SAND2011-2064 C

Used Fuel Disposition Campaign

Options for a Test and Evaluation Facility for Very Long Term Storage of Used Nuclear Fuel

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History of Storage Efforts

Recent Events – What Has Changed?

1. **Decision not to dispose of fuel at Yucca Mountain**
   - Store in place until alternative fuel cycle options are evaluated
   - Evaluate better disposal alternatives

2. **November GAO Report**
   - Evaluates centralized and regional storage compared with current practice
   - Conclusions generally favorable to centralized storage

3. **Public opinion on nuclear energy generation**
   - Although public fears regarding nuclear energy remain and are probably enhances by the effect of the tsunami on the Fukushima reactor, development of nuclear power is likely to continue.

Overview of Storage Concepts

Microns
Fuel Grains

Scale

Miles

Planning Phase

- **R&D Opportunities**
  - ***Fuel Considerations***
  - ***Cask/Storage Systems***
- **Security**
  - ***Fuel/Cask self protection***
  - ***Site/Boundary physical protectio***
- **Conceptual Evaluation**
  - ***Storage system consideration***
  - ***Site considerations***
  - ***Regional/Country considerations***
  - ***Transportation***

Program Implementation Plan for fielding a Test and Evaluation Facility

Implementation Plan

Short-term Goal
- **Develop plans for a licensed demo storage site**

Long-term Goal
- **Field a licensed demo storage facility**
- **Develop plans for a commercial scale storage facility**

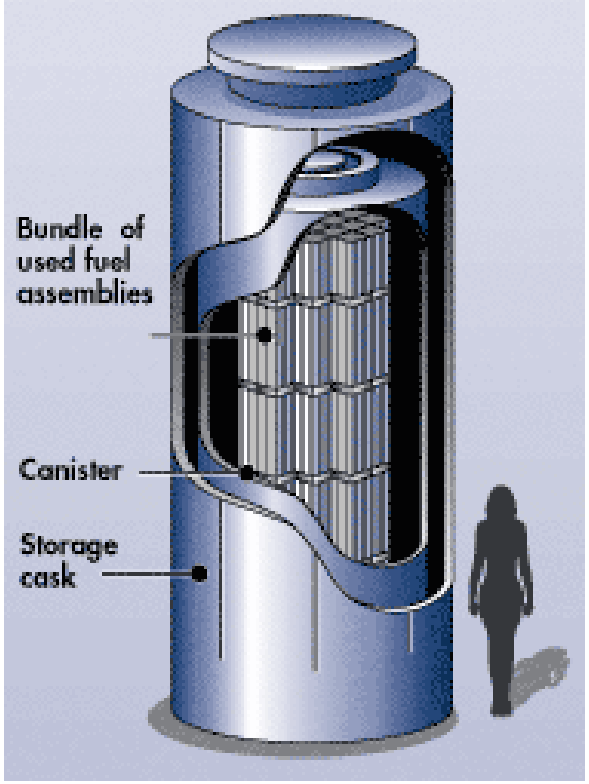
Time

Overview of Research and Development Opportunities

Dry storage of UOX used fuel

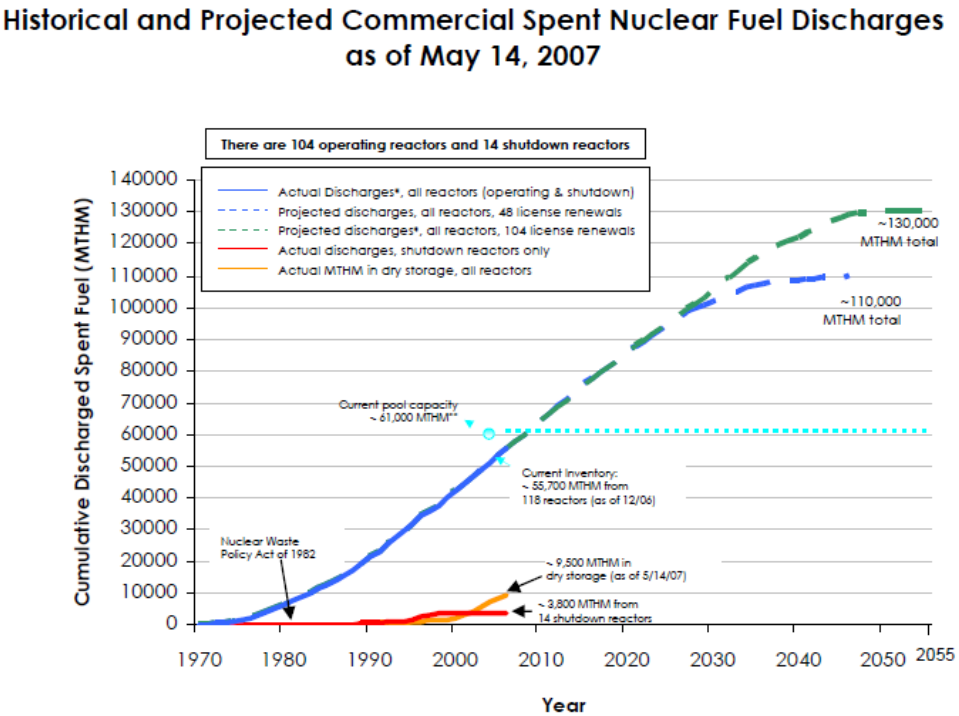
- **Evaluation of the current status of technical issues associated with long-term storage**
- **Evaluation of evolving technical and regulatory concerns**
- **Development of recommendations for further investigations**

Eventual inclusion of other fuels



Very Long Term Storage Issues

- High burnup fuel (>45 GWd/MT)
- Long term storage of high and low burnup fuels
- Retrievability and transportation after storage



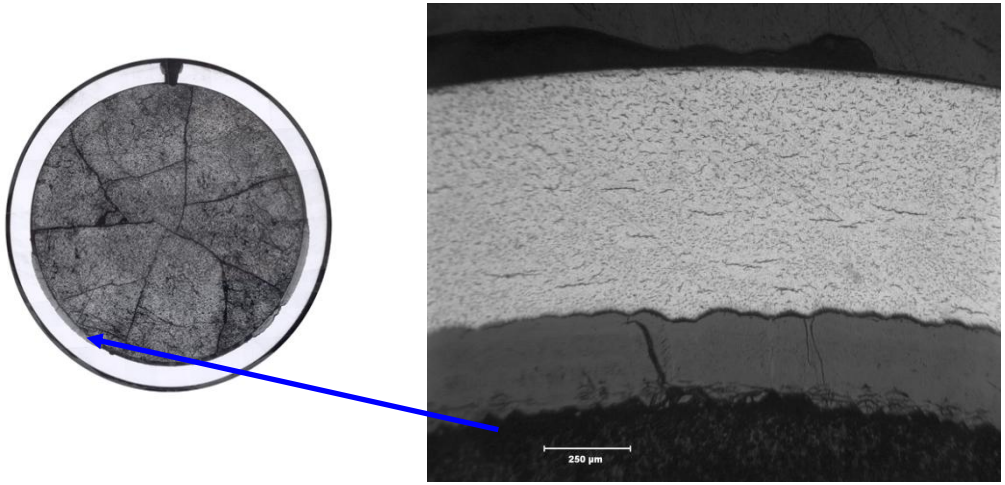
Sources: * Based on actual discharge data as reported on RW-859's through 12/31/02, and projected discharges, in this case, based on 104 license renewals.
** Represents the aggregate industry pool capacity based on pool capacities provided in 2002 RW-859 (less FCR) and supplemented by utility storage plans. However, the industry is not one big pool and storage situations at individual sites differ based on pool capacities versus discharges into specific pools.

Issues Related to High Burnup

- **Cladding**
  - Creep
  - Fracture toughness
  - Ductility under impact
  - Hydriding
  - Corrosion
- **Fuel**
  - Fission gas pressure
  - He pressure

Cladding Fuel-Side Corrosion Observed in Tests Conducted in Humid Air at 175°C

Polished cross-section illustrating two regions of fuel-side corrosion. Illustrates the corrosion layer and the precipitated hydrides in the cladding adjacent to the corrosion layer.



CSNF Waste Form Degradation: Summary Abstraction, ANL-EBS-MD-000015 REV01C, Authored by J. Cunnane.

Issues Related to Long-Term Storage of High and Low Burnup Fuel

- **Concrete**
  - Calcium leaching – penetrations
  - Freeze/thaw reactions
  - Marine environment
- **Embedded Steel**
  - Corrosion
- **Cladding**
  - Creep rupture
    - –Fatigue
  - External oxidation
    - –Clad splitting by UO_2 oxidation
  - Stress corrosion cracking

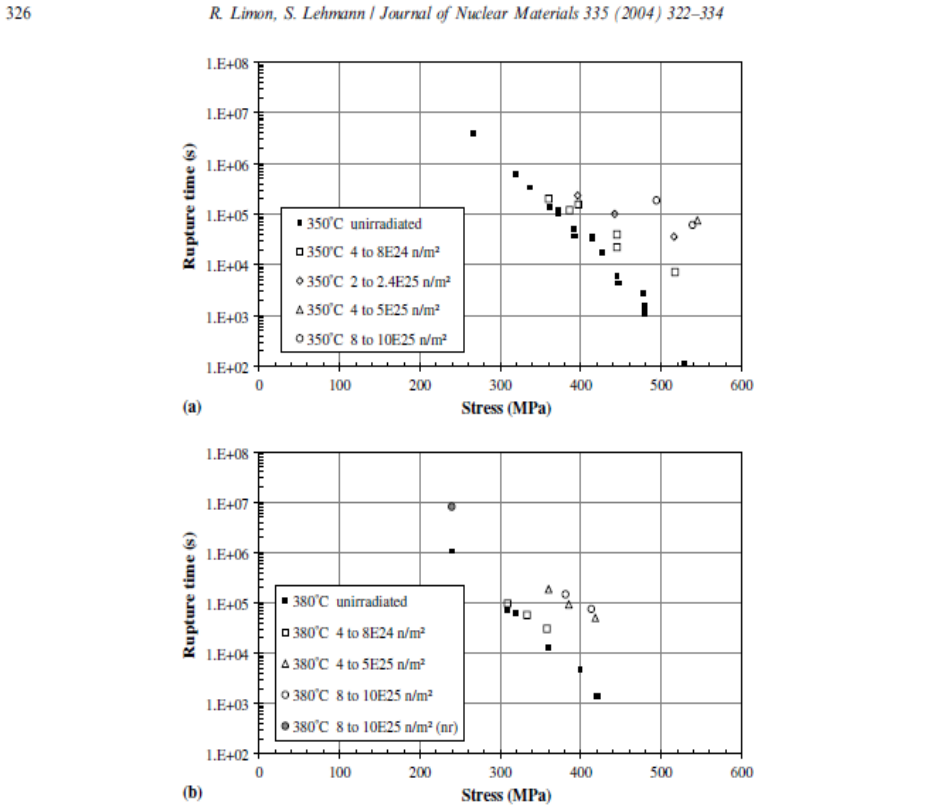
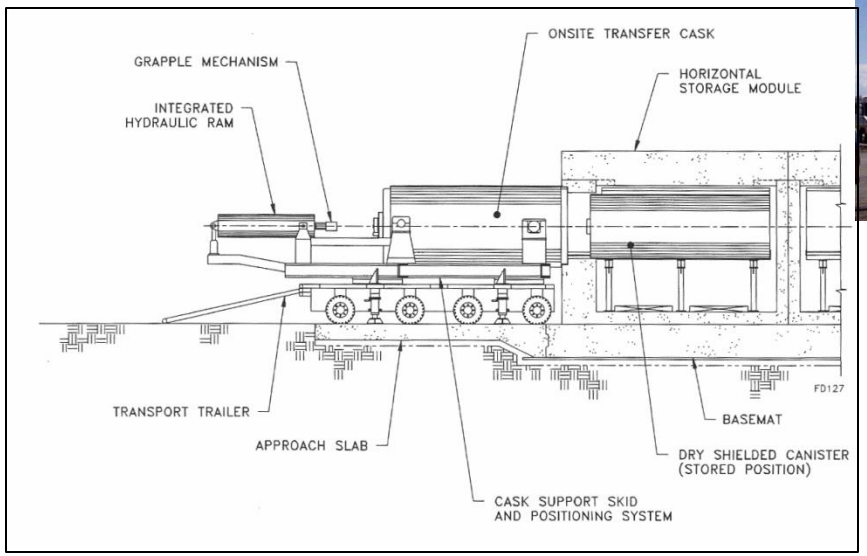


Fig. 3. (a) Irradiated CWSR Zircaloy-4 rupture time as a function of stress and fast neutron fluence at 350 °C. (b) Irradiated CWSR Zircaloy-4 rupture time as a function of stress and fast neutron fluence at 380 °C.

Conditions to Be Evaluated

Placement & Retrieval



Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, Final Safety Analysis Report (6/2004)

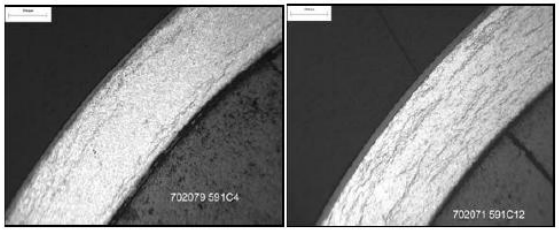
Castor V/21 on Transporter Headed to Hot Shop

EPRI ELECTRIC POWER RESEARCH INSTITUTE

http://www.iaea.org/OurWork/ST/NE/NEFW/nfcms_spentfuel_02_tasks.html

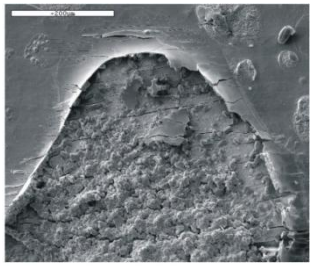
Technical Gaps Identified by FEPS Analysis

- Fuels
  - *Hydride re-orientation*
  - *Hydride embrittlement*
  - *Delayed hydride cracking*
  - *Corrosion*
  - *Plenum gas pressure*
  - *Creep*



Hydride Orientation in Clad

- Casks
  - *Seals*
  - *Bolted and welded closures*
  - *Neutron shields*
  - *Concrete degradation*



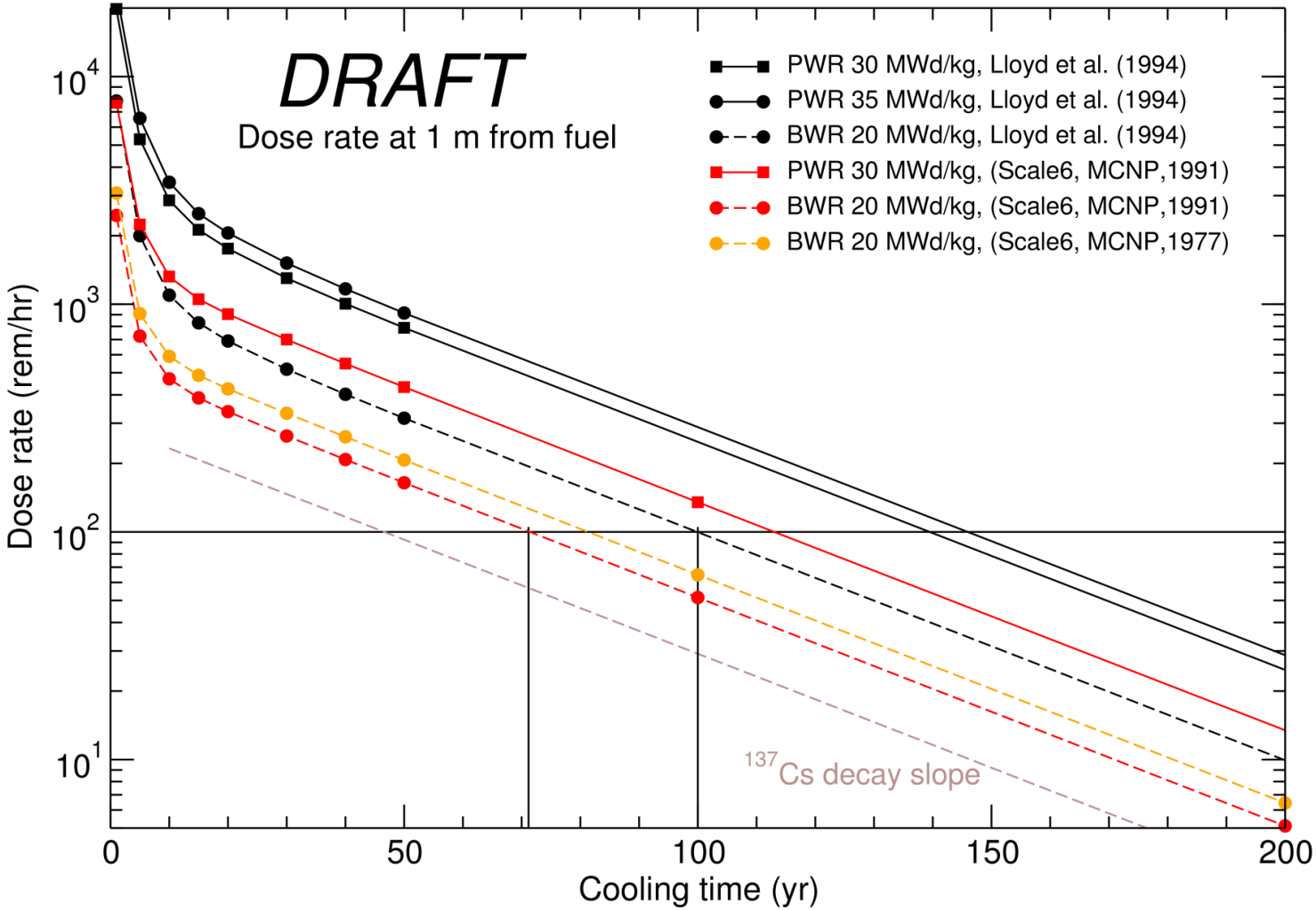
Seal Corrosion,
D. Wolff, et al., PATRAM 2004

- Cask Systems
  - *Concrete degradation*
  - *Effect of marine environment*

Security Issue: Self-protection of Used Fuel

- **Dose rate calculations**
  - Previous calculations extended to 200 years – dose falls below 100 rem/hr at about 100 years for BWR fuel and between 120 to 150 years for PWR fuel
  - New calculations indicate used fuel falls below current threshold after about 70 years
  - Increases with increasing burn-up
  - After about 20-30 years, tracks with Cs-137 decay
- **"Self-Protection" in today's world**
  - Regulations were written prior to 9/11 events
  - NRC is engaged in discussions looking at the validity of the current thresholds and is considering raising the standard.
  - Used fuel stored for extended periods of time will go below the higher thresholds earlier

Self-Protection: Dose Rates for PWR/BWR Low Burn-up Fuels



Dose calculations by Richard Wittman, Brady Hanson, and Amy Cassellas, Pacific Northwest National Laboratory

Other Issues

- **Fuel*:***
  - *Type – e.g., high burnup (informed from the R&D Work Package)*
  - *Availability of Post Irradiation Examination (PIE) facilities*

- **Dry Storage System:**
  - *NRC certified*
  - *Accessibility to fuel*
  - *Specific long-term storage issues (informed by the R&D Work Package)*

- **Site:**
  - *Existing v. new*
  - *DOE v. private*
  - *Security framework (informed from the Security Work Package)*

- **Licensing:**
  - *DOE v NRC license*
  - *Impact of NWPA constraints*

- **Transportation:**
  - *Degree of transportation involved*
  - *Security framework (informed from the Security Work Package)*

Past Storage Efforts

1. **GE Morris**
   - Only away-from-reactor pool storage, originally licensed in 1982
   - One 20 year license extension to 2022; first NRC storage site license extension

2. **Nuclear Waste Negotiator**
   - Independent agency created under the NWPA: 1987 – 1995
   - Chartered to site and store spent nuclear fuel
   - Eventually unsuccessful

3. **INL Dry Cask Storage Characterization Project**
   - Demo program to characterize long term storage behavior of low burnup fuels
   - Joint program sponsored by DOE, NRC, and EPRI
   - Program lasted 4 years; 1999 – 2002; SNF in dry storage for 15 yrs

4. **Private Fuel Storage (PFS)**
   - Utility consortia to regionally store up to 44,000 MTU used fuel in Utah
   - NRC licensed in Feb 2006 for 20 years
   - Dept of Interior denied land lease in Sept 2006
   - Law suit filed by PFS in 2007

5. **On-site storage**
   - Current practice
   - Dry cask storage is becoming the standard

Alternatives Considered for a Test and Evaluation Facility for VLTS

- **A utility ISFSI**
  - Existing facility with no enhancements
  - Modified ISFSI to allow for enhanced monitoring

Minor augmentation of an existing utility ISFSI program

- **An industrial facility**
  - One facility
  - An aggregate of industrial facilities

Demonstration at an existing commercial ISFSI

- **The National Laboratories**
  - A National Laboratory facility
  - The National Laboratory facilities considered together (in the aggregate)
  - The National Laboratory aggregate modified

Demonstration at an existing federal surface storage facility

- **A newly constructed site**

Construction and operation of a demonstration project at a new site

Requirements for a TEF

Comply with relevant regulations: 10 CFR Parts 61, 71, 72, 73; relevant ISGs, DOE Orders 435.1, 250.1, 226.1
Be capable of addressing data gaps
Can obtain both high and low burnup fuel, canisters and other components
Can perform necessary testing and evaluation
Can conduct R&D on material of the storage system pre- and post-storage
Be able to Instrument casks appropriately
Manage waste, including fuel and other materials after examination, appropriately
Ensure availability of transportation where required

Criteria for Evaluating a TEF

CRITERION	METRIC
A. Testing capability for fuel & cladding	Capability to perform fuel rod non-destructive examination (NDE)
	Capability to perform fuel rod destructive examination (DE)
	Capability to perform fuel segment NDE tests.
	Capability to perform fuel segment Destructive Examination (DE) tests.
	Capability to perform cladding NDE tests.
	Capability to perform cladding DE tests
	Capability to perform accelerated aging tests
B. Testing capability for storage systems	Capability to perform accelerated aging tests
	Capability to perform monitoring
	Capability to perform inspection
	Capability to facilitate R&D on non-irradiated components of the storage system

Criteria for Evaluating a TEF

CRITERION	METRIC
C. Fuel & material handling capability	Capable of handling complete fuel assemblies and transportation casks.
	Capability to extract pre-canistered fuel
	Capable of extracting individual fuel rods,and transferring for examination.
	Capable of segmenting rods and packaging the segments for shipment.
	Capable of storing used fuel assemblies dry for future examination.
	Capable of storing excess fuel segments for future evaluation.
	Capable of dry loading and transferring a used fuel assembly from multiple *in*-situ storage test location for periodic examination.
D. Waste management	Capable of disposing waste generated from fuel examinations.
	Has a disposition path (a storage capability) for used nuclear fuel evaluated during the testing and examination program.
E. Spectrum of acceptable materials for in situ storage testing	Quantity and variety of used fuel dry storage systems are acceptable for use.
	Capable of hosting multiple commercially acceptable storage systems.
	Capable of hosting sufficient quantities and variety of used fuels.

Used Fuel

Criteria for Evaluating a TEF

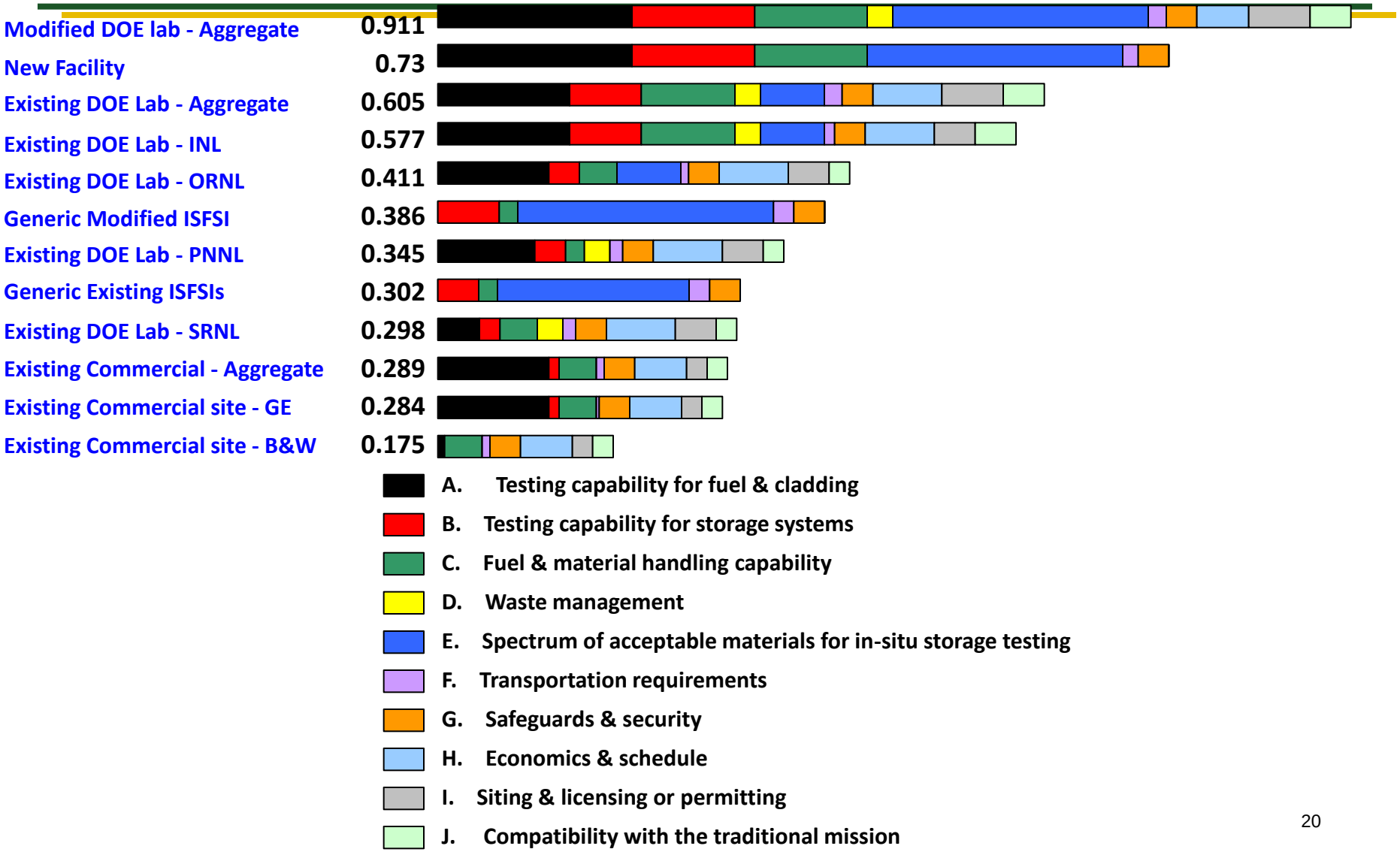
CRITERION	METRIC
F. Transportation	Capable of receiving casks both by truck and rail.
	Nuclear material transfer that can be accomplished by onsite transportation.
	Off-site transportation can be accomplished within the testing state
	Off-site transportation can be accomplished within the contiguous 48 states.
G. Safeguards and Security	Physical security is adequate for the protection of nuclear materials.
	MC&A Program is adequate for the safeguards of nuclear materials
H. Economics and schedule	Cost of any new facilities or modifications required at an existing facility
	Time to implement the fuel testing capability
	Time to implement the storage testing capability
I . Siting and licensing or permitting	Relative difficulty of licensing or permitting the facility
	Absence of state or local regulations that would prohibit receipt and storage of the requisite quantities of used fuel at the site.
	Current authorization basis envelopes planned nuclear operations.
J. Compatibility with traditional mission	Administrative functions and facilities are available to support nuclear operations (medical, HP, human resources, finance)

Criteria Weighting

Criteria	A	B	C	D	E	F	G	H	I	J	Total	Revised (Saaty) %
A. Testing Capability for fuel and clad	1.00	3.00	4.00	6.00	0.25	5.00	6.00	2.00	4.00	2.00	2.48	19%
B. Testing Capability for Storage Systems	0.33	1.00	0.50	6.00	0.25	4.00	5.00	2.00	4.00	3.00	1.61	12%
C. Fuel and Material Handling Capability	0.25	2.00	1.00	2.00	0.20	4.00	5.00	2.00	3.00	2.00	1.47	11%
D. Waste Management	0.17	0.17	0.50	1.00	0.20	4.00	6.00	0.50	0.33	2.00	0.68	5%
E. Spectrum of acceptable material for in-situ Storage Testing	4.00	4.00	5.00	5.00	1.00	5.00	5.00	2.00	3.00	3.00	3.35	26%
F. Transportation Requirements	0.20	0.25	0.25	0.25	0.20	1.00	0.33	0.17	0.33	0.50	0.30	2%
G. Safeguards and Security	0.17	0.20	0.20	0.17	0.20	3.00	1.00	0.20	0.50	0.33	0.34	3%
H. Economics and Schedule	0.50	0.50	0.50	2.00	0.50	6.00	5.00	1.00	0.50	4.00	1.22	9%
I. Siting and Licensing or Permitting	0.25	0.25	0.33	3.00	0.33	3.00	2.00	2.00	1.00	5.00	1.02	8%
J. Compatibility with traditional mission	0.50	0.33	0.50	0.50	0.33	2.00	3.00	0.25	0.20	1.00	0.58	4%

Used Fuel Disposition

Relative Utility of Alternatives



Backup Viewgraphs

Alternative Descriptions for Long-Term T&E Facility

Assumption:

- *All alternatives will make the assumption that we will load wet, dry and remain dry.*
- *DOE will not pay to have commercial facilities modified*

***1) Generic Existing ISFSIs** – Current existing capabilities (No action alternative)*

- *Limited to current ISFSI inventory*
- *No fuel consolidation*
- *No modification to sites*

***2) Generic Modified ISFSI** – Assumed modifications will allow site to meet only the storag, fuel and cladding requirements that can be done soley via monitoring;, The storage system cannot be opened dry on site.*

- *Fuel shipments and addition of casks to accommodate spectrum of available fuels and casks*
- *ISFSI storage system modified to include cask monitoring*
- *No modification to existing on-site fuel and cladding testing capabilities*
- *Not aware of any reactor site with hot cell and PIE capability*
- *IFSI can store several different type of fuels and cask; and monitor*

Alternative Descriptions for Long-Term T&E Facility

***3) Existing DOE laboratory site**s – Current existing capabilities*

- *In-situ storage testing based on existing capability*
- *Fuel rods harvested at storage location*
- *Fuel and cladding testing using existing capabilities at DOE sites*
- *Ranked individually and then ranked as an aggregate*
- *ANL, not ranked individually, but included in aggregate*
- *Aggregate can't score less than any individual. It can score higher.*

***4) Existing Commercial sites** – Current existing capabilities*

- *In-situ storage testing based on existing capability*
- *Fuel rods harvested at storage location*
- *Fuel and cladding testing at commercial sites*
- *Ranked individually and then ranked as an aggregate*

a) B&W, b) GE

Alternative Descriptions for Long-Term T&E Facility

5) Modifications of DOE laboratory complex in the aggregate *will meet all testing and demonstration requirements at DOE laboratory sites. –Complex enhanced to accommodate storage of the spectrum of fuels required*

- *Complex enhanced to accommodate full spectrum of in-situ storage testing requirements*
- *Complex enhanced to harvest fuel rods at storage location without re-wetting the fuel*
- *Complex enhanced to accommodate all fuel and cladding testing requirements*

Ranking modified aggregrate not individually. Discussion:

- *Scoring should ensure we don't loose synergy.*
- *Take ranking from Existing Facilities alternative and determine what modifications are needed*

6) New site *– This site/facility will contain all capabilities needed to meet all testing and demonstration requirements*

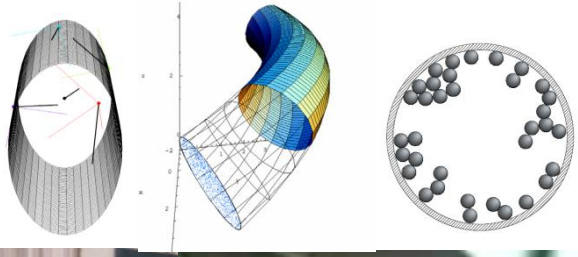
- *Site designed to accommodate storage of the spectrum of fuels required*
- *Site designed to full spectrum of in-situ storage testing requirements*
- *Site designed to harvest fuel rods at storage location without re-wetting the fuel*
- *Site designed to accommodate fuel and cladding testing*

Discussion

- *Green-field, not site specific*
- *All capabilities in one location*

Potential R&D Activities

- **Modeling and Simulation**
  - Initial conditions to end state as function of burnup
    - Gas migration
    - Phase change behavior
    - Changes in cladding properties



- **Lab Scale Testing**
  - Pre-characterization
  - Destructive examination and testing
  - Accelerated aging

- **~15-yr Demonstration**
  - Remotely instrumented fuel assemblies
    - Fuel clad temperature
    - Clad integrity
    - Gas monitoring