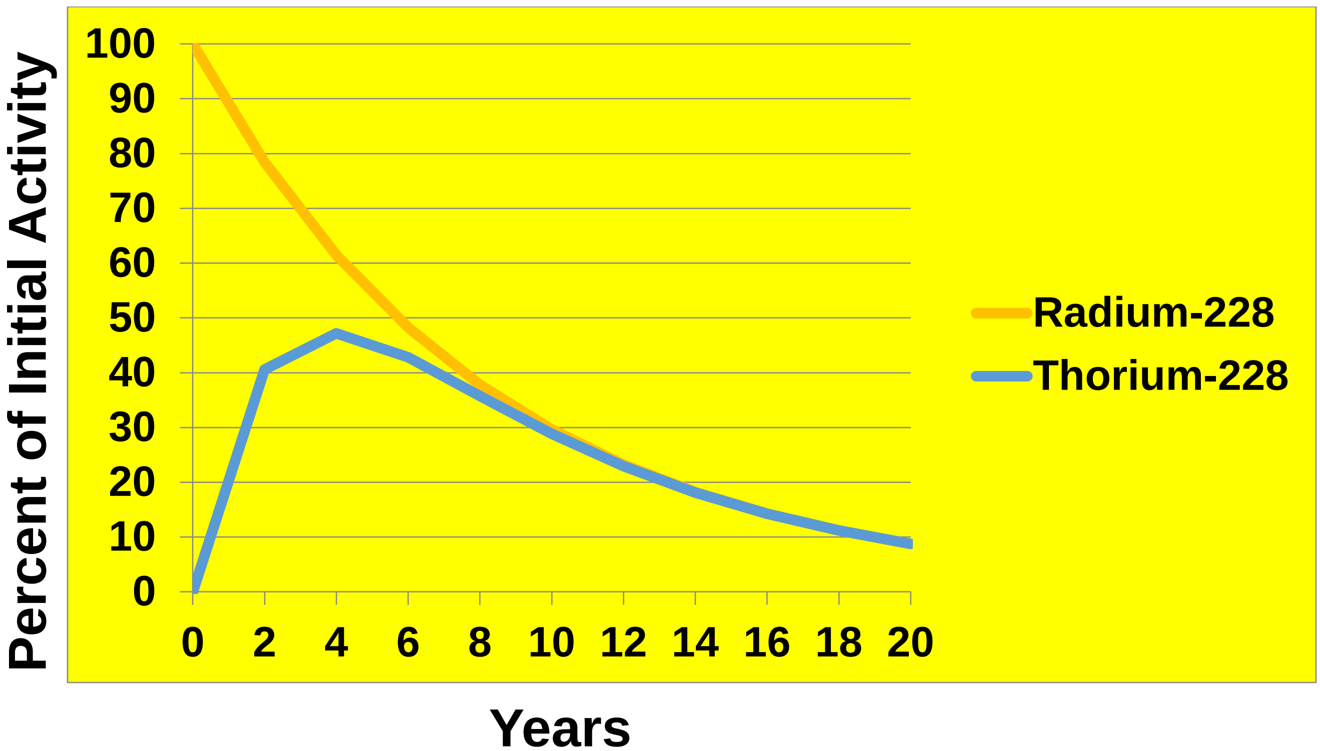
Figure 2 - Radioactive Decay Chain of Thorium-232



Of specific interest within the Uranium-238 decay chain are the notably longer half-lives, on a relative basis to its subsequent radioactive progeny, of Radium-226 and Lead-210. The nominal half-life of 1,600 years for Radium-226 allows for its prolonged persistence, whereas Lead-210 can persist for decades. The longevities of these two radionuclides contrast with the comparatively shorter half-lives associated with the Thorium-232 decay progeny. The 5.7 year half-life of Radium-228, as shown in Figure 2, allows for its rapid depletion in the absence of precursor Thorium-232. The rates of the decrease of the relative radioactivities of Radium-228 and its progeny Thorium-228 are depicted in Figure 3. This graphic documents that a Radium-228 TENORM product (absent its precursor Thorium-232) will decay to extremely low levels of radioactivity within a period of a few decades, and provides basis for the absence of specific regulations pertaining to the disposal of Radium-228-dominated TENORM.

Note that this graphic first assumes the presence of only Radium-228 with the subsequent in-growth of Thorium-228 until secular equilibrium is reached with Radium-228, followed by their common decrease in radioactivity. Secular equilibrium is a condition in which the precursor radionuclide and its progeny have the same level of radioactivity. It develops when the precursor radionuclide and all progenies are retained in immediate proximity over a duration commensurate with multiple half-lives of the relatively most stable radioactive progeny. Referring again to Figure 3, given the 1.9 year half-life of Thorium-228, approximate equilibrium with respect to its precursor Radium-228 is shown to be reached within about eight years, or slightly more than four half-life periods.

Figure 3 – Radioactive Decay of Radium-228 and Thorium-228



Importance of Geochemical Behavior of Individual Radionuclides

Whereas the above discussion has emphasized the radioactive behavior of the pertinent radionuclides, it is also important to understand the chemical behavior of each radionuclide as well. Radionuclides are essentially metals, with the notable exception of gaseous Radon, and as such will chemically behave exactly the same as the non-radioactive isotopes of the same element in a given environment. Understanding the chemical makeup of these radionuclides is therefore vital to their fate and transport behavior (i.e., dose potential) since it is these characteristics that define a radionuclide's solubility and mobility. Conceptual formation processes leading to the development of TENORM from the Uranium decay chain are presented in the following subsections.

Formation of a Radium-226-Dominated TENORM

One increasingly common form of TENORM is associated with drilling residuals, scale-impacted tubulars, and processing equipment employed during oil and natural gas production. Uranium-238 is naturally present within the rocks and sediments hosting the hydrocarbon resources, and its radioactive decay produces Radium-226. Because of Radium-226's specific geochemical behavior, some of this Radium dissolves into the saline fluids associated with the hydrocarbons. The saline fluid's combination of elevated chloride [Cl^-] ions and temperature enhances the solubility of naturally occurring barium [Br^{+2}] and strontium [Sr^{+2}] ions. As these saline solutions are pumped to the surface during oil and gas production, cooling allows for the precipitation of barium and strontium ions as low-solubility sulfate minerals. During the formation of these minerals, some Radium isotopes, including both Radium-226 and Radium-228, are co-precipitated. Given suitable conditions, barium and/or strontium-dominated sulfate minerals may incorporate sufficient Radium to become classified as TENORM.

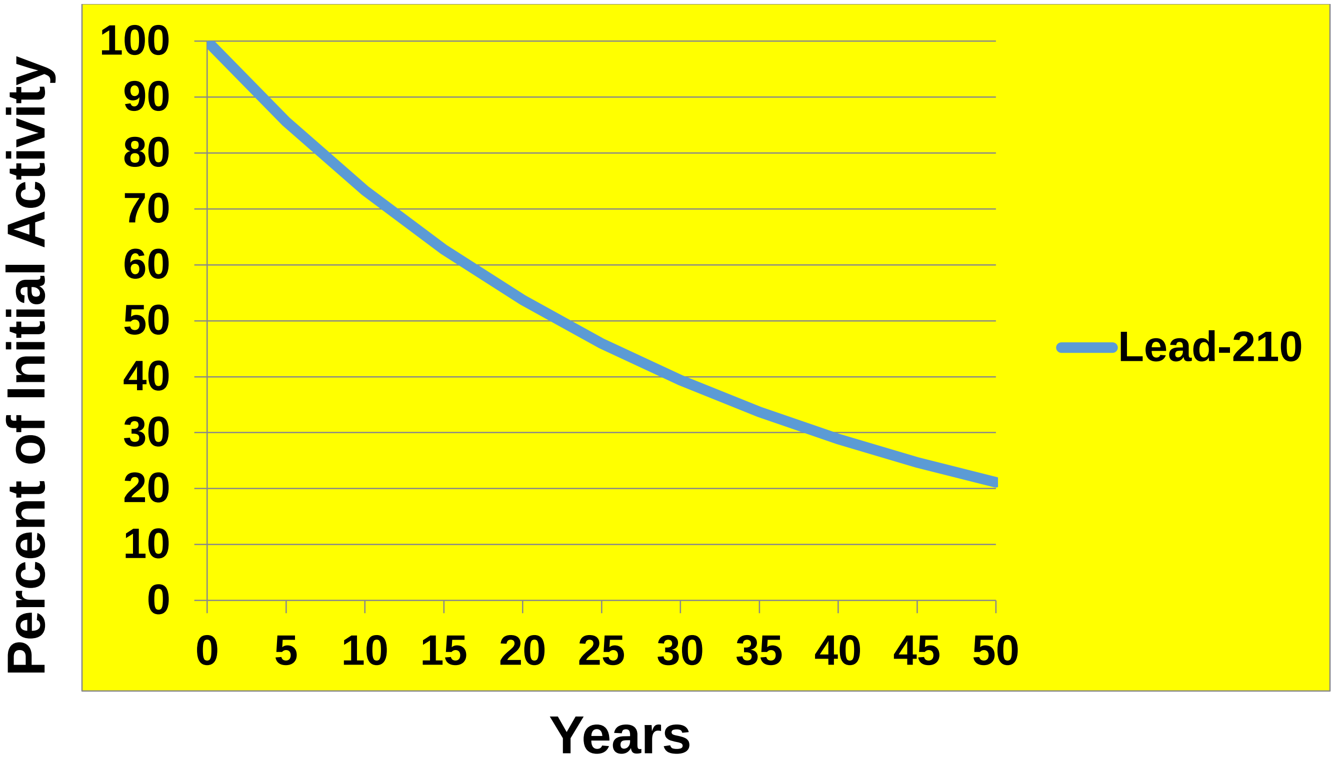
Whereas the low solubility of these minerals typically prevent the aqueous mobilization of Radium isotopes from the well-crystalized mineralogical structure, the subsequent production of Radon-222, a chemically inert gaseous phase, may be only partially retained within the crystalline structure. This results in the release of this radioactive gas, assessed in terms of its human health risk in the following sections. The retention of some of the Radon-222 within the barium and strontium sulfate minerals also allows for production of subsequent decay products, including both Bismuth-214 and Lead-214, the most important gamma radiation-emitting radionuclides present within the Uranium-238 and Radium-226 decay chains. Although directly attributed to Radium-226, human health-related risk assessments of gamma radiation exposure are, in fact, focused on emanations derived from the Bismuth-214 and Lead-214 progenies. As will be further discussed, the fact that these important gamma emitters are present higher in the radioactive decay chain than Lead-210, has important implications in assessing human health risks stemming from this specific radionuclide.

Formation of a Lead-210-Dominated TENORM

Radium-226, present in both the host rocks and dissolved within the oil and gas-associated produced fluids, also allows for the sustained production of Radon-222 and its incorporation within both aqueous and free gas phases. Upon separation of natural gas from the aqueous phase (produced fluids) Radon-222 is preferentially partitioned into the gas phase. Due to the relatively short half-life of Radon-222 (3.8 days), and the even shorter half-lives of progenies immediately downchain, ultra-fine grain Lead-210 is formed as an elemental metal solid phase. During the onward handling, storage, and processing of natural gas – particularly the production of propane – Radon-222 and its Lead-210 progeny may be further concentrated, with the physical deposition of particulate Lead-210 leading to a potential TENORM. Although Lead-210 itself is a weak gamma emitter, this specific TENORM does not contain the relatively more gamma energetic Bismuth-214 and Lead-214 radioisotopes. Nor can it emit a radioactive gas phase, as can the Radium-226 TENORM discussed above.

Consequently, the dominant threat is inhalation of particulates, an exposure pathway only present for workers and not for a future hypothetical site resident. Further, radioactive decay will result in the natural attenuation of this radionuclide over the course of several decades, as shown in Figure 4.

Figure 4 - Radioactive Decay of Lead-210



Leveraging the Combined Understanding of Radioactive and Geochemical Behavior of Pertinent Radionuclides in Various TENORM

The above discussion establishes that for specific forms of TENORM, the rates and formation of radioactive products can be calculated. Further, the degree and rates of solubilization of radionuclides can also be estimated. The above understanding also allows fluxes of radioactive gas (Radon-222) and various types of radiation (alpha, beta, and gamma) to be calculated. It is through these processes that inputs to human health risk assessments can be developed, along with a basis for formulating subsequent bounding case sensitivity analyses, which are discussed below.

C. Primary Public Exposure Pathways

When TENORM waste is initially buried at a disposal facility, some members of the public near the disposal site may be exposed to some level of radiation. However, the magnitude of the exposure is dependent on many factors and assumptions, including the amount and form of the TENORM disposed, design and performance of the disposal facility, and the location and consumption habits of the exposed individual.

The pathways for public exposure include:

1. **Direct Radiation (External)**: Members of the public can be exposed externally if living or visiting on or near the disposal facility.
2. **Particulate Inhalation (Internal)**: Contaminated dirt and dust can be re-suspended, carried by the wind, and inhaled by members of the public.
3. **Radon Inhalation (Internal)**: When Radium-226 undergoes radioactive decay, it will temporarily become gaseous Radon-222. When in this gaseous state, it is highly mobile and can be inhaled, resulting in internal exposure.
4. **Ingestion (Internal)**: For worst case modeling purposes, it is conceivably possible a member of the public could consume contaminated food and drink. Over long time periods, disposed TENORM could migrate from the disposal facility, where it could enter groundwater. From there, it could enter drinking water or be incorporated into locally grown edible crops and then ultimately ingested by a member of the public. If cattle or other meat animals consume contaminated water or vegetation, the public exposure would occur during consumption of the meat or milk.

The magnitude of public dose is very dependent on the assumptions used in the dose assessment. Individuals who are assumed to build their residence on top of the disposal facility and spend nearly all of their time in or around their home would have much higher exposures, especially from radon emanation. Individuals who are assumed to consume locally grown contaminated food or drink from nearby contaminated drinking water wells would also have higher exposures.

The applicable pathways for a member of the public are dependent on the timeframe of exposure. In the near term, it is assumed that institutional controls (corporate land ownership, signs, fences, governmental deed restrictions) are in place to preclude individuals from building residences or installing drinking water wells directly on top of any disposal facility. Only in the very long term – hundreds or thousands of years – can the designed institutional controls and societal memory of the facility be assumed to have disappeared, making all of the exposure pathways possible.

The 1999 ANL study provided the technical validation of the current MDEQ disposal guidelines for TENORM-contaminated material up to 50 pCi/g of Radium-226. During the operational phase of the facility, the public exposure was evaluated for inhalation, external, and ingestion exposures for individuals residing 24 hours per day, 7 days per week, living adjacent to the disposal site. For the long-term, future use scenarios, individuals are assumed to build a house without a basement atop the landfill, which they occupy for 18 hours per day. This individual consumes 50 percent of their food from locally raised crops, milk and meat, but get their water from an off-site, non-contaminated source.

Depending on the ultimate future use of the disposal facility land, there could be other public exposure pathways. The facility could become a recreational site like a park, golf course, or ski slope, or a commercial or industrial development. However, any evaluated exposures from those scenarios would be much less than those of the on-site resident.

According to the 1999 ANL study, the most significant member of the public dose is approximately 7 mrem/year to the future use on-site resident. All other public doses are less than 1 mrem/year. This is far below the 100 mrem/year above background limit for the public.

D. Primary Worker Exposure Pathways

Workers at a disposal facility can be exposed to TENORM waste in a variety of manners. In general, occupational exposures can be minimized by using only the workers necessary to complete a job, and efficiently and quickly processing the waste packages to their ultimate location – the disposal cell.

The pathways for occupational exposure include:

1. **Direct Radiation (External)**: TENORM waste packages, when they arrive at the disposal facility, must be handled, transported, or processed in accordance with the practices at the particular disposal facility. The magnitude of external exposures from a given source depends on the duration of exposure, the distance from the source to the exposed individual, and any shielding between the source and the exposed individual. The direct radiation occupational exposure is therefore job task dependent, as someone who handles TENORM waste or waste packages will be expected to be exposed differently from a truck or fork lift driver who only transports the material.

2. **Particulate Inhalation (Internal)**: If TENORM waste packages are not sealed, or include bulk material in packages that are open or must be dumped or processed in any way, particulates (including TENORM) can be re-suspended into the workplace airborne environment. Workers are internally exposed when breathing radioactively contaminated air.

3. **Radon Inhalation (Internal)**: When Radium-226 undergoes radioactive decay; it will temporarily become gaseous Radon-222. When in this gaseous state, it is highly mobile and can be inhaled, resulting in internal exposure.

4. **Ingestion (Internal)**: When working in air contaminated with radioactive particles, some contamination can be inadvertently ingested by workers.

Occupational exposures typically do not include ingestion pathways from the consumption of contaminated water, food, or milk. The assumption is that workers get their food and drink from off-site, clean sources. Occupational exposures are also limited to 40 hours per week, based on a typical work schedule.

If a worker is designated a "radiation worker," then a higher limit for occupational exposure, currently 5000 mrem/year per the U.S. Nuclear Regulatory Commission, would be applicable. The radiation worker limit is significantly higher than the limit for members of the public, 100 mrem/year above background. The higher limit, coupled with the limited exposure times, results in occupational exposures being generally lower and of a lesser concern than public exposures. If a worker is not designated a "radiation worker," with all of the exposure controls also put in place, the public dose limit applies to workers as well. According to the 1999 ANL study, the maximum occupational dose is approximately 2 mrem/year to landfill operators during the operational phase of the facility, well below either the radiation worker or member of the public limits.

E. Federal and State Standards

In studying an appropriate TENORM disposal standard for Michigan, the TDAP considered available information describing applicable federal and state legal authorities, regulations, rules, and other restrictions and guidelines. In general, at the federal level, the legal authorities over matters involving TENORM (or the more broadly defined NORM) are somewhat complicated and overlapping among several agencies as a result of the various laws implemented to protect health and the environment. The end result is that both federal authority and associated federal radiological standards specifically applicable to the landfill disposal of TENORM are extremely fragmented and, at best, limited in scope or application.

On the other hand, legal authority for the management of the more broadly defined NORM, including TENORM wastes, on the basis of radiological concerns impacting human health or the environment seems to more clearly rest with the individual states, and in most cases has resulted in specific rules or regulatory restrictions with clear application, at least in a broad sense, to the control of the radiological hazards relating to NORM and TENORM. For example, there is uniform agreement among the states for an exempt activity concentration level of 5 pCi/g for Radium-226. That is, no states restrict the possession, use, management, or disposal of Radium-bearing materials at activity concentrations below this level for health or safety. However, the promulgation of standards for the management of TENORM wastes above 5 pCi/g varies widely amongst states, both in scope and specificity.

In Michigan, the legal authority, originally promulgated as part of the Public Health Code, currently rests within the MDEQ. Associated rules and regulatory authority are implemented through Michigan's "Ionizing Radiation Rules." In 1996, Michigan established specific guidelines applicable to the disposal of wastes containing Radium-226, the primary radionuclide of concern to health, safety, and environmental protection. The MDEQ disposal guideline is unique among the states for its specificity regarding the landfill disposal of TENORM. The Michigan landfill disposal limit is set at 50 pCi/g for Radium-226 and is applicable to any Radium-226 waste material, regardless of origin. The MDEQ disposal guidelines address the management of decontamination and residual wastes from past practices, such as those involving the radioluminous instruments industry and industries involved in the fabrication and use of both sealed and unsealed sources for industrial and medical purposes, as well as the current waste generating practices exemplified by the oil and gas industry.

Several other states impacted by TENORM wastes from the oil and gas industry have or are considering allowable activity concentration standards for Radium, which may include Radium-226 and Radium-228, for landfill disposal. Theoretically, it would make sense for Michigan to include Radium-228, but in practice it would make little difference since it doesn't significantly contribute much long-term dose.

The 1999 ANL study included a useful and representative review of applicable federal and state regulatory standards and guidelines specific to the handling and disposal of TENORM wastes. Specific details relating to applicable federal and state authority and regulatory requirements are available in the study. The study includes details for several individual states, including Michigan, which ANL identified as having significant oil and gas production and associated TENORM wastes. The 1999 ANL study also provided details concerning federal requirements from a non-radiological perspective related to the construction, operation, closure, and post-closure of hazardous and nonhazardous landfills regulated under the federal Resource Conservation and Recovery Act (RCRA).

MDEQ staff, TDAP members, and select Michigan landfill operators provided additional Michigan-specific details that meet or exceed the federal RCRA requirements. These non-radiological requirements applicable to Michigan landfills are described in detail in the next section.

Both radiological and non-radiological requirements were considered in the development of the MDEQ disposal guideline. With the help of MDEQ staff, the TDAP also determined that no significant changes have occurred in the area of new or revised regulation or standard development since the 1999 ANL study. Many individual states allow for landfill disposal of TENORM wastes on a case-by-case basis, and several states are reportedly working on specific TENORM waste management standards that may be issued in the near future, particularly North Dakota and Pennsylvania.

F. Landfill Design and Closure Requirements

Introduction

Several TDAP members visited both hazardous waste and municipal solid waste landfills during the review process, since Michigan's regulations allow TENORM disposal in both. The objective was to study and compare elements of design, construction, and operations.

Industrial landfills were not included in the scope of the investigation since these landfills are prohibited from receiving TENORM for disposal in Michigan.

Landfill Regulations

Commercial landfills can be divided into three general categories: hazardous waste landfills, municipal solid waste landfills, and industrial landfills. Construction and operating criteria for landfills at the federal level are provided in Title 40 of the Code of Federal Regulations (CFR), *Protection of the Environment*. The U.S. Environmental Protection Agency (EPA) regulates criteria for municipal solid waste landfills in 40CFR Part 258 (as implemented from Subtitle D of the Resource Conservation and Recovery Act [RCRA]) and hazardous waste landfills in 40CFR Part 264 (as implemented from Subtitle C of the RCRA). The EPA defines each type of landfill in the following manner:

- *"A municipal solid waste landfill [MSWLF]) unit means a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined under §257.2 of this chapter. A MSWLF unit also may receive other types of RCRA Subtitle D wastes, such as commercial solid waste, nonhazardous sludge, conditionally exempt small quantity generator waste and industrial solid waste. Such a landfill may be publicly or privately owned. A MSWLF unit may be a new MSWLF unit, an existing MSWLF unit or a lateral expansion. A construction and demolition landfill that receives residential lead-based paint waste and does not receive any other household waste is not a MSWLF unit*."
- A (hazardous) landfill means "a *disposal facility or part of a facility where hazardous waste is placed in or on land and which is not a pile, a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit*."

States may provide additional requirements above and beyond what is required by the U.S. EPA in terms of design specifications, operating standards, and post-closure requirements. The MDEQ regulates landfills under Chapter 3 of the Natural Resources and Environmental Protection Act of 1994, as amended, with hazardous waste landfills under Part 111 and solid waste landfills under Part 115. MDEQ classifies landfills in Michigan as Type I (Hazardous Waste), Type II (Municipal Solid Waste), or Type III (Industrial Waste). Only Type I and Type II landfills are allowed to receive Radium-226 TENORM for disposal, so only these landfill types will be discussed from this point further.

General Design Elements

Nearly all landfill cells consist of three major components:

- Liner: A system of natural and engineered barriers underlying the waste cell designed to prevent unauthorized leakage or migration of waste materials into the environment.
- Waste Cell: The portion of the landfill where authorized wastes are placed for disposal.

- Cap: The cover placed over closed waste cells to protect and isolate the contents from water infiltration due to rain and runoff, prevent the unintended spread of contamination from wind erosion, and prevent unintended contact with the waste by people and wildlife.

The requirements for each portion of a landfill may vary depending on landfill type, additional state regulatory requirements, and extent of natural geological features available.

Hazardous Landfill Design

Hazardous waste (Type I) landfills are designed to the most rigorous construction and performance standards under both RCRA and State of Michigan regulations. These include minimum standards for the natural siting location standards, the design and construction of the landfill liner, leachate collection system, leak detection systems, secondary liner, and final cap. Since the Wayne Disposal Inc. (WDI) hazardous waste landfill facility in Belleville, MI, is the only commercially available Type I landfill in the State of Michigan, the WDI facility is used here to demonstrate typical design elements. A cross-sectional view of the WDI landfill and its major design components is provided in Figure 5.

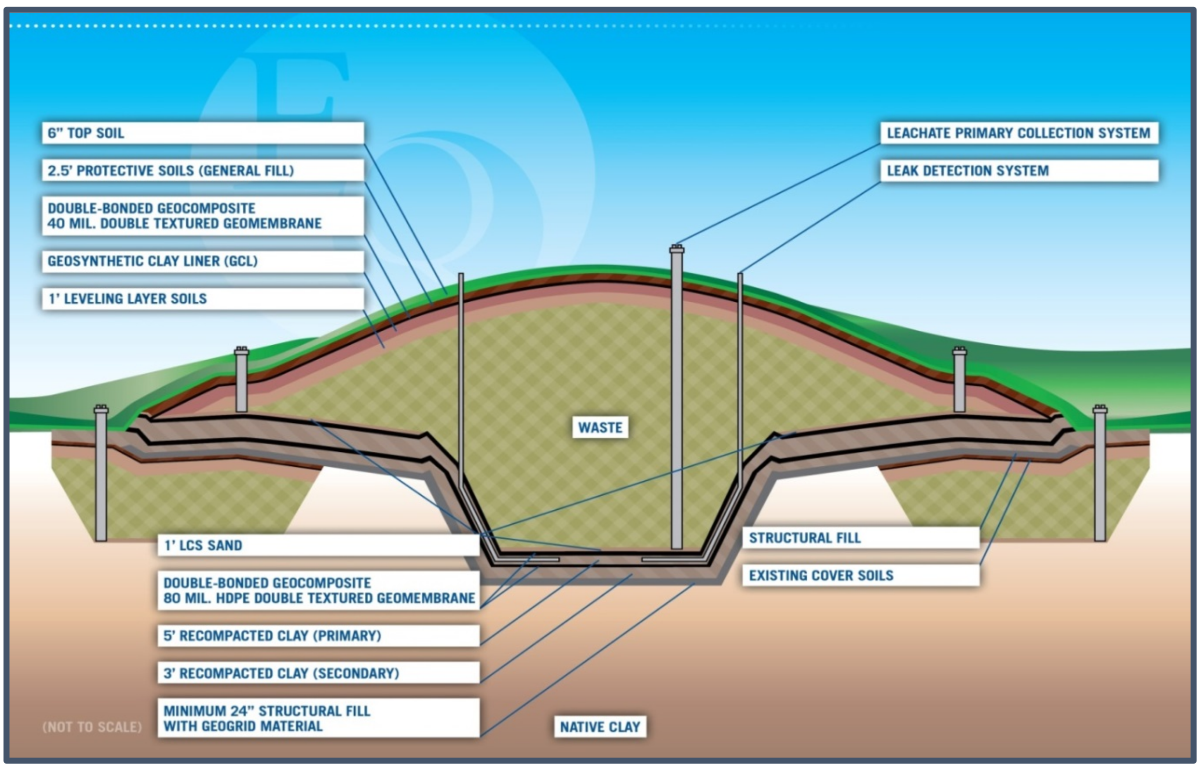


Figure 5 - Cross-Sectional View of WDI Landfill (graphic courtesy of US Ecology, Inc.)

Landfill Liner

A Michigan Type I landfill must contain a double-composite landfill liner system using a combination of natural and synthetic materials. The WDI landfill includes a leachate collection system and a leak detection system, which consist of the following components listed in descending order:

Leachate Collection System (Primary)

- 1-foot layer of sand to protect the liner system and assist with leachate drainage. Type I landfills are prohibited from allowing more than 12 inches of leachate to collect on the primary liner prior to removal. This requirement mitigates the potential for transport through the liner and has the additional benefit of protecting the liner from accelerated physical degradation.
- The primary double-bonded geocomposite drainage layer.
- The primary 80-mil high-density polyethylene (HDPE) textured geomembrane.
- The primary 5-feet layer of low-permeability recompacted clay (1×10^{-7} centimeters per second [cm/sec]).

Leak Detection System (Secondary)

- The secondary, double-bonded geocomposite drainage layer.
- The secondary 80-mil HDPE textured geomembrane.
- The secondary 3-feet layer of low-permeability recompacted clay (1×10^{-7} cm/sec).

Location Siting Standards

- Minimal 10 feet natural clay at 1×10^{-7} cm/sec permeability below and lateral to the cell

The leak detection system allows any leakage through the primary composite liner to drain to a sump within 24 hours and be removed from the system. The requirements for a leak detection system are unique to Type I landfills in Michigan. In addition to these engineered barriers, WDI also conforms to MDEQ's maximum natural geology underlayment requirement, which is a minimum of 10 feet of natural very low-permeability clay beneath the liner system. The physical layout of the liner system is shown at the bottom of Figure 5.

Both leachate collection and leak detection are required components of a Type I landfill design in Michigan. Leachate from a Type I landfill is itself a "listed" RCRA hazardous waste that requires disposal at a Type I landfill after treatment. The WDI facility collects all of its landfill leachate and treats it on-site within its Wastewater Treatment Plant. The leachate goes through multiple chemical, biological, and physical treatment processes to destroy or remove the hazardous components of the leachate from the treated water. This includes removal of TENORM like Radium-226. The removed constituents are placed back into the WDI landfill while the treated water is discharged to the municipal sewer system to receive additional treatment by a licensed municipal wastewater treatment plant. Prior to release into the sewer system, the effluent must meet discharge limits per a discharge permit from the MDEQ.

Landfill Cover

When a waste cell is closed, a cover is installed to protect the contents of the waste cell and prevent intrusion from water, people, and wildlife. The cover design for the WDI Type I landfill includes the following components, listed in decending order from the top down:

- 6-inch topsoil/vegetative layer to prevent soil erosion from wind and rain.
- 2.5 feet of protective soils with permeability less than $1x10^{-5}$ cm/sec.
- A double-bonded geocomposite drainage layer.
- A 40-mil textured HDPE geomembrane liner.
- A low permeability geosynthetic clay liner that contains $1x10^{-9}$ cm/sec bentonite.
- 1-foot leveling layer of clay materials placed between the cover and waste materials.

The physical makeup of the WDI landfill cover is shown at the top of Figure 5.

Municipal Solid Waste Landfill Design

Design and construction of MSWLFs (Type II) is relatively similar to the hazardous waste landfills described in the previous section. However, significant differences are possible depending upon location of the landfill and installed options by the owner/operator.

Landfill Liner

Liner systems for MSWLFs can vary considerably depending on the natural geology present where the landfill is constructed. MSWLFs are required to have a primary liner system with a 60-mil flexible membrane liner underlain by 2 feet of recompacted clay or a geosynthetic clay material with an equivalent permeability of $1x10^{-7}$ cm/sec. If the location of the landfill exhibits a minimum of 10 feet of $1x10^{-7}$ natural clay below the liner, then a MSWLF operator may permit the landfill with only the primary liner. If the location does not have the minimum thickness of natural low-permeability clay beneath the landfill cell, then a secondary liner system is also required. This secondary liner is essentially a repeat of the primary liner with consistent materials and thicknesses.

MSWLFs collect landfill leachate in a manner similar to hazardous landfills. The leachate collection system piping is bedded within a sand layer just below the waste and pumped to centralized collection points for handling. Some Type II facilities process their leachate through an onsite evaporator system to reduce moisture and return the dried solids to the landfill for disposal. However, many Type II landfills directly discharge their untreated leachate to publicly owned treatment works. However, these treatment works are typically designed to treat sewage like human waste, not industrial contaminants, including radionuclides in TENORM.

A secondary leak detection system is not explicitly required for MSWLFs. If the landfill is underlain with a minimum of 10 feet of $1x10^{-7}$ natural clay below the liner, then a secondary system is not required. However, landfills that are required to install a secondary liner system are required to include a secondary collection or leak detection in the design, or some operators may voluntarily choose to install elements of a system to detect landfill liner leakage.

Landfill Cover

Final cover design is similar between Michigan Type I and Type II landfills. Like Type I landfills, Type II landfills will typically include a topsoil/vegetative layer, protective soil, a geocomposite drain, a geomembrane liner, a geosynthetic clay layer, or a leveling layer of clay, and a permeable soil layer that collects and vents landfill gas to gas risers.

MSWLFs can have waste-to-energy (WTE) power plants installed on their property. WTE plants are designed to collect the methane gas created during natural degradation of organic wastes within a MSWLF and burn it for energy generation on the premises. MSWLFs that have WTE plants installed require gas collection piping installed throughout the landfill waste cell and final cover to facilitate efficient collection of the methane. An example of an installed WTE system within a MSWLF is shown in Figure 6.

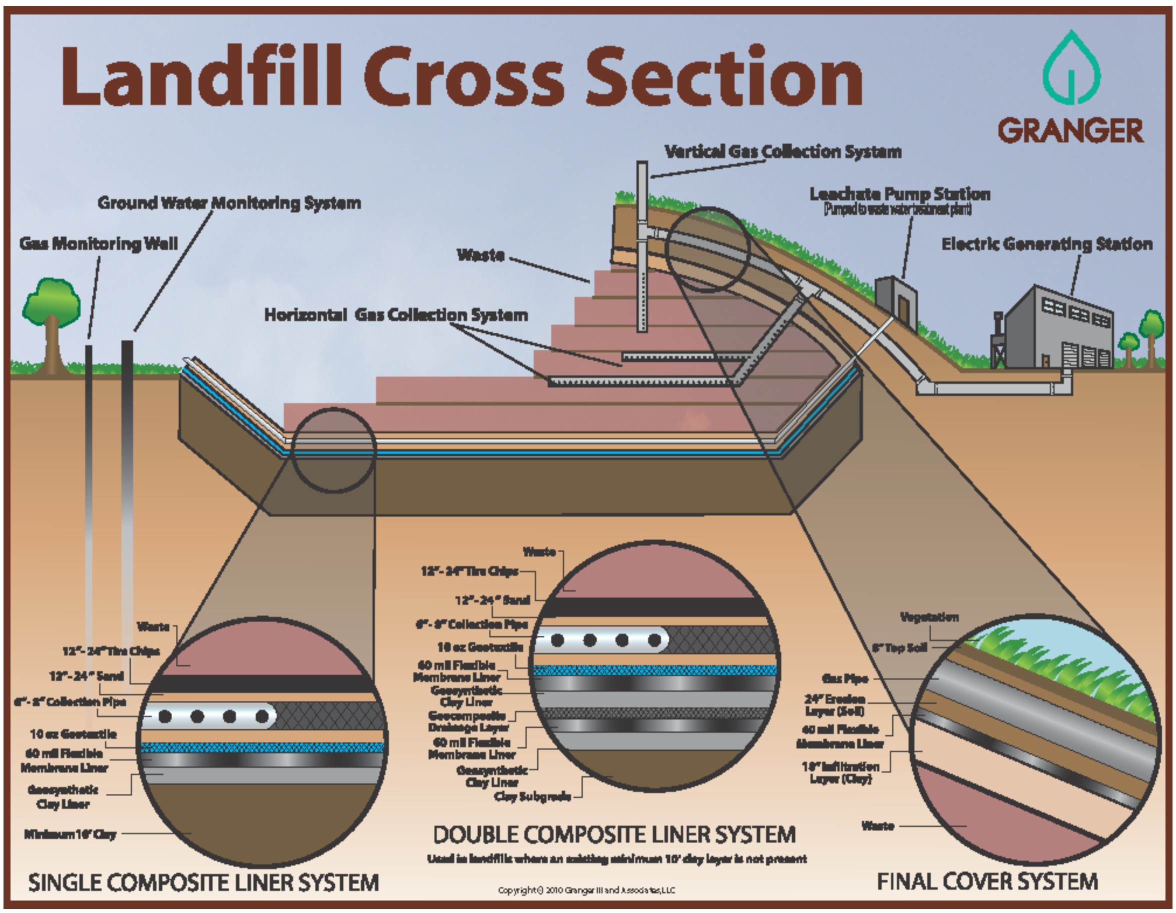


Figure 6 - Cross-Sectional View of Typical MSWLF (Graphic courtesy of Granger III & Associates, LLC)

Comparison of Type I and Type II Landfills

The TDAP had an opportunity to learn a great deal about the design, construction, and regulatory requirements for both Type I and Type II landfills as part of this research. A summary comparison of the landfill design and regulatory requirements between Type I and Type II landfills is presented in Table 1.

In addition to the design differences between Type I and Type II landfills, the TDAP also observed operational differences between the two types of facilities. For instance, waste transport vehicles delivering waste to the WDI Type I facility unload the waste into a waste transfer tank. The waste is then transported to the landfill in dedicated vehicles that stay in the landfill unless thoroughly decontaminated. Trucks that deliver waste to WDI also go through a wheel and undercarriage wash before leaving the facility, even though they never travel into the active landfill zone. At Type II facilities, waste transport vehicles generally drive into the active landfills to dump their contents and are not cleaned before leaving the site. In addition, the WDI facility has fugitive dust controls, including a wind-speed limit that requires the facility to suspend waste acceptance operations when winds reach a certain speed. While there is not a specific wind speed limit at Type II facilities, there are requirements to control dust and blowing papers, and to prevent the creation of nuisance dust conditions. The operations plan for the landfill must include these provisions.

Table 1. Design Requirements Comparison of Type I and Type II Landfills in Michigan

Design/Licensing/Operating Criteria	Type I Landfill (subtitle C) Hazardous Waste Landfill	Type II Landfill (subtitle D) Solid Waste landfill
Liner Construction	• **Primary Liner**: FML (meet chemical resistance and long-term compatibility, typically 80-mil HDPE) and 5' recompacted clay ($1x10^{-7}$) (GCL is not allowed.) • **Mandatory Leak Detection System** • **Secondary Liner**: FML (meet chemical resistance and long-term compatibility, typically 80-mil HDPE) and 3' recompacted clay ($1x10^{-7}$) (GCL is not allowed.) • **20' natural clay base and sides** ($1x10^{-6}$) (location standards)	• Primary Liner 60-mil FML and 2' of recompacted clay ($1x10^{-7}$) or GCL. • Conditional Leak Detection – none if underlain by 10' of native soil ($1x10^{-7}$) • Secondary Liner - none if underlain by 10' of native soil ($1x10^{-7}$). If not, repeat primary liner.
Leachate Collection System?	Yes	Yes
Leachate Treatment	Extensive on-site treatment followed by discharge to POTW. Recovered solids disposed in Type I landfill.	Local POTW release or evaporation and local disposal
Final Cover Design	• Not less than 2'protective soil materials or the maximum depth of frost penetration, whichever is greater, such as topsoil (not less than 6"), subsurface drainage media, or cobbles to prevent animal burrowing. The protective material shall protect the clay and any synthetic component. • 40-mil HDPE or LLDPE FML • 3' recompacted clay ($1x10^{-7}$)	• 6" vegetative top layer • 24" soil layer for lateral drainage • FML and Min. 18" earthen material ($1x10^{-5}$) or GCL • 12" permeable soil layer gas collection layer or equivalent

Acronyms and Abbreviations:

LDCRS = Leak Detection, Collection and Recovery System | *POTW= publicly-operated treatment works* | *HDPE = high-density polyethylene*

SCS = Secondary Collection System | *FML=flexible membrane liner* | *GCL=geosynthetic clay liner*

IV. Summary of Findings and Recommendations

Governor Rick Snyder charged the TDAP with a technical review of the MDEQ disposal guidelines, specifically TENORM containing Radium-226. To be thorough, the panel examined many radionuclides found in TENORM, determining that of those reviewed; Radium-226 posed the most credible threat to the public, workers, and the environment because of its long half-life and its production of the progeny Radon-222. In fact, the primary health risk was determined to be exposure to Radon-222, and its production by Radium-226 is independent of the original source of the Radium-226, so the analysis is valid for all Radium-226 disposals.

It should be emphasized that the 1999 ANL study focused on assessing the appropriateness of MDEQ's 1996 disposal guideline, including a detailed radiological dose/risk assessment. It concluded that the MDEQ disposal guideline of 50 pCi/g is "protective of human health." The TDAP thoroughly reviewed the entire 1999 ANL study and is in agreement with its conclusions and recommendations as they relate to the overall safety of the current MDEQ disposal guideline.

However, the MDEQ disposal guidelines do not differentiate between Type I and Type II landfills, but the TDAP discovered significant differences in levels of protection between them that could inform future regulatory decisions. Whereas many decisions regarding enhanced or redundant protections at Type II facilities are left to the discretion of the owner/operator, they are explicitly required at Type I facilities. This distinction is expected given the different types of waste that these landfills are primarily designed, licensed, and permitted to accept.

However, these differences in landfill design and operating characteristics were not independently considered as part of the TENORM acceptance rulemaking process. Instead, the 1999 ANL study undertook a 'baseline' evaluation, modeling a 'typical' Type II facility that meets the minimum expected Michigan regulatory requirements. The additional levels of protection afforded by Type I landfills were not explicitly evaluated in the 1999 ANL study; although the report did suggest Type I landfills would likely exhibit similar levels of protection for TENORM levels greater than 50 pCi/g. Given the information provided herein, the TDAP concurs with the 1999 ANL study findings that MDEQ could consider approving an elevated TENORM acceptance at Type I landfills in Michigan.

In addition, the TDAP noted the leachate collection systems and ground water monitoring wells that are part of Type I and Type II landfills. These already established systems could be used to monitor for possible migration of the Radium-226 after placement.

In summary, the TDAP makes the following recommendations:

1. **Consider clarifying the applicability of Michigan's TENORM disposal regulation, *EQC 1602, Cleanup and Disposal Guidelines for Sites Contaminated with Radium-226*.** This regulation could be strictly interpreted to apply to only the <u>cleanup</u> of sites <u>in Michigan</u> contaminated with Radium-226. This is an administrative limitation that is not supported by any technical evaluation. Further, in practice, the State of Michigan has not limited TENORM disposal to that requirement. Any future generated or discovered TENORM waste could be interpreted

to not be covered under the current disposal guidance. The TDAP recommends that MDEQ separate EQC-1602 into two documents, one that provides cleanup guidelines and one that provides disposal guidelines.

2. **Consider requiring all landfills that accept TENORM waste to restrict its placement.** The primary dose contributor is Radon-222 emanating from the landfill. By restricting the placement of Radium-226 TENORM such that it remains at least 10 feet below the bottom of the landfill cap, in keeping with the ALARA principle, the dose contribution becomes negligible.

3. **Consider requiring all landfills that accept TENORM waste to restrict the total volume of TENORM waste placed annually.** The primary factor affecting worker dose is the amount of waste being handled annually. Restricting the total volume of TENORM waste helps to limit worker exposure. A landfill may submit a worker safety plan for review by MDEQ. With MDEQ approval of the worker safety plan, the annual volume limit may be raised.

4. **Consider requiring all landfills that accept TENORM waste to monitor leachate and ground water monitoring wells for Radium-226.** Landfills currently have leachate collection systems and ground water monitoring wells which are routinely tested. Adding a Radium-226 test to the testing protocol provides additional assurance that no excess Radium-226 is being released to the environment or public water treatment system.

5. **Consider modifying regulatory guidelines to clearly identify that different limits should apply between Type I and Type II landfills.** Currently, the Michigan regulations apply the same 50 pCi/g limit for both Type I and Type II disposal facilities. Type I landfills are more robust facilities suitable for disposal of TENORM waste at activity concentrations higher than those allowed at Type II landfills. The limits for Type I facility could be determined on a case-by-case basis, as there is currently only one such facility in the state.

6. **Consider developing regulatory guidelines for the safe handling of TENORM contaminated with Lead-210.** Currently only Radium-226 is considered in the MDEQ disposal guidelines. Due to its short half-life, the TDAP does not consider Lead-210 to pose a long term disposal risk; however, Lead-210 may pose a health risk to workers, particularly in the gas and pipeline cleaning industries.

V. Areas for Future Consideration

The TDAP's discussions were extensive, but could not address all issues discovered during deliberations but outside the charge of the panel. However, they might warrant additional consideration. These issues include:

1. The presence of Thorium-232 in the North Dakota TENORM study suggests that it may be a contributor to some exposure pathways. Its potential health effects on worker health and safety may warrant further studies.
2. Consider the need for Radon-222 monitoring near landfill vents.
3. Biogenic gas generation in a landfill could result in the release of Radon-222 in a way that may not have been modeled. Consider investigating the effects of biogenic gas production on the transport of Radon-222 in a landfill.
4. Consider the potential for possible increased Radon-222 as effluent from a waste-to-energy plant.
5. Modeling assumes extremely high solubility of Radium, which may be unrealistic for many common forms of Radium in TENORM, such as Radium-enriched barite. Consider evaluating the specific solubility of the Radium compound of interest when determining leachability and acceptance criterion.
6. Consider an evaluation of the effectiveness of the TENORM self-reporting regime to comprehensively identify, label, and dispose of Michigan's TENORM materials.

VI. Glossary

Absorbed Dose - The amount of energy deposited in any substance by ionizing radiation per unit mass of the substance. It is expressed numerically in rads (traditional units) or grays (SI units).

Activity - The rate of disintegration (transformation) or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).

ALARA – As low as reasonably achievable**.** Making every reasonable effort to maintain radiation exposures as far below the dose limits as is practical, taking into account the available technology, the economics of improvements in technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Background Radiation - Radiation from cosmic sources, naturally occurring radioactive material like radon, and global fallout in the environment from the testing of nuclear explosive devices or from past nuclear accidents like Chernobyl. These all contribute to background radiation, but are not under the control of the licensee. Background radiation does not include radiation from source, byproduct, or special nuclear materials regulated by the U.S. Nuclear Regulatory Commission.

Cover (or Cap) - A landfill design feature that includes all material, soil, membranes, vegetation, etc. that are installed above waste disposed in a landfill.

Curie - The original unit used to express the decay rate of a sample of radioactive material. The curie is equal to that quantity of radioactive material in which the number of atoms decaying per second is equal to 37 billion.

Dose - A general term used to refer to the effect on a material exposed to radiation.

Dose Equivalent - The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).

External Radiation - The situation in which the source of exposure is external to, that is, outside the body.

Half-life - The half-life of any radioactive material is the length of time necessary for one half of the atoms of that material to decay to some other.

Internal Radiation - The situation in which the source of exposure is internal to the body, generally as a result of an individual inhaling or ingesting radioactive material.

Leachate Collection and Removal System - A landfill design feature installed immediately above the liner that is designed, constructed, maintained, and operated to collect and remove leachate from the landfill.

Leak Detection System - A landfill design feature that must be capable of detecting, collecting, and removing leaks of hazardous constituents at the earliest practicable time through all areas of the top liner likely to be exposed to waste or leachate during the active life and post-closure care period.

Liner - A landfill design feature that prevents any migration of wastes out of the landfill to the adjacent subsurface soil, groundwater, or surface water at any time during the active life (including the closure period) of the landfill. The liner must be constructed of materials that prevent wastes from passing through the liner.

Member of the Public - Any individual except those receiving an occupational dose.

mil – A unit of measure equivalent to 1/1000th of an inch.

mrem - A unit of dose equivalent, equal to 1E-03 rem.

NORM - Naturally Occurring Radioactive Material. Includes primordial radionuclides naturally present in the rocks and minerals of the earth's crust as well as cosmogenic radionuclides produced by interactions of cosmic nucleons with target atoms in the atmosphere and in the earth.

Occupational Dose - The dose received by an individual in the course of employment when assigned duties involve exposure to radiation or radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include doses received from background radiation.

picocurie (pCi) - A unit of radioactivity, equivalent to 1E-12 Curies.

Radiation - Means alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions.

Radioactive Contamination - Deposition of radioactive material in any place where it is not wanted.

TENORM - Technologically Enhanced Naturally Occurring Radioactive Material. TENORM is produced when radionuclides that occur naturally in ores, soils, water, or other natural materials are concentrated or exposed to the environment by human activities, such as uranium mining or sewage treatment.

Type I Landfill - A designation used in the State of Michigan to mean a hazardous waste landfill. The Wayne Disposal Site is the only Type I landfill in Michigan.

Type II Landfill - A designation used in the State of Michigan to mean a standard, Municipal Solid Waste Landfill.

VII. Acronyms

ANL – Argonne National Laboratory

ALARA – As Low As Reasonably Achievable

CFR – Code of Federal Regulations

CHP – Certified Health Physicist

DOE – U.S. Department of Energy

EQC – Environmental Quality Circular

FML – Flexible Membrane Liner

GCL – Geosynthetic Clay Liner

HDPE – High-Density Polyethylene

HELP – Hydrologic Evaluation of Landfill Performance

ICRP – International Commission on Radiological Protection

LDCRS – Leak Detection, Collection, and Recovery System

MDEQ – Michigan Department of Environmental Quality

MSWLF – Municipal Solid Waste Landfill

NCRP – National Council on Radiation Protection

NORM – Naturally Occurring Radioactive Material

NRC – U.S. Nuclear Regulatory Commission

Pb – Lead

POTW – Publicly Operated Treatment Works

Ra – Radium

RCRA – Resource Conservation and Recovery Act

RESRAD – Residual Radioactivity (Computer code)

Rn – Radon

SCS – Secondary Collection System

SWIFT II – Sandia Waste Isolation Flow and Transport (Computer code)

TDAP – TENORM Disposal Advisory Panel

TENORM – Technologically Enhanced Naturally Occurring Radioactive Material

TSD-DOSE – Treatment, Storage, and Disposal Facilities Dose (Computer code)

WDI – Wayne Disposal, Inc.

WTE – Waste-to-Energy