Strategic Implications of Heat in a High-Level Radioactive Waste Repository

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Main Points of Talk

- Strategic implications of
  - temperatures greater than the boiling point of water
  - temperatures between ambient and the boiling point of water
  - ambient temperatures
- Strategic implications of heat on the
  - selection of Yucca Mountain as a repository site
  - need for long-term surface storage

Definitions for this Talk

- "Hot" means distribution in space and time of rock temperatures greater than the boiling point of water sufficient to produce significant dryout benefits to repository performance
  - hot enough long enough over a large enough volume to do some good

- "Warm" means a repository is designed to remain below some maximum temperature, such as 90° C

- "Ambient" means within a few degrees of the ambient rock temperature prior to waste emplacement

Only three concepts address 10,000 year isolation from a simple viewpoint

- Partitioning and transmutation
- Super container concept
- Hot repository for 10,000 years

Perspective of this Talk

- Mainly directed at effect of heat on a potential repository at Yucca Mountain
- Drying will limit container corrosion and prevent dissolution and aqueous transport of radionuclides
- The repository can be designed to optimize effects of heat
- The Engineered Barrier System and the natural environment work together - they cannot be assessed independently
- Yucca Mountain is a fractured open system - additional fractures resulting from heat or EBS designs are not likely significant to isolation
- Emphasis on 1,000 and 10,000 year time frames is based on need for compliance with EPA standard and the NRC sub-system performance objectives

Strategic Implications of a Hot Repository

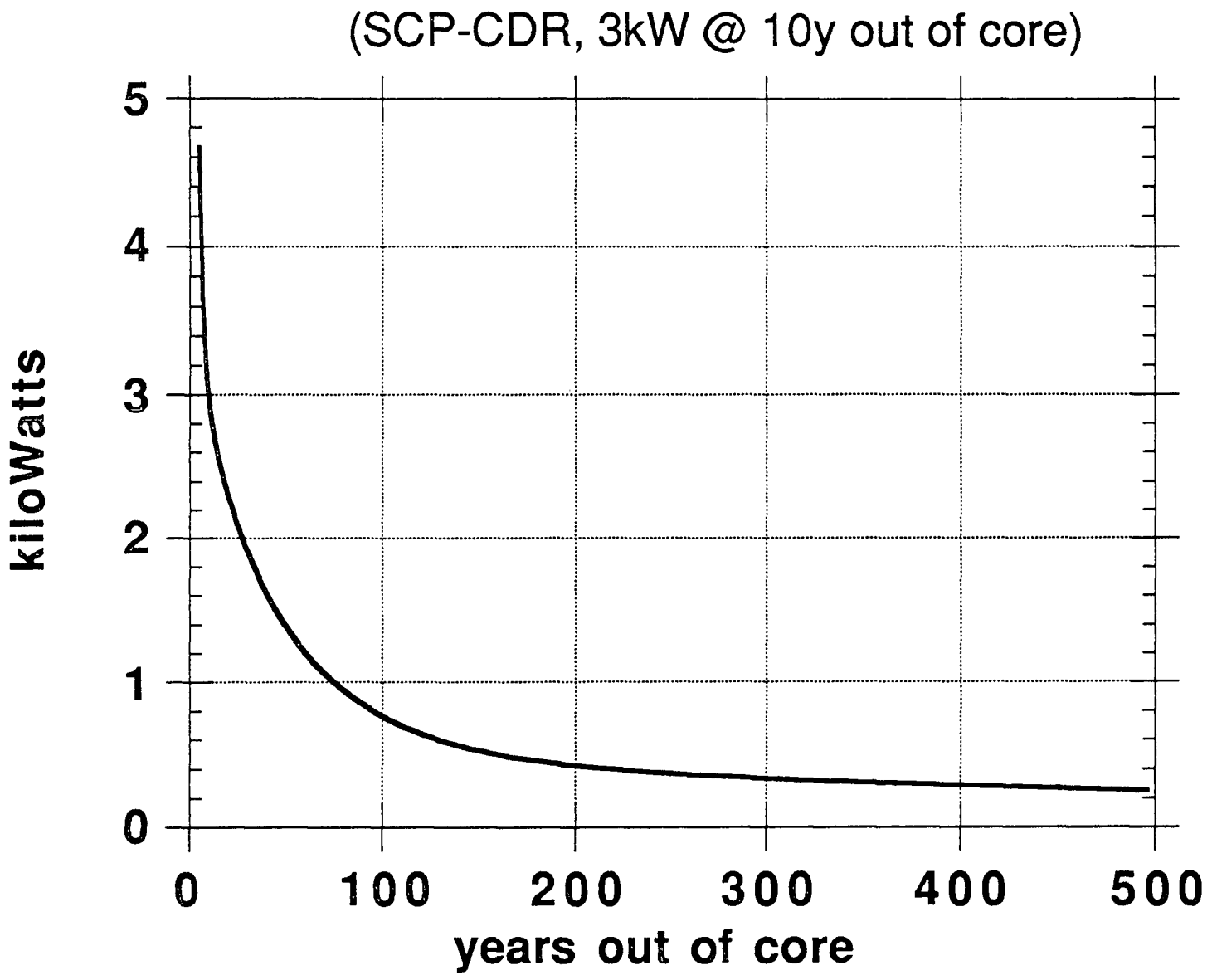
- If above boiling point of water for 10,000 years
  - only have to show that repository will not flood for 10,000 years to meet EPA standards and NRC subsystem requirements for EBS

- If above boiling point of water for 1,000 years
  - demonstrate substantially complete containment by showing that repository does not flood for 1,000 years
  - must also show compliance with EPA standard and other NRC subsystem requirements
  - must also model sub-boiling processes beyond 1,000 years

Implications of Methods of Keeping the Repository Hot

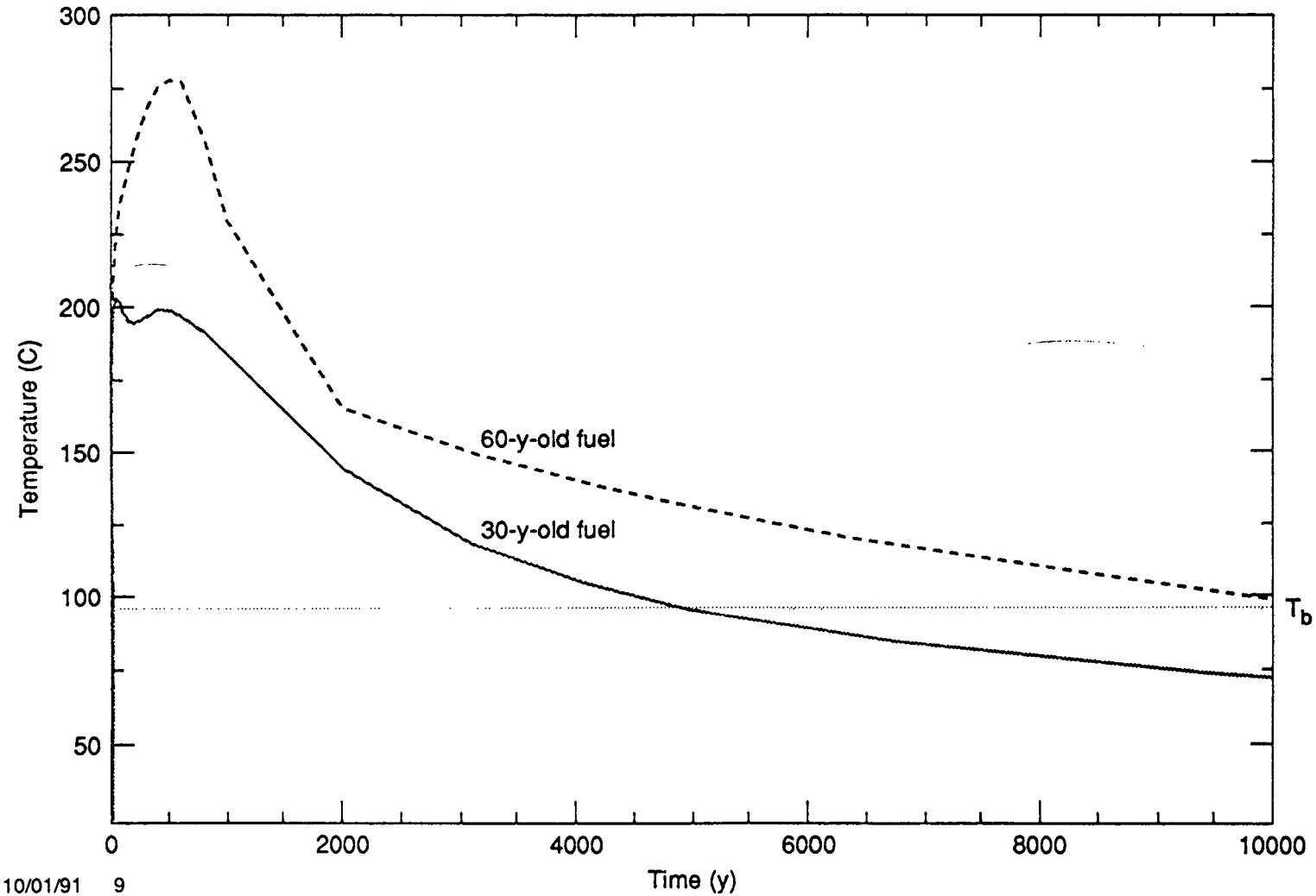
METHOD	IMPLICATION
Closer borehole/drift spacing	Cost savings
— young fuel	Limited by facility constraints and temperature limits on components
— old fuel	Long-term central storage facility
Put very young fuel in repository	Limited by system constraints
Age fuel and pack more in containers	Possibly limited by criticality
Rock with low thermal conductivity	Thermal conductivity of most rock media may be too high - this may be tuff - specific
Drift emplacement	Possible technical and cost advantages

WP Heat Load for PWR Spent Fuel



A Substantial Increase in Boiling and Dry-Out Benefits is Obtained for 60-yr-old Fuel, with Dry Steam Boiling Conditions Persisting for 10,000 yrs

Drift wall temperature for drift emplacement for an APD of 114 kW/acre



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Advantages and Disadvantages of Hot Temperatures

Advantages

— presumption that aqueous corrosion and dissolution do not operate
  - easy to explain

— Ability to validate models of fluid flow
  - matrix dominated flow
  - more homogeneous response
  - more amenable to verification by field testing

Disadvantages

— concept unique to United States

— within the United States, unique to Yucca Mountain or other unsaturated sites

— possible change in hydraulic properties of rock

— possible effect on retrievability

Strategic Implications of a "Warm" Repository

- Will have to show that repository will not flood in 1,000 or 10,000 years, just as in the "hot" scenario

- If temperature remains below boiling
  - cannot assume absence of liquid water on containers or waste

- At temperatures between ambient and boiling
  - still have to model and understand nearly all processes involved at temperatures above boiling as well as additional processes in the sub-boiling region
  - how will these sub-boiling hydrothermal process models be validated?

- Must decide two issues
  - what upper temperature limit is technically justified?
  - how will this limit be achieved?

Implications of Methods of Keeping Repository "Warm"

METHOD	IMPLICATION
Store on surface for 50-100 yrs.	Long-term central storage facility Safeguards and security issues Less safe than in repository
Decrease areal loading	
— by spacing	Increase in cost
— less waste per container	Increase in cost, solubility-limited release increases with number of sources
Redesign using drift emplacement and an engineered cooling system	Cost (?) Rethink isolation strategy

Advantages and Disadvantages of Warm Temperatures

Advantages

— this is the international "standard" conceptual design

Disadvantages

— at Yucca Mountain, possible change in hydraulic properties of rock

— most potentially deleterious processes that operate above boiling also operate in this thermal range

— appears to also have disadvantages of the ambient concept
  - difficulty of model validation
  - fracture-dominated flow

— possible effect on retrievability

Strategic Implications of Ambient Temperatures

- Will have to show that the repository will not flood in 1,000 or 10,000 years, just as in the hot scenario

- Relieved of having to address processes at greater than ambient temperatures in the repository
  - however, thermal gradient in the site cannot be neglected in modeling
  - vapor-phase transport is still very important, must model two-phase transport

- Have to be able to describe and model scenarios for water to contact and corrode containers and dissolve waste

Implications of Methods of Keeping Repository Ambient

METHOD	IMPLICATION
Partitioning and transmutation	Increase in cost
	Need 200-year surface-storage facility for Cs-Sr
	Need to locate, construct, license and operate P-T facilities
	Legislative and licensing changes

Advantages and Disadvantages of Temperatures near Ambient

Advantages

— Yucca Mountain ambient (23° C, atmospheric pressure) is close to STP, where there are thousands of measurements of all types of physical and chemical phenomena

Disadvantages

— validation of near-field flow models is harder

— at Yucca Mountain under current conditions, flow appears fracture dominated; under possible future pluvial conditions there is even more chance of fracture dominated flow

— fracture-dominated flow leads to faster transport should waste ever be dissolved

Strategic Implications of Heat on Selection of Yucca Mountain as a Repository Site

- Although the SCP-CD design would lead to a 1,000 year hot repository, performance assessments are conducted for warm conditions
- Assuming expected Yucca Mountain conditions, most containers would remain dry even if temperatures were ambient
- Aging of fuel increases the length of time that a repository at Yucca Mountain can remain hot
- Aging helps the "warm" repository concept at any site or media.
- Therefore, remaining at Yucca Mountain or switching to another site is not impacted by technical issues regarding fuel age
- Hot repository concept may be unique to Yucca Mountain; warm and ambient repositories could be anywhere

Strategic Implications of Heat on the Need for Long-Term Surface Storage

- Surface storage can be replaced by enhanced ventilation and other engineered cooling in the underground facility during the 50 year retrievability period

- At Yucca Mountain, a wide range of thermal environments can be achieved by repository design without long-term surface storage
  - can have a hot repository without surface storage (but must redesign repository to achieve 10,000 years hot)
  - can have a warm repository without surface storage (but may not handle 70,000 MT)

- An ambient temperature repository requires long-term surface storage (for Cs-137 and Sr-90)

General Strategic Conclusions

- The ambient repository concept requires partitioning and transmutation, which has strategic implications well beyond high-level waste management

- With the warm repository concept, the issue can be stated
  — is there a simple licensing strategy that can keep the site characterization effort bounded?

- With the hot repository concept, site characterization at Yucca Mountain becomes focussed on one issue: will the repository flood in 1,000 or 10,000 years?