Managing Spent TRISO Fuel for High Temperature Reactors Using Deep Isolation's Universal Canister System

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ONWARDS UPWARDS

DEEP ISOLATION®

BERKELEY LAB

Berkeley UNIVERSITY OF CALIFORNIA

NAC INTERNATIONAL

IAEA International Atomic Energy Agency

Agenda

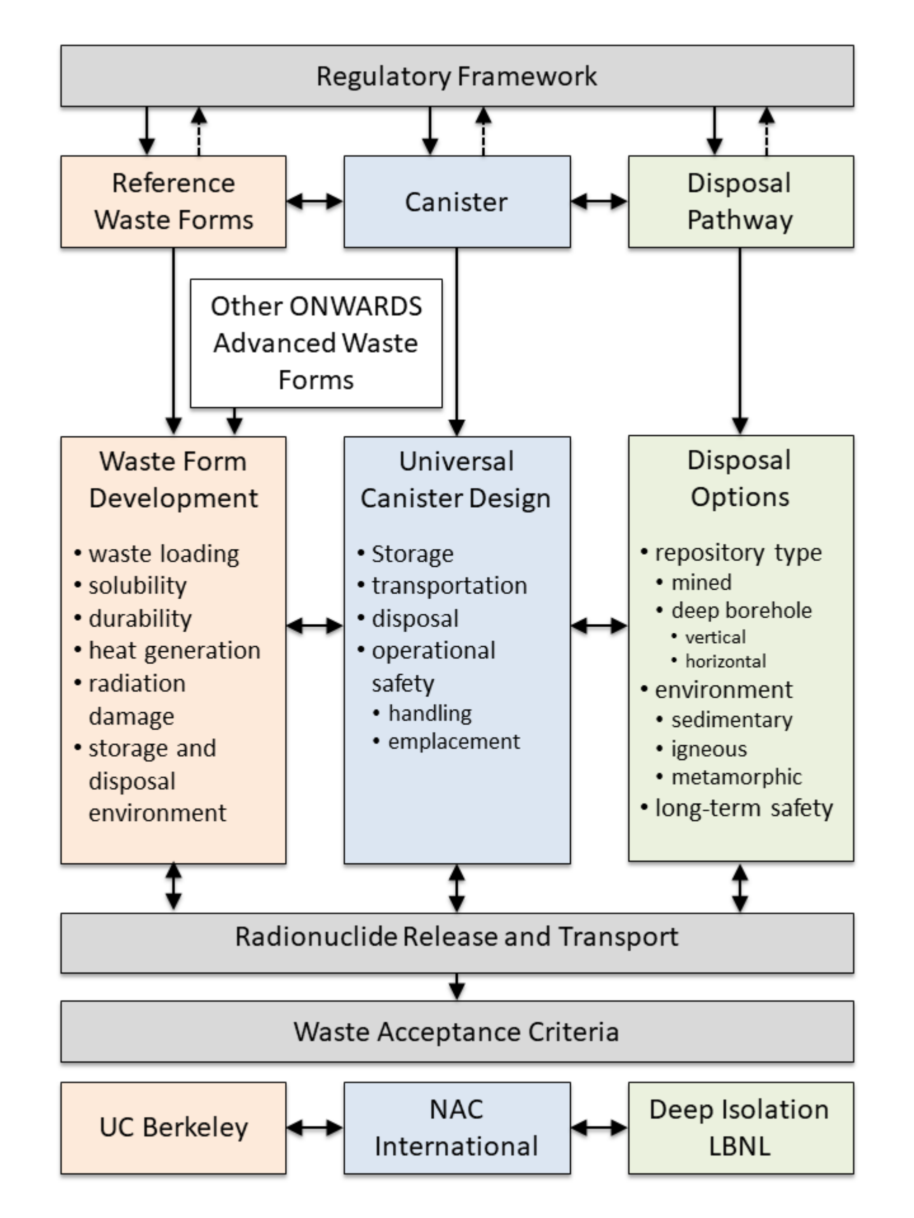
- Overview of Project UPWARDS and Project PUCK
- Universal Canister System Development
- TRISO Waste Characterization
- Performance Assessments
- Waste Acceptance Criteria Development
- Conclusion
- Questions

Project UPWARDS

__U__niversal __P__erformance Criteria and Canister for Advanced Reactor __W__aste Form __A__cceptance in Borehole and Mined __R__epositories Considering __D__esign __S__afety

Four workstreams:

1. Waste Form Development
2. Canister Design and Prototype
3. Models and Generic Performance Assessment
4. Waste Acceptance Criteria

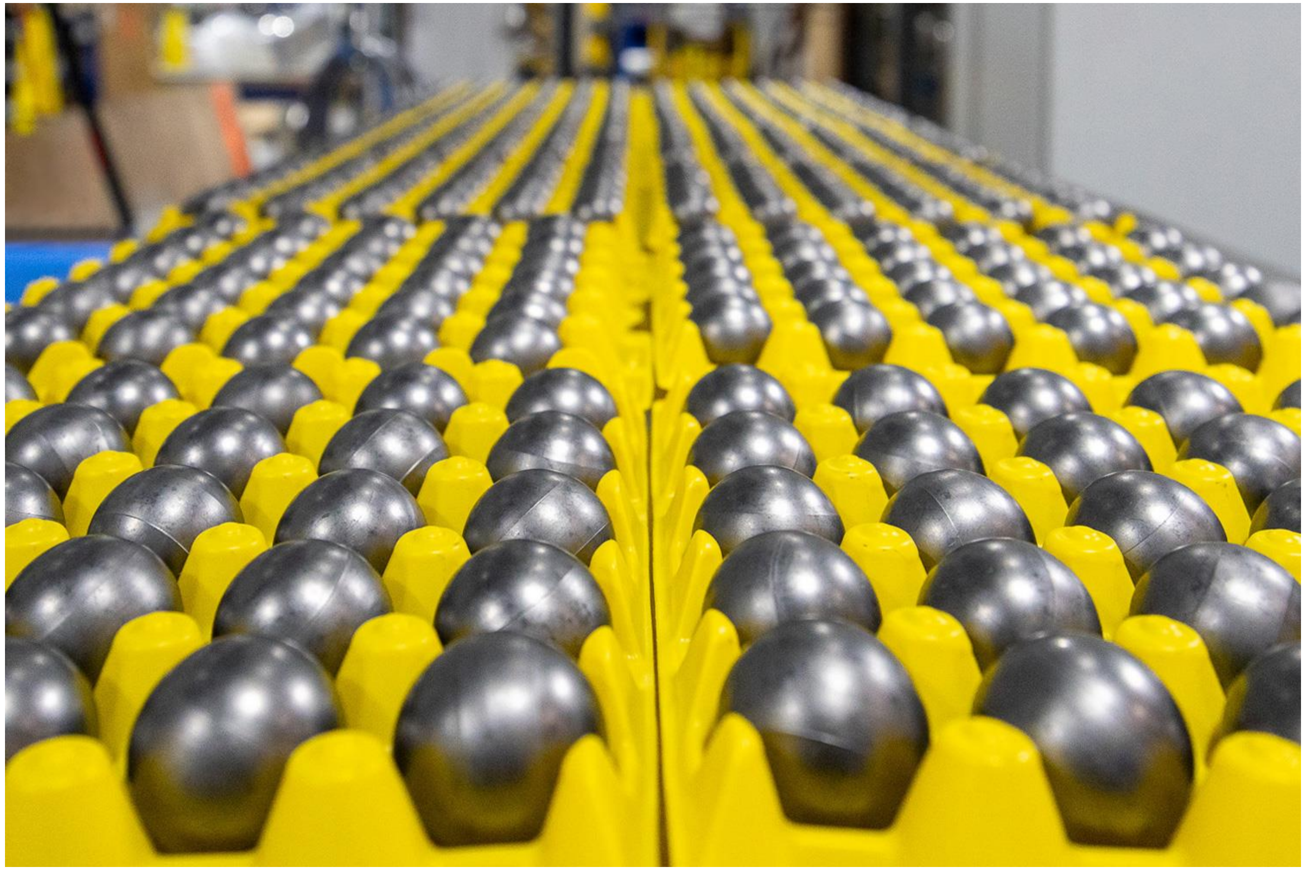


Project PUCK

Performance Validation of the Universal Canister System for Kairos Power

Two main workstreams:

1. Waste Form and Canister Analysis
2. Techno-Economic Analysis



The Universal Canister System: Overview

1

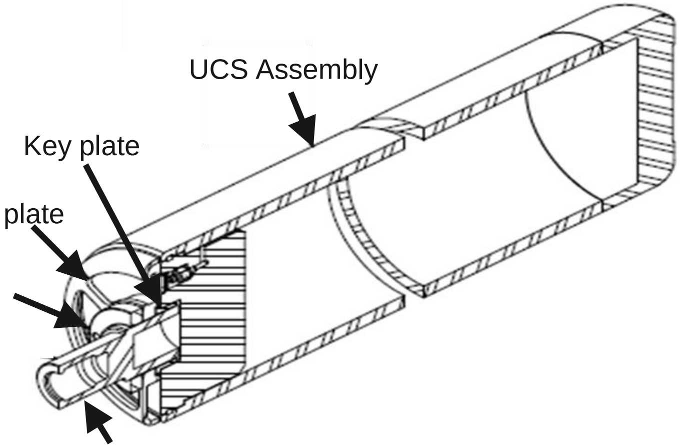
Engineered for all major current and advanced nuclear fuels.

- Oxide Fuels (UO_2)
- High-Temp Gas Cooled Reactor (TRISO)
- Liquid Metal-Cooled Fast Reactor
- Molten salt reactor (coolant/fuel)
- Vitrified waste (canister)

2

Supports **open** and **closed** fuel cycles.

Universal Canister System



A family of canisters that:

- Are engineered in a range of sizes (to accommodate a wide variety of advanced reactor waste forms) and thicknesses (to provide structural stability in a range of different disposal depths).
- Share common, standardized features, including closure designs and lifting attachments designed for interoperability with standard lifting and emplacement technologies used on a daily basis in the oil and gas industry.

	Class 1	Class 2	Class 3
TRISO blocks	0	6	6
TRISO compacts	162	198	216
Vitrified Waste Containers	0	3	3
LWR spent fuel assembly	1	0	0
Shell ID	12.75”	14.50”	17.50”
Shell OD	14.75”	16.75”	20.35”
Max weight content	2,000 lbs	2,500 lbs	4,000 lbs

3

Enables waste to be packaged once

– avoiding costs and risks of future repackaging, even when disposal path is uncertain.

WAC

(Waste Acceptance Criteria)

- UCS integrates with modern transport systems
- UCS integrates with interim dry cask storage systems
- Geologic disposal
  - In a traditional mined facility
  - In deep boreholes

4

Designed to integrate with all forms of transport, storage, & disposal.

UCS Prototype Fabrication

UCS Prototype canister
without lift adapter assembly

Disassembled lift adapter assembly

UCS Prototype Fabrication

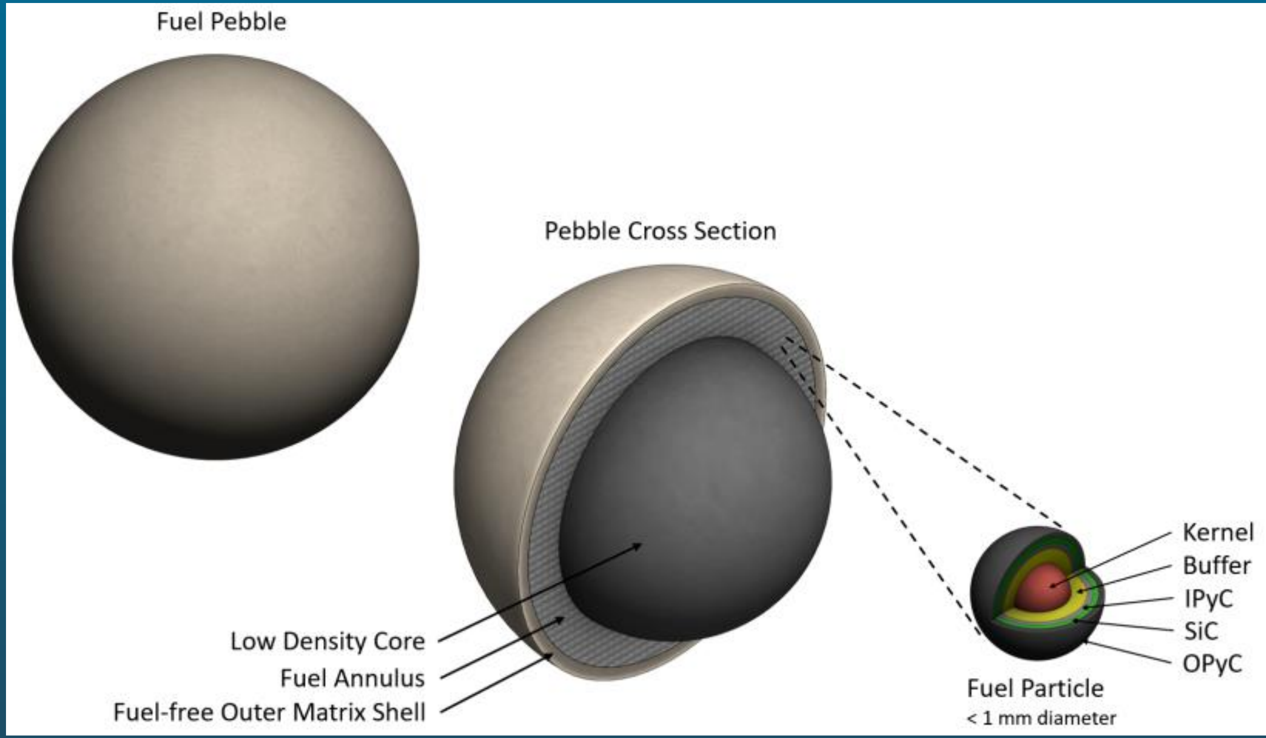
Fully assembled prototype UCS canister

Completed UCS prototype canister

TRISO Waste Characterization

- Highly durable, being used by multiple AR developers
- Spherical pebbles, cylindrical compacts, and full prismatic assemblies
- Experimentation
  - Dissolution of impermeable SiC layer
  - Purity, temperature, and pH effects
- Purity (~97.5% : >99.9995%)
  - 5x faster @ lower purity
  - Further studies assumed CVD high-purity SiC
- Temperature
  - Activation energy (E_a) for performance assessments
  - Potential Si saturation at high temperatures
- pH
  - Dissolution follows pH power law relationship

TRISO fuel properties & key characteristics



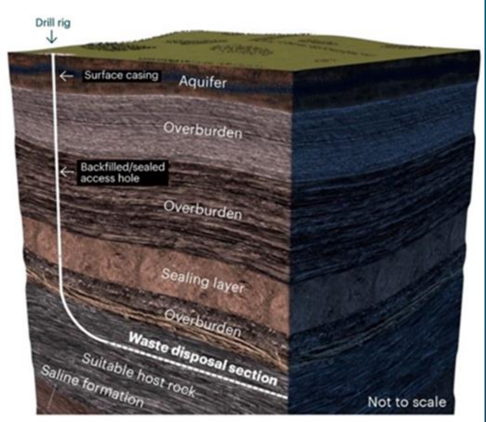
- Pebble diameter
- Mass of Uranium
- Particle packing fraction
- Number of TRISO particles
- Fuel kernel material
- Kernel diameter
- Buffer thickness
- IPyC thickness
- SiC thickness
- OPyC thickness

Performance Assessments

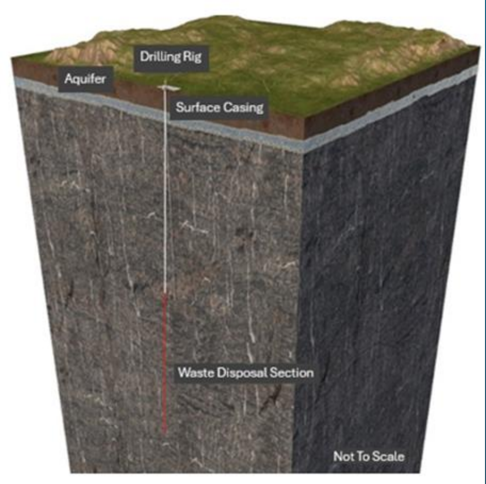
- Numerical modeling
  - TOUGHREACT
  - iTOUGH2
- Multiple waste forms
  - LaBS glass
  - TRISO
  - Intact halide salts
- Multiple disposal pathways

Mined repository

Horizontal borehole repository



Vertical borehole repository



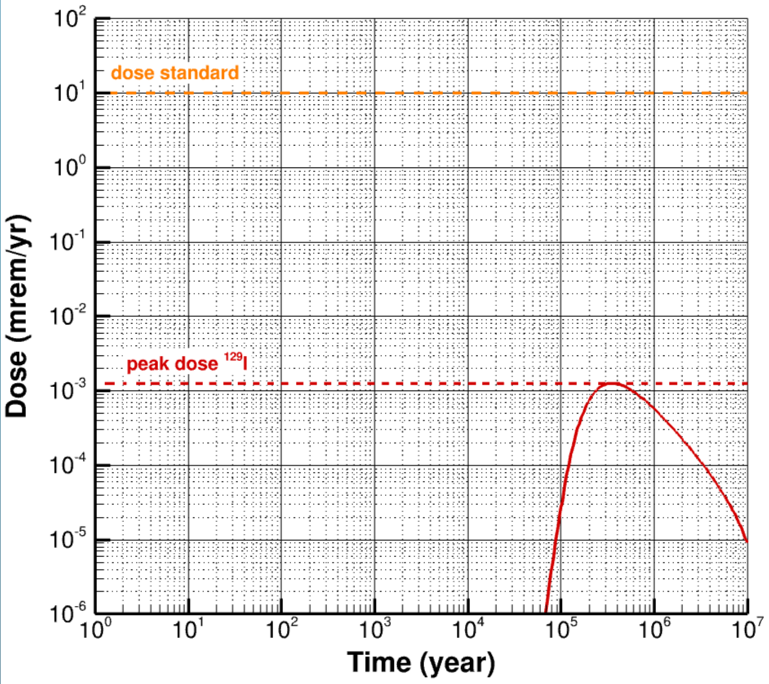
Waste Form-Repository Pairings

		Repository Concept		
		Mined Repository	**Vertical Borehole**	**Horizontal Borehole**
Waste Form	**LaBS**	Host formation: Shale Multiple Class 3 UCSs in overpack	Host formation: Fractured rock String of Class 3 UCSs	n/a
	TRISO	Host formation: Shale Multiple Class 1–3 UCSs in overpack	Host formation: Fractured rock String of Class 1–3 UCSs	Host formation: Shale String of Class 1 or Class 2 UCSs
	Molten Salt	Host formation: Shale Multiple Class 1–3 UCSs in overpack	Host formation: Fractured rock String of Class 1–3 UCSs	Host formation: Shale String of Class 1 or Class 2 UCSs

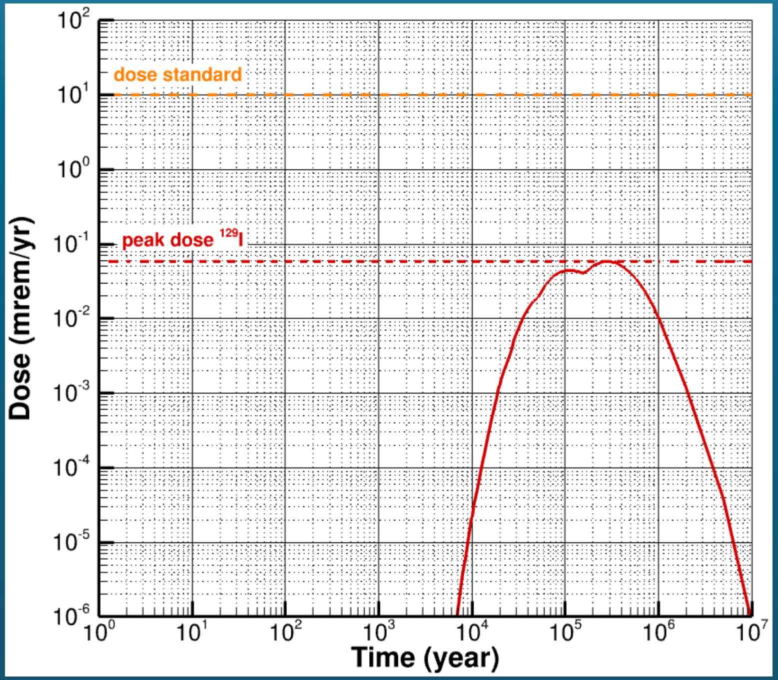
Performance Assessment Screening Models

- UCB research/experimental results → PA modeling inputs
- ~80 adjustable parameters
- Down-selection of radionuclide inventory
  - Characteristics of each RN
  - Properties of waste
  - Conditions in repository system & influence on RN transport
- Performance Metrics
  - A: Exposure dose
  - B: Waste temperature

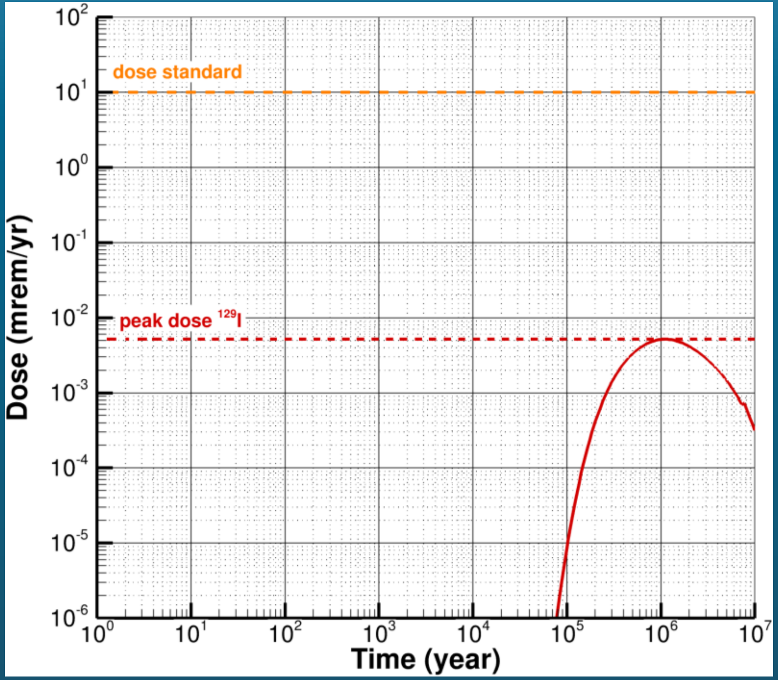
PA Results for Kairos Power



*Exposure dose for reference parameter set (^{129}I) for a **horizontal borehole** repository*

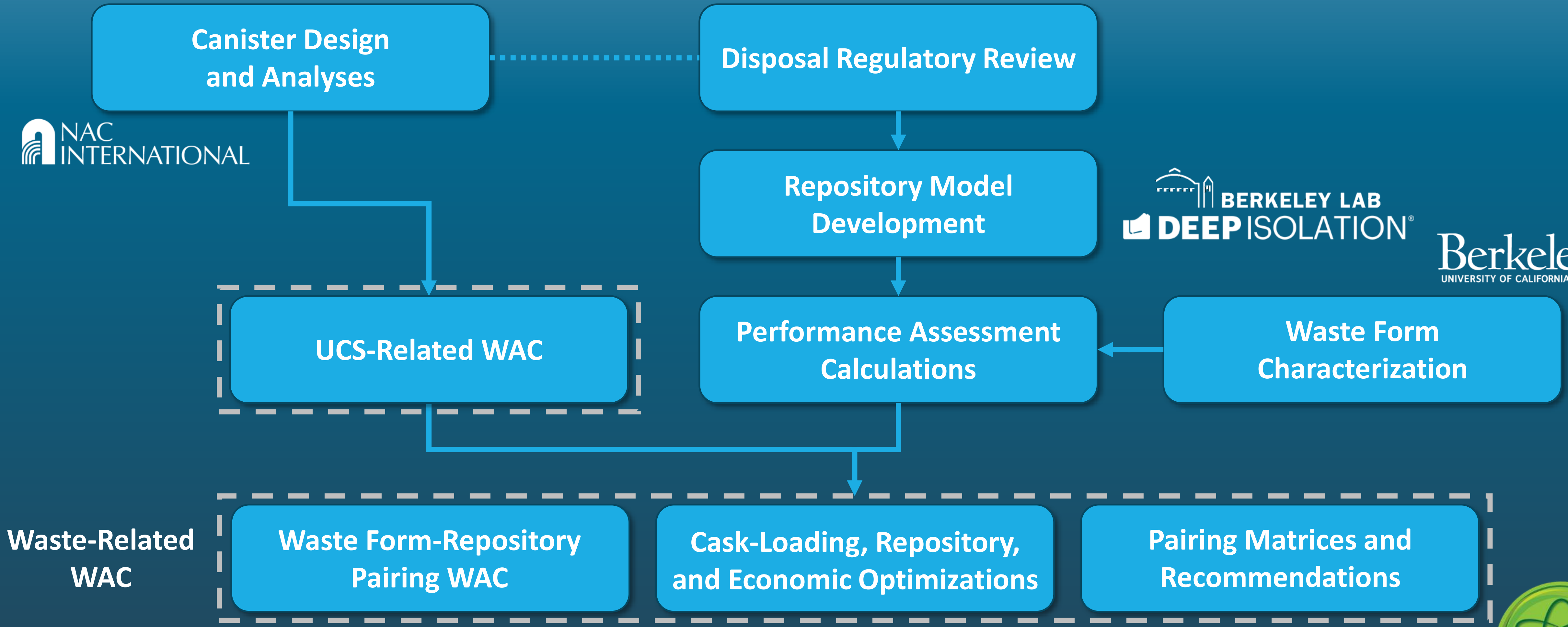


*Exposure dose for reference parameter set (^{129}I) for a **vertical borehole** repository*



*Exposure dose for reference parameter set (^{129}I) for a **mined** repository*

Waste Acceptance Criteria Development



Two Categories of WAC

Canister-related criteria*

- UCS Design Specification
- Preliminary design analyses

**Potential for waste form-agnostic criteria*

Pairing-specific criteria

- Results of safety & performance assessments
- Unique to each pairing of waste form & repository configuration

TRISO-specific criteria

- Varying criteria depending on repository configuration
  - Mined repository; vertical borehole; horizontal borehole
- Waste loading of safety-relevant RNs
  - mass of ^{129}I, ^{238}U, and ^{235}U per UCS
- Heat loading
  - kW of decay heat per UCS
- Waste age
  - Years of cooling time between waste generation and emplacement in repository

*Waste acceptance criteria are **interdependent** with repository site-selection criteria*

Performance Metrics

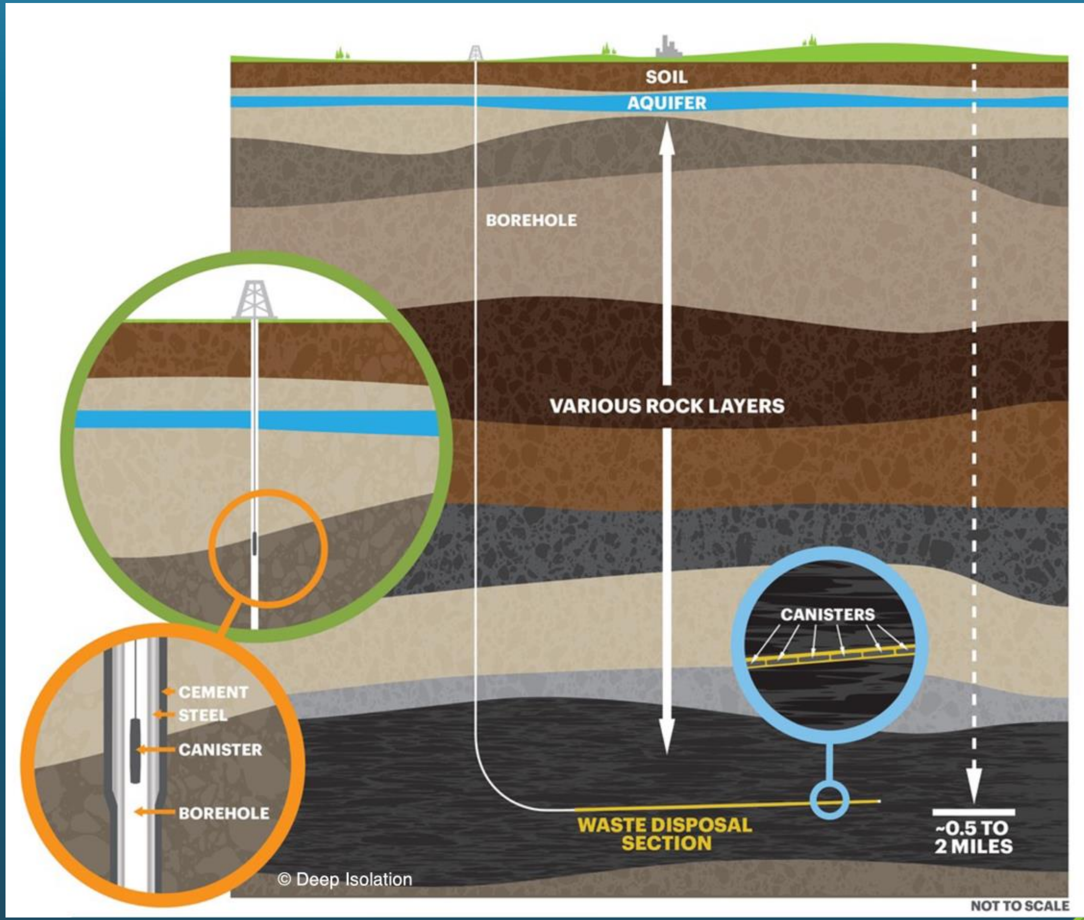
A. Peak Dose
- 1 mrem/year
  - Self-imposed limit @ 10% of regulatory limit
  - Compensates for number of Monte Carlo samples

Waste acceptance criteria are ***interdependent*** *with repository site-selection criteria*

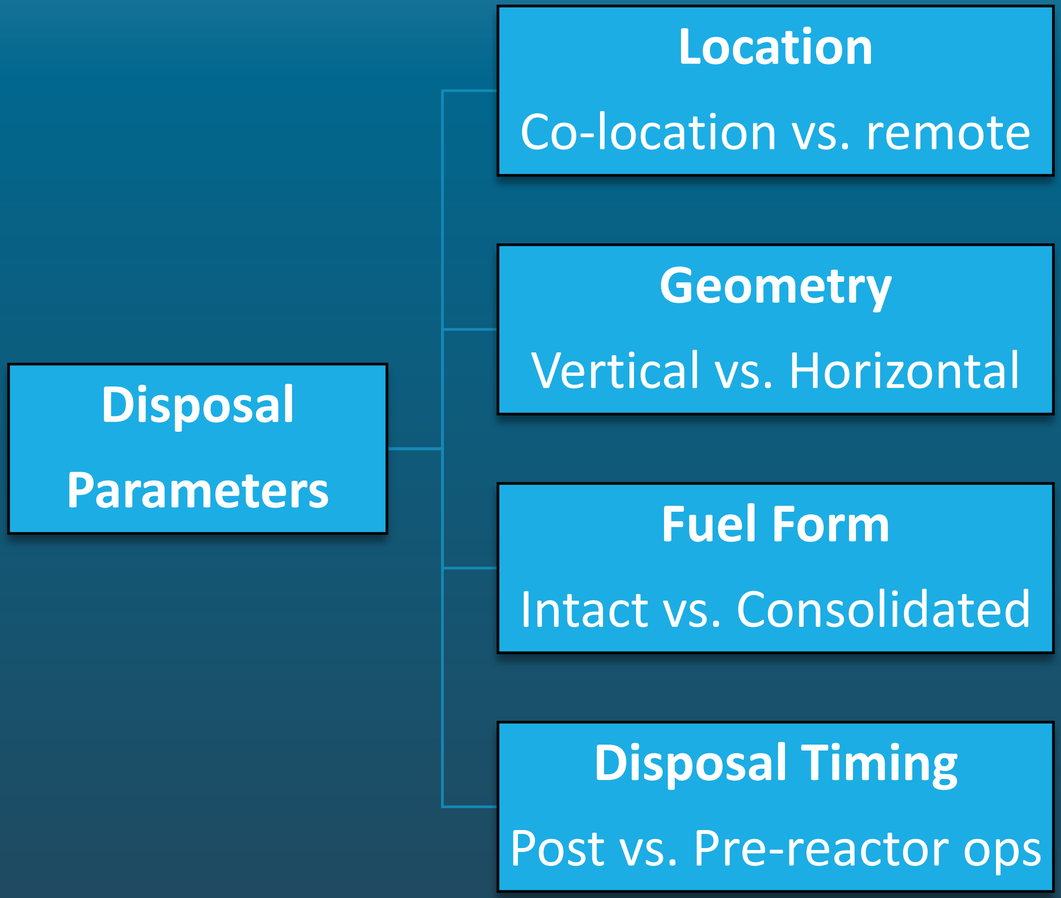
B. Peak Temperature
- Varied by repository type
  - MGR – 100°C
    - Based on atmospheric boiling and illitization of bentonite
    - Potential to relax to 200°C
  - Borehole – 250°C
    - Based on margin to maximum service temperature of duplex SS
    - 200°C limit if shallower than 1 km
      - Boiling concern

Repository Optimization

- Trade space identified for
  - Canister-to-canister spacing within repository
  - Spacing between boreholes or deposition tunnels
- Margin to limits of performance metrics reduces with closer or larger packaging
- Site- and inventory-specific analyses could lead to further efficiencies



PUCK Techno-Economic Analysis



- Cost competitiveness and optimization potential
  - Co-location + Horizontal DBD = ~40% cost savings vs. reference PWR disposal
- Volume reduction as a transformative option
  - >40% cost savings vs. intact TRISO spheres
- Expedited disposal versus extended dry storage
  - >30% cost savings through expedited disposal operations

Conclusions

- Project UPWARDS ***developed*** and Project PUCK ***validated*** the use of the ***Universal Canister System (UCS)*** as a ***viable*** storage, transport, and disposal system for commercial spent TRISO fuel.
- Safety and performance assessment modeling results indicate ***acceptable radiological and thermal performance***, several orders of magnitude below safety standards.
- Techno-economic analyses show ***significant life-cycle cost savings*** through co-location, horizontal borehole disposal, and expedited disposal operations.

Thank you!

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