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Safety of long-term dry storage in Germany - Challenges and Perspectives

global research for safety

EUROSAFE 2017

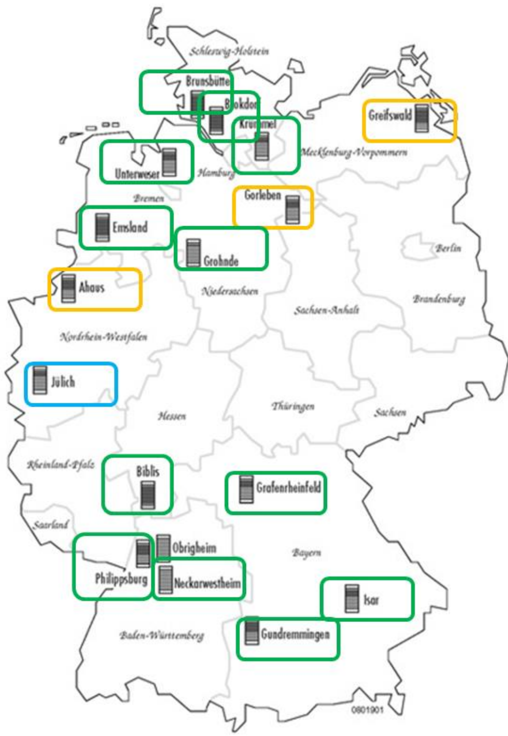
Outline

- Current and future situation of spent fuel in Germany
- Central Elements of safe long-term storage
- Current Research at GRS
  - Temperature field in cask
  - Fuel rod mechanics
- Summary

Current Situation of Spent Fuel in Germany

- End of 2022: Ending of operating licenses for commercial power plants
- Spent nuclear fuel will be stored in final disposal
  - No final disposal available, yet
  - Estimated timeline for availability 2050 – 2080
- Spent fuel stored in pools or dry (dual purpose) casks
  - Majority CASTOR® Designs (GNS)
  - Spent UO2 and MOX fuel from power reactors (high BU)
  - Vitrified high active waste (HAW) from reprocessing
  - Spent fuel from research reactors

Current Situation of Spent Fuel in Germany



- Centralized storage facilities
- Local storage facilities
- On-site storage facilities

Interim storage facility	Casks no.	In operation since
TBL Ahaus (ZL)	329	Juni 1992
TBL Gorleben (ZL)	113	April 1995
Zwischenlager Nord (ZL)	74	Ende 1999
AVR-Behälterlager Jülich	152	August 1993
SZL Biblis	75	18.05.2006
SZL Brokdorf	29	05.03.2007
SZL Brunsbüttel	11	05.02.2006
SZL Grafenrheinfeld	21	27.02.2006
SZL Grohnde	30	27.04.2006
SZL Gundremmingen	48	25.08.2006
SZL Isar	36	12.03.2007
SZL Krümmel	29	14.11.2006
SZL Lingen	38	10.12.2002
SZL Neckarwestheim	53	06.12.2006
SZL Philippsburg	58	19.03.2007
SZL Unterweser	27	18.06.2007
Total	**1123**	–

- Main protection goals are provided by cask functions:
  - Confinement of radioactive inventory
  - Sub-criticality
  - Radiation shielding
  - Decay heat removal
- Transportability of the cask during storage period.
- Storage building provides additional protection against radiation, weather and acts as physical barrier.

Future Situation

- In 2019: Single Operator of all interim storages will be the state owned *Gesellschaft für Zwischenlagerung* (BGZ).
- Licenses for storages will expire before final storage is available: TBL Gorleben 2034, onsite storage Lingen 2042 (N.B.: 6/8 years before expiring the remaining of the casks has to be clarified)
- Extending/Re-newing the licenses:
  - What are the relevant conditions and parameters?
  - Which are important additional (chemical and physical) effects?
  - E.g.: How to exclude systematic cladding failure on long time scales?
    - For 40 years: Max. hoop stress of 120 MPa and a clad strain of max 1 % circumferential (T_{max}~370°C)

Long-Term-Storage

Four central elements for a safe long-term storage

Operational experience	Periodic safety review
Research and developement programs	Continuous ageing management

Research and developement programs

Several R&D programs started.
Managed by GRS:

- Grant No. 3615R03310
  - generate basic information and data
  - provide possible concepts and strategies of a future interim storage
  - In co-operation with BAM, Öko-Institut, TÜV-Nord

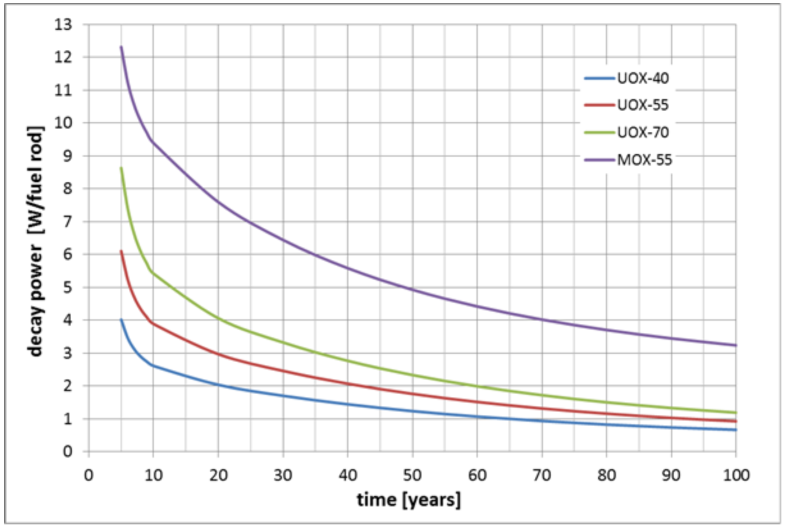
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

- Grant No. RS1552 BREZL
  - R&D program to (theoretical) investigate the fuel rod integrity
  - In co-operation with TÜV-Nord

Federal Ministry for Economic Affairs and Energy

Fuel Rod Integrity

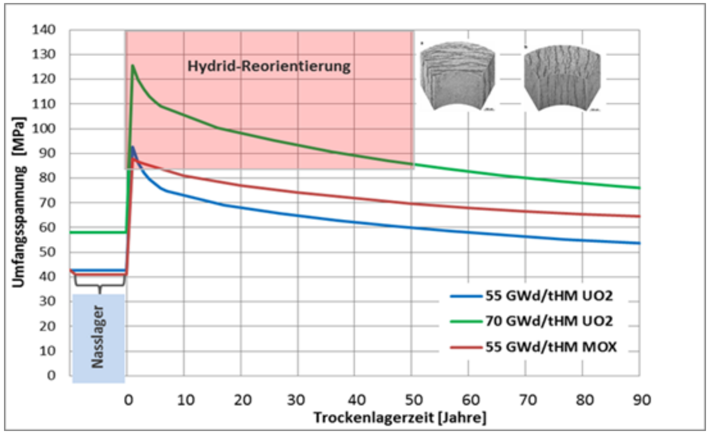
- Further embrittlement of fuel rods under long-term dry storage condition
- Numerous obstacles in describing material evolution in cask interior: no sufficient experimental data base, theoretical modelling
- Based on previous investigations (c.f. EUROSAFE 2013) BREZL aims to combine detailed temperature calculations (COBRA-SFS) with calculations of mechanical parameters (TespaRod)

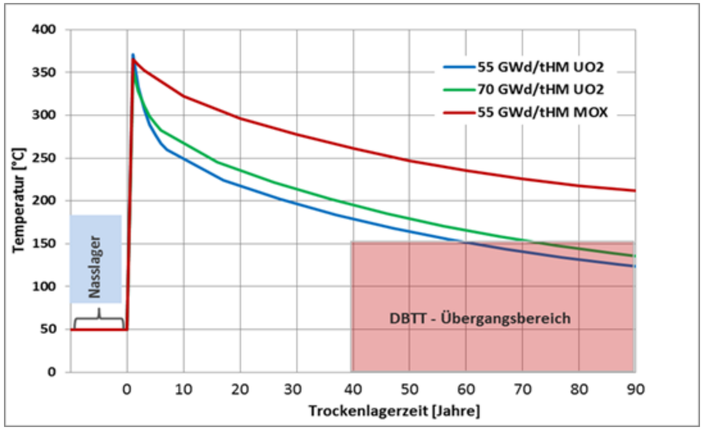


Thermal Model Development

- Gap analysis identified thermal profiles as a *High Priority* (NRC, EPRI)
  → Almost all degradation mechanisms are temperature dependent

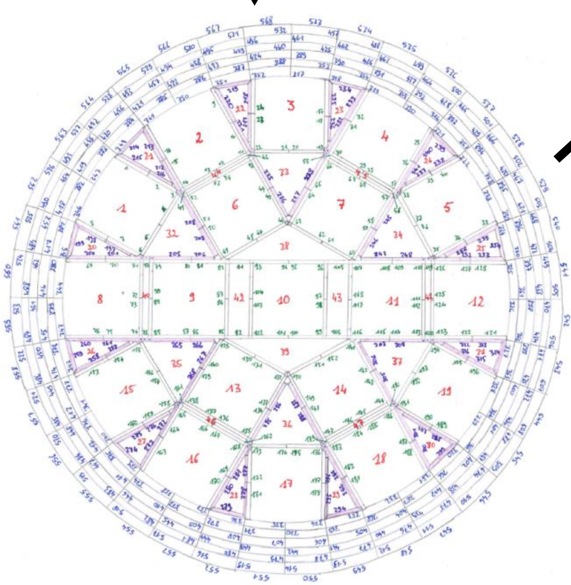
- Realistic 3D temperature profiles required
  - Conservative models are used to assure peak cladding temperatures to be within technical specifications. This might lead to
    - Over prediction of hydride reorientation
    - Under prediction of low temperature effects, e.g. DBTT





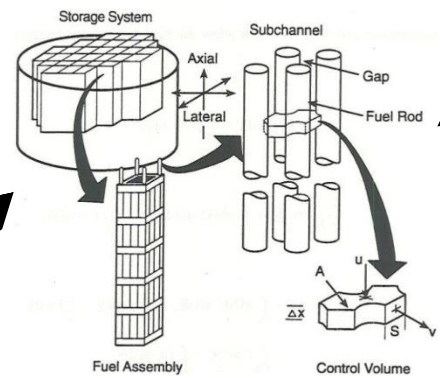
Modelling of Generic CASTOR®-like Cask

Credit: GNS, product information CASTOR® V/19

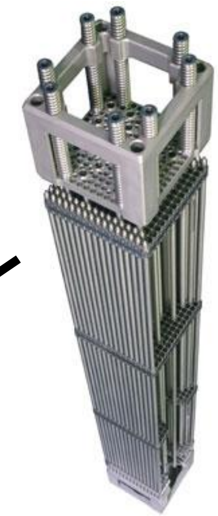


COBRA-SFS

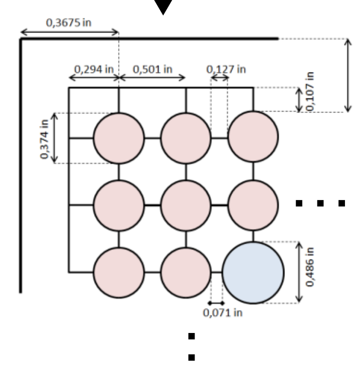
Thermal-hydraulic analysis code for spent fuel storage and transportation casks



Credit: T.Michener et al., PNNL-24841



Credit:nuclear-power.net

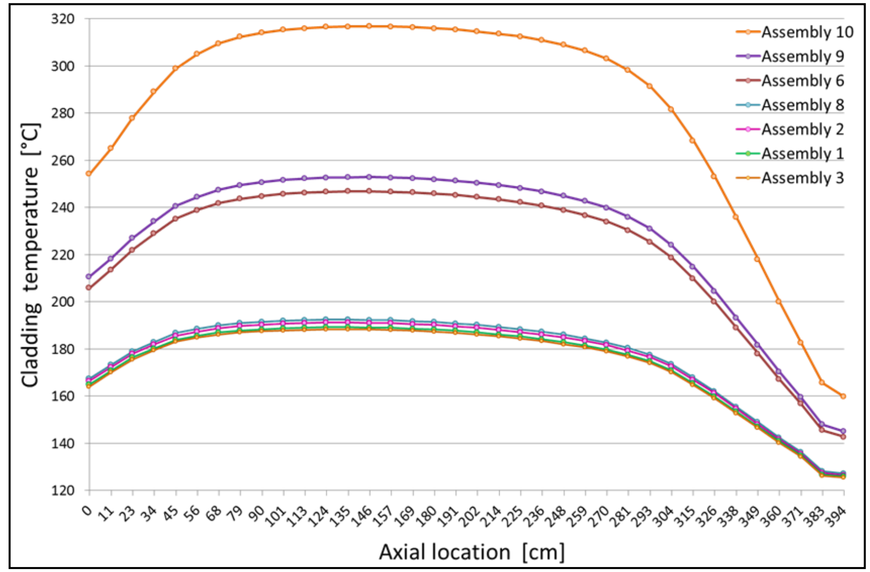


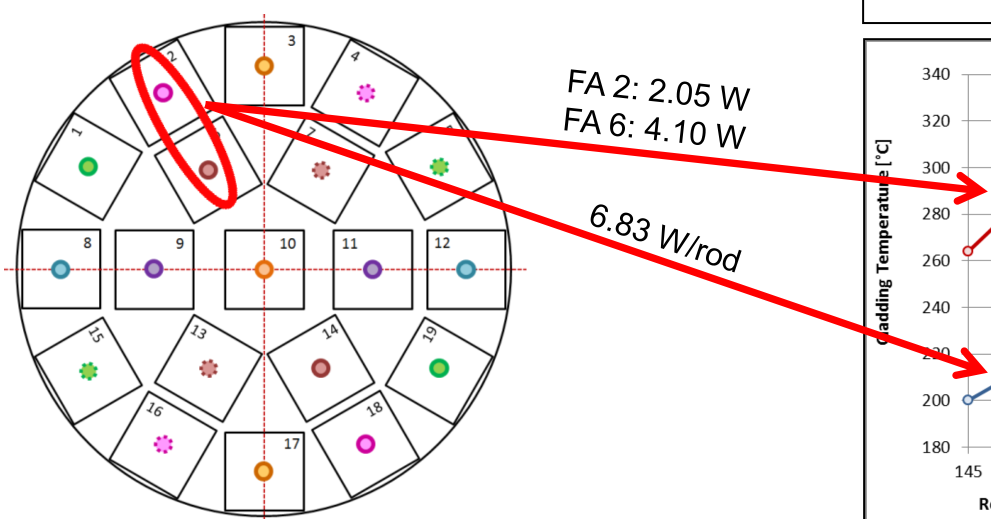
Example Results

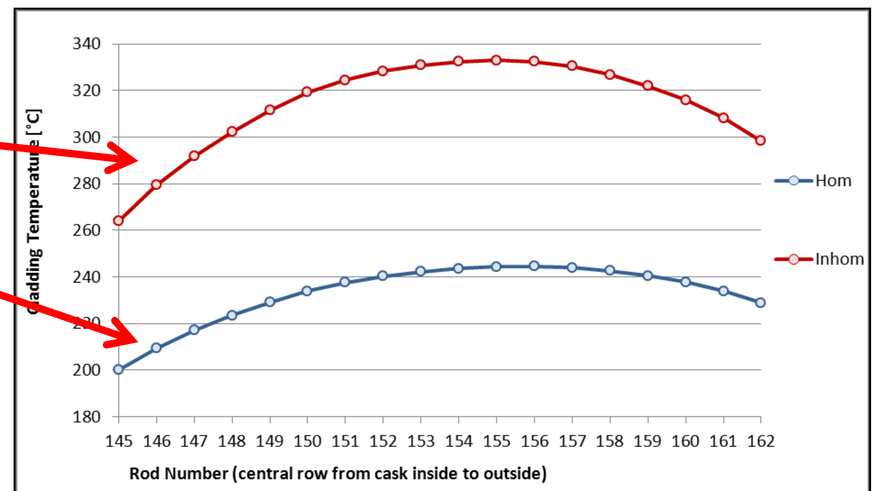
Assume:

- 18x18-24 PWR
- Total cask power 39 kW
- Homogeneous loading
- Axial burn-up profile

} 6.83 W/rod





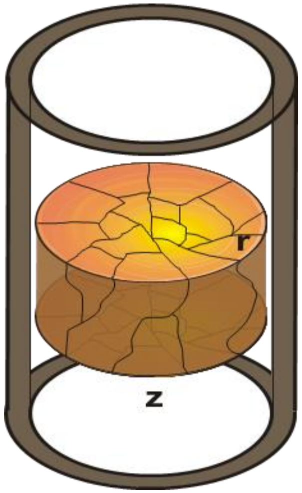


Summary Fuel Rod Temperature

- Large spatial temperature deviations (> 100 °C) observed
- Comparable large temperature effect of inhomogeneous loading schemes
- Validation of model would need further experimental data

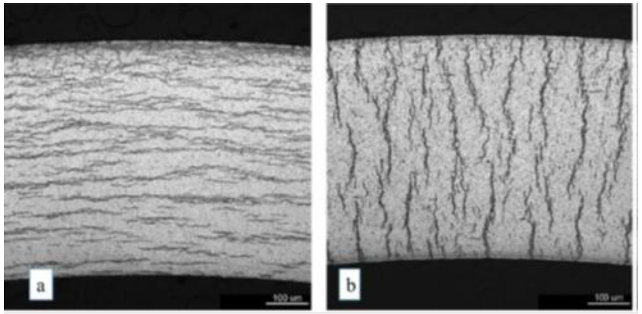
Fuel Rod Mechanics

- “Hot” fuel rods:
  - Fission gases and He from α-decay build up pressure
  - Stress and temperature lead to cladding creep, weakens the cladding thickness



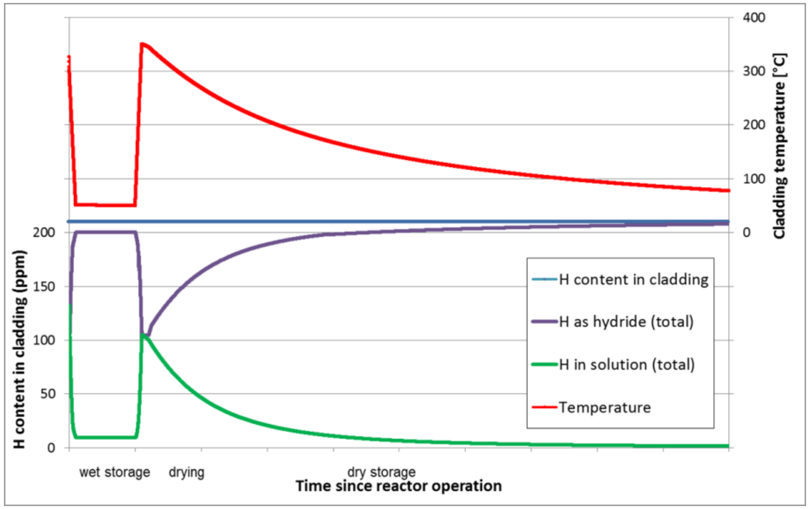
- “Colder” fuel rods
  - Hydrogen pick up during operation
  - Circumferential precipitates after operation (a)
  - Partly dissolves during cask drying
  - Radial precipitates during storage (b)
  - Cladding embrittlement may occur

Source: Moore, 1969



Hydrogen Solubility and Behaviour

- Goal: Development of hydrogen model for fuel rod code TESPA-ROD
- Effects to be covered:
  - Hydride solubility under stress
  - Axial diffusion of hydrogen
  - Influence of radial hydride fraction on mechanical behaviour



- Challenges:
  - Experiments show large differences to each other
  - Influence of stress, material, texture, irradiation, Pellet-Cladding interaction, …

Summary Fuel Rod Mechanics

- No simple conservative assumption found, yet.
- Behaviour of hydrides in zircoium-based materials is determined by a complex system with many variables.
- Re-orientation of hydrides depends on fuel rod material and its properties.
- Experimental and theoretical data not always consistent.

Summary

- Cask is central safety element for storage of SNF and HAW.
- Operation experience of dry storage of more than 25 years and 15 different cask types.
- Research on aging effects on both experimental and theoretical items is necessary.
- Direct validation of theoretical models not always possible.
- Lots of open question concerning description of fuel rod mechanics under long-term storage conditions.

Thank you for your attention

2nd Workshop on

Safety of Extended Dry Storage of Spent Nuclear Fuel

When: June 6 – 8 2018

Where: GRS, Munich, Germany

What: Small and focused conference on advances in the field of safety aspects of extended dry storage of spent nuclear fuel

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