FRM II: Results and experience of the major maintenance shutdown after ten years of operation

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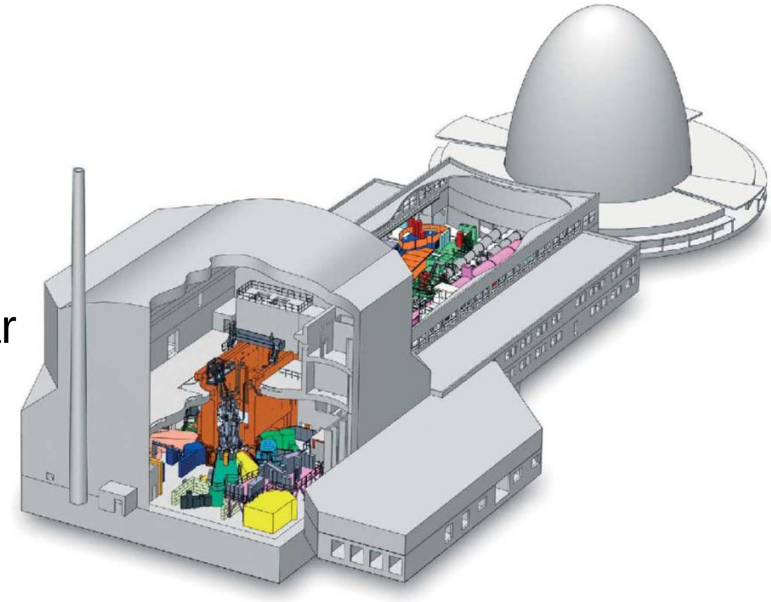
The FRM II



- Pool type reactor
- P = 20 MW, typical 4 cycles à 60 d per year
- Heavy water moderator
- First criticality March 2nd, 2004
- User facility
- 12 beam tubes
- Irradiation facility, medical treatment, isotope production

- Annually about 1800 scheduled tests
- Special test program required by law
  10 years after first criticality
- (fundamental safety review required 10 years
  after startup of routine operation, "PSÜ")

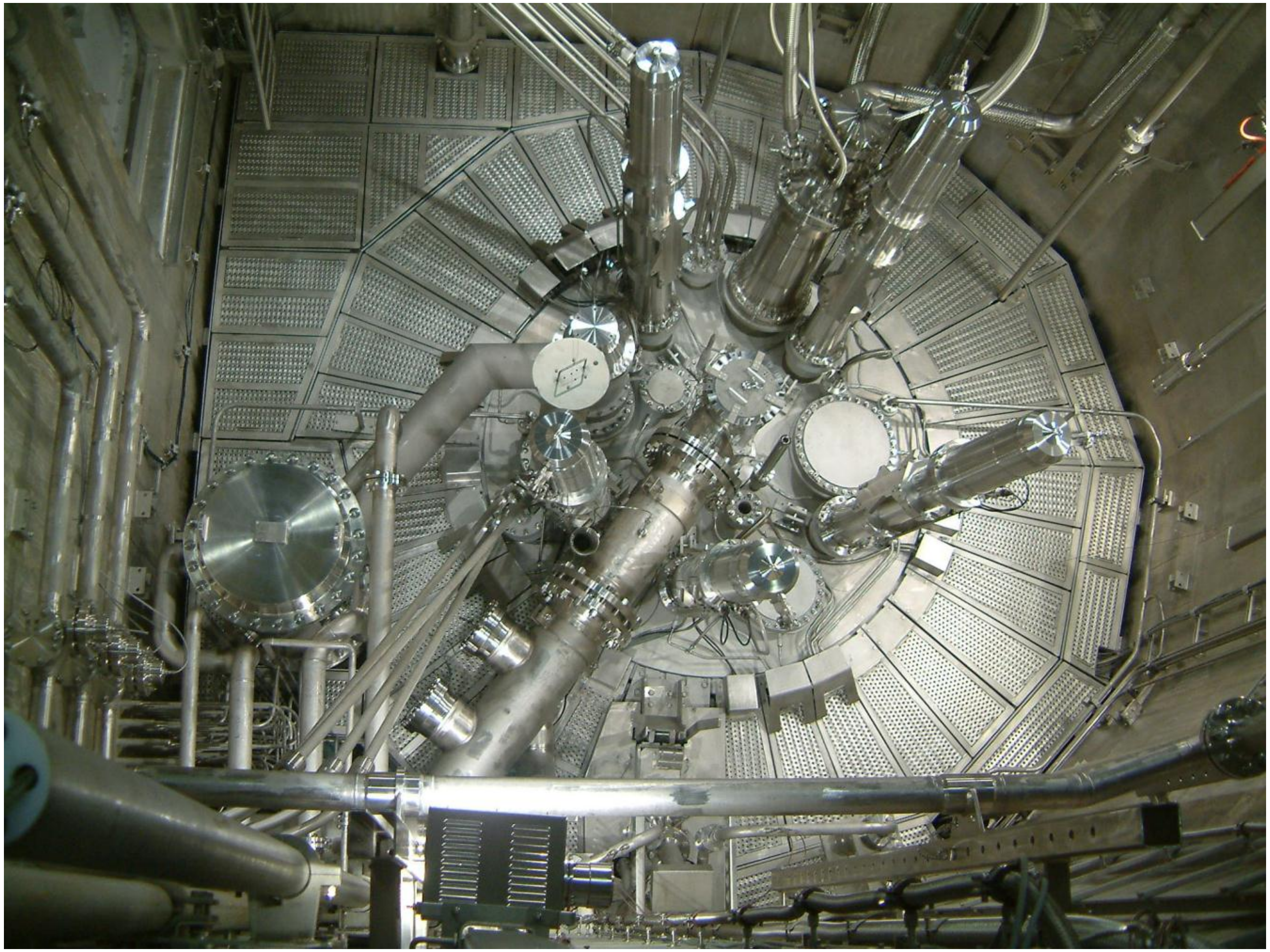
Test Program 10 Years After First Criticality

- Visual inspection and pressure tests of
  - Central channel
  - Moderator tank
  - Beam tubes
  - Hot source
  - Cold source

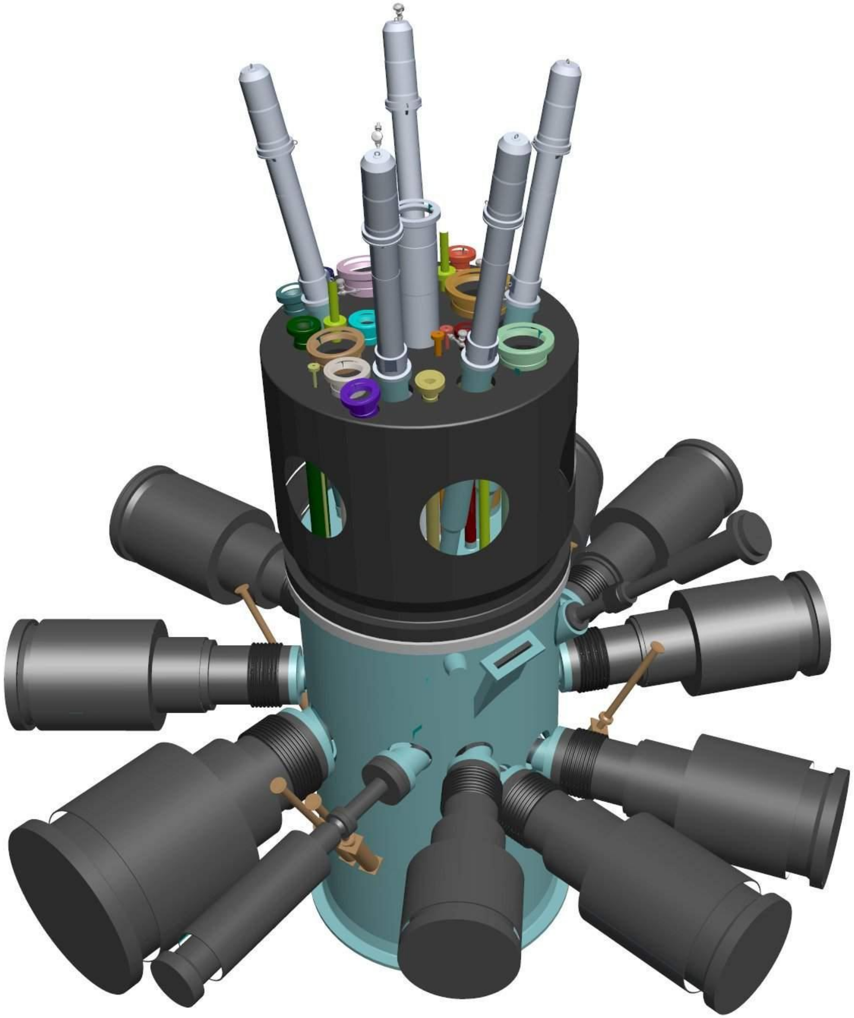
- Inspection of conventional pressure vessels
- Additional inspections, checks, overhauls

- In many cases: precise definition of test procedure was (re-)started from scratch in discussion with expert organization and lizensing authority
- Unconventional setup requires unorthodox procedures (accessibility, radiology, set of rules to be applied)

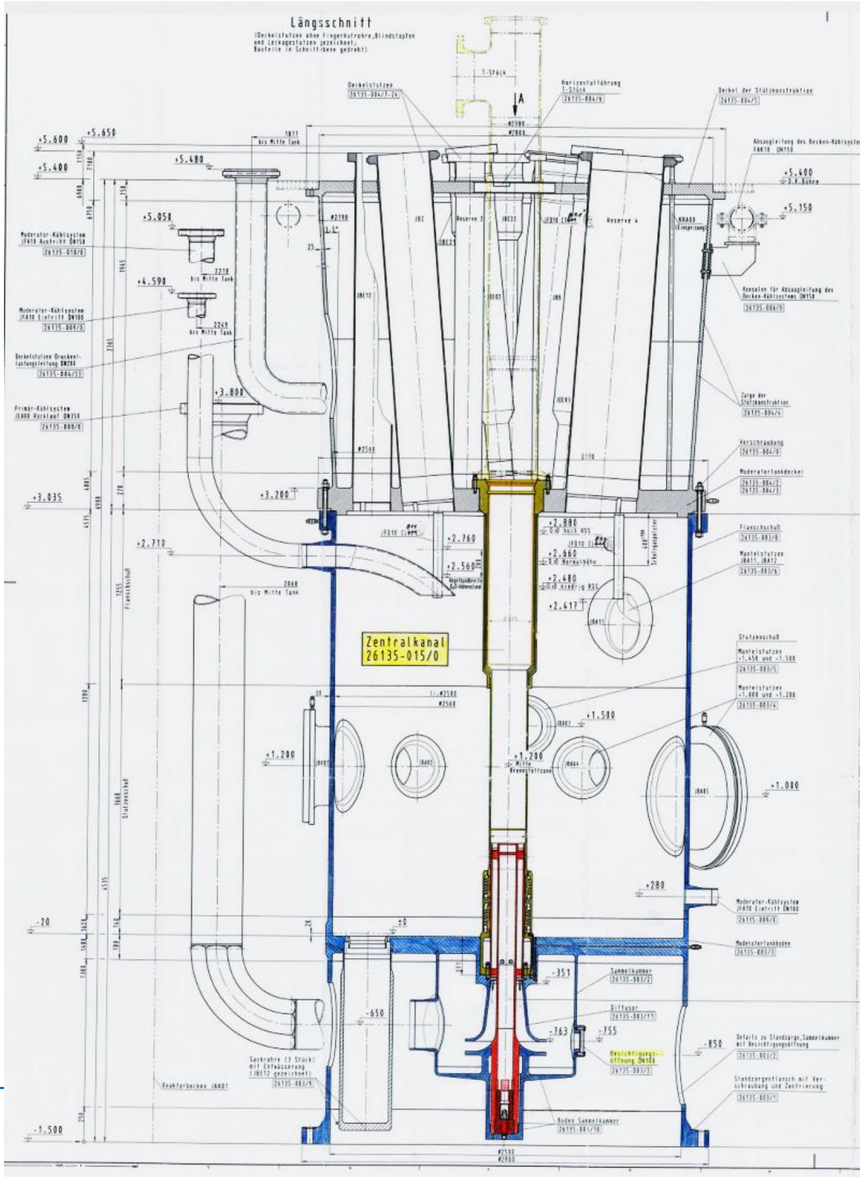
View Into the Empty Reactor Pool



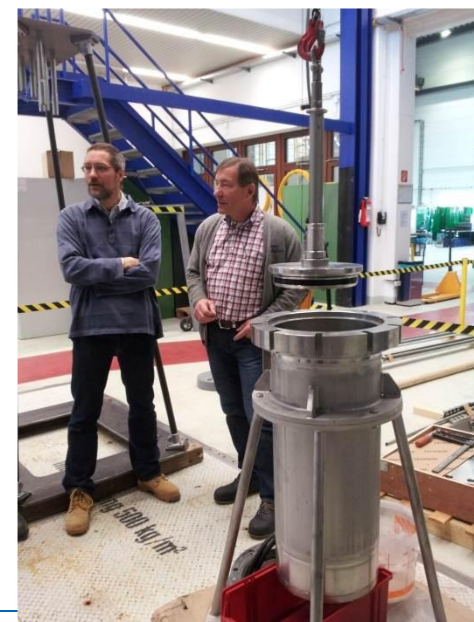
Overview: Moderator Tank and Adjacent Systems



The Central Channel

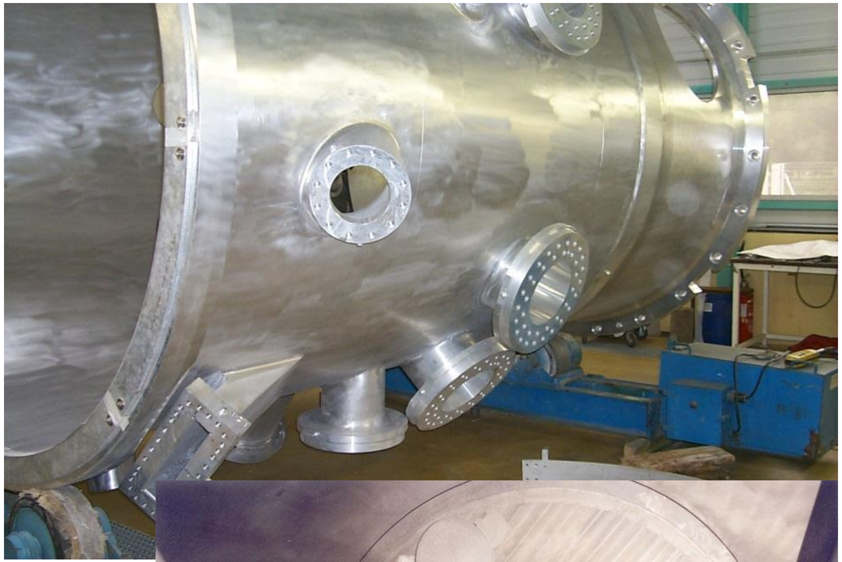


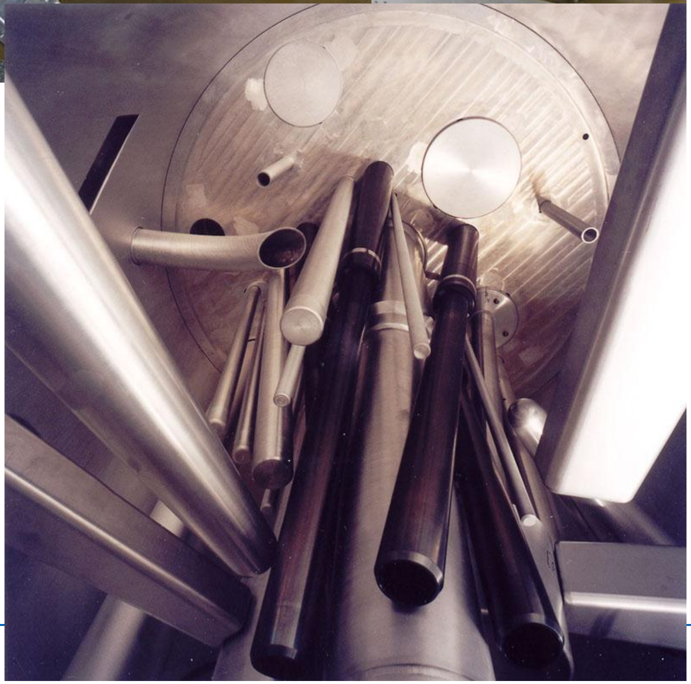
- Part of primary circuit
- Houses fuel element
- P_N = 16 bar (upper part)
- Open to pool (downstream from fuel element)



Moderator Tank

- Diameter 2500 mm
- Height 3350 mm
- Material: AlMg3 EN AW-6754
- Design pressure P_N = 2.2 bar
- Design temperature T_N = 80 °C
- Medium: D_2O
- For testing filled with H_2O
- Combined gas/water pressure test under water at $1.1 \times P_N$
- Visual inspection

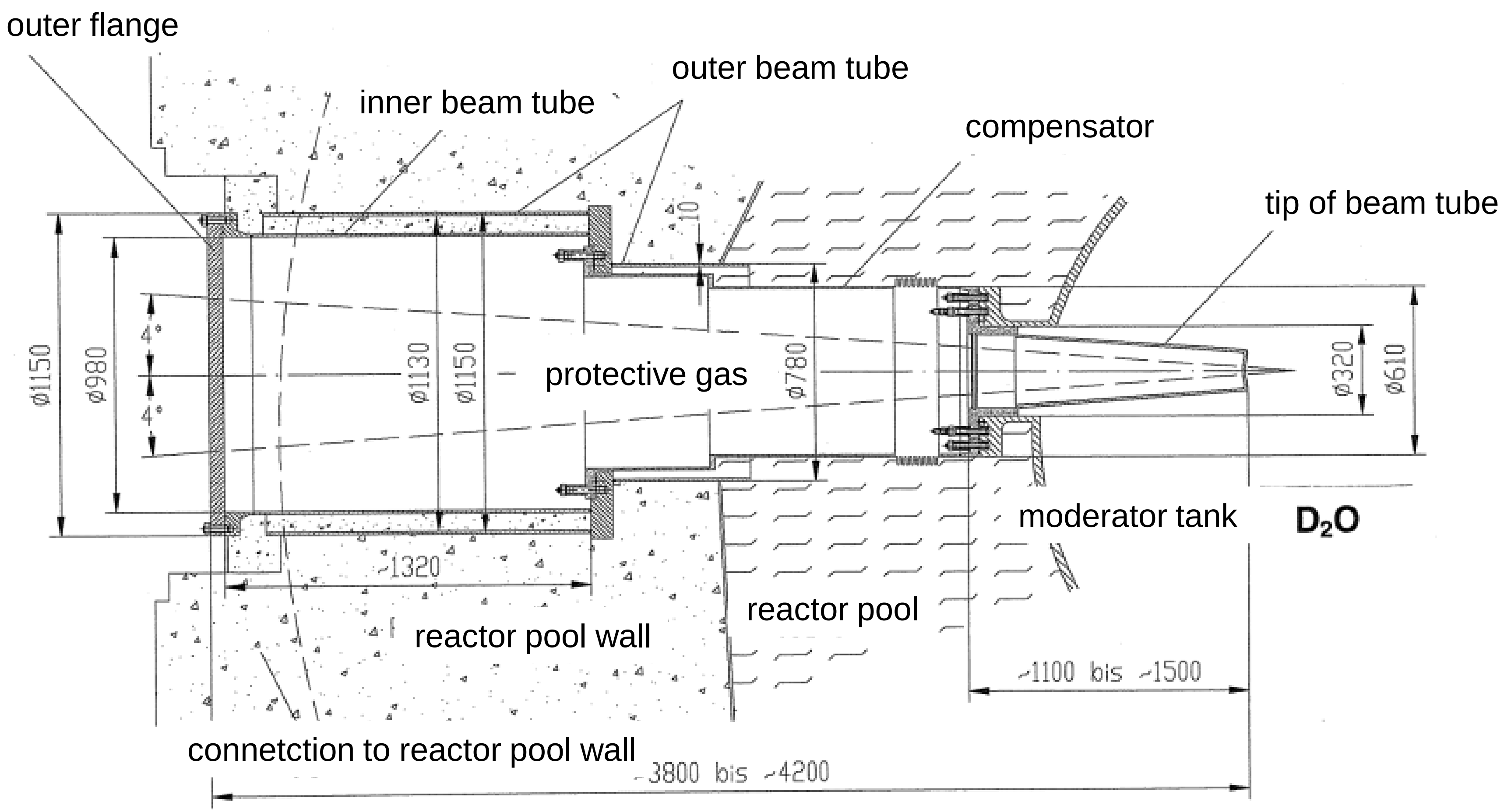




Beam Tubes

- 10 horizontal, 1 inclined, 1 spare
- Visual outer inspection
- Visual inner inspection waved due to complete operational data on pressure, temperature, gas quality.

Beam Tubes


outer flange
inner beam tube
outer beam tube
compensator
tip of beam tube
protective gas
moderator tank
D_2O
reactor pool
reactor pool wall
connetction to reactor pool wall
Ø1150
Ø980
Ø1130
Ø1150
Ø780
Ø320
Ø610
4°
4°
10
~1320
~1100 bis ~1500
~3800 bis ~4200

Beam Tubes

Hot and Cold Sources

Cold Source

- T = 25 K
- Moderator: 4.3 kg of D_2
- Material: Zircaloy
- Tests of tightness and outer visual inspection
- Check of operational data

Hot Source

- T ≈ 2000 K
- Moderator: Graphite
- Material: Zircaloy
- Tightness/pressure test
- Outer visual inspection

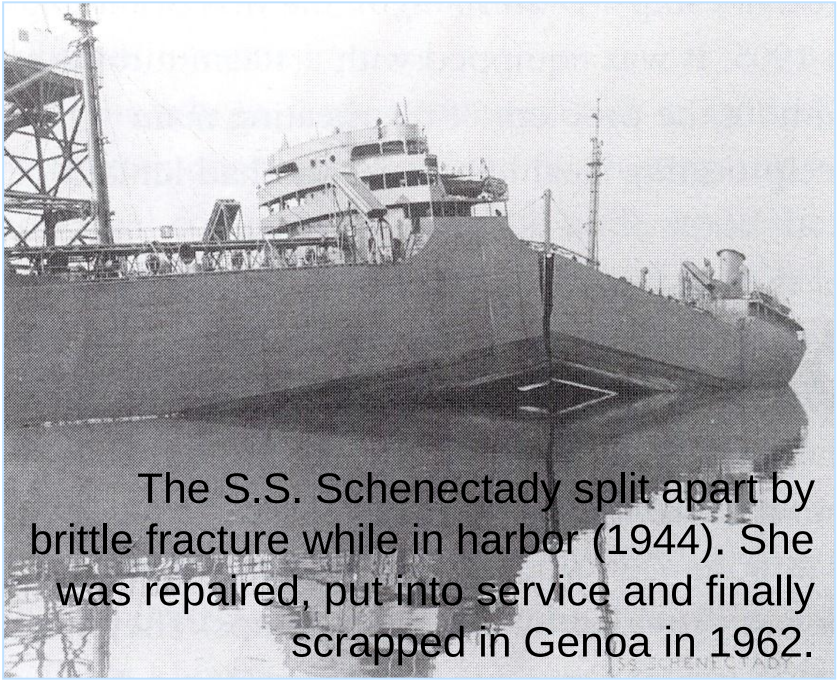
Selected Additional Tests and Inspections

- Inspection of JBE46, future ^{99}Mo production facility
- Inspection of spare flanges
- Inspection of control rod
- Inspection of shut-down rod drives
- General inspection of cell coolers
- Pressure tests and visual inspection of parts of the heavy- and light-water-system

View into one of the four cell coolers, stripped of most of its inner components

PLEASE ASK FOR DETAILS !

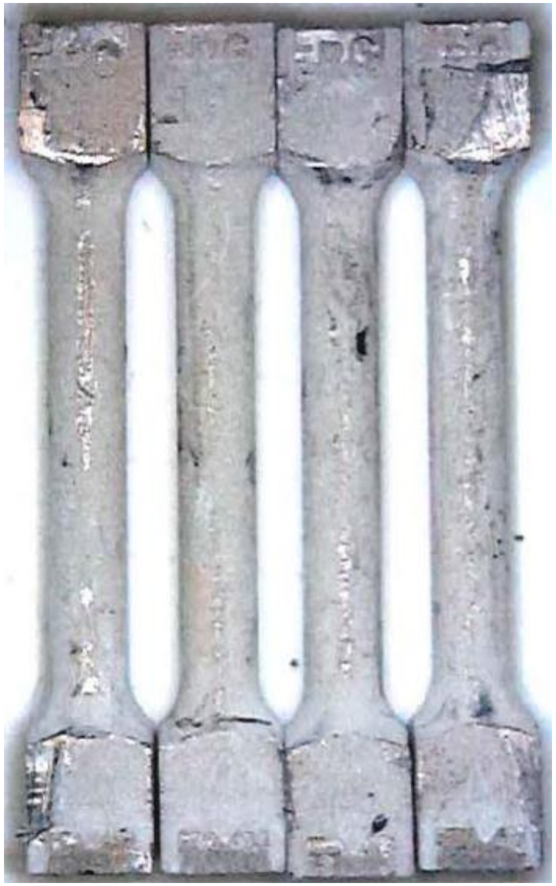
Ageing and Fracture Mechanics

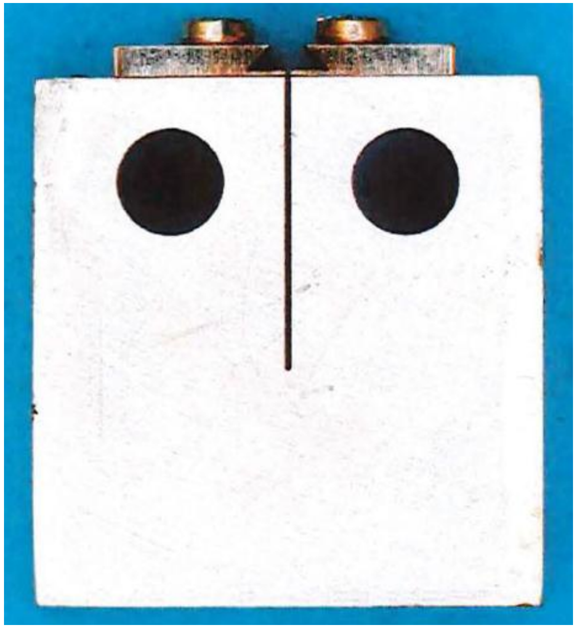


The S.S. Schenectady split apart by brittle fracture while in harbor (1944). She was repaired, put into service and finally scrapped in Genoa in 1962.

- Material undergoes transformation of its mechanical properties under neutron irradiation.
- In the case of the FRM II the components subject to the highest neutron flux are made from EN AW-6754 (AlMg3).
- Loss of ductility and increased hardness occurs due to Silicon formation through capture of thermal neutrons.
- Initial criterion of minimum ductility 5 MPa$\sqrt{m}$ was reached after thermal neutron fluence of 2.5E22 n/cm^2.
- New „modern“ criterion: define maximum undeteced fracture and calculate its growth. Compare properties of fractured material to required properties.

Irradiated Samples for Fracture Mechanics Tests (DIN EN ISO 6892-1)

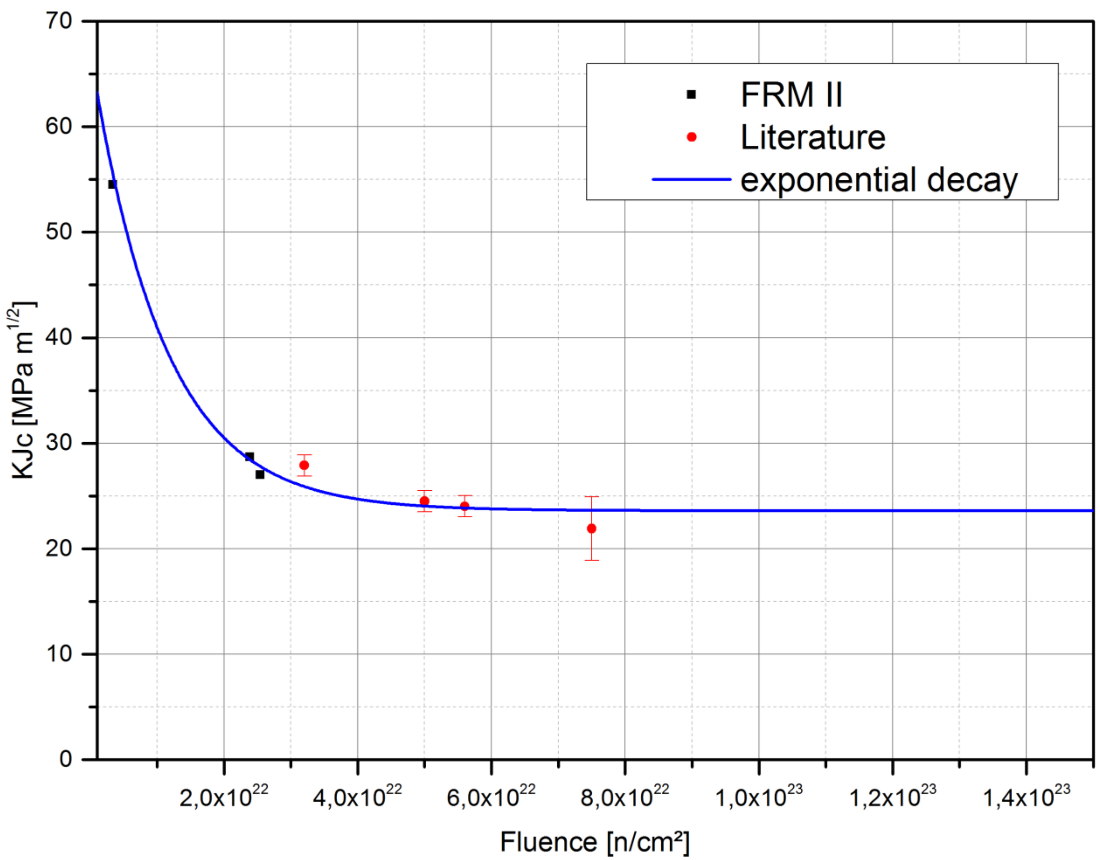


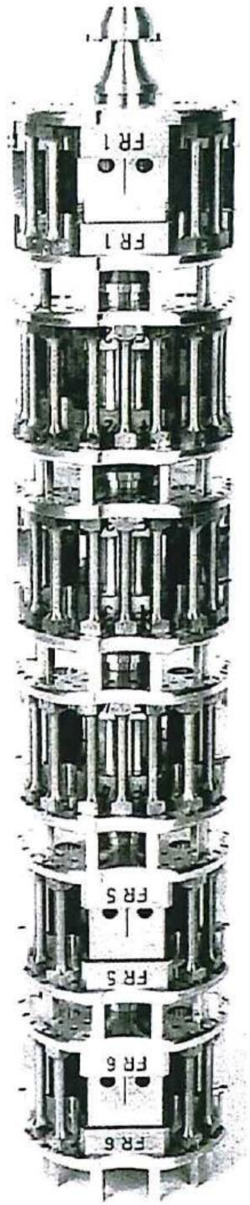


Compact tension specimen for fracture toughness testing (Aluminum) after irradiation and preparation for testing

Tensile specimens made from Aluminum after irradiation.

Fracture data as function of neutron fluence





Stack of specimen for fracture toughness testing
as mounted in the FRM II moderator tank

Fracture mechanics calculations and experiments – conclusion

- At the FRM II a material testing program for AlMg3 is in place.
- Experimentally the actual material data could be measured as function of irradiation. This program is still ongoing.
- Using calculations and these data it could be proven that the original concept of minimum ductility was over-conservative.
- The lifetime of the components under the heaviest neutron flux could be extended, thus increasing availabilty and while also avoiding radioactive waste.

Overall Conclusion

- Ten years after first criticality, the tests required by law have been successfully carried out.
- Using a combination of experiment and calculations the permissable lifetime of the components made of AlMg3 close to the reactor core could be significantly expanded.

Thank you for bearing with me

"While you were napping at your desk, we drained all of your blood and replaced it with coffee."