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Relationship between Geologic Disposal Characteristics and Advanced Nuclear Fuel Cycles with Partitioning and Transmutation

Roald Wigeland (INL)

William Halsey (LLNL), Temi Taiwo (ANL), Michael Todosow (BNL), and Jess Gehin (ORNL)

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Background

- **In the U.S, nuclear fuel cycles are being evaluated for their potential to address the issues with nuclear power**
  - The “Options Study” (started 3/09) has just been completed (9/30/10)
  - More detailed evaluations are ongoing
  - Comprehensive consideration of all fuel cycle options, such as uranium and thorium, once-through and recycle, and various disposal options
    - *No constraints on the choice of fuel cycles, technologies, or options*
    - *No presumption of technical maturity or current technical viability*
- **The project focuses on developing understanding of the capabilities of advanced nuclear fuel cycles**
  - Collect information and performance estimates
  - Summarize the impact of advanced nuclear fuel cycles
- **Nuclear waste management is one of the major issues, especially for used (spent) nuclear fuel and high level waste**
  - Low-level waste (LLW) also needs to be considered

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Nuclear Fuel Cycle Options Study

- **The focus was on identifying fuel cycle options, if any, that have the potential to make a "significant" difference**
  - A "significant" difference is one that is clearly greater than the uncertainties
    - *Incremental differences are often smaller than the uncertainties*
  - The reference in the U.S. is today's once-through fuel cycle using LWRs
- **The importance of considering the entire integrated nuclear fuel cycle, from mining to disposal, was emphasized**
  - Disposal environment characteristics affect the impact of alternative fuel cycles, such as recycling in a fuel cycle
- **At the same time, we are participating in the OECD/NEA WPFC Task Force on Potential Benefits and Impacts of Advanced Fuel Cycles with Partitioning and Transmutation (P&T), (WPFC/TFPT)**

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Evaluating Impact of Partitioning and Transmutation

- **The risk from radioactive waste disposal is usually expressed by the estimated dose rate to the public, i.e., is the isolation capability sufficient to protect the public?**
  - Dose rate can be considered as the result of two factors
  - Radiotoxicity of the emplaced wastes represents the “source term” of hazardous materials
  - The engineered repository system and the geologic environment represent the “exposure pathway” for hazardous materials to potentially reach the biosphere
- **Many studies have been performed for a variety of geologic disposal options**
  - Salt, Clay (and clay/granite), Volcanic tuff, …
- **Each geologic environment has characteristics that determine what constituents of the emplaced wastes will be of most concern for potential exposure**

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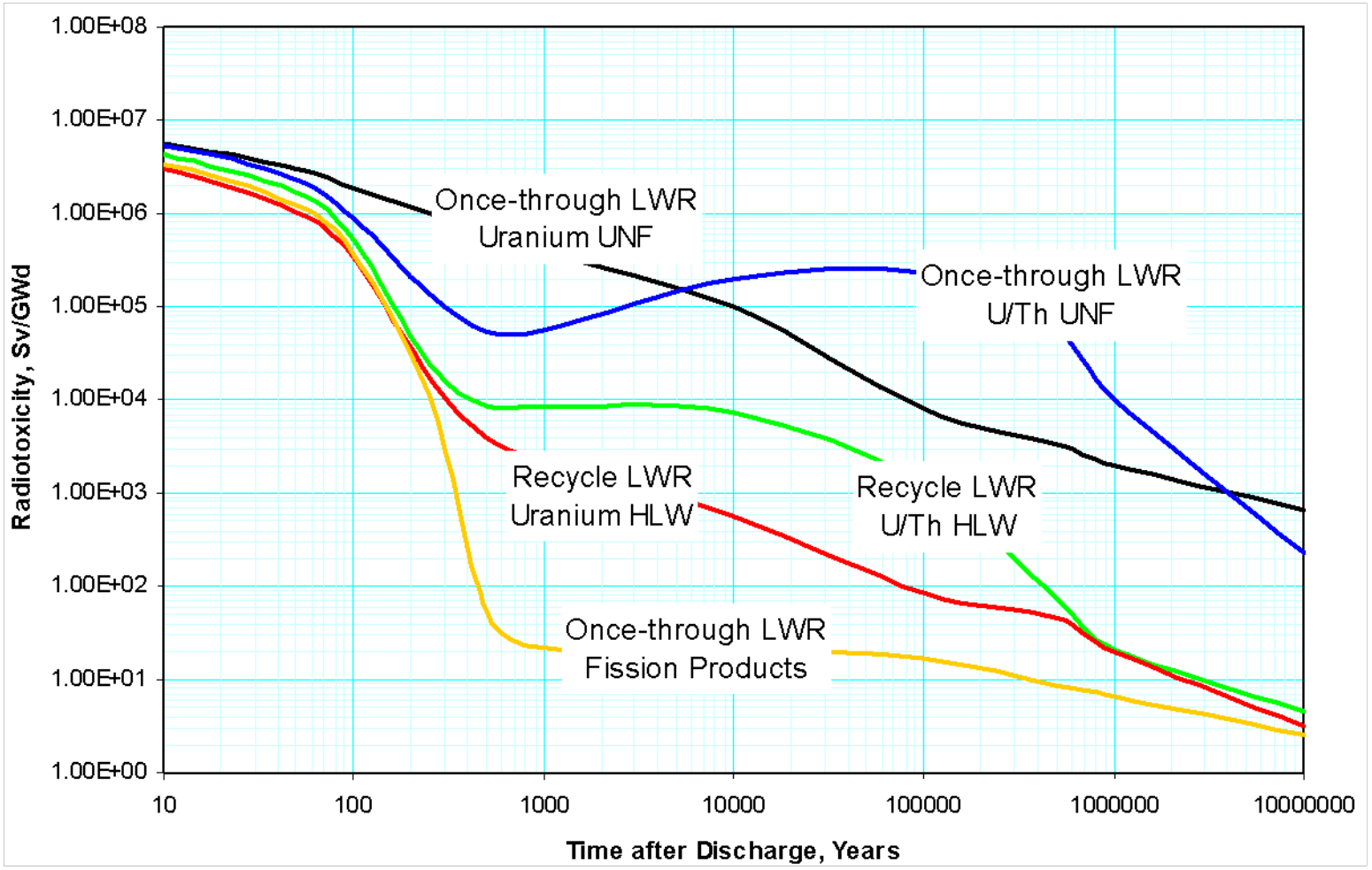
Radiotoxicity of Used Fuel, HLW, and Fission Products from LWRs



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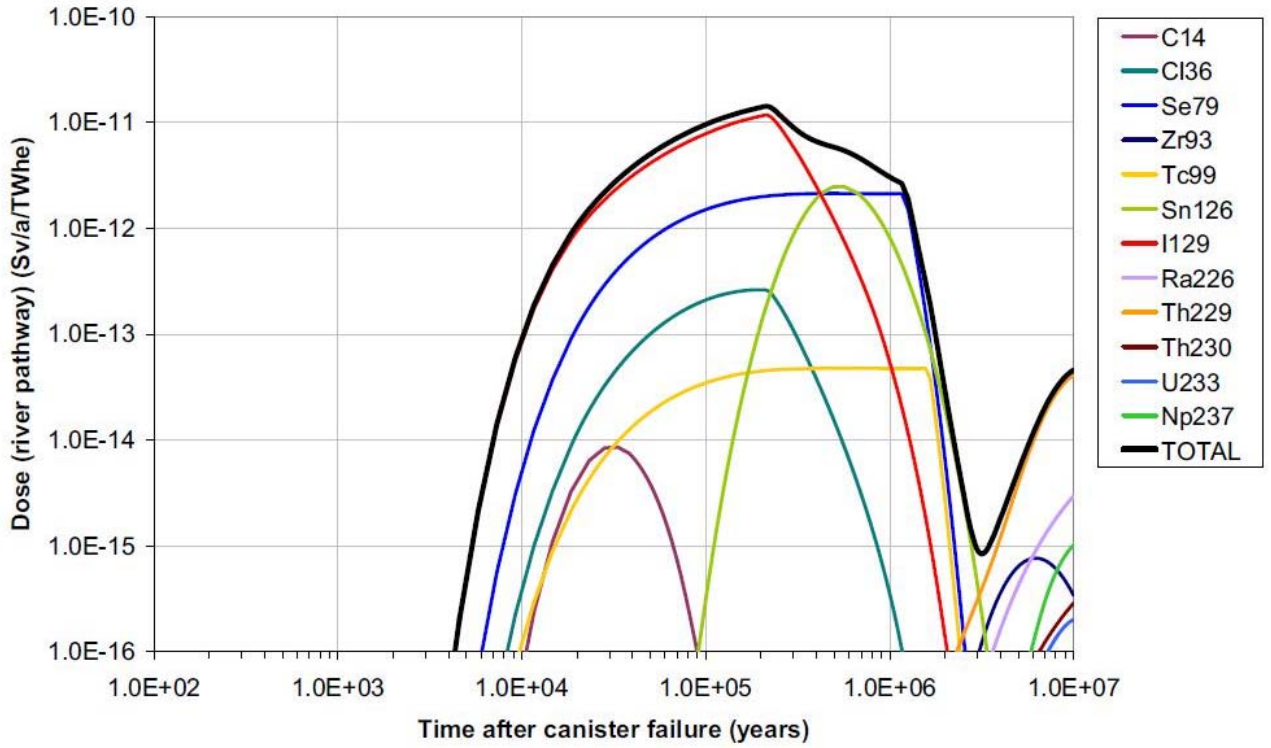
Used Fuel Disposal Example in a Thick Clay Layer (Red Impact Study)



- **Fission products dominate the expected dose rate for nominal undisturbed performance for a repository in a thick saturated clay layer**
  - Actinide transport is hindered by the geologic environment

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Summary of Geologic Disposal

- **Studies indicated that geologic repository performance can be considered in two parts, undisturbed and disturbed**
  - Undisturbed performance assumes the repository environment doesn't change
  - Disturbances modify the repository environment

Factors Affecting Deep Geologic Disposal for Integrated Nuclear Fuel Cycles Related to Engineered Repository Performance in a Geologic Environment

Both undisturbed and disturbed conditions must be considered for estimating performance

Undisturbed Repository Conditions

Range of reported repository sensitivities

Example repository environments: Salt, Deep Boreholes, Clay, Granite/Clay, Volcanic Tuff

Dominant Factor:	**Dominant Factors:**	**Dominant Factors:**
Decay Heat	Fission Product Content Decay Heat	Actinide & Fission Product Content Decay Heat

Disturbed Repository Conditions

Probability of Occurrence

Part or whole repository involvement

Natural Events | **Human Intrusion**

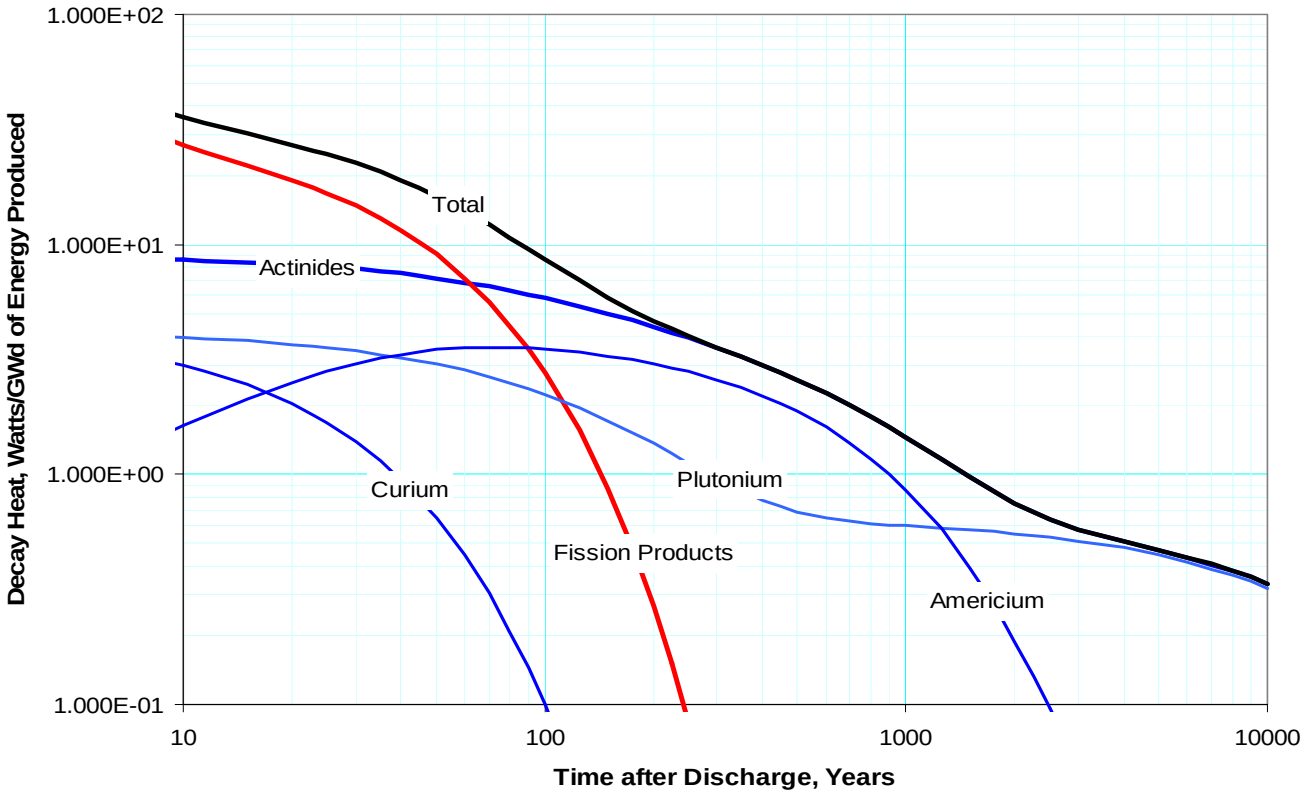
Disturbance effect can be geology dependent

Dominant Factors:
Actinide Content dominates
Fission Product Content may also be relevant

Nominal Undisturbed Conditions

- **Uncertainties may be low, depending on the ability to characterize the repository environment**
- **Decay Heat only**
  - Decay heat can directly impact the ability of the disposal environment to provide the required isolation
    - *Some examples are deep boreholes and salt*
- **Decay Heat and Fission Products**
  - Decay heat may be more of an operational issue affecting use of repository space, while fission products may dominate the dose rate
    - *Typical of thick saturated clay layers and disposal in clay/granite repositories*
- **Decay Heat, Fission Products, and Actinides**
  - Decay heat more of an operational issue affecting use of repository space, but both actinides and fission products contribute to dose rate
    - *Disposal in unsaturated volcanic tuff may exhibit these characteristics*
- **Longer term decay heat is mainly caused by actinide elements**

Used Nuclear Fuel Decay Heat



- **Reducing decay heat usually requires recycle of actinide elements**
  - Fission products can be mainly handled by shorter-term storage

Disturbed Conditions

- **Disturbances alter the repository environment**
- **Disturbances can be either natural or man-made**
  - Natural disturbances include seismic and igneous events, and other natural occurrences that change the conditions in the repository
  - Man-made disturbances are usually assumed to be intrusion events, including drilling through the repository, and can also change repository conditions
- **For disturbances, the exposure pathway can be very different from that for undisturbed conditions**
  - Part or all of the repository may be involved
  - Actinides may become more important for the resulting exposure
    - *Radiotoxicity may be more directly relevant*
- **Uncertainties about the disturbances and their effects tend to be large, especially for human intrusion**
  - For some repository studies, human intrusion scenarios can be a significant contributor to the overall risk

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Repository Performance Dominated by Undisturbed Conditions

- **If decay heat is the dominant factor affecting repository performance**
  - Fission product decay heat can be addressed with interim storage, or separations could be used to isolate high decay heat fission products
  - Actinide decay heat persists for longer times and is addressable by either separation and recycle of the actinides, or by substantial reduction in the volumetric heat rate
- **If fission product content and decay heat are the dominant factors**
  - In addition to the decay heat approaches described above, fission product recycle is not likely to be effective for reducing fission product content since most fission products are not amenable to neutron transmutation (^{99}Tc and ^{129}I can be transmuted)
- **If actinide content, fission product content, and decay heat are all important factors**
  - In addition to the decay heat and fission product approaches, recycle of the actinide elements to reduce actinide content can be effective

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Repository Performance Dominated by Disturbed Conditions

- **Uncertainty will be high, in proportion to the ability to predict events**
- **Human Intrusion**
  - Where no groundwater is present for undisturbed conditions, effects can be significant, especially if water is introduced as a result. Radiotoxicity is important.
  - Where groundwater is always present, the effects of human intrusion appear to be relatively minor. An alternative fuel cycle may have little or no effect in this case
- **Natural Events**
  - Effects of natural disturbances such as seismic and igneous events may be significant since the disturbed environment may not have the same isolation capability or exposure pathways. Studies assumed that the entire inventory of the repository may released from the repository environment.
- **Overall, it appears that the consequences of disturbances can be reduced by lowering the radiotoxicity of the inventory in the repository**

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Repository Performance Affected by Undisturbed and Disturbed Conditions

- **The studies that have been reviewed demonstrate that both nominal undisturbed conditions and disturbed conditions would likely be considered in developing the performance assessment of geologic disposal.**
  - Relative importance varied between the studies
- **For any alternative fuel cycle, the geologic disposal environment and any associated engineered systems should be considered as part of the integrated fuel cycle since it will determine what, if any, impact the alternative fuel cycle would have on waste management.**
  - Radiotoxicity and Exposure Pathways combined
- **For identifying those fuel cycles that may be able to make a significant difference to the current nuclear waste management situation, measures to address both undisturbed and disturbed conditions are considered.**

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Impact of Fuel Cycle Choice – Once-Through

- **Use of fuel in a reactor with a once-through fuel cycle requires that the quantity of nuclear fuel provided for power production eventually needs to be buried at a geologic disposal site**
  - Fission products build nearly linearly with fuel burnup and actinide content approaches (but does not reach) a quasi-equilibrium level with ongoing isotopic evolution with increasing burnup
  - Only shorter term decay heat can likely be managed with storage
  - This limits the potential waste management benefit for once-through systems to only modest improvements
  - An exception to this may be an externally driven system with sufficient neutrons to approach nearly complete burnup, where the final actinide content could be lowered.
    - *Fission product content still requires geologic disposal*

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Impact of Fuel Cycle Choice – Recycle

- **With recycle, actinides are typically separated and reused in fuel, producing further energy and fission products**
  - on the basis of energy generated, the amount of highly hazardous material per unit of energy produced that would need to be buried using geologic disposal may be greatly reduced
  - This reduction could be used to lower the inventory to be disposed in a given repository site, reducing potential releases and making uncertainties less important.
  - Alternatively, the greatly lower decay heat and radionuclide inventory could permit a disposal site to effectively accept high-level waste associated with greater energy generation.
    - *If fission products dominate risk, this possibility may be limited*
  - It is noted that even with actinide recycle where all UNF is processed, there would always be the need for isolation of HLW as provided by a geologic disposal site
    - *Fission products and the radioactive material losses during reprocessing*

Fuel Cycle Options

- **The following categories of both uranium-based and thorium / fissile-based fuel cycles contain one or more options that may be beneficial:**
  - Recycle options with all UNF processed, recycle of actinide elements
  - Recycle: Critical – thermal neutron systems
  - Recycle: Critical – fast neutron systems
  - Recycle: Critical – thermal and fast neutron systems
  - Recycle: Subcritical – thermal neutron systems
  - Recycle: Subcritical – fast neutron systems
  - Recycle: Subcritical – thermal and fast neutron systems
  - Recycle: Critical and Subcritical – thermal neutron systems
  - Recycle: Critical and Subcritical – fast neutron systems
  - Recycle: Critical and Subcritical – thermal and fast
  - Once-through: Subcritical – fast neutron systems, essentially complete fuel consumption
- **The key aspects of the recycle fuel cycles are that all UNF needs to be processed, since UNF actinide content is large compared to processing and fuel fabrication losses, and that all of the actinides should be recycled, not just uranium and plutonium**

Conclusions

- **P&T can be effective in improving nuclear waste management for used fuel and HLW**
  - Processing of all UNF and recycle of actinides
  - Lowers decay heat, either enabling some disposal options or improving use of other options
  - Lowers long-term radiotoxicity on a per energy generated basis, mainly relevant to disturbed repository conditions
  - Can be used to either lower the disposal hazard, or to increase the amount of used fuel that a repository can handle by only disposing HLW
- **Uncertainty dominates predictions of repository performance**
  - P&T can be used to reduce the risk of disposal by reducing inventory, also lowering the importance of uncertainties
    - *May provide a more credible basis for ensuring regulatory limits are not exceeded*
- **In general, the less hazardous waste content per GWd, the better**