Phenomena in the operation history of the AVR experimental reactor

by Lothar Hahn

Presentation at the NURIS conference

April 16-17,2015 / Vienna

Phenomena in the operation history of the AVR experimental reactor

Content

1. Introduction
2. Description of the AVR
3. Specific features of the AVR and its operation
4. Temperatures in the primary circuit
5. Primary circuit contamination
6. Possible causes for the excessive core temperatures
7. Possible causes for the increased fission product release into the primary circuit
8. Uncertainties and unresolved safety issues
9. Concluding remarks

Phenomena in the operation history of the AVR experimental reactor

1. Introduction

- **AVR GmbH = Arbeitsgemeinschaft Versuchsreaktor GmbH, (Association Research Reactor Limited), founded 1959**
- **AVR = High temperature experimental reactor**
- **Construction start: 1961**
- **first criticality: 1966**
- **grid connection: 1967**
- **commercial operation: 1967**
- **shut down: 31.12.1988**

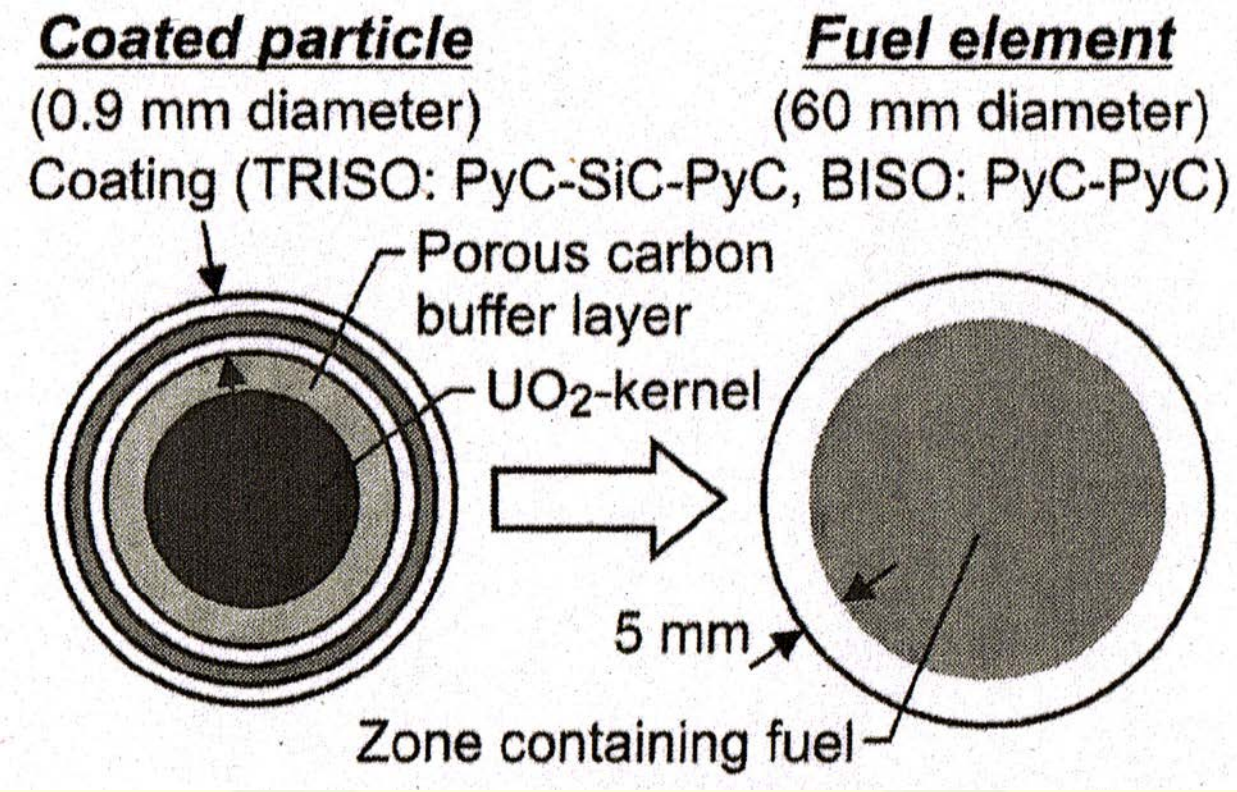
Phenomena in the operation history of the AVR experimental reactor

2. Description of AVR

- use of noble gas helium as coolant
- uranium-235 and thorium-232 as fuel material
- spherical fuel elements
- graphite as moderator material
- extremely high, previously unattainable coolant temperatures
- pebble bed with 100 000 spherical fuel elements
- each fuel element contained 10 000 to 40 000 coated fuel particles
- fuel elements supplied from above and removed in the base
- cooling gas through the pebble bed from bottom to top
- steam generator above the core
- secondary steam/water circuit with turbine driving the generator

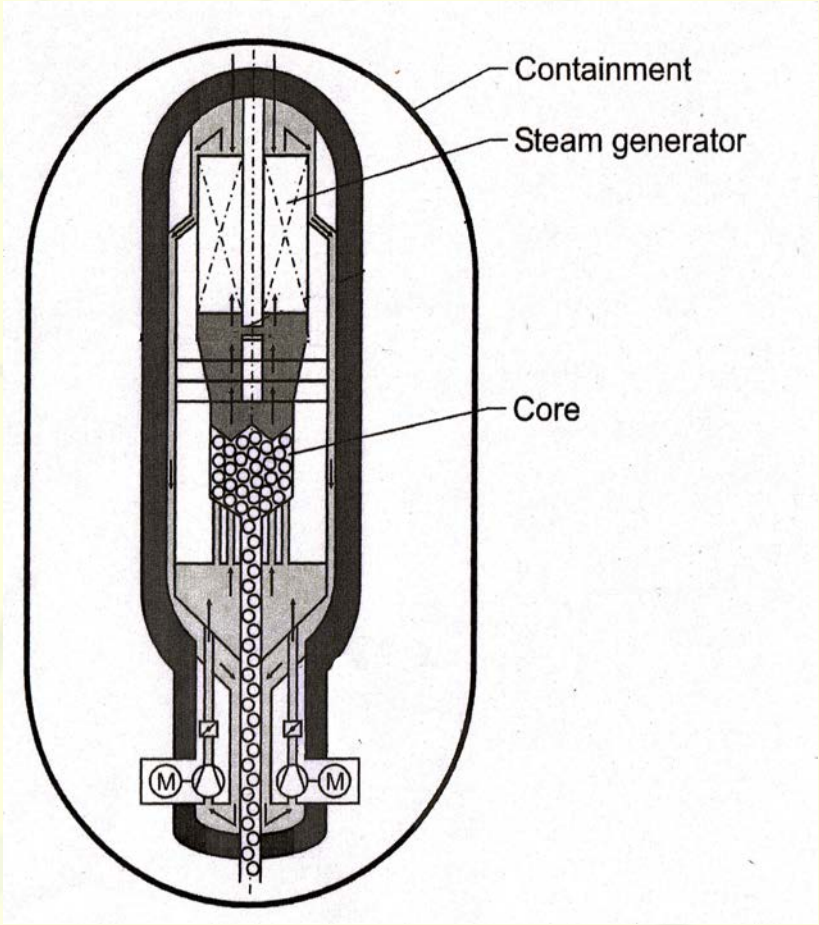
Phenomena in the operation history of the AVR experimental reactor

Figure 1: AVR fuel elements



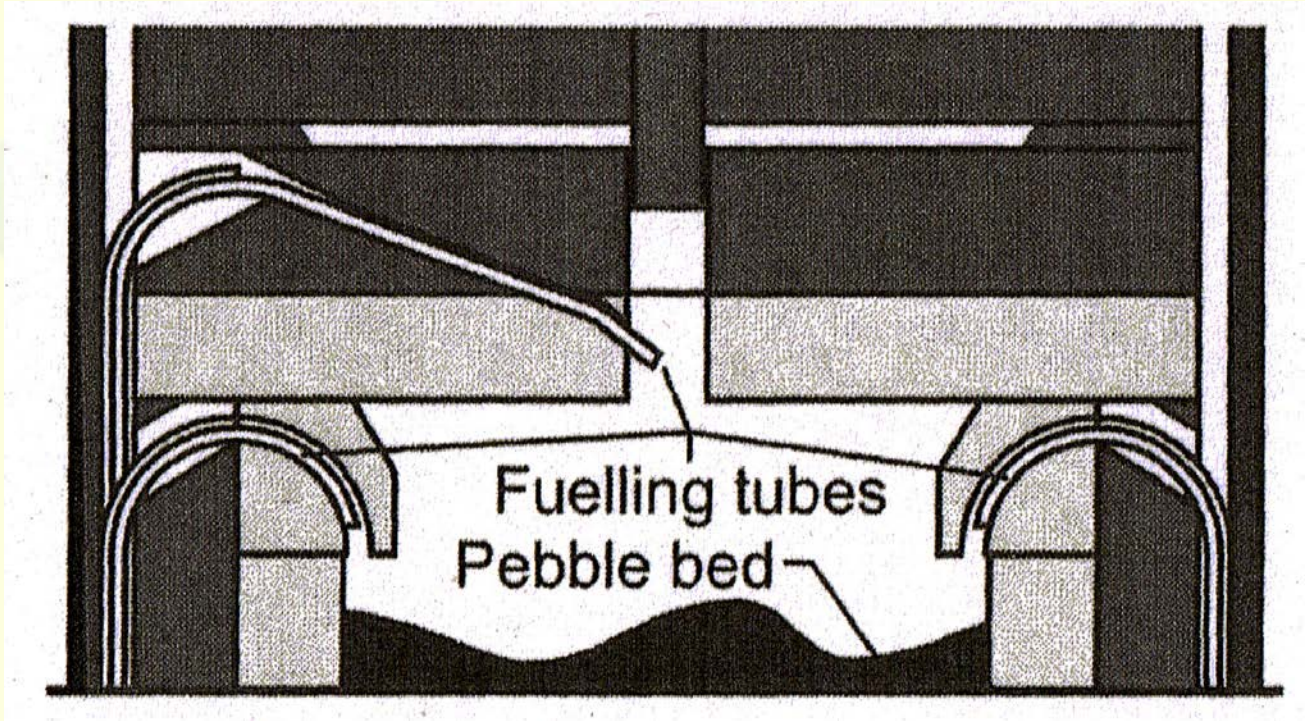
Phenomena in the operation history of the AVR experimental reactor

Figure 2: Principle of AVR



Phenomena in the operation history of the AVR experimental reactor

Figure 3: AVR fueling facilities



Phenomena in the operation history of the AVR experimental reactor

3. Specific features

- **15 different fuel element types with different fuel composition and different coating were tested over the operation time**
- **typically 6-8 fuel element types simultaneously during the most part of operation time**
- **no direct and continuous measurement of maximum fuel element and gas temperatures and the corresponding temperature profiles**
- **average gas outlet temperature was determined on the basis of measured parameters**
- **average gas outlet temperature was stepwise increased from 700°C to 950°C in 1974**

Phenomena in the operation history of the AVR experimental reactor

4. Temperatures in the primary circuit

- only discontinuous measurements of the core temperature maximum by monitoring spheres with melt wires
- three measurement campaigns in 1970, 1972 and 1986
- 1986 15 % of the melt wires melted at the highest expected temperature (1280°C)
- Conclusion: The AVR was - at least temporarily - operated with significantly exceeded temperatures

Phenomena in the operation history of the AVR experimental reactor

5. Primary circuit contamination

- **activity levels low until 1973**
- **drastic increase of the concentrations of different radionuclides as Cs-137 and Sr-90 by a factor of 100 to 1000**
- **Main release mechanism**
  - *** Fission product release from defective fuel elements or coatings**
  - *** Diffusion through intact coatings (especially metallic fission products)**
  - *** Release from contaminated graphite matrix outside the coatings**
- **Main influence factors**
  - *** the type of fuel element and its coating**
  - *** the temperature of the fuel element**
  - *** different physical conditions to which the fuel element was exposed during its course through to core and which resulted for example in the burn-up**

Phenomena in the operation history of the AVR experimental reactor

6. Possible causes for the excessive core temperatures

- **Two categories of causes:**
  - *** deficiencies in modeling the core and primary circuit behaviour**
  - *** weaknesses in measurement techniques**
- **Examples for the first category**
  - *** coolant bypass flows not considered**
  - *** poor understanding of fuel flow behavior**
  - *** until 1984 only 2-D-models**
- **Example for the second category**
  - *** burn-up measurement of removed fuel elements until 1981**

Phenomena in the operation history of the AVR experimental reactor

7. Possible causes for the increased fission product release into the primary circuit

- **Quality of certain fuel element and coating types**
- **Exceeded core tempertures**
- **Insufficient determination of certain fuel element parameters (like burn-up or irradiation time)**

Phenomena in the operation history of the AVR experimental reactor

8. Uncertainties and unresolved safety issues

- **Large uncertainties due to insufficient simulation and measurement techniques**
- **Large uncertainties due to incorrect operation strategies**
- **Missing investigations resulted in unresolved safety issues, e.g.**
- **Why no more temperature measurement campaigns between 1972 and 1986?**
- **Why no post-shut-down examination program to reveal the causes for certain observations?**
- **Why no evaluation of the effects of exceeded temperatures on the safety?**
- **Particularly why no analysis of the influence of exceeded temperatures on the safety in the case of steam generator accident with large water ingress?**

Phenomena in the operation history of the AVR experimental reactor

9. Concluding remarks

- **Only two phenomena in the operation history are presented**
- **Other relevant issues like the steam generator accident in 1978 not covered, but evaluated by the expert group**
- **Final report of the expert group and the summary under www.fz-juelich.de, AVR-Expertengruppe**
- **Many uncertainties and several open questions remain**
- **Last comment: The expert group has the impression that the operator of AVR and the HTR proponents in general had too much confidence in the supposed safety features of AVR and the HTR in general**