Decommissioning problems of German pebble bed reactors

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Decommissioning effort of German pebble bed reactors (PBR) = extraordinarily high, even compared with US-HTGR of same time

Two German PBR, owned by utilities; major development effort by Research Centre Juelich FZJ

- AVR Juelich adjacent to FZJ, 13 MWel, 1967 – 88
- THTR-300 (Hamm) 300 MWel, 1985 - 89, 14 months operation only

Reasons for difficult decommissioning are mainly PBR-generic, but were enlarged by careless operation

Some PBR generic reasons:

- Low power density = high material consumption:
  a) strongly increases the amount of waste
  b) high construction costs, forcing application of low cost materials (e.g. impure carbon brick instead of nuclear graphite in AVR and THTR, strong activation)
- Contamination increase by (near)-accidents due to:
  - Impossible in-core instrumentation in PBR
  - Incomplete knowledge on core behaviour/pebble flow
- Poor retention capability of fuel for certain nuclides (diffusion through barriers at elevated temperatures)
- Moderator and fuel are strongly bonded in the fuel pebble (> 95 vol-% = moderator)

- Problematic features of carbon/graphite: burnable, porous, high sorption capability for radioactive nuclides, easily leachable, fast radiolytic attack in presence of water/air, C-14 formation from nitrogen impurities
- Pronounced friction of fuel element graphite in He (= sub-µ dust, broken fuel pebbles)

➔ ***Problems still unresolved for future PBR***

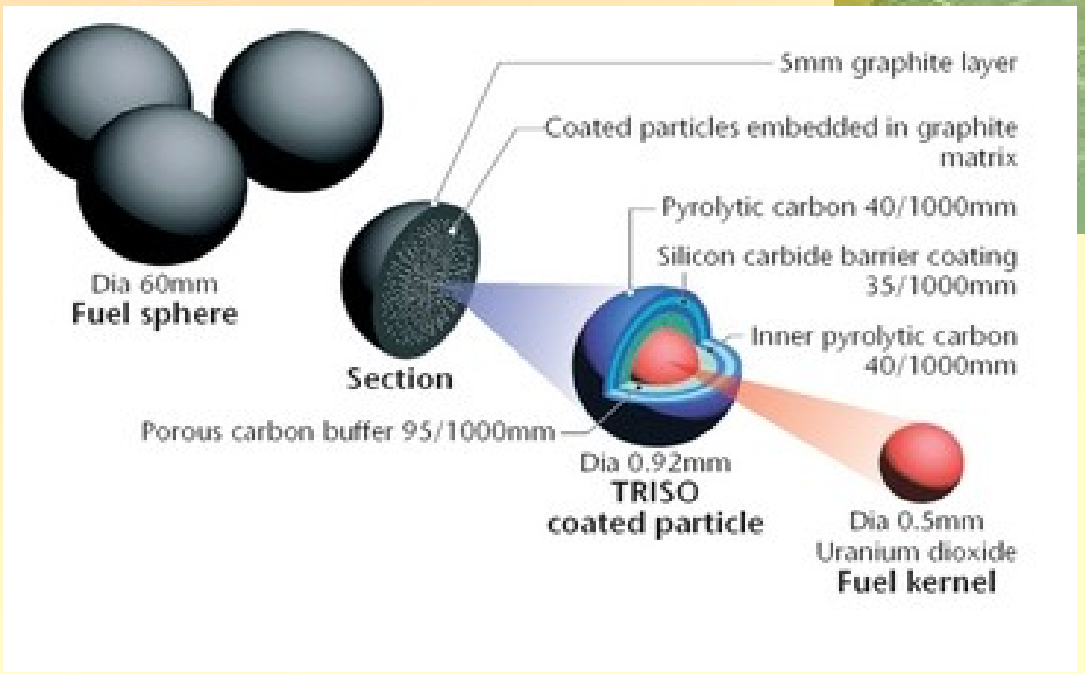
Example of careless operation

- February 1974: AVR gas temperature reaches 950°C
- April/May 1974: Plate-out specimens in hot gas reveal strong increase of Sr-90 release. Sr-90 concentrations even too high for analysis in AVR labs (occupational safety)
- Decision: Sr-90 detection in hot gas stopped, but temperatures remained at high level
- Consequence: AVR confessed in 2000: most heavily Sr-90 contaminated nuclear facility worldwide (100 TBq Sr-90)

PBR fuel element waste

- 290.000 spent AVR fuel pebbles currently stored in Juelich (152 castor containers, 28 tons each); owner since 2003: FZJ, low cost FZJ storage facility, since 2013 without license
- 610.000 spent THTR fuel pebbles (303 castors, owner: utilities) in intermediate storage Ahaus (license until 2036)
- ***History***:
  - ✔ From 1972: Construction of FZJ-reprocessing facility JUPITER (separation of moderator and fuel by burning graphite = reprocessing head end); never operated: too high C-14 emissions in burning
  - ✔ 1976: License to dump 100.000 spent AVR pebbles as MAW (thin-walled drums) in the now collapsing salt mine Asse-II. Not realized because of opposition in the Asse-region (legal actions)
  - ✔ 1978 – 2012: Intermediate storage, almost no relevant r&d on PBR disposal at FZJ

Juelich storage facility



AVR: 80 % without SiC
THTR: Complete without SiC

✔ Since 2012: German funded development work for a reprocessing head end (liquid salt based) to separate fuel and moderator at US Savannah River Site (SRS)

- ➢Plans (LoI 2014) to export spent PBR fuel to the US for reprocessing and disposal
- ➢US-EIA on treatment of AVR- and THTR-spent fuel expected May 2015

▪ **Remarks on fuel export plans:**

A) Probably not consistent with present German law:

✔ Allows spent fuel export for research reactors (= neutron sources) only

✔ Allows reprocessing for noncommerical fuel only

➔ ***FZJ redefines experimental NPP AVR into research reactor***

✔ Doubts about legal correctness of FZJ export plans seem to grow also in the federal government

B) Proliferation aspects of spent PBR fuel

- 80 % of AVR and all THTR fuel used HEU (92 % enriched)
- But HEU: 1 g U/fuel element; LEU: 6 – 21 g U/fuel element = U-mass: 30 % HEU and 70 % LEU fed into AVR
- Proliferation risk of US-origin HEU = main argument in FZJ export plans
- U-235 consumption in HEU fuel elements is about 85 % (AVR), and < 50 % (THTR due to its early collapse)
- In average, spent AVR-fuel is no longer HEU (13 % fissile Uranium)
- However 97 of 152 AVR castors contain only spent HEU fuel (85 kg U, 56 % fissile)
- Spent THTR fuel contains about 420 kg U (76 % fissile: 80 kg U-233, 230 kg U-235) = far more proliferation relevant than the AVR one

➢ *Resumee: Spent THTR fuel requires downgrading, AVR fuel probably not*

C) Time scale

- FZJ intends to make a contract with DOE/SRS on export still 2015
- Juelich castor repository to be emptied by government order of 2014 (safety concern)
- Crane facility of FZJ nuclear department not sufficiently maintained, lost its license 2012. Repair will finish November 2016 (earliest possible castor shipping)
- Alternatives:
  - Transport to Ahaus (possible 2018), but Ahaus license can most probably not be prolonged 2036
  - New storage and conditioning facility in Juelich (at least 5 years for construction) for AVR and THTR = most sustainable solution

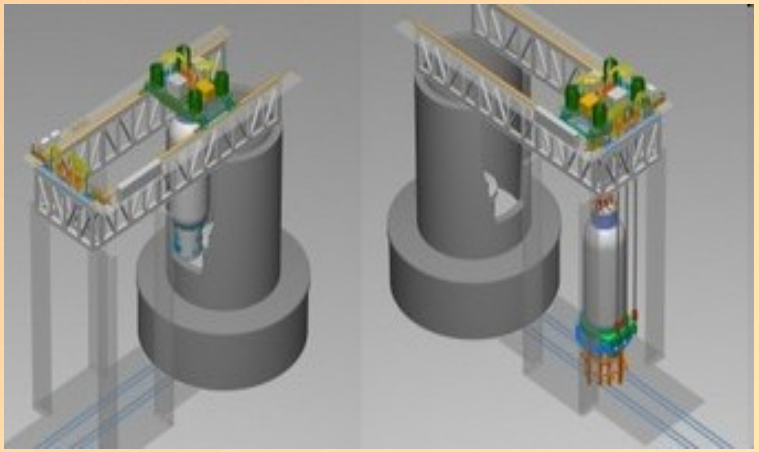
D) Discussion

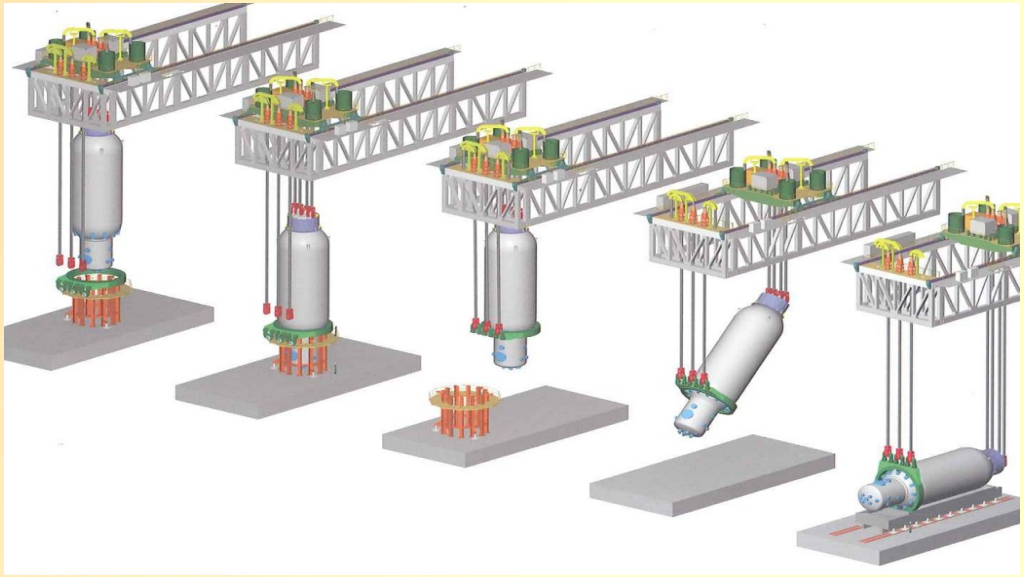
- Development of a reprocessing head end for PBR fuel elements = highly beneficial for future PBR, but not required for disposal of only AVR and THTR fuel elements
- *Why ?*
  - 1 TWh electricity by PBR results in 90 castor containers of spent fuel = unacceptable much, compared with LWR.
    - *Probably one main intention of PBR-supporters in FZJ for their export/reprocessing plans = development to solve waste volume problems for future PBR*
  - Alternative waste handling has not yet been examined
  - Grinding, downgrading and matrix solidification of spent PBR-HEU pebbles at FZJ is probably a more adequate solution for the existing waste, allowing to avoid numerous risky waste shippings and to fulfill EU-request to handle/store NPP nuclear waste in country of origin.

Other PBR waste

I. AVR Juelich

- Complete AVR dismantling (intended to start about 2018) was given up 2003 after 15 years of successless preparation
- Government took over AVR from utilities 2003
- Method for dismantling not yet available (Sr-90, Cs-137....)
- Additional containment (60 m high) since 2006 around the AVR in order to allow further treatment
- Reactor vessel was grouted 2008 with light concrete in order to fix the heavily contaminated fine grain dust
- The whole integrated reactor vessel (2100 tons) will be stored in a separate intermediate storage at FZJ from 2015 for at least 60 years
- Current vessel position is beside its original one, transport to FZJ storage facility intended for late spring 2015
- Problem 1: Radiolytic decomposition of vessel concrete, forming with carbon plenty of methane (C-14, H-3)





- Problem 2: Vessel still contains at least 200 fuel elements (e.g. in cracks of the broken bottom reflector)
- Problem 3: Vessel can never be stored in the MAW final repository „Schacht Konrad“ (300 TBq of long-lived C-14)
- From 2015: Removal of residual facilities on the AVR-site
- Until 2024 (?): Cleaning of soil and groundwater beneath the reactor from Sr-90 (amount uncertain, contamination occurred during severe water ingress accident 1978, as discovered 1999)
  - ✔ Current discussion: Is cleaning up to a depth of 10 m sufficient ? Complete cleaning of the groundwater layer (17 m) requires additional effort of > 100 Mio €
- Costs: Spent since 1988 up to now: 700 Mio € (not including fuel)
- Total AVR decommissioning costs expected: 1.5 – 2.5 bn € (public money)

- „Benefits“ of the selected procedure:
  - allows to finish main AVR-decommissioning process in legal terms 2024:
    - ✔ because the heavily contaminated reactor vessel outside of the AVR site will formally be handled as MAW, no longer as a „reactor“
    - ✔ because the cleaned AVR site can be returned to other use and the reactor can be skipped from official lists of existing reactors
- Safe enclosure on the AVR site with chemical cleaning of the soil/groundwater might have been a technically more suitable solution, but the „AVR-ruin“ would have existed in legal terms for many additional decades

II. THTR-300

- „Safe enclosure“ since 1997 until 2027
- Short operation time and lower operation temperatures than AVR as advantages for decommissioning, but far more broken pebbles
  - Still contains 1.6 kg of fissile material (3000 broken pebbles of 27.000 not yet removed)
- Many details of reactor contamination unkown, but major dust problem as in AVR
- Planning of dismantling intended to start 2017
- Dismantling phase from 2027, duration 20 years (?)
- Costs: no reliable estimates available yet

Resumee

- Several severe unresolved PBR decommissioning problems do not allow PBR to be classified as Generation IV candidate
- Problems with existing German PBR waste urgently require:
  - ✔ development of a long term concept
  - ✔ more engagement e.g. of FZJ in solution of PBR decommissiong (less in waste export and in reactor development)