An Evaluation of the Effects of Incomplete Drying Process in Long-Term Storage of Spent Nuclear Fuel

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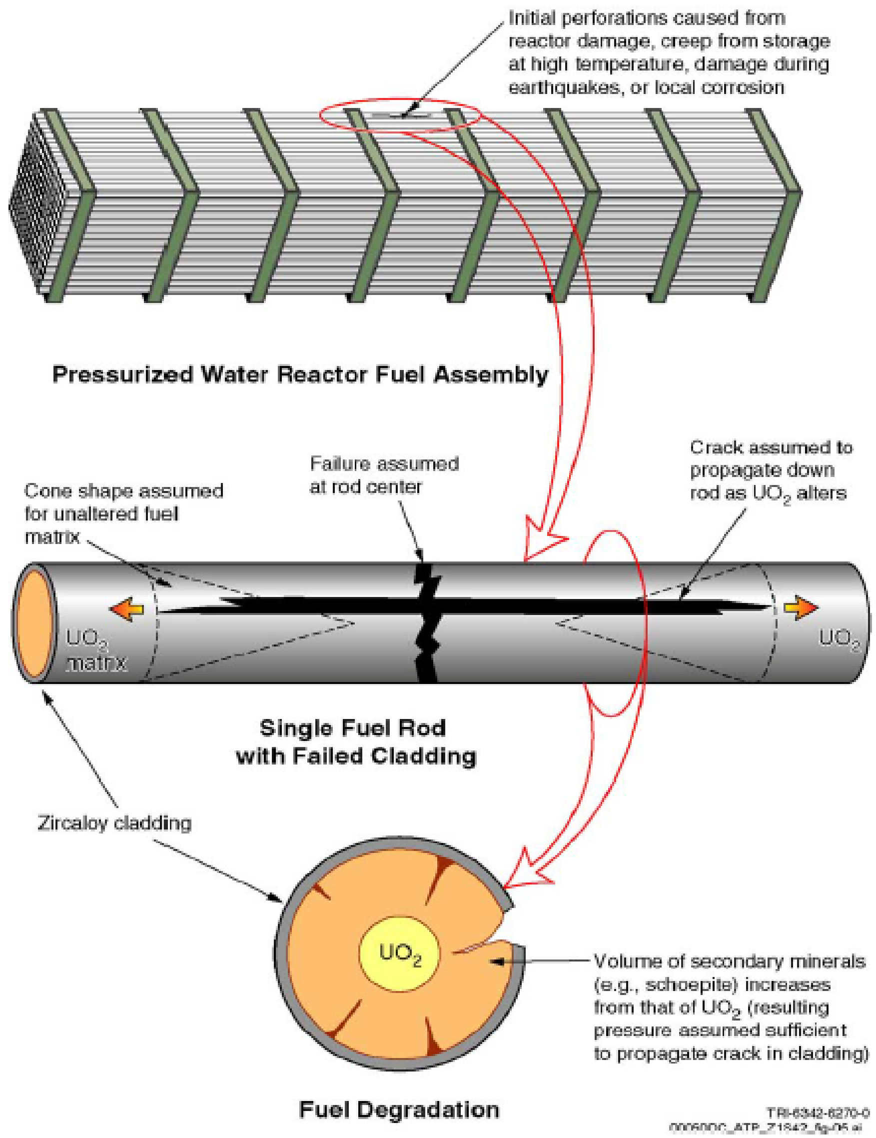
Cladding Integrity with Water



DOE (2002)

Introduction

- Evaluate potential impacts of incomplete drying that the NRC staff is planning to consider in preparing regulatory bases for long-term spent nuclear fuel (SNF) storage in extended periods.
- Assess the uncertainties associated with this potential impact with respect to future regulatory consideration.
- Methodology for this evaluation involves radiolysis kinetics, chemical reaction kinetics, and mechanical failure criteria.
- Present staff's preliminary conclusions and expectations from the impact studies of the incomplete drying process for long-term SNF storage in extended periods.

Reviewed Activities

- SNF cladding oxidation and corrosion
- Hydrogen absorption in the cladding (especially during cladding corrosion) and its effects on the cladding integrity
- SNF oxidation and hydration when cladding breaches are present
- Hydrogen flammability assessments
- Heat transfer degradation
- Criticality margins
- Hydrogen absorption on canister/cask structural materials
- Corrosion due to gamma radiolysis by radionuclide decay
- Canister/cask pressurization assessment
- Shadow (e.g., galvanic) corrosion effects on the SNF rods
- Galvanic corrosion among internal materials (e.g., coating material, aluminum basket, neutron absorbers, steel, and cladding), localized corrosion and stress corrosion cracking of each internal material

Adequacy of Current Assessment of Drying Process in Long-Term Storage

- In the long-term storage, it is expected that the SNF temperature and the radiation level decrease substantially with time compared with the current short-term storage.

- Residual water will be consumed by chemical reactions with cladding, SNF and other internal components, while remaining water initially vapor will condense as the temperature decreases.

- It is unknown how these changes affect the long-term performance of the canister system containing SNF.

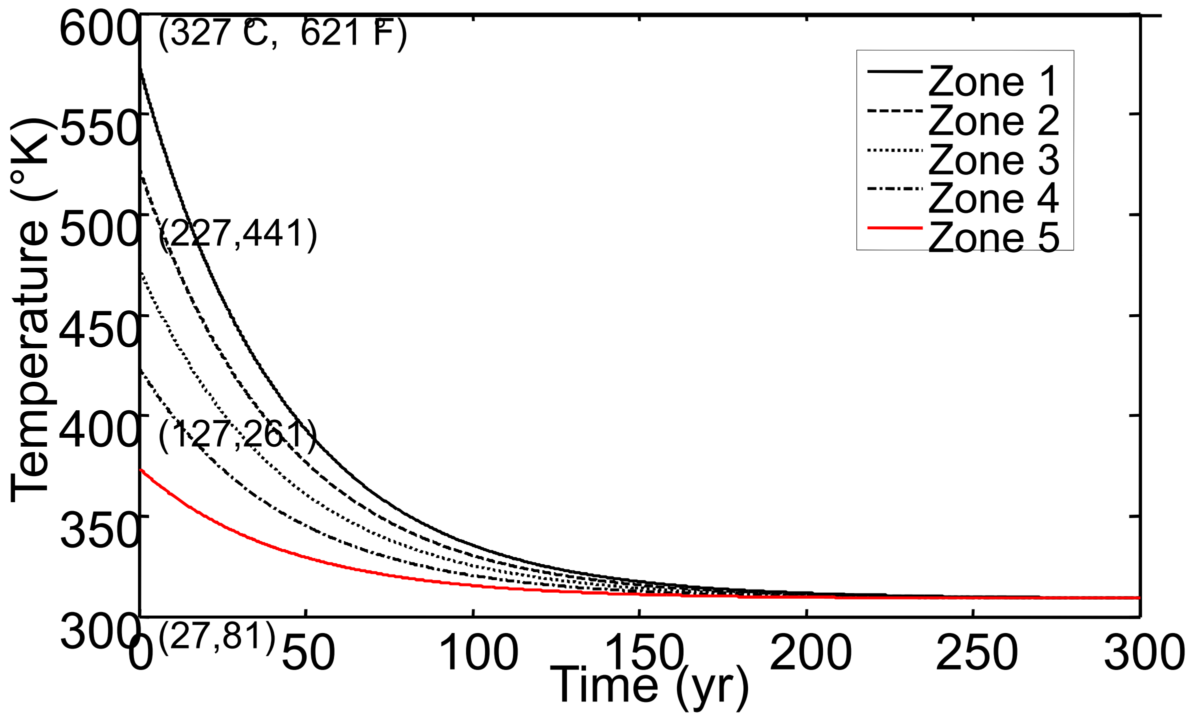
Scope of Evaluation

- Amount of residual water:
  - 0.55 to (55) mol (1 liter); the canister is air-tight without any leakage; the canister is dried and backfilled with helium.
  - The amount of water is estimated by measuring the amount of trapped water at defective cladding; defective cladding, 0.01 to 1.0 %
  - Current drying methods may not have counted chemisorbed water.

- Temperature (T):
  - divided in five zones spatially, and decreased with time in each spatial zone (figure next page)

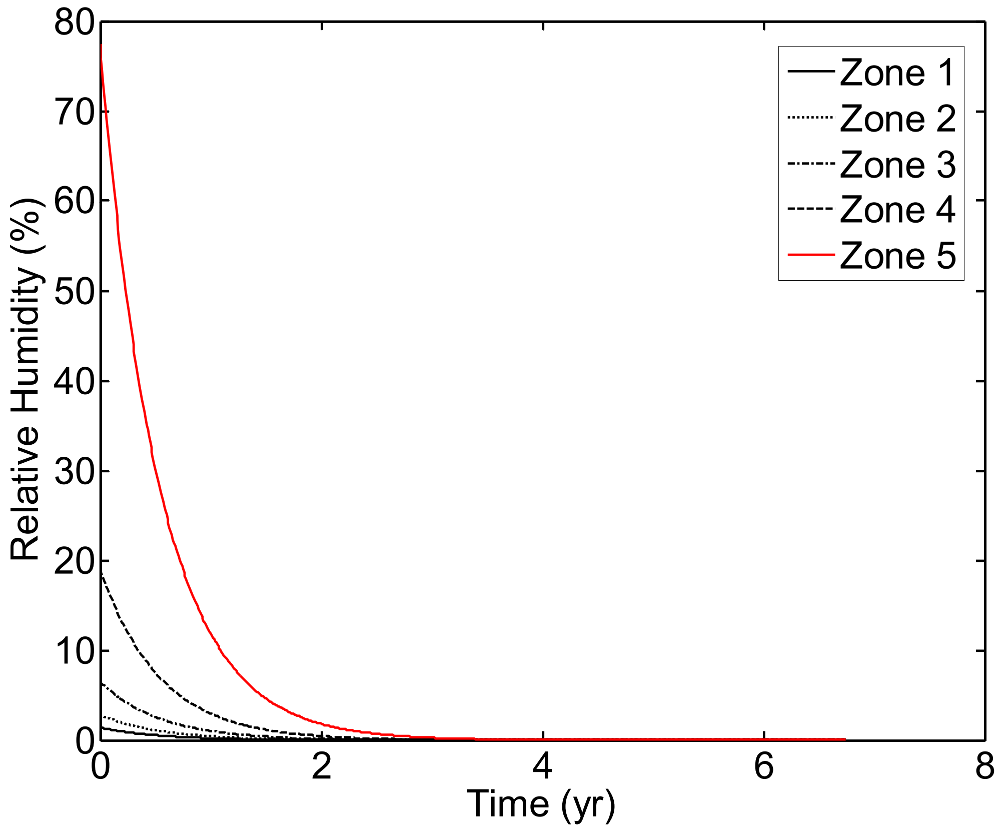
- Relative humidity (RH):
  - divided in five zones spatially, and decreased with time in each spatial zone (figure next page); assumed a uniform absolute humidity and saturation humidity at each domain temperature for relative humidity calculation

Integration Results for Case 1: Temperature Profile



- Each zone was defined based on isothermal temperature contour along radial and longitudinal directions.
- Many cases were studied, varying heat loading and canister size. Cases are not based on any Safety Assessment Report.

Integration Results for Case 1: RH Profile



Scope of Evaluation (continued)

- Time
  - up to 300 years
- Reference canister and cask
  - Derived from CASTOR V21
    - Choice of cask: VSC-17
- SNF selection
  - Derived based on experimental observations of Westinghouse 15x15 PWR Fuel

Findings

- Water molecules could be dissociated into oxygen (or other oxidizer) and hydrogen by radiolysis.
- Water consumption by radiolysis and chemical reaction will proceed with time.
- Cladding has a large surface area to consume water by oxidation and aqueous corrosion.
- The SNF matrix has a large surface area for chemical reaction with oxygen or water at defective cladding, especially when individual grains are exposed.
- Hydrogen could be generated by radiolysis and aqueous corrosion of metals with water.

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Findings (continued)

- Hydrogen molecules formed from radiolysis will not be absorbed in metals because a diatomic hydrogen molecule is much larger than an atomic hydrogen.

- Hydrogen generation with higher volume (e.g., 4 volume %) of trapped water could pose a hydrogen flammability issue.

- The oxidation/hydration of the SNF matrix at defective cladding may increase the localized volume, imposing stress on the defective cladding.

- Cladding damage would be determined primarily by the amount of initial residual water, fraction of initial defective cladding, and choice of radiolysis kinetics. The temperature effect is secondary.

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Preliminary Conclusions

- The amount of residual water significantly decreases with time by radiolysis, oxidation and aqueous corrosion.
- Consequence of cladding oxidation is insignificant.
- Oxygen and hydrogen generated do not lead to significant pressurization in the assumed range of the amount of initial residual water.
- Hydrogen generated does not significantly affect the structural integrity of internal components.
- It is unlikely to have cladding splitting or reaching hydrogen flammability, except upper bounds (i.e., limited conditions) of the amount of initial residual water, fraction of initial defective cladding, and faster radiolysis kinetics.

Preliminary Conclusions (continued)

- Effects of incomplete drying may not impact the life extension of the cask.

- The significance of uncertainties are not completely assessed. The deficiencies of the current assessment of drying process may not include uncertainties associated with chemisorbed water.