TÜV NORD
Inspection

Specific Aspects of High Burnup or Mixed Oxide Fuel Rods during Dry Storage

Gerold Spykman

TÜV NORD Inspection

c/o TÜV NORD EnSys Hannover GmbH & Co. KG

Department Reactor Technology and Fluid Mechanics

Section Reactor Core Components

Am TÜV 1, 30519 Hannover, Germany

gspykman@tuev-nord.de

Outline

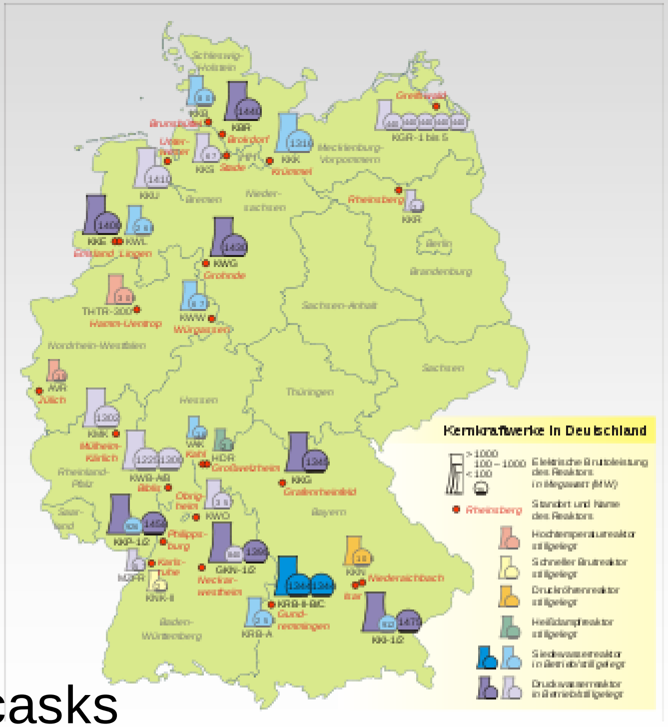
- Introduction
- Interim Storage of Spent Fuel in Germany
- Exclusion of a systematic cladding failure of LWR fuel during interim storage in casks – present verification situation
- Extension of the interim storage time with respect to cladding behavior of high burnup fuel and mixed oxide fuel
- Conclusions

Introduction

TÜV NORD Inspection

- The TÜV NORD Group is a technical support organization acting in a variety of fields as e.g. safety of conventional technology, education, quality and environmental management as well as nuclear safety

- In the field of nuclear safety the TÜV NORD EnSys Hannover and the TÜV NORD SysTec are companies of the TÜV NORD Group supporting the regulatory authorities with approximately 400 employees covering all aspects of nuclear safety



Source: Wikipedia „Kernkraftwerke in Deutschland“

- TÜV NORD is in contract for
  - NPPs in operation
  - NPPs in decommissioning
  - Licensing of interim storage facilities and casks
  - Surveillance of interim storage facilities

Interim Storage of Spent Fuel in Germany

TÜV NORD Inspection

- Storage facilities for dry storage
  - Two central storage facilities (Ahaus and Gorleben)
  - Local storage facilities on NPP site
- Cask Types
  - CASTOR cask types
  - TN cask type in licensing process (PWR fuel)
- Main fuel designs
  - PWR fuel from KWU Type NPPs from different vendors and PWR fuel from VVER 440
  - BWR fuel from several vendors
  - Fuel from pebble bed reactors (HTR and AVR)
- Burnup limitations (example for PWR fuel, CASTOR type cask)
  - Uranium and mixed oxide fuel with an average burnup up to 55 MWd/kgHM
  - High burnup fuel with an average burnup up to 65 MWd/kgHM is limited to a number of four assemblies on special positions in the cask
  - Number of MOX fuel with an average burnup up to 55 MWd/kgHM is limited to a number of six assemblies on special positions in the cask

Requirements on Storage of Spent Fuel in Germany

TÜV NORD Inspection

- Limitation of storage time by the cask license to 40 years starting at loading date
- Since the discussion on final repository in Germany is starting from scratch ("Standortauswahlgesetz") the needed time scale for interim storage will exceed the storage time limit given by the license
- Requirements on interim storage are formulated in the guidelines of the German Nuclear Waste Management Commission (ESK)
- ESK considers in their requirements a storage period of 40 years
- ESK states if this period is not sufficient additional and appropriate verifications on long term behavior of the casks and the fuel has to be provided
- Within these verifications the available experience of the 40 year storage period can be considered

Requirements on Cladding Integrity

TÜV NORD Inspection

- Beside the cask itself the fuel matrix and the fuel rod cladding are stipulated as barriers for fission product retention
- Cladding integrity prevents fuel relocation which has an important impact on fuel handling and e.g. thermal or radiological assessments
- Within the limitation of the storage time to 40 years the following requirements on an exclusion of a systematic cladding failure are formulated:
  - The cladding hoop stress should not exceed 120 MPa

    Within this criterion stress corrosion cracking and hydride reorientation as failure mechanisms will be excluded
  - The cladding hoop strain should not exceed 1 %

    Within this criterion an increase of the hoop stress at higher strain levels and the failure caused by strain should be excluded
  - The cladding temperature should not exceed 370 °C

    Within this criterion the annealing of irradiation hardening and the dissolution of the hydrogen precipitates in the cladding will be excluded
  - Cladding corrosion during the storage time should be limited

Cladding Integrity in an Extended Storage Time

TÜV NORD Inspection

- It has to be evaluated, whether the requirements for 40 years are still valid and applicable for a longer time span
- In the long term other effects of degradation may take over the leading part in the assessment of cladding integrity
- High burnup fuel and mixed oxide fuel are identified as the fuel with the highest loads and with the highest potential for a systematic cladding failure
  (see also IAEA Standard on Storage of Spent Nuclear Fuel)
- The examinations carried out on spent fuel after a dry storage period do not cover high burnup fuel or mixed oxide fuel
  (see also Examination of Spent PWR Fuel Rods after 15 Years in Dry Storage, NUREG/CR-6831 and ANL-03/17 reports, 45 MWd/kgHM)
- From our point of view future examinations of LWR fuel with respect to cladding integrity for an extended dry storage period should focus on high burnup and mixed oxide fuel

Considerations for Cladding Integrity during an Extended Storage Time

TÜV NORD Inspection

- Reorientation of hydrogen precipitates:
  - Hydrogen is picked up from the waterside corrosion during the in pile life of the fuel
  - After a certain concentration is reached the hydrogen precipitates following the thermal gradient in the cladding
  - These precipitates are orientated circumferential and have only minor effects on the load of the hoop stress
  - During the storage these hydrogen precipitates can reorientate in the radial direction by dissolving and precipitating again after a heat up and cool down phase
  - Under the conditions within the cladding e.g. temperature and hoop stress the reorientation can be going on slowly and will lead to delayed hydrogen cracking after a long period of time
  - Mostly affected will be the cladding of high burnup fuel and MOX fuel

Considerations for Cladding Integrity during an Extended Storage Time

TÜV NORD Inspection

- Fission gas release from high burnup structure:
  - During the operation of the fuel the ratio of released fission gas to the produced fission gas is up to a range of 20 % depending on the fuel type and the power history
  - More than 80 % of the produced fission gas is trapped in pores, grain boundaries and in intergranular bubbles
  - Especially from the rim zone of high burnup fuel and the zones of the plutonium grains in MOX fuel, which show closed porosity with high cavity pressure, can be addressed as a source for a fission gas release during storage
  - Another candidate for increasing the inner fuel rod pressure is the alpha decay that leads to a higher helium release from the fuel
  - Additional gas release will increase the inner fuel rod pressure with its consequences to the hoop stress, hoop strain and hydrogen precipitates reorientation

Considerations for Cladding Integrity during an Extended Storage Time

TÜV NORD Inspection

- Cladding degradation by irradiation damages and fuel side chemical interactions:
  - Degradation of the cladding by inner side corrosion of the cladding and embrittlement by oxygen uptake from free oxygen from the fuel
  - It is assumed that no oxygen is available and the ceramic fuel is chemically stable, but it is not known today whether this is also valid for the high burnup structure (HBS) at the outer rim of the pellets of high burnup fuel
  - The material micro structure has changed in the HBS after a certain burnup and this region of the pellet has a lot of pores with fission products. There may be chemical interaction with the oxide fuel that may lead to an additional cladding corrosion
  - Chemical interaction of fission products like iodine or other halogens which support stress corrosion cracking
  - Failures caused by changes in the crystal microstructures by mobile dislocations and line defects

Conclusions

TÜV NORD Inspection

- An overview over the situation in Germany of the dry storage of spent fuel in casks was given with respect to the cladding integrity
- Some from the TÜV NORD point of view possibly important effects of cladding degradation during dry interim storages for a longer time were addressed
- The assessments of these effects will cause some experimental examinations of spent fuel after a longer storage time
- These examinations should be used for the development of models to be used for the forecast of the fuel performance during longer storage times
- We suggest to implement these models in available fuel performance codes to perform fuel life time calculations including the interim storage period and to take benefit from the methods of sensitivity analyses and probabilistic methods

TÜV NORD
Inspection

Thank you for your attention