Topics - 2

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Safety Assessment of the HTR Module in Germany

- The task as defined in the contracts
- Overview of the plant concept
- The methodology applied in safety assessment of the HTR-2 NPP
- The most important results

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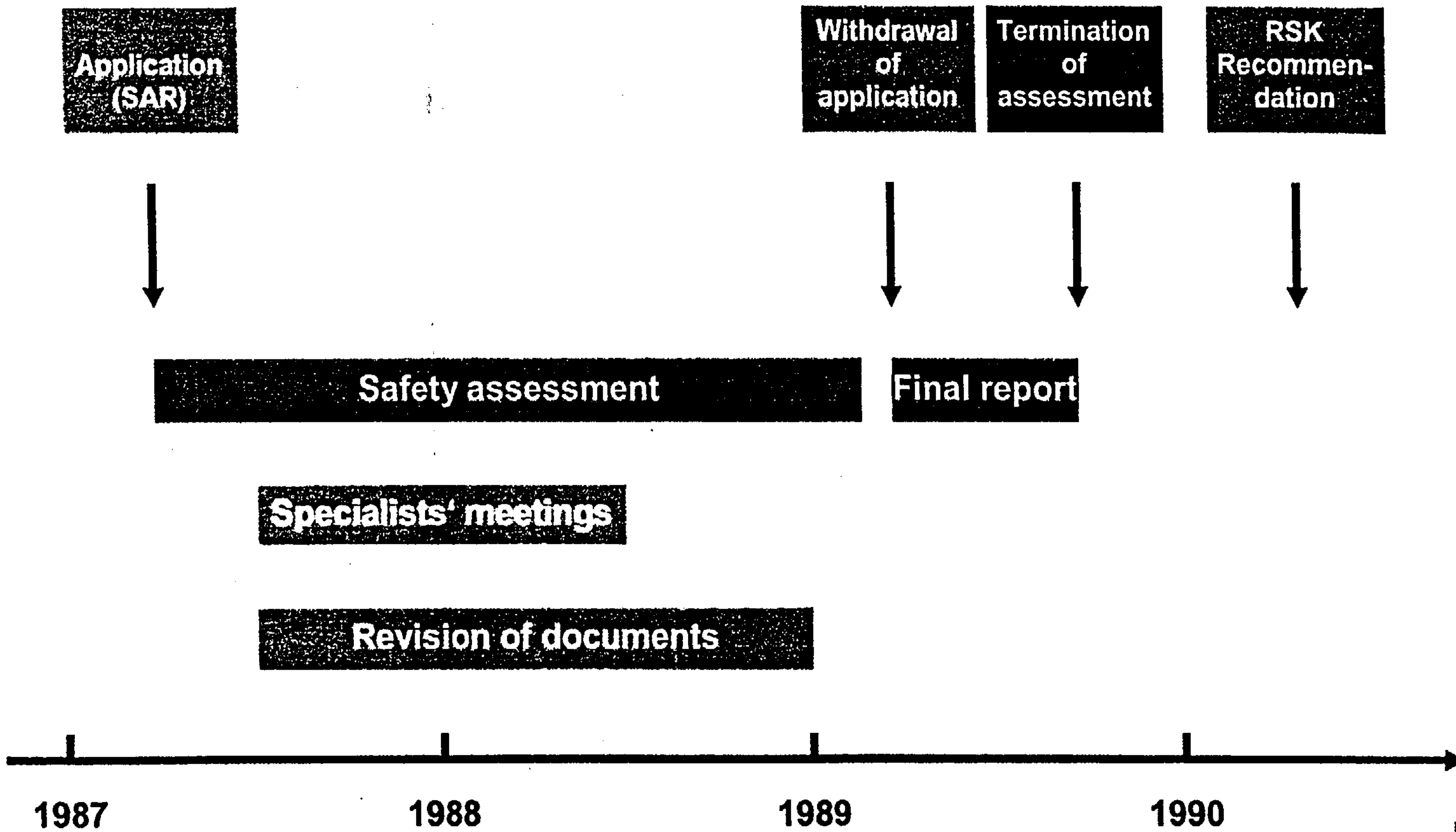
Licensing of the German HTR-2 NPP



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The Tasks as Defined in the Contracts - 1

Two different and consecutive steps in safety assessment of the HTR-2 NPP:

- Site-independent application for a preliminary license:
  - ⇨ Task carried out for the Ministry of Environmental Protection in the federal state Lower Saxony
  - ⇨ Compliance of the HTR-2 NPP concept with the requirements of applicable laws, ordinances and technical rules
  - ⇨ Documentation of the safety assessment results in a Safety Assessment Report as a technical basis for the license to be granted

The Tasks as Defined in the Contracts - 2

- Compilation of the safety assessment results without reference to a licensing procedure

  ⇨ Task carried out for the Federal Ministry for Research and Technology

  ⇨ Compliance of the HTR-2 NPP concept with the requirements for nuclear facilities in Germany

  ⇨ Definition of topics where further development steps might become necessary

  ⇨ Documentation of the results in a report

Federal work scope

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The Tasks as Defined in the Contracts - 3

Aim of the second step: To ensure that future development steps will be carried out under consideration of the respective regulations for nuclear safety in Germany

- Consequence: The final report does not contain (formalized) proposals for licensing restrictions as usually in a safety assessment report prepared in a licensing procedure
- Instead, a number of (unformalized) recommendations is given concerning deficiencies with respect to the applicable laws,ordi nances and rules

Applicability of Nuclear Safety Regulations for the HTR -2 NPP

Class of regulation	Example	Relevance
Laws and Ordinances	Nuclear Energy Act Radiation Protection Ordinance (RPO)	Obligatory
Guidelines	BMI/BMU Criteria for NPP Event Guideline § 28.3 RPO	Partly Obligatory
Technical Rules	KTA Rules DIN/ISO Standards	Concept-Specific

Derivation of Assessment Criteria

"Filtering and enrichment" process typical for prototype plants:

- Scanning of existing rules and guidelines for HTR-2 NPP relevance
  - ⇨ Reduction of the existing requirements to those relevant for the HTR-2 NPP
  - ⇨ If applicable, consideration of concept-specific or intrinsic requirements and added these, as needed.
- Scanning of HTR-specific publications
  - ⇨ If applicable, consideration of HTR-specific published data and added, as appropriate

⇨ Comprehensive and consistent set of design and evaluation deterministic criteria applicable to the HTR-2 NPP

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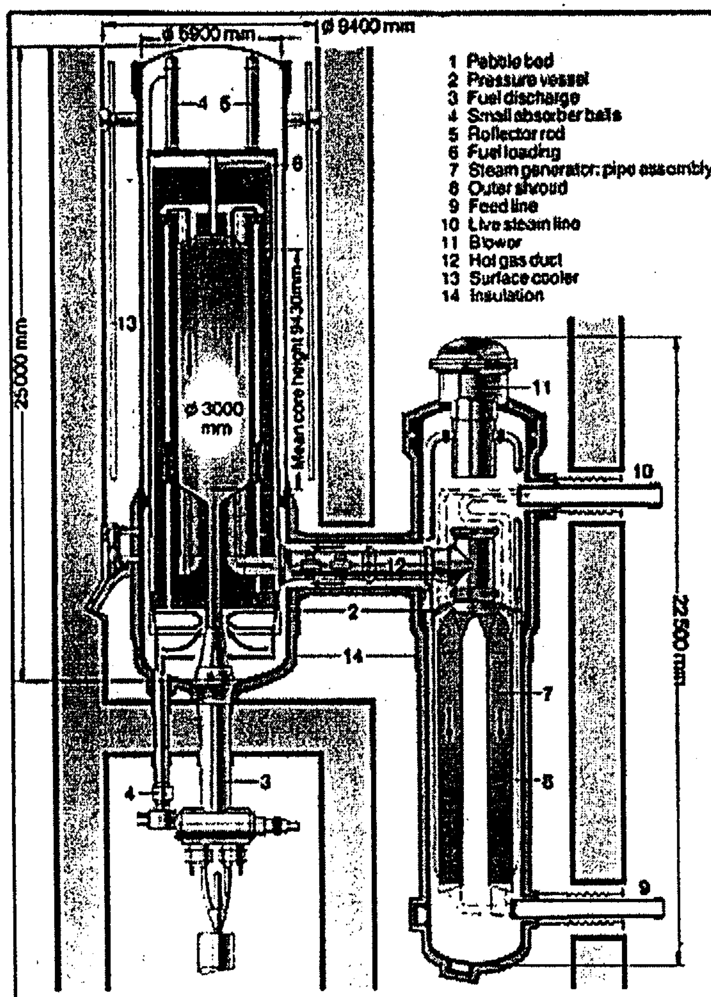
Design Basis of the HTR-2 NPP

Reactor concept characterized by limitation of fuel temperatures such that even in case of failure of all active cooling systems and the loss of coolant event no considerable release of radioactive fission products from the fuel elements will take place

The Pressure Vessel Unit of the HTR-2 NPP



Design Features - 1

- Modular HTR-2 NPP consisting of two reactors

- Two-circuit high temperature gas-cooled reactor:
  - ⇨ Primary circuit with helium as coolant
  - ⇨ Secondary circuit with steam turbine to generate power

- Power rating: 200 MW th; low power density

- Primary circuit and steam generator of secondary circuit housed in the Pressure Vessel Unit (PVU)

Design Features - 2

- Reactor core:
  - ⇨ Tall and slim geometry
  - ⇨ 2 independent shut-down systems: reflection rods and small spheres
  - ⇨ Core components: metallic, graphitic and carbon materials
  - ⇨ 360,000 fuel elements

- Fuel elements
  - ⇨ Spherical shape, diameter 60 mm
  - ⇨ Graphitic matrix
  - ⇨ Fuel kernels in TRISO particles
  - ⇨ Fuel design temperature: 1620 °C

Design Features - 3

- Decay heat transfer
  - ⇨ No active system required for short-term cooling after shut-down
  - ⇨ Decay heat removal passively via heat-up of core and area surface coolers outside RPV
  - ⇨ Fuel design temperature not exceeded
  - ⇨ Surface cooler to protect the reactor cavity

- Activity retention
  - ⇨ TRISO particles intact below fuel design temperature
  - ⇨ Pressurized boundary (PVU and other components)
  - ⇨ Fuel design temperature not exceeded during normal operation and after design basis events

Design Features - 4

- Safety enclosure/confinement
  - ⇨ No safety containment comparable to that of an LWR
  - ⇨ Safety confinement designed for
    - ◆ controlled and filtered activity release during normal operation
    - ◆ controlled and filtered activity release during and after small pipe break (Φ < 10 mm)
    - ◆ controlled and filtered activity release including unfiltered pressure relief of the building during and after large pipe break (Φ < 65 mm)

Design Basis Events

Listing of design basis events submitted by the applicants:

- Assessment criteria: Guideline §28.3 of the Radiation Protection Ordinance, modified under consideration of HTR-2-specific aspects
- Result: Revision and enlargement of the design basis event catalogue
- Action by the applicants: Inclusion of revised listing into the revised Safety Analysis Report

Basic Assumptions of the Event Analysis - 1

Basic assumptions of the event analysis needed to be modified in the event analysis, e.g.:

- Failure of the first criterion to activate the reactor protection system
- Consideration of a single failure and repair fault in systems crucial for event management
- Non-consideration of non-safety-related systems in the event analysis

Action by the applicants: Revision of the initially submitted event analysis in the revised Safety Analysis Report

Basic Assumptions of the Event Analysis - 2

Effect of revision of the event analysis:

- Introduction of additional safety measures, e.g. control rod insertion limitation and additional criteria to activate the reactor protection system
- Modification of limiting safety-relevant data, e.g. increase of the fuel element design temperature from 1600 to 1620 °C
- Additional analyses to demonstrate the acceptability of the revised design

Shut-Down Margin

Requirement introduced by TÜV: Shut-down in all operation modes to a core temperature below 50 °C

Results of safety assessment:

- Necessary measures: insertion limitation of the control rod system and filling height limitation of the small spheres shut-down system
- Necessity of an initial start-up measuring programme causing a modification of the loading strategy

Reactivity Events

Confirmation by TÜV that withdrawal of all reflector rods with maximum speed during full load operation is the relevant design basis reactivity event

Results of safety assessment:

- Power limitation to a maximum of 105% of the rated reactor power necessary
- Precautions against an unintended blower start at high helium temperatures
- Further investigations concerning the compaction of the pebble bed due to an earthquake

Disturbed Heat Removal Without Loss of Coolant - 1

Analysis of the applicants: Failure of the external mains feed simultanuously to loss of auxiliary power due to failure of the emergency power generation system for the cases:

- Short-term loss of auxiliary power (< 2 hours)
- Medium-term loss of auxiliary power (< 15 hours)
- Long-term loss of auxiliary power (> 15 hours); not included into basic design by the applicants

Disturbed Heat Removal Without Loss of Coolant - 2

Results of safety assessment:

- Confirmation that no limiting data (e.g. fuel temperature, radiation exposition) exceeded for low- and medium-term loss of auxiliary power
- Exclusion of long-term loss of auxiliary power from basic design only acceptable, if adequate QA measures foreseen ensuring a short-term repair of the emergency power system

Loss-of-Coolant Events - 1

Analysis of loss-of-coolant PRIMARY and SECONDARY loss-of-coolant events with respect to:

- **Maximum temperature of fuel and components**
- **Resulting loads, e.g. differential pressure loads on the reactor building or graphite corrosion**
- **Radiation exposition**

Design basis for PRIMARY COOLANT COMPONENTS:

- **Exclusion of a failure of the pressure vessel (basic safety)**
- **Rupture of a large connection pipe (Φ < 65 mm)**
- **Rupture of a small connection pipe**
- **Rupture of pipes with primary coolant outside the reactor building**

Loss-of-Coolant Events – 2

Results of safety assessment for PRIMARY loss-of coolant events:

- Break exclusion confirmed on the basis of fracture-mechanical analyses, but investigation programme and inset probes necessary to determine the neutron-induced embrittlement of the RPV
- Main steam nozzle: Mixed welding seam to be shifted from the high-temperature area
- Modification of the thermal insulation of the RPV necessary
- Filtering concept for medium size ruptures to be modified
- Confirmation that the rupture of a large pipe covers the consequences of all postulated ruptures
- Fuel design temperature not exceeded
- Radiation exposition limits not exceeded

Loss-of-Coolant Events – 3

Results of safety assessment of SECONDARY loss-of-coolant events:

- Modification of the main steam lock-off system to ensure pressure values within the reactor building below limiting values
- Differential pressure values close to the rupture position higher than the design value; to be considered in building design (not concept-relevant)
- Ingress of water into the primary circuit:
  - ⇨ Leakage quantity restricted to 600 kg
  - ⇨ High-quality initiation of countermeasures required
  - ⇨ Reactivity gain within acceptable limits
  - ⇨ Corrosion attack on fuel elements within acceptable limits

External Events

Results of safety assessment:

- Seismic design of some components and structures needed to be improved
- Probabilistic method to determine the seismic data acceptable
- Aircraft impact and shock wave after a detonation not to be considered as design basis events due to their low frequency to occur
- Plant design suitable to confirm the precaution of sufficient risk-reducing measures for events beyond design basis

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Summary

- Consequent and consistent plant concept characterized by pronounced features of inherent safety
- Concept is suitable to meet the requirements of the design basis as well as the regulatory requirements
- Proposals of the TÜV for further investigations or modifications of the detail design are not concept-relevant, instead they confirm the logical consistency of the basic safety concept of the HTR-2 NPP
- There is no doubt that with respect to safety a license could have been granted