World Nuclear Transport Institute
Technical and Operational Issues Related to the Transport of High-burnup and Irradiated Mixed Oxide Fuels

WNTI Experience

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Mission

World Nuclear Transport Institute

- Dedicated to the safe, secure, efficient and reliable transport of radioactive material

- The ears and the voice of the radioactive material transport industry
Background of WNTI

► WNTI was established by Industry in London in 1998 to represent the collective interests of the radioactive materials transport sector

► Three Founder Members: BNFL in the UK, COGEMA in France and FEPCo in Japan; now INS, Orano and FEPCo

► Initial focus was maritime transport issues for the Founder Members, and thus IMO/London

► WNTI now has 48 Members from across our industry sectors and around the globe (utilities, fuel producers, logistics companies, package designers and producers, transport stakeholders...)

► WNTI supports the work of key intergovernmental organisations, such as the IAEA and the IMO, in promoting an efficient, harmonised international transport safety and security regime

► Exchanges within intergovernmental organisations, with national competent authorities and collaboration with related industry organisations are essential for the WNTI
Industry representation at international organisations (IAEA, IMO, etc.)

Publications
- Factual information (factsheets, etc.)
- Good practice guides & Standards for the transport industry
- Website www.wnti.co.uk

Working Groups for industry members

Thematic / Regional Workshops
WNTI Membership
1. Has there been a significant change in your country’s spent fuel inventory, including mixed oxide (MOX) and higher burnup uranium oxide (UOX), since the last reporting date (December 2016)?

- High burnup uranium oxide spent fuel
  - The general trend is an increase of the burnup of the spent fuel (or a stability of the burnup of the spent fuel for the utilities where burnup is deemed high enough)

- Mixed oxide (MOX) spent fuel
  - The general trend is a stagnation in the use of mixed oxide (MOX)
In general, there is no strict definition of high burnup fuel.

However, fuel assemblies with an average burnup higher than 55 GW.d/tHM are usually considered as high burnup fuel assemblies.

- In general, the maximum average burnup of the fuel assemblies is 65 GW.d/tHM and for some BWR fuel types 67 GW.d/tHM (Examples from Germany and Switzerland).

- For some fuel assemblies, the maximum average burnup of the fuel assemblies can reach 75 GW.d/tHM (PWR) or 80 GW.d/tHM (BWR) (Example from Germany).
In general, MOX fuel is defined as mixed oxide (uranium + plutonium) fuel to be used in light water reactor (PWR, BWR, VVER, or similar reactors)

MOX fuel assemblies are characterized by:

- the plutonium contents in each zone (the plutonium contents vary from one rod to another one, and there are – for instance – three zones with different plutonium contents)
- the plutonium isotopes vector (Pu-238/Pu-239/Pu-240/Pu-241/Pu-242) [comparison between the actual isotopic composition and the vector used for the design of the package shall take into account the opposite impact on reactivity of the neutron poisons and of the fissile isotopes]

Fuel to be irradiated in fast breeder reactor can also be made of a mixture of uranium oxide and plutonium oxide, but they are generally not classified as MOX fuel
4. Are there any unique operational constraints in managing higher burnup/MOX spent fuel in your country?

► Preparation / Loading

— One of the unique characteristics of higher burnup / MOX spent fuel assemblies is their higher dose rates, and more particularly the neutron dose rate. This yields to the need:
  - To select an appropriate packaging design for the transport of the spent fuel assemblies
  - To prepare the loading of the packaging accordingly (to draft adequate procedures, to make available appropriate equipment, etc.)

— The limitations of the number of the fuel assemblies and the requirements regarding the positions of the fuel assemblies can be more stringent for high burnup and MOX spent fuel assemblies

— See Item 9 “Examples of operational experience regarding higher burnup / MOX spent fuel transport (or preparation for such transport)”
4. Are there any unique operational constraints in managing higher burnup/ MOX spent fuel in your country?

► Transport

— No operational constraint during the transport of higher burnup / MOX spent fuel assemblies has been identified
5. Is there any data your country requires to justify the transport of higher burnup/MOX spent fuel, including after extended storage periods?

See:

— Item 7 “Are different approaches used in your country to assess the structural performance of higher burnup spent fuel compared to lower burnup spent fuel? Please summarize any differences”

— Item 8 “With reference to the below safety functions of transport packages, how would you demonstrate compliance for higher burnup/MOX spent fuel? Are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?”
6. Are you required to provide evidence of defence in depth to your regulatory authorities, with respect to transport of higher burnup/MOX spent fuel?

- In general, there is no requirement regarding the need to provide evidence of defence in depth to the regulatory authorities, with respect to transport of higher burnup/MOX spent fuel.

- In some instances, especially for criticality safety, defence in depth analyses had to be performed for high burnup fuel assemblies.
  - Realistic scenarios for fuel rod grid expansion and fuel leakage are considered for accident conditions of transport.
  - Further scenarios with more severe assumptions are done in the defence in depth analysis.

- See also Item 8 “With reference to the below safety functions of transport packages, how would you demonstrate compliance for higher burnup/MOX spent fuel? Are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?”
For all fuel assemblies (any burnup / UOX or MOX), for the safety assessment of the package design (including thermal analysis, release of activity, criticality safety, dose rate analysis), the structural performance of spent fuel assemblies is important as it may have direct consequences:

- on the geometry of the fuel assemblies (deformation of the fuel rods, deformation and failure of the grids, and subsequent changes in the pitch of the fuel rods)
- potentially on dispersion of the fuel pellets within the packaging (following failure of fuel rods)

after normal and accident conditions of transport.

Burnup is a significant parameter which influences the structural performance of spent fuel assemblies. Therefore, structural analysis of spent fuel assemblies has to take into account the burnup of the assemblies (including relevant material data for the cladding and tests)
8. a. With reference to “confinement”, are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?

- The “confinement system” is a concept which is linked to criticality analysis.

- High burnup fuel
  - The result of the assessment of the structural performance of the fuel assemblies has to be considered (see above Item 7)
  - Burnup credit
    - The reduction of $k_{eff}$ is more important when the burnup is higher
    - The availability of experimental data to be used for the qualification of the calculation codes (evolution of the composition of the fuel / calculation of $k_{eff}$) is limited for high burnup (and is currently available for uranium oxide fuel only)
8. a. With reference to “confinement”, are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?

► Mixed oxide (MOX) spent fuel

- Burnup credit: not used for MOX spent fuel (qualification under consideration)
- Pu contents vary from one fuel rod to another one
  - Consideration of the maximum Pu contents in a cross section
  - Consideration of the Pu contents mapping in a cross section
  - Consideration of the average Pu contents in a cross section (subject to appropriate qualification)
8. b. With reference to “containment”, are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?

► “Containment” is a concept which is linked to the release of activity

► Source term / Inventory of gases available for release from the packaging:

\[
\text{quantity of fission gases generated in the fuel} \\
\times \text{fraction of gases which can be released out from the pellet (to the inside of the fuel rod)} \\
\times \text{fraction of failed rods}
\]

— The assessment of the release of activity from the package is highly influenced by the fraction of gas which can be released out from the pellets (to the inside of the fuel rod)

— The fraction of gas which can be released out from the pellets is highly influenced by the characteristics of the fuel, and particularly its burn-up and its nature (MOX when applicable)

— The fraction of failed rods may also be influenced by the characteristics of the fuel rods
8. c. With reference to “heat dissipation”, are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?

- High burnup uranium oxide spent fuel
  - The residual heat power from an oxide spent fuel increases more than proportional with the burnup

- Mixed oxide (MOX) spent fuel
  - For the same burnup, the residual heat power is quite higher for a MOX fuel than a uranium oxide spent fuel

- The “heat dissipation” issue with higher burnup/MOX spent fuel is not unique but is more important for this fuel
8. d. With reference to “shielding”, are there any unique issues in demonstrating compliance with SSR-6 with regard to higher burnup/MOX spent fuel?

- High burnup uranium oxide spent fuel
  - The neutron emission dramatically increases with the burnup [the neutron emission is proportional to the burnup to the power (about) 4]
  - The neutron emission decreases slowly with the cooling time
  - Additional validation may be required for calculation codes

- Mixed oxide (MOX) spent fuel
  - For the same burnup and same cooling time, the neutron emission is quite higher for a MOX fuel than a uranium oxide spent fuel [more than one order of magnitude higher]

- The “shielding” issue, and particularly the neutron dose rate issue, with higher burnup/MOX spent fuel is the most significant issue as regards compliance with the Transport Regulations (SSR-6)
9. Are there any examples of operational experience you can share regarding higher burnup/MOX spent fuel transport (or preparation for such transport)?

- High burnup / MOX spent fuel assemblies are routinely loaded and transported in several countries (Belgium, Germany, France, Switzerland, etc.)
9. Are there any examples of operational experience you can share regarding higher burnup/MOX spent fuel transport (or preparation for such transport)?

Measurement of dose rate (1/2)

- When preparing the transport, calculations of dose rates around the package are made, and consider the characteristics of the spent fuel assemblies
- For “optimized” loadings, the dose rates may be very close to the regulatory limit of $0.1 \text{ mSv/h}$ (typically at two meters from the external surface of the vehicle)
- Higher burnup / MOX spent fuel features higher production of neutrons
  - Neutron dose rates are difficult to measure precisely
  - The higher production of neutrons generates a higher production of high energy secondary gammas, and some measurement devices may overestimate high energy gamma dose rates (gamma emitters with energy up to $10 \text{ MeV}$)
9. Are there any examples of operational experience you can share regarding higher burnup/MOX spent fuel transport (or preparation for such transport)?

— Measurement of dose rate (2/2)

  — The dose rate (gamma + neutron) measured prior to shipment may not be in accordance:
    o with the calculations
    o with the dose rate measured by the consignee
      • Different sources to calibrate the measurement devices
      • Different locations to carry out the measurement

  — Orano and EDF have been working with the manufacturers for several years to modify and correctly calibrate neutron and gamma measurement devices to obtain reliable dose rate measurements, and thus optimize the content of the casks, while complying with regulatory limits
9. Are there any examples of operational experience you can share regarding higher burnup/MOX spent fuel transport (or preparation for such transport)?

- Measurement of dose rate (Conclusion)

- Measurement of dose rate is a sensitive issue for the transport of higher burnup / MOX spent fuel assemblies, as the dose rates around the packages are close to the regulatory limit, which need to be managed carefully (appropriate measurement device, etc.)

- Consignors and consignees should have reliable and consistent means of measurements (devices, procedures, etc.) [for instance, in France, EDF (consignor) and Orano (consignee) have a common protocol for that purpose]

10. Have there been new cask designs dedicated to the transport of higher burnup/MOX spent fuel?

► Examples for designs from Orano TN

— Transport cask / France / High burnup uranium oxide spent fuel
  o TN 12/2 and TN 13/2 → TN G3

— Transport cask / France / MOX spent fuel
  o TN 12/2 → TN 112

— Dual-purpose cask / Belgium / High burnup uranium oxide spent fuel
  o TN 24 D → TN 24 DH

— Transport cask / Switzerland / High burnup uranium oxide spent fuel
  o TN 9/4

— Dual-purpose cask / Switzerland / High burnup uranium oxide spent fuel
  o TN 24 BH

— Dual-purpose cask / Germany / High burnup uranium oxide spent fuel
  o TN 24 E
10. Have there been new cask designs dedicated to the transport of higher burnup/MOX spent fuel?

- Examples for designs from GNS
  - Dual-purpose cask / Germany / High burnup uranium oxide spent fuel
    - CASTOR® V/19 and CASTOR® V/52
  - Dual-purpose cask / Germany / MOX spent fuel
    - CASTOR® V/19 and CASTOR® V/52
  - Dual-purpose cask / Switzerland / High burnup uranium oxide spent fuel
    - CASTOR® V/19 (CH) and CASTOR® V/52 (CH)
  - Dual-purpose cask / Switzerland / MOX spent fuel
    - CASTOR® V/19 (CH)
  - Dual-purpose cask / Belgium / MOX spent fuel
    - CASTOR® geo24B
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