Spent Fuel Management in the decommissioning process for the AVR and THTR-300 High Temperature Reactors

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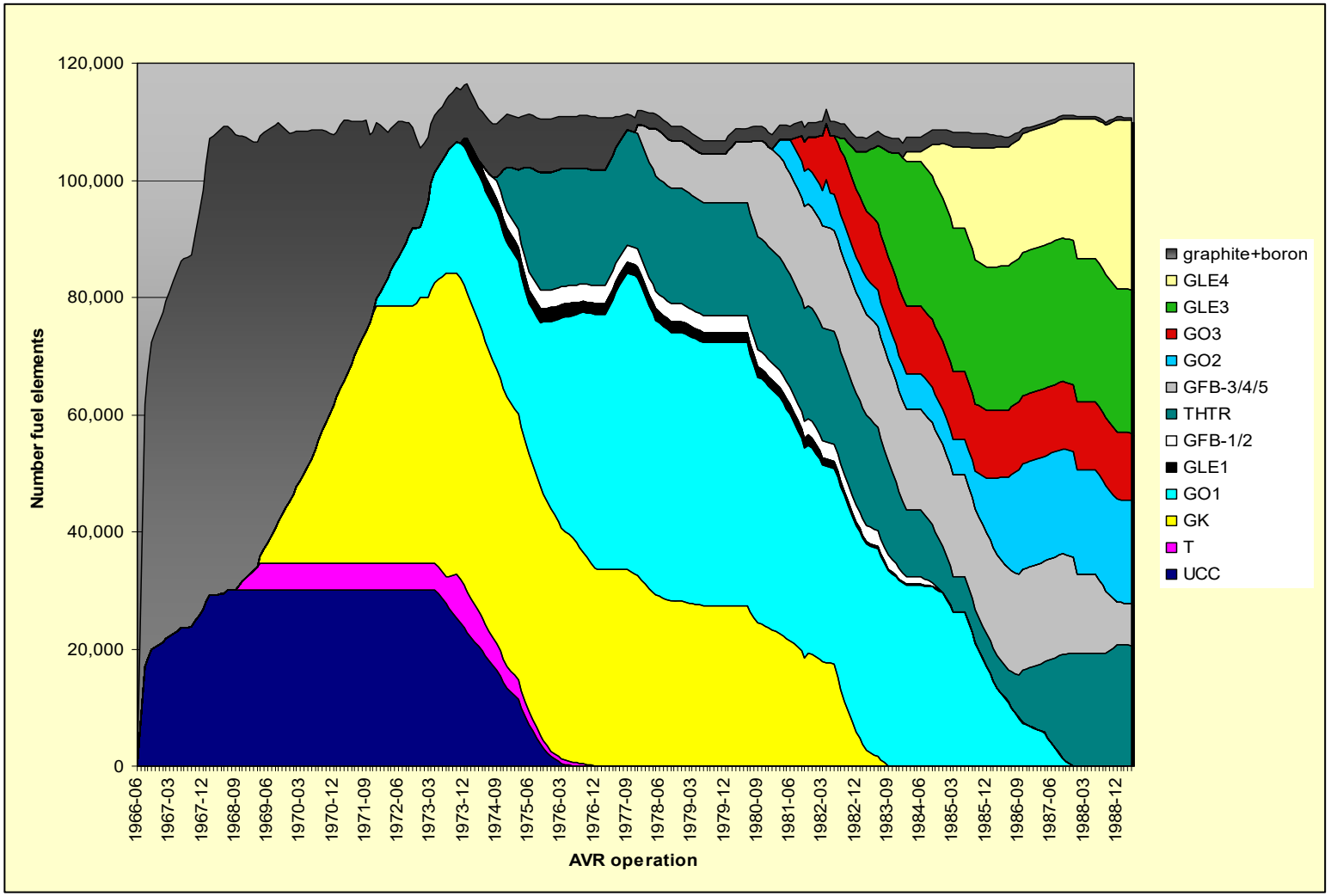
IAEA TM on the Management of Spent Fuel (Pebbles and Compacts) from High Temperature Reactors,
July 7-11, 2025, Vienna

AVR timeline

- 46 MWt, 15 MWe
- Power operation 1967-1988
- License for decommissioning **„Safestore“** in 1994
- Defueling 1994-1998
- Decision to return site to **„Green Field“** in 2003
- Construction material lock (2004-2006)
- License for complete dismantling in 2009
- Removal of RPV in 2015

Fuel composition in the AVR



shell type
pressed type

carbidic
oxidic

HEU thorium
LEU

BISO
TRISO

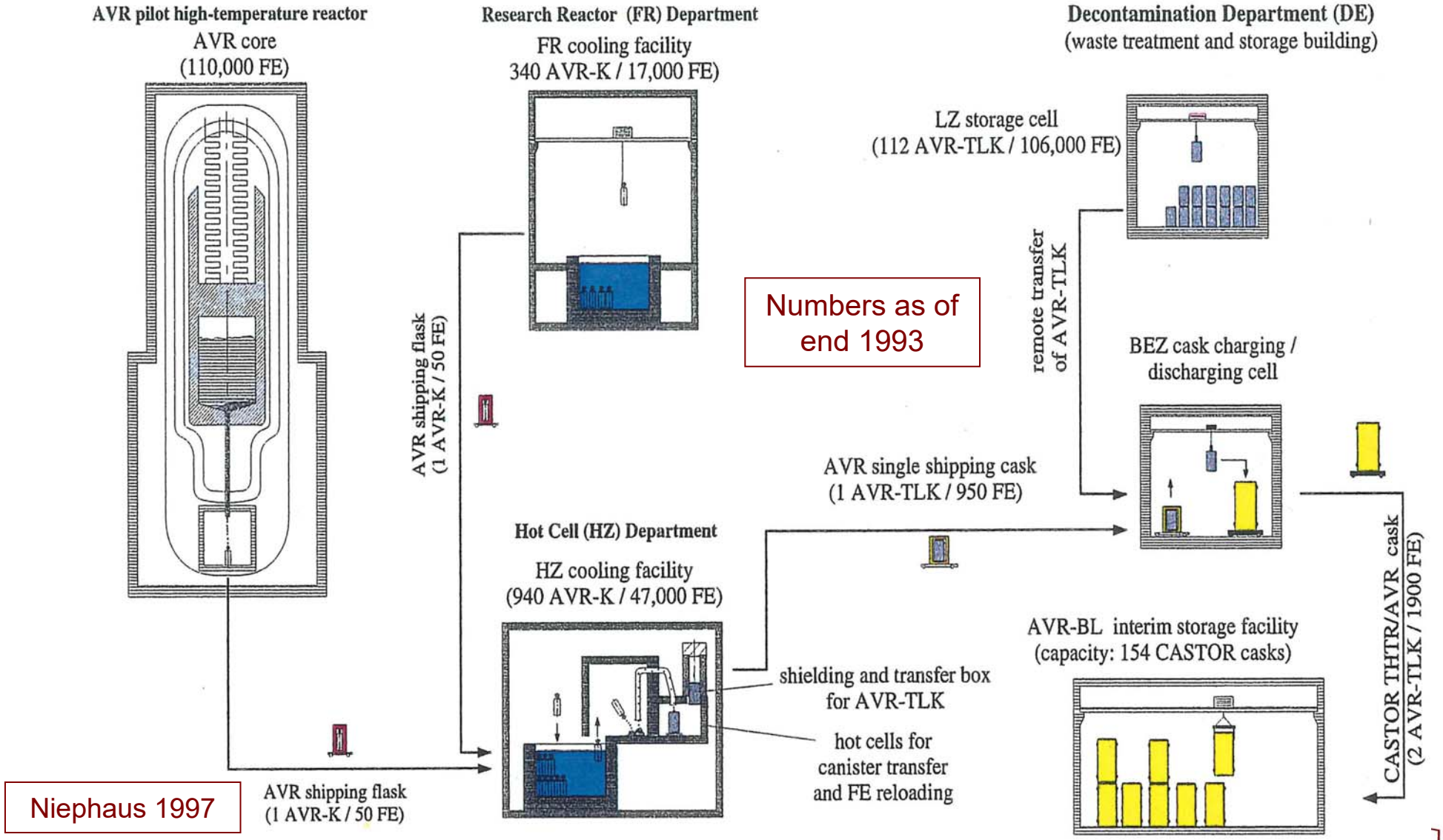
one-cp
two-cp

A3-3 matrix
A3-27 matrix

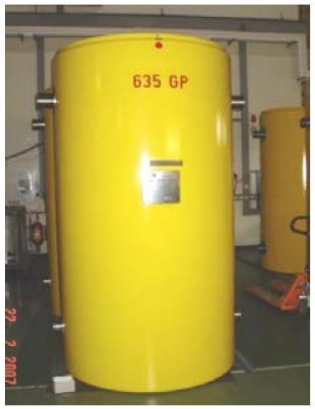
Five classes of AVR fuel

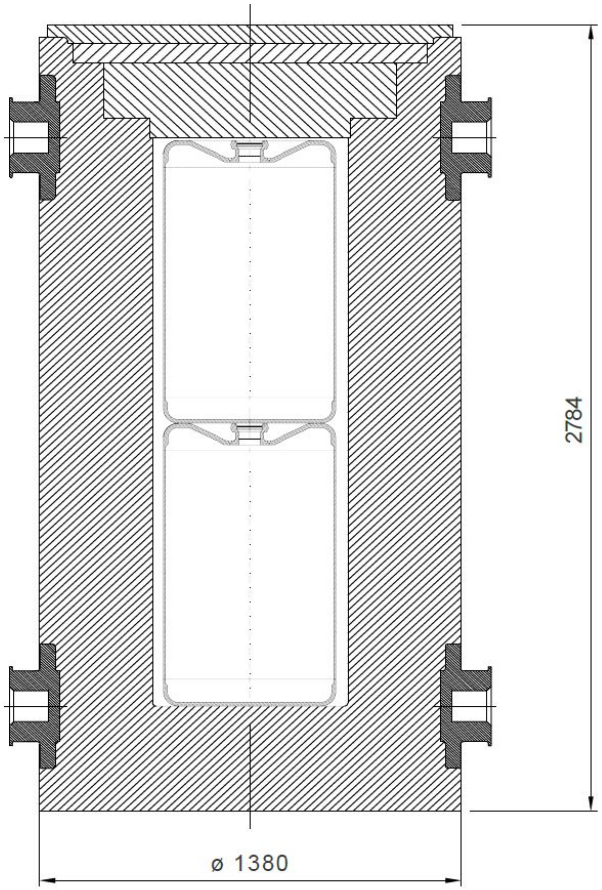
Fuel type	Burnup	Reactor	Charged	Total Fuel [%]
HEU, 5 g Th	14.9 (av)	AVR	196,139	21.6
10 g Th	6.7 (av) 5.0	AVR THTR	38,465 617,606	4.2 68.0
		All HEU	**852,200**	**93.8**
LEU, 7 % enr.	8.0	AVR	2400	0.3
10 % enr.	8.5	AVR	24,611	2.7
16.7 % enr.	8.6 (av)	AVR	29,090	3.2
		All LEU	**56,101**	**6.2**
		All	**908,301**	**100.0**

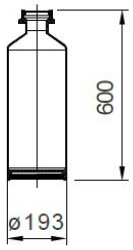
AVR spent fuel management

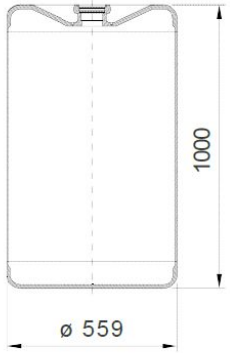


AVR fuel shipping containers









50 AVR-FE	x	19	=	950 AVR-FE	x	2	=	1.900 AVR-FE

Flask **Canister** **CASTOR cask**

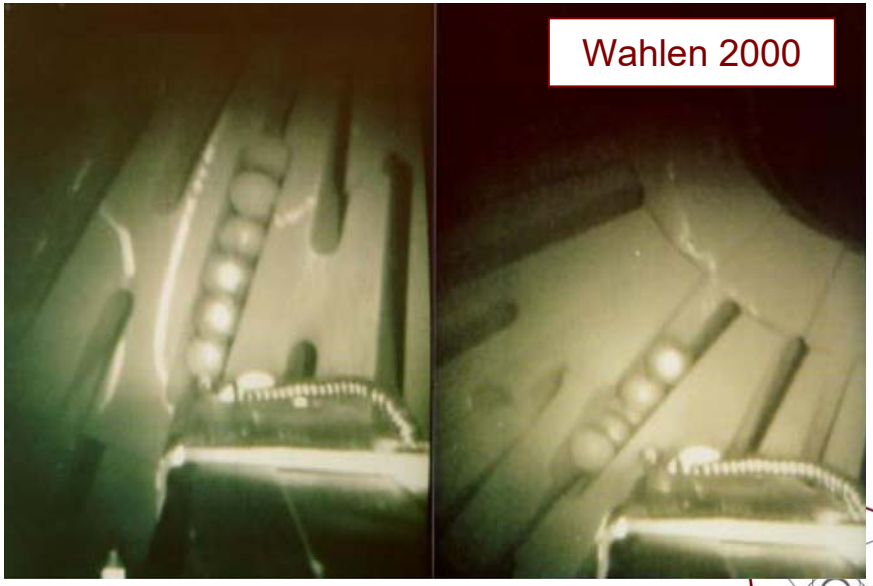
AVR fuel elements (today)

- Total of 152 CASTOR casks in AVR-TL, containing 288,161 fuel spheres with 1.8 t of HM (~75kg of fissile material)
- Total number of fuel spheres inserted into AVR was 290,705
- Difference of 2544 spheres:
  - 197 as broken pieces in core (unretrievable)
  - 62 in FZJ Hot Cells
  - remainder mostly broken spheres or used for (destructive) research, encased as MAW in concrete in 200 l drums
- Also stored residue of 124 absorber spheres

JEN

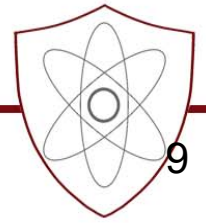
AVR core visual inspection in 1999

- Radial drilling of borehole into cavity
- Also sampling to determine radiological starting position
- Cracks and shifts of bottom reflector blocks
  complete and fragments of spheres stuck inside gaps
- 33 spheres could be made to roll off.
- Residual fuel in core evaluated to be equivalent to < 197 spheres
  containing: 510 g-U, 7 g-Pu, 98 g-fissile material



Graphite and absorber elements

- About 79,550 graphite and absorber spheres employed in AVR
- Most (~70,300) were discharged by 1973
- About 52,500 were stored in Asse in the period 1973-1978, others remained in Jülich
- In Asse, 101 drums of 200 l volume were declared to contain „spheres“ fixed in concrete



Change of competences

- **Licensing Authority (since Jan 1st, 2014)**
  BASE = "Bundesamt für die Sicherheit der nuklearen Entsorgung"
  (Federal Office for the Safety of Nuclear Waste Management)
  responsible for intermediate and final storage and transportation of high level radioactive waste
- **JEN (since Sept 1st, 2015)**
  JEN = “Jülicher Entsorgungsgesellschaft für Nuklearanlagen”
  comprising former AVR and parts of nuclear FZJ
  embedded in EWN company
  (wholly owned by Federal Government)

Status of interim store Jülich

Interim store at Jülich with protective wall against aircraft crash and 24/7 surveillance by two patrol cars

- Started operation in 1993
- License expired in June 2013
- New license to be based on latest safety requirements
  (e.g. new reference earthquake, once per 100,000 yrs)
  owner must prove that ground does not liquefy in such an earthquake, or if liquid, dose will be below allowed limits
- Legal basis since is a directive of the State Government to immediately remove waste from this store
- Statement in 2022 that earthquake would not affect nuclear safety

Options of removing AVR spent fuel as of 2012

- Relocation to the USA
  (return HEU fuel to the country of origin)
- Transport to central interim store in Ahaus
  (where spent THTR fuel is already located)
- New construction of interim storage at Jülich site

All options to be investigated independently with no preference for neither option

(1) Relocation to the USA

- Savannah River National Laboratory (SRNL)
  to receive AVR (+ THTR) spheres,
  (digestion of pebbles, extract fissile fuel from particles, downblending to LEU)
- Letter of Intent signed in April 2014
- Environmental assessment successfully conducted by 2016
- **Option deleted in 2022 in consultation with Government**
  (too cost-extensive, processing technologies not mature yet)

(2) Transport to central interim store Ahaus

- License for storage in Ahaus granted in July 2016
- License for transport still pending
  (Transportation not allowed by German law, but exceptions possible)
- Central interim store Ahaus was refurbished to meet new safety requirements
  (10 m high wall against airplane crash, kerosine drain)
- CASTOR casks meet license by design against 3g in all directions
- Federal ministries judge option as „principally preferable“

(3) Construction of new interim store

- Must meet latest safety requirements
  (prove of design against theoretically conceivable extreme earthquake "once per 100,000 yrs")
- Will be by far most expensive solution and take longest time
- Site for the new build has been identified
  (adjacent to AVR site)
- Environmental assessment successfully conducted
- Option would be dropped as soon as license for transport to Ahaus be granted

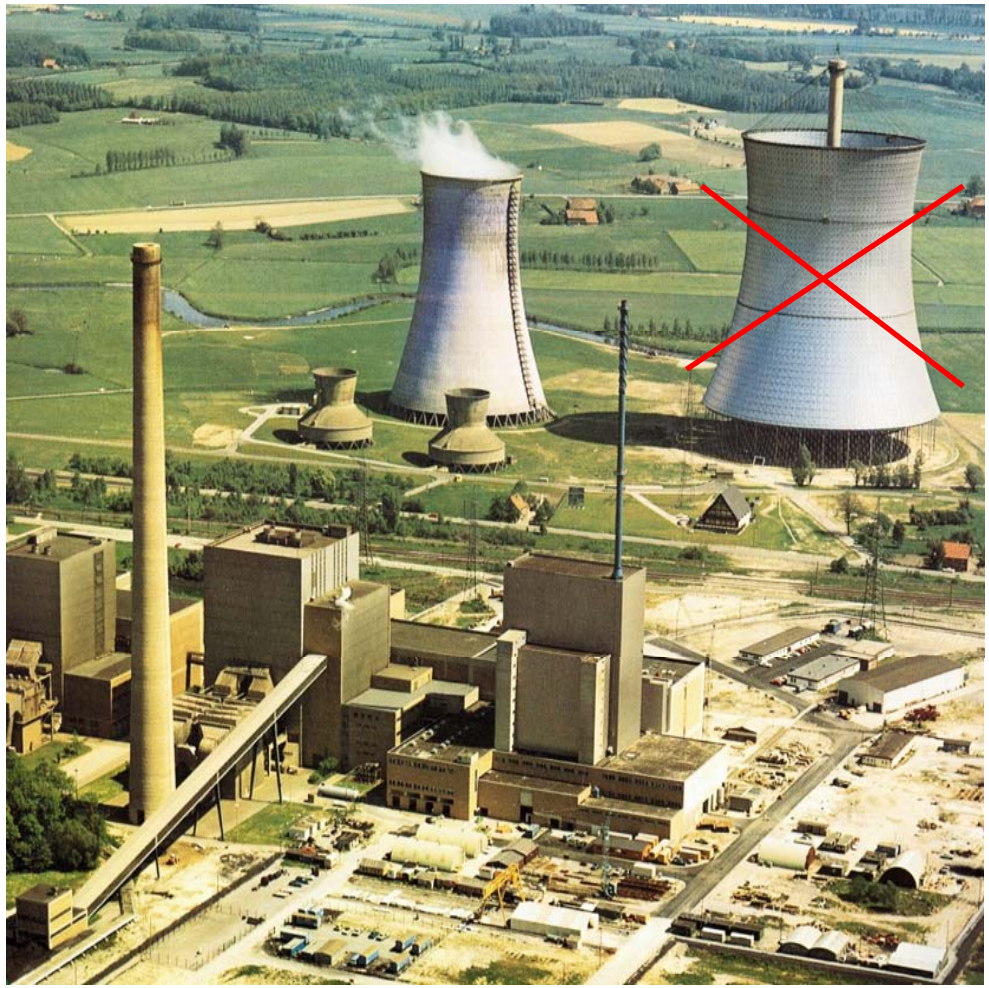
Issue still to be considered

- In 2033, CASTOR casks will be 40 yrs old.
  (40 years was the initially foreseen storage duration)

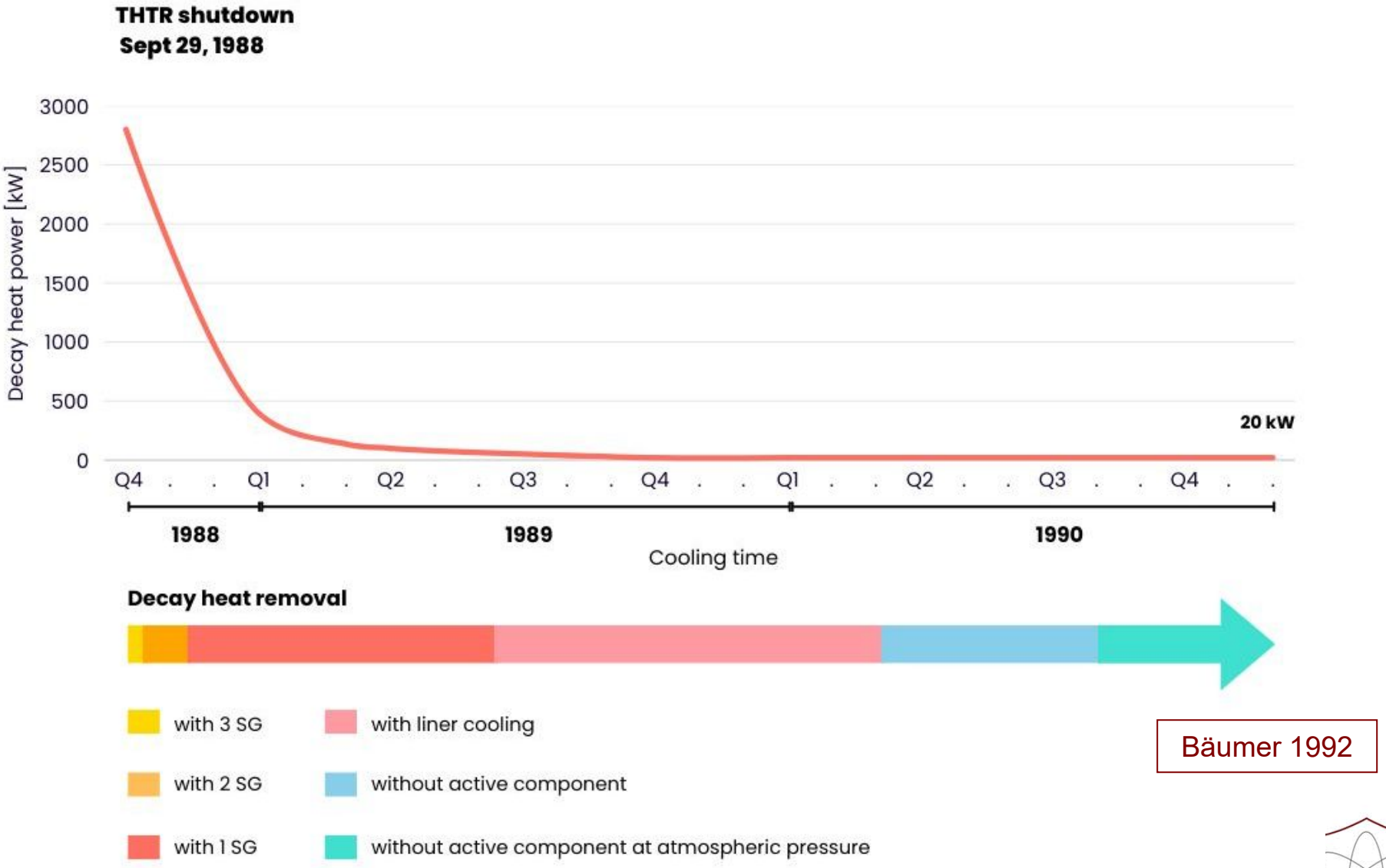
- In 2036, the operation license for the interim store Ahaus will expire. What is needed for a license renewal is still open.

THTR-300

- 750 MWt, 300 MWe
- Operation 1985-1989
  only 423 efpd
- Start of „Safestore“
  decommissioning in 1989
- Explosive dismantling
  of cooling tower in 1991
- License granted for
  core unloading in 1993
- „Safestore“ status since 1997



Decay heat power after shutdown

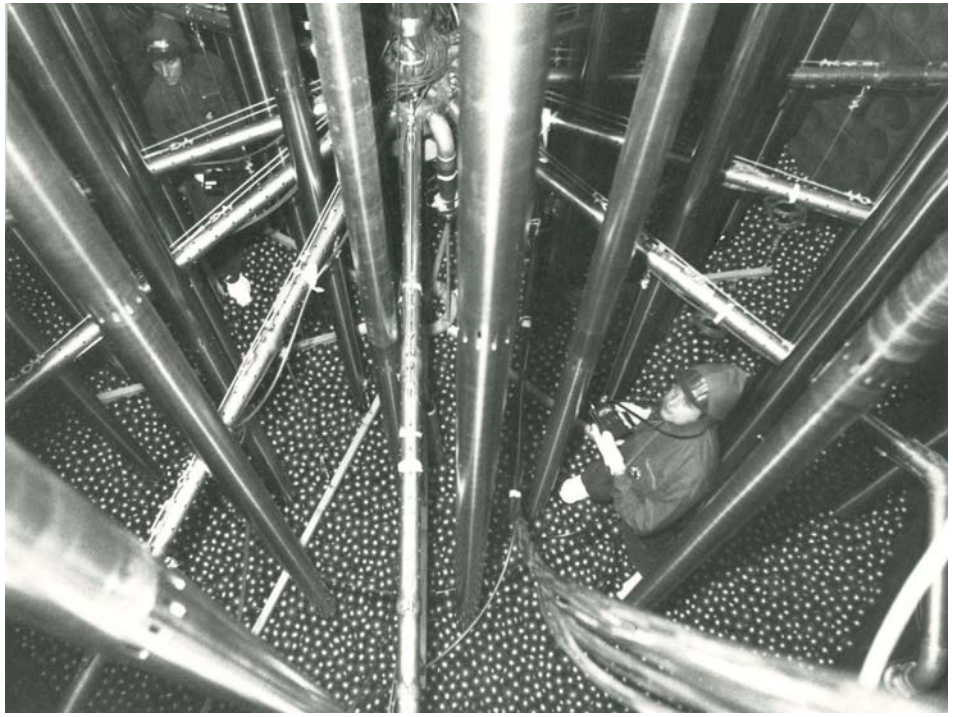


Bäumer 1992

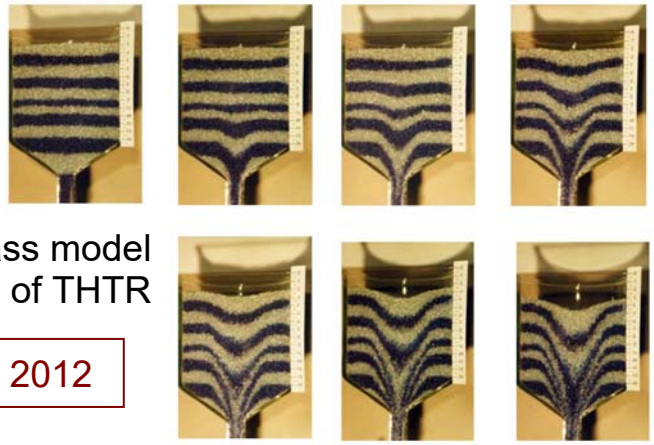
Decommissioning phases in more detail

Phase 2: Defueling

- License for fuel unloading (granted after 4 yrs)
- Tests conducted to examine
  - pebble flow in glass model
  - control rod bending
- Core inspection
- Decommissioning of burnup measurement reactor

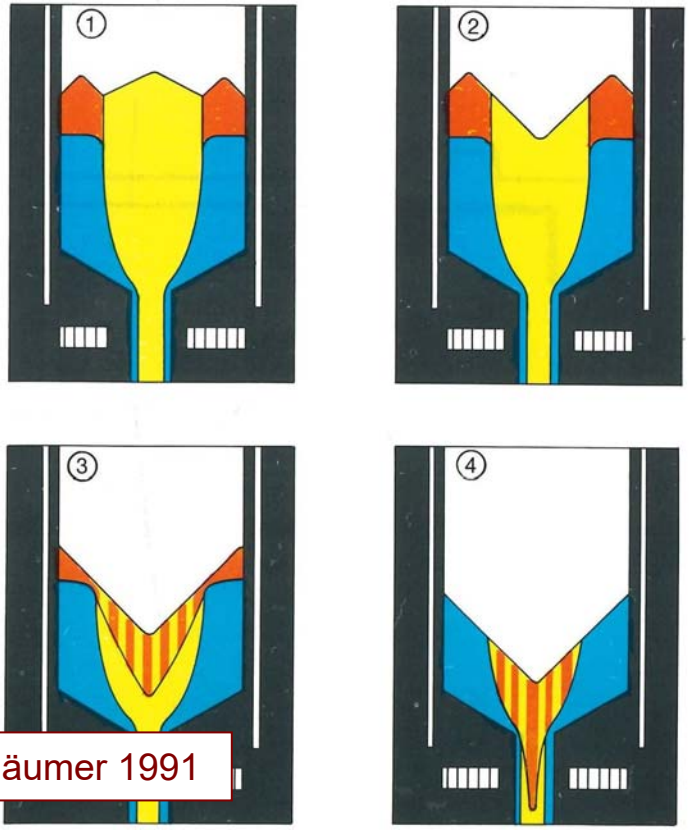


THTR fuel discharging



1:40 glass model of THTR

Kalinowski 2012



Bäumer 1991

- Sequence of removal of certain sections of pebble bed
- First phase spheres from center part
- Minimum burnup spheres from surface outer region with low neutron fluence (fresh fuel)
- Maximum toward the end from bottom outer region with high fluence
- Maximum average burnup in cask 8.8% FIMA

THTR fuel discharging

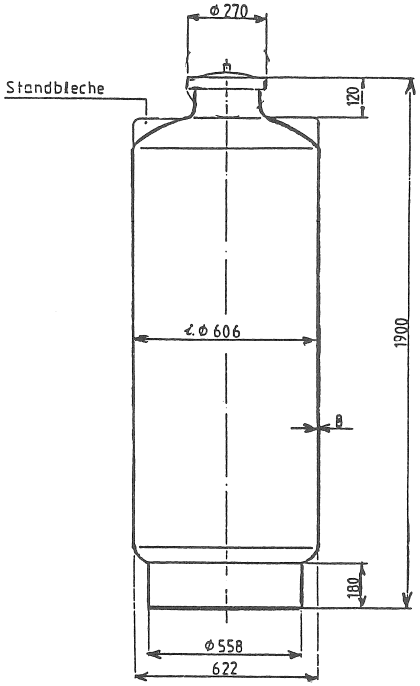
- Requirement: maintaining k_{eff} reactivity below 0.95
- Predictive reactivity calculations with 3D-model (FZJ)
  differed from 2D-calculations;
  to be on the safe side, suggestion to add 7000 absorber spheres;
  4200 absorber spheres were eventually added
- Bending of control rods was considered no issue,
  as it was concluded from a test that only a
  1.5 m bending would lead to irreversible damage

THTR spent fuel management – as done

- Defueling starting Dec. 1993, completed Oct. 1994
  Residual fissile material in core:
  0.976 kg (equ. ~2200 fuel spheres), required < 2.5 kg
- Operating elements sorted and transferred to
  steel canisters of 2100 spheres capacity
- Selection efficiency of operating elements: 97%,
  i.e. 3% of ~344,000 graphite and absorber spheres
  gone into fuel canisters
- 10 scrap containers filled during reactor operation,
  4 more filled during unloading process
- 500 W AMR and its 767 strip-shaped U-Al alloy FE with 3.9 kg-U in two more CASTOR casks
- Fuel canisters to be stored for 1-2 yrs cooling time in
  on-site intermediate store

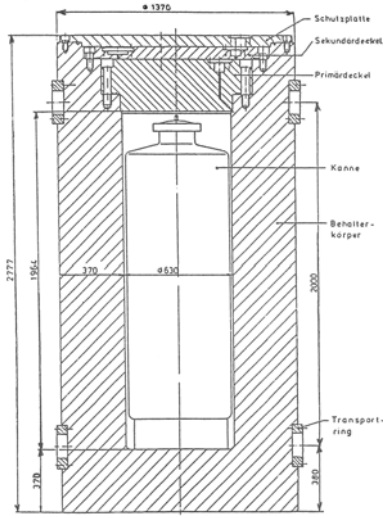
THTR on-site intermediate store

- Total capacity:
  216 canisters on 72 positions
  plus 9 more for high active waste
- Licensed in 1982
- Commissioned in 1984
- Received first fuel in 1988
- Thermal power of 232 kW,
  active air cooling system
- Shielding with concrete walls
  of 1.9 m thickness
- Protected against external events
- Minimum cooling time 1-2 years
- Repackaged into CASTOR casks
  (one canister/cask)



Contents 2100 FE
(1 canister per 4.2 days of operation @ 80% power)
Made of normal steel
Weight: 0.35 t

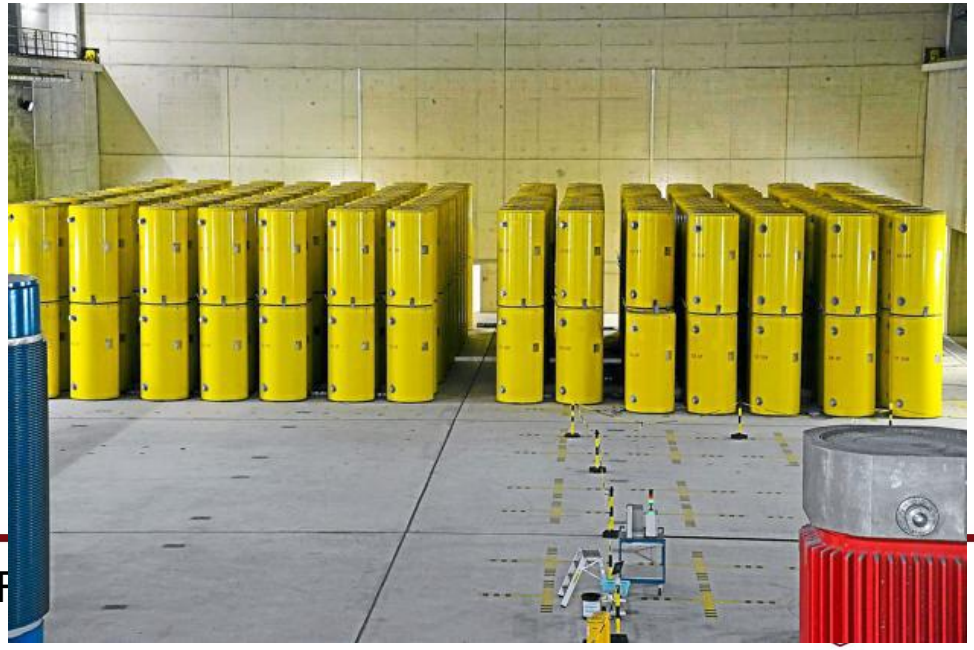
THTR spent fuel cask



Made of spheroidal cast iron
Weight: 26 t
Leak tightness of primary lid: < 10^{-8} Pa m^3/s
Neutron dose rate at filled cask: < 1 µSv/h

305 CASTOR casks at
central intermediate store
BZL Ahaus by April 1995

6-axle railcars
each to carry 3 CASTOR casks,
two railcars per shipment to Ahaus



THTR Safestore

- The safely enclosed section of THTR includes
  - 134 canisters with graphite spheres
  - 25 canisters with absorber spheres
  (total graphite mass: 62,740 kg)
  - 4558 kg of graphite blocks from AMR
- Small part of still available fresh THTR fuel spheres (= 15,248) inserted in AVR
- Main part (= 362,348) reprocessed in Dounreay, with the fissile and fertile material sent back to NUKEM

Summary(1)

- **AVR: “Green Field” decommissioning**
  - reactor vessel in interim store at Jülich
  - fuel in 152 CASTOR casks in interim store at Jülich (AVR-TL)
  - license expired in 2013, therefore fuel must be removed (options: central interim store Ahaus, new build)
- **THTR: “Safestore” decommissioning**
  - since 1997 in state
  - fuel in central interim store Ahaus (license will expire in 2036)

Summary(2)

HTR spent fuel legacy in Germany

	AVR	THTR	Total
# Casks	152	303[(a)]	455
# Fuel spheres	288,200	628,053	916,253
Fuel type	BISO and TRISO	BISO	BISO and TRISO
Total Uranium (g)	547,819	420317	968,136
U-235 (g)	59,443	233,706	293,149
U-233 (g)	25,173	78,886	104,058
Fraction U-235+U-233 (%)	15.4	74.4	41.0
Thorium (g)	1,288,508	6,172,679	7,461,188
Plutonium (g)	6,047	1,034	7,081

(a) Excluding the two CASTOR casks that contain the burnup measurement reactor.