Back-End Management of Advanced Reactors (BEMAR)

Ned Larson

Presented at Nuclear Waste Technical Review Board Meeting

Summer 2023 Meeting

Idaho Falls, Idaho

August 30, 2023

U.S. DEPARTMENT OF ENERGY | *Office of* NUCLEAR ENERGY

Disclaimer

This is a technical presentation that does not take into account contractual limitations or obligations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961).

To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this report in no manner supersedes, overrides, or amends the Standard Contract.

This presentation reflects technical work which could support future decision making by DOE. No inferences should be drawn from this presentation regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository.

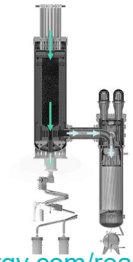
Some Advanced Reactors Under Development

ADVANCED REACTOR DEMONSTRATION PROGRAM (ARDP)

Demonstrations

X-energy

Xe-100



https://x-energy.com/reactors/xe-100

TerraPower

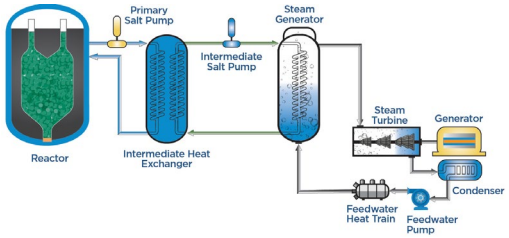
Natrium

https://www.terrapower.com/

Risk Reduction

Kairos Power

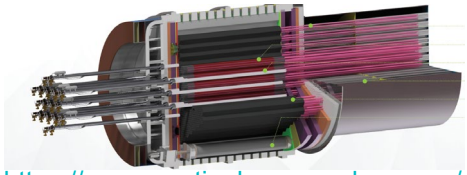
KP-FHR



https://kairospower.com/technology/

Westinghouse

eVinci

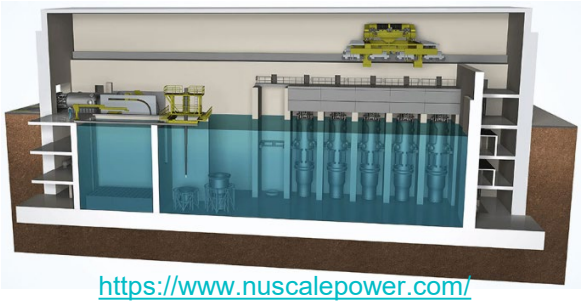


https://www.westinghousenuclear.com/

CARBON FREE POWER PROJECT

NuScale

VOYGR-6



https://www.nuscalepower.com/

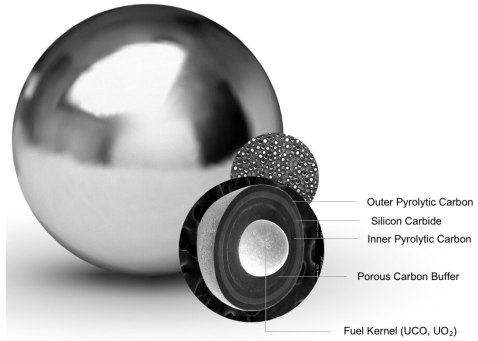
Ultra Safe Nuclear

Micro Modular Reactor

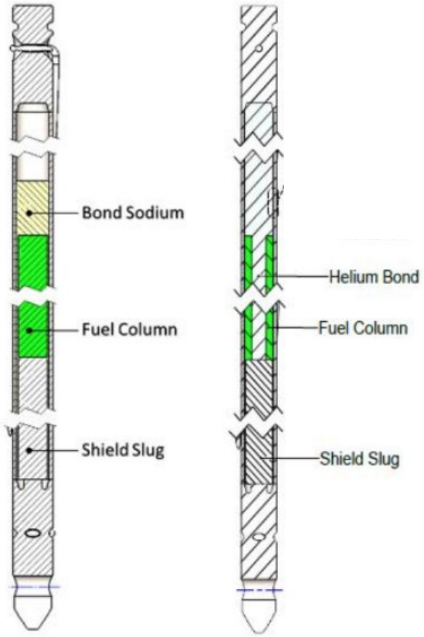
https://www.usnc.com/mmr/

What About the Spent Fuel?

- Advanced reactor designs vary in size, power levels, and the forms of fuels they will use
- These fuels and the expected spent nuclear fuel (SNF) may differ substantially from the existing commercial SNF inventory—and may need different handling, storage, transportation, or disposal options
- These fuels present a challenge for our R&D program



https://x-energy.com/fuel/triso-x



Natrium Advanced Reactor Fuel Cycle Management – NEA Presentation

Nuclear Waste Policy Act of 1982 (as amended) (NWPA)

- Established the Federal responsibility for the disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW)

- Assigned to DOE the responsibility of developing capabilities for disposal and, if necessary, consolidated interim storage (referred to in the NWPA as “monitored retrievable storage”)

NWPA Contracting Requirement

See Section 302(b): (b) ADVANCE CONTRACTING REQUIREMENT–

(1) (A) The Commission shall not issue or renew a license to any person to use a utilization or production facility under the authority of section 103 or 104 of the Atomic Energy Act of 1954 (42 USC 2133,2134) unless–

(i) such person has entered into a contract with the Secretary under this section; or

(ii) the Secretary affirms in writing that such person is actively and in good faith negotiating with the Secretary for a contract under this section.

(B) The Commission, as it deems necessary or appropriate, may require as a precondition to the issuance or renewal of a license under section 103 or 104 of the Atomic Energy Act of 1954 (42 USC 2133, 2134) that the applicant for such license shall have entered into an agreement with the Secretary for the disposal of high-level radioactive waste and spent nuclear fuel that may result from the use of such license.

The NRC Asks for Proof

KAIROS

Department of Energy
Washington, DC 20585

November 6, 2022

VIA ELECTRONIC MAIL

Peter S. Hastings, PE
Vice President, Regulatory Affairs & Quality
Kairos Power LLC
121 West Trade Street, Suite 1010
Charlotte, NC 28202
hastings@kairospower.com

Re: Confirmation of Active and Good Faith Negotiations for Disposal Contract

Dear Mr. Hastings:

I am writing to affirm that Kairos Power LLC ("Kairos") is actively and in good faith negotiating with the Secretary of Energy for a contract under section 302(b) of the Nuclear Waste Policy Act of 1982, as amended ("NWPA").

Although section 302(b)(1)(A)(ii) of the NWPA assigns to the Secretary of Energy the function of making the above affirmation, section 304(b) of the NWPA further provides that the director of the Office of Civilian Radioactive Waste Management (OCRWM) "shall be responsible for carrying out the functions of the Secretary under [the NWPA], subject to the general supervision of the Secretary." In 2010, OCRWM was closed and the functions relating to the Standard Contract were assigned to the Office of the General Counsel. Those functions were later assigned by the General Counsel to my office.

DOE is reviewing the issue of the appropriate contract mechanism and will be in contact for further discussions.

Sincerely,

/s/ Constance A. Barton

Constance A. Barton
Contracting Officer, Director
Office of Standard Contract Management
Office of the General Counsel

cc via email:
Darrell Gardner (gardner@kairospower.com)

ML23019A362

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SAFETY EVALUATION

Related to the
Kairos Power LLC
Construction Permit Application for
the Hermes Test Reactor

Docket 50-7513

Completed: Month 2023

ML23158A268

ABILENE CHRISTIAN UNIVERSITY

From: Edward Helvenston
Sent: Tuesday, May 9, 2023 1:36 PM
To: Rusty Towell; Lester Towell; Jordan Robison; Tim Head; Alexander Adams
Cc: Richard Rivera; Zackary Stone (He/Him/His); Michael Wentzel; Boyce Travis
Subject: ACU MSRR Section 1.7 and 9.5 Audit Questions

Dear Dr. Towell,

Below are questions the U.S. Nuclear Regulatory Commission (NRC) staff has prepared for Abilene Christian University (ACU) related to the ACU Preliminary Safet
and Section 9.5, "Possession and Use of Byproduct, Source, and Special Nuclear Material." The NRC staff would like to discuss these questions within the scope o
plan dated 3/2/2023, ML23065A052), and I am providing in advance to facilitate discussion during an audit meeting. We will add this email, with the questions, t

Thank you,

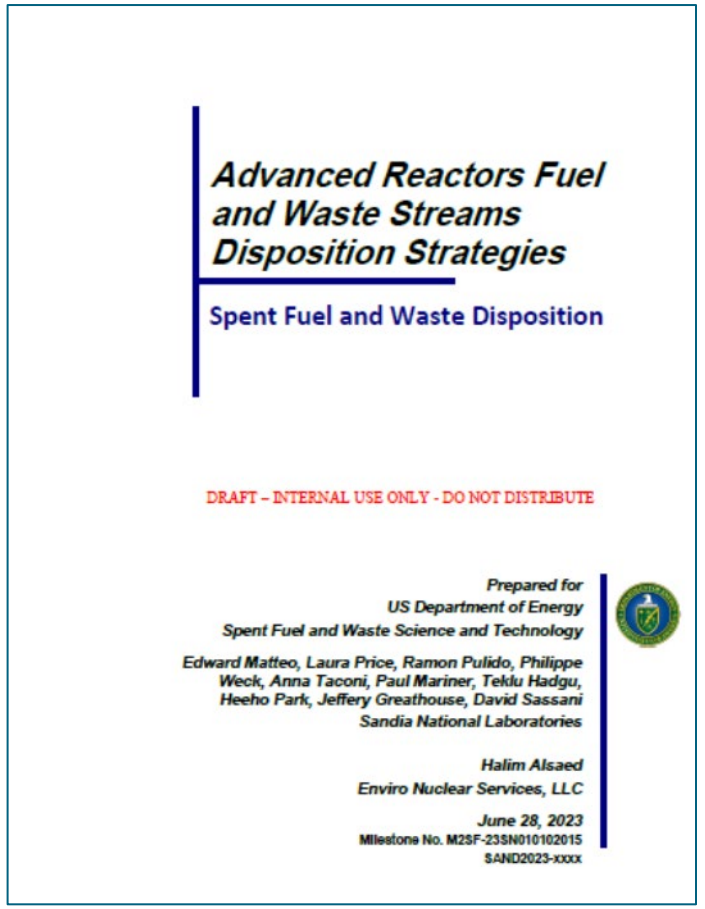
Ed Helvenston, U.S. NRC
Non-Power Production and Utilization Facility Licensing Branch (UNPL)
Division of Advanced Reactors and Non-Power Production and Utilization Facilities (DANU)
Office of Nuclear Reactor Regulation (NRR)
O-6B22
(301) 415-4067

Item #	Question
1.7-1	Section 302 of the Nuclear Waste Policy Act of 1982, as amended (the NWPA) (42 USC § 10101 et seq.), specifies that the NRC may require, as a precondition to issuing a facility operating license for a research reactor, that the applicant have entered into an agreement with the U.S. Department of Energy (DOE) for the disposal of high-level radioactive waste and spent nuclear fuel that may result from the use of such license. Furthermore, the NWPA specifies that the NRC shall not issue a license to any person to use a utilization facility under section 103 or 104 of the AEA unless: (i) such person has entered into a contract with DOE for disposal under section 302 of the NWPA or (ii) DOE affirms in writing that that such person is actively and in good faith negotiating with DOE for such a contract. The staff notes that to be in compliance at the CP stage, an applicant needs to submit documentation showing communications in good faith between the applicant and DOE to enter into a contract for the disposition of high-level waste and nuclear fuel. (See, for example, ADAMS Accession No. ML23019A360.) MSRR PSAR Section 1.7, "Compliance with the Nuclear Waste Policy Act of 1982," states: "Abilene Christian University intends to enter into a contract with the Department of Energy for required fuel cycle services. This will be discussed further in the Operating License application, consistent with Section 302(b)(1) of the Nuclear Waste Policy Act of 1982." MSRR PSAR Appendix 15A provides a letter from DOE to ACU, dated November 15, 2019, indicating that DOE will consider ACU requests for fuel services including fuel disposition once ACU has an NRC-licensed research reactor. However, this letter does not appear to provide specific documentation from DOE of communications between ACU and DOE to enter into a fuel disposal contract. Please discuss whether ACU has specific documentation showing communications in good faith between ACU and DOE to enter into a contract for

ML23129A780

DOE Has Two Efforts to Address the Spent Nuclear Fuel

- Report with non-proprietary publicly available data is being prepared that will be shared with the public when final
- Report with proprietary data is being prepared for each reactor and will be provided to General Counsel by BEMAR team



Advanced Reactors Fuel and Waste Streams Disposition Strategies

Spent Fuel and Waste Disposition

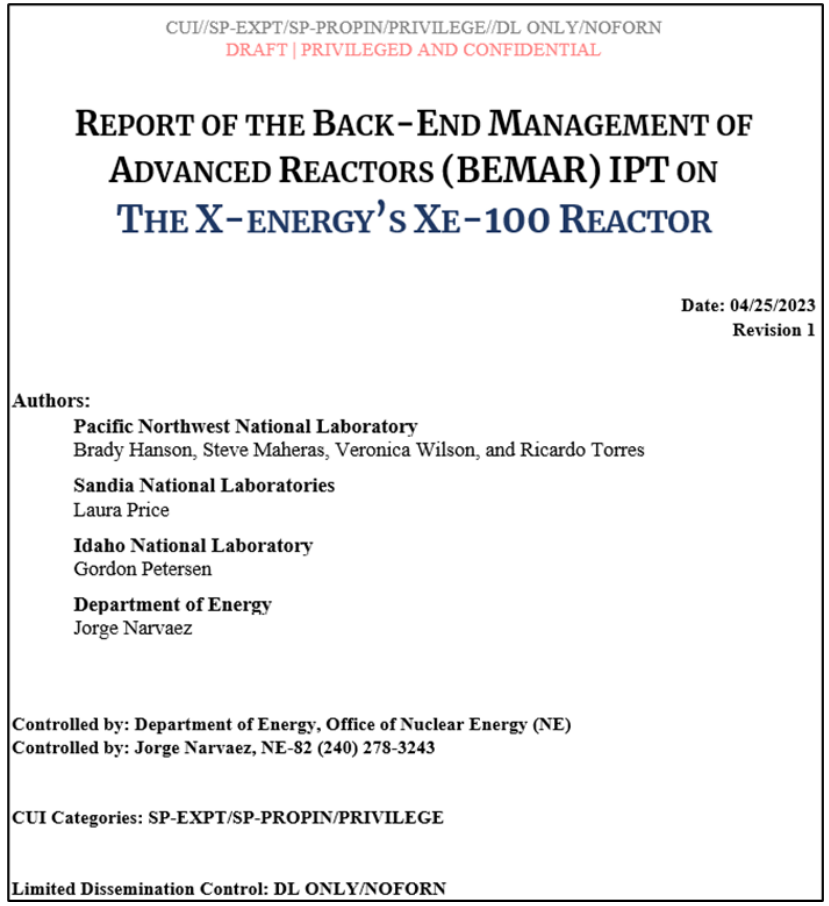
DRAFT – INTERNAL USE ONLY - DO NOT DISTRIBUTE

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology

Edward Matteo, Laura Price, Ramon Pulido, Philippe Weck, Anna Taconi, Paul Mariner, Teklu Hadgu, Heeho Park, Jeffery Greathouse, David Sassani
Sandia National Laboratories

Halim Alsaed
Enviro Nuclear Services, LLC

June 28, 2023
Milestone No. M2SF-23SN010102015
SAND2023-xxxx



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REPORT OF THE BACK-END MANAGEMENT OF ADVANCED REACTORS (BEMAR) IPT ON THE X-ENERGY'S XE-100 REACTOR

Date: 04/25/2023
Revision 1

Authors:

Pacific Northwest National Laboratory
Brady Hanson, Steve Maheras, Veronica Wilson, and Ricardo Torres

Sandia National Laboratories
Laura Price

Idaho National Laboratory
Gordon Petersen

Department of Energy
Jorge Narvaez

Controlled by: Department of Energy, Office of Nuclear Energy (NE)
Controlled by: Jorge Narvaez, NE-82 (240) 278-3243

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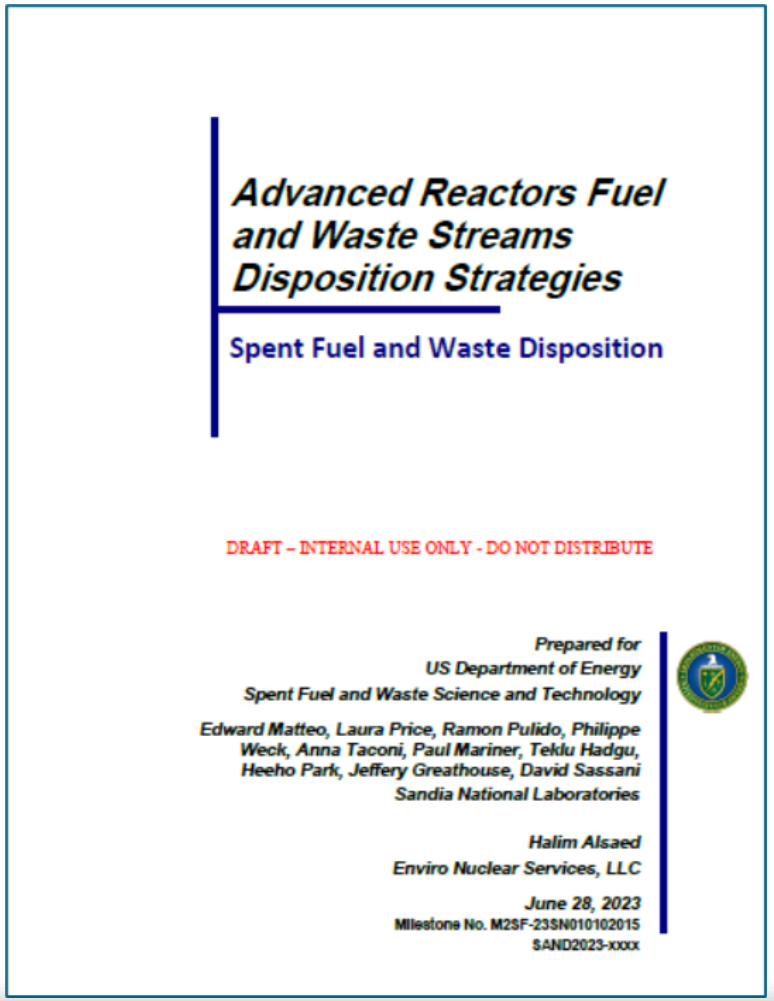
To Be Public Report (When Final)



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Disposal Options Considerations for Potential Waste Forms from Advanced Reactors (AR) – Public Report

- Some existing DOE-managed SNF (DSNF) are similar to potential advanced reactor fuels
  - Have been included in US disposal program (DOE, 2008; SNL, 2014)
  - Only very minor component of disposal inventory
  - Included with very conservative instantaneous degradation rate
  - Some not included without treatment (e.g., Na-bonded SNF–not directly disposable)
- Use experience with SNF from prior similar reactors for strategies
  - TRISO fuels – e.g., Fort St. Vrain
    - Potential slow degradation rates (Sassani and Gelbard, 2019)
  - Metallic Na-bonded fuels – e.g., EBR-II, Fermi
    - Treatment to remove metallic sodium
  - ORNL molten salt reactor experiment

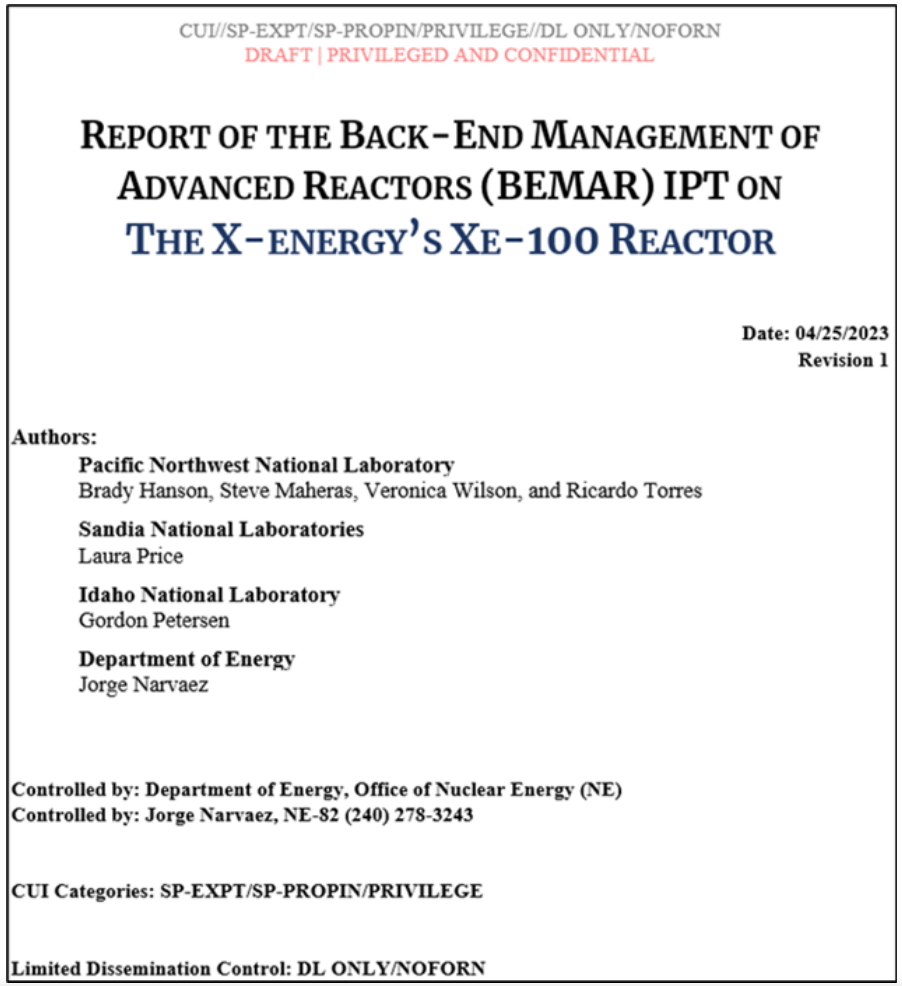
Disposal Options Considerations for Potential Waste Forms from Advanced Reactors (AR) (cont) – Public Rprt

- Degradation rate behavior constraints are essential for primary disposal inventory
  - Ancillary chemical impacts should be evaluated
- Potential for criticality over repository time scales
  - Enrichment
  - Burn-up specifics
  - Packaging (neutron absorbers)
- Thermal output per waste package is dependent on
  - Fission product content
  - Packaging size
  - Aging and storage
- Secondary waste streams from operations and treatment

How Might Alternative Nuclear Fuel Cycles Impact Geological Disposal? – Public Report

- For a given amount of electric power, alternative fission-based nuclear fuel cycles may result in
  - Changes in the radionuclide inventory and materials
    - Reprocessing can reduce actinide content of final waste product
    - Different materials for AR than in a typical LWR (e.g., graphite, chloride salts)
  - Changes in the volume of waste
    - Reprocessing can reduce the volume of waste requiring deep geologic disposal
    - Defining final waste form volumes needed for some AR
  - Changes in the thermal power of the waste
    - Separation of minor actinides can reduce thermal power of the final waste form
    - Higher enrichment/burnup AR fuels
  - Changes in the durability of the waste in repository environments
    - Treatment of waste streams can create more durable waste forms
- For each potential change, consider
  - How will these changes impact repository safety?
  - How will these changes impact repository cost and efficiency?

Proprietary Reports



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Back-End Management of Advanced Reactors (BEMAR)

- BEMAR is an Integrated Project Team (IPT) formed in 2022 under the direction of the DOE Office of General Counsel
- To contribute to these efforts, BEMAR is implementing a Systems Engineering approach
- BEMAR is collecting advanced reactor data by engaging the advanced reactor vendors that are willing to work with us

BEMAR Goals and Timeline

Gather and consolidate advanced reactor data to:

- **Make a technical assessment of the feasibility of storage, transportation, and disposal advanced reactors SNF**
  - **About 4 to 6 months are needed to produce a report**
- **Develop a rough-order-of-magnitude cost estimates (or cost comparisons to the existing SNF inventory) for such storage, transportation, and disposal**

BEMAR Team

- DOE needs to fully understand what it is being asked to receive
- The Reactor manufacturers/owners need to satisfy the NWPA's advance contracting requirement to fully proceed with their project
- In DOE, the following are working on this requirement
  - Office of General Counsel, (Lead Office)
  - Office of Nuclear Energy
  - Office of Clean Energy Demonstration
  - Specialists from 5 National Labs
- A specialized team of 30 individuals has been assembled to analyze each advanced reactor design
- We are currently working together to review the issue of the appropriate contract mechanism for the different types of advanced reactor SNF

BEMAR Membership and Collaboration

- Systems Engineering Approach
- Specialists in:
  - Nuclear, Civil, Mechanical Engineering
  - Neutronics
  - Numerical modelers
  - Logistics
  - Transportation
  - Storage
  - Disposal
  - Geology, Geochemistry, Hydrology/transport
  - Project Management
  - Cost Estimating
  - Regulatory Issues
  - Legal Issues
- More than 30 total members participate periodically

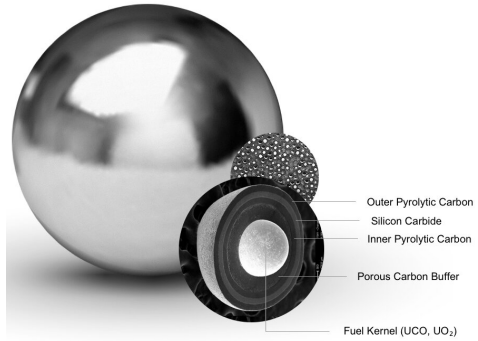
Core Team Members

Ned	Larson	NE-81	IPT Co-Leader
Jorge	Narvaez	NE-82	IPT Co-Leader
Connie	Barton	GC-73	GC
Michael	Kido	GC-72	GC
Cyrus	Nezhad	GC-72	GC
Charles	Sherrill	GC-72	GC
Brady	Hanson	PNNL	Storage Lead
Steve	Maheras	PNNL	Transportation Lead
Laura	Price	SNL	Disposal Lead
Stuart	Arm	PNNL	Member
Scott	Sanborn	SNL	Member
Nick	DiNunzio	PNNL	Member
Robby	Joseph	INL	Member
Gordon	Petersen	INL	Member
Emily	Stein	SNL	Member
Ricardo	Torres	PNNL	Member
Veronica	Wilson	PNNL	Member

BEMAR Collaboration with Advanced Reactor Vendors

Data Collection

- We are collecting data by engaging the advanced reactor vendors that are willing to work with us
- The data collected will allow us to understand not only the fresh fuel, but also the expected irradiated fuel
- Types of data we are collecting
  - Physical characteristics
  - Chemical composition
  - Radionuclide inventory
  - Operations and waste management



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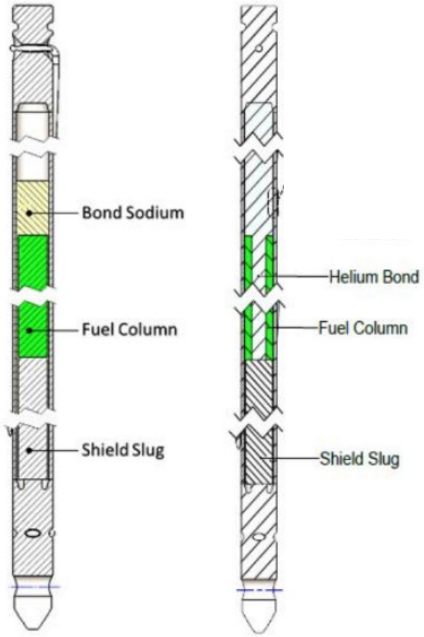


Natrium Advanced Reactor Fuel Cycle Management – NEA Presentation

Data Types

Physical Characteristics

- Fuel unit type (i.e., pebble, compact, assembly, etc.)
- Shape and dimensions of fuel element, pins, assemblies, etc.
- Mass and density
- Core shape and dimensions

Chemical Composition

- Initial enrichment
- Fuel, clad, coolant and associated hardware composition
- Discharge burnup

Data Types (continued)

Radionuclide inventory

- Fissile and fertile isotopic composition
  - Radionuclides used for burnup credit in criticality calculations
  - Significant source of heat for 100 years and beyond
- Long-lived fission products

Operations and waste

- Number of fuel elements/ assemblies
  - Position within reactor core
  - Inventory
- Fuel irradiation time
- What constitutes “failed fuel”?
- SNF mass and volume
- SNF decay heat
- Canister design
- Reactor configuration
  - Electricity
  - Process heat

Informing General Counsel (GC) – The Ultimate Goal

The BEMAR Team will produce one technical report for each advanced reactor vendor or design that the team analyzes.

The report will include:

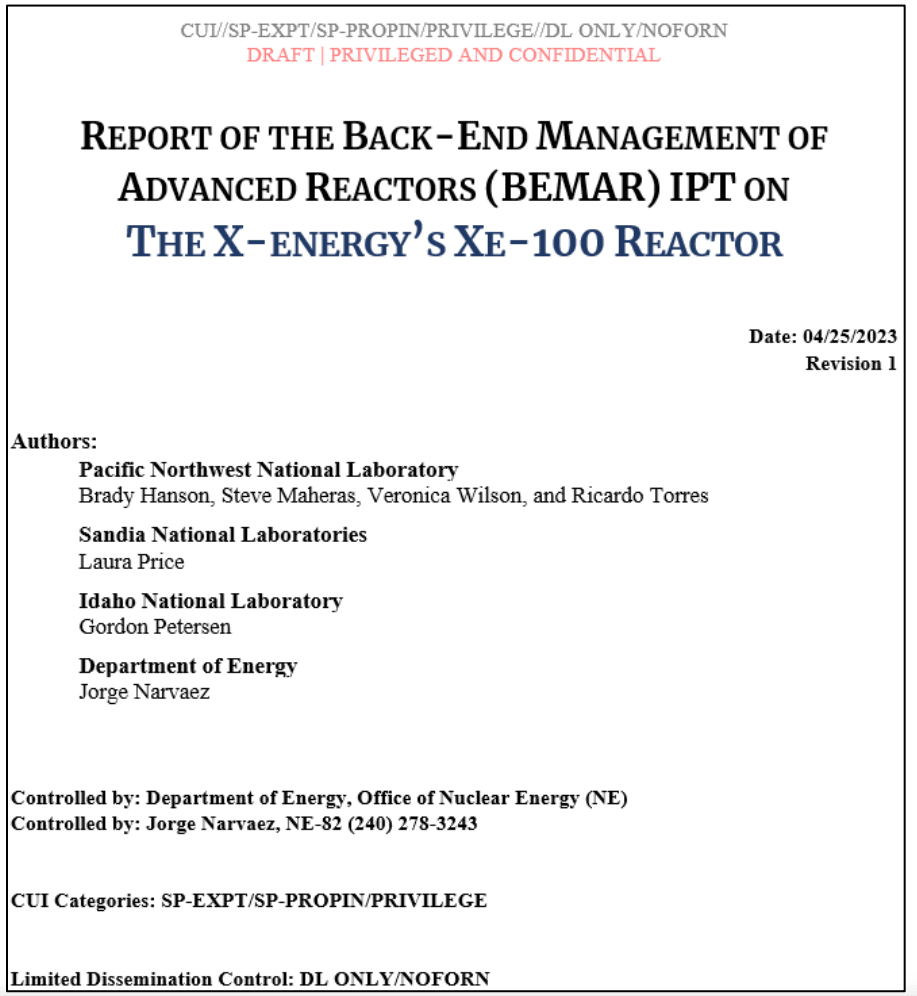
- Expected amount of SNF and HLW
- Transportation, storage, and disposal considerations
- How it affects the current Standard Contract
  - Original vs Amended
- Rough order of magnitude cost comparison with light water reactors (LWR) activities
- Report includes business proprietary and export-controlled data
- Give preliminary assessment of potential issues for Post-Closure Safety Assessments (generic concepts)
  - Full Post-Closure Safety Assessment cannot be done without a repository (site and design)
  - Only high-level analyses to identify potential issues for generic disposal concepts are being performed at this time
  - Detailed analyses of features, events, and processes for generic disposal concepts are to be initiated (in R&D side)
- This is NOT a design review by the DOE

Challenges

- Are Non-Disclosure Agreements (NDA) needed?
  - So far, no
  - Might need for some vendors in the future
- Vendor data is Business Proprietary or Export Controlled
  - Information marked as Controlled Unclassified Information (CUI)
  - Dissemination controls
- Vendor data evolves as design evolves
- CUI Training Availability
- Size of the IPT – currently at 30 members
- Many moving parts
  - Organizing data, scheduling meetings, tracking responses
  - Managing records
- We are moving forward in good faith, but it is not believed that all possible reactors will be constructed

First Report: Xe-100 Reactor

- Revision 1: sent to GC on 25 APR
  - Received GC feedback on 02 JUN
- Revision 2: to be sent to GC by end of JUL
- Future revisions
  - Incorporate cost analysis
  - Update report based on design changes/new data



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Thank you

Questions?