New Technical Concepts of Spent Fuel Pool-Cooling and Implementation

Dr. Thomas Fuchs
Section Leader Numerical Methods and Ageing Management in PWR System Engineering
Hamburg, 2016/05/12
1) Introduction

2) Passive Single-Phase Heat-Removal Systems

3) Passive Two-Phase Heat-Removal Systems

4) Hybrid Systems AREVA Cooling Tubes (ACT) and KERENA SFP Cooler

5) Conclusion
1. Introduction
1. Introduction

**Pool Cooling Concepts**

**Direct Cooling:**
- HX at outside of pool, effective heat-transfer
- but risk of pool drainage

**Indirect Cooling:**
- Immersed Water-Water HX, additional barrier
- but moderate heat transfer
1. Introduction

Technological Framework

- Passive Heat Removal System
- Active Heat Removal System
- New Build
- Retrofit
- Time Frame
- Regulatory Demands
- Social and Political Acceptance for Solution
- Monetary Background
- Facility Design
- Heat Sink: Water or Air
- Consider Core During Outage

Demanding Framework Influences
2. Passive Single-Phase Heat-Removal Systems
2. Passive Single-Phase Heat-Removal Systems

Wet Spent Fuel Storage Facility – Goesgen NPP

Overview

Key data of the storage facility
- commissioning in 2008
- 1\textsuperscript{st} stage of expansion (in 2008):
  - 504 positions for spent fuels
  - 0.5 MW heat removal capacity
- 2\textsuperscript{nd} stage of expansion (in 2016):
  - overall 1008 positions for spent fuel
  - min. 1.25 MW heat removal capacity

First-of-a-kind passive cooled wet spent fuel storage
2. Passive Single-Phase Heat-Removal Systems

Wet Spent-Fuel Storage Facility – Goesgen NPP
Passive Fuel Pool Cooling System, Design Basis

► Regulatory demands
  • Maximum allowable spent-fuel pool temperature according to KTA 3303 (45 °C during normal operation, 60 °C during abnormal conditions and max. 80 °C during accident conditions)

► Ambient air design temperature
  • Normal operation: 26 °C → ΔT=T_{pool}-T_{air}= 19 K
  • Abnormal operation: 28 °C → ΔT=T_{pool}-T_{air}= 32 K (limiting case)
  • Accident conditions: 32 °C → ΔT=T_{pool}-T_{air}= 48 K

► Functional design
  • Normal operation → natural and forced convection augmented by fans
  • Accident and abnormal operation → natural convection without fans

► Decay heat power to be removed from the spent fuel pool
  • Cooling system installed in two stages 0.5MW + 0.75MW
2. Passive Single-Phase Heat-Removal Systems

Principle of a Single-Phase Heat-Removal System

Characterizing equations

Heat flow

\[ \dot{Q}_{HX} = R^{-1} \Delta T_{HX} \]

Driving pressure difference

\[ \Delta P_{driving\_circuit} = f(\rho(z, T)) \]

\[ \dot{Q}_{circuit} = \dot{M}c(T_R - T_{D-C}) \]
2. Passive Single-Phase Heat-Removal Systems

Simplified Temperature Distribution for a Single-Phase System

\[ \Delta T_{\text{available}} = 32\text{K} \]

\[ \Delta T_{\text{Atmo-D-C}} \approx 12\text{K} \]

\[ \Delta T_{\text{R-Pool}} \approx 3\text{K} \]

\[ \Delta T_{\text{circuit}} = \Delta T_{\text{D-C-R}} \approx 17\text{K} \]

\[ \dot{Q}_{\text{circuit}} = \dot{M}c(T_R - T_{D-C}) \]

Conflicting effects

\[ \dot{Q}_{\text{HX}} = R^{-1}\Delta T_{\text{HX}} \]

Enhancement of the heat transfer

- Decrease thermal resistance of HXs
- Decrease flow resistances in the system
- Increase elevation of the Water-Air HX
2. Passive Single-Phase Heat-Removal Systems

Modular Heat Transfer Unit

Goesgen second stage with 750 kW heat removal capacity
Basic Design 2014

Quantitative scale up based on the improved “heat transfer unit”

Improved numerical simulations and fine tuning

Feasibility study
10 MW facility
January 2013
2. Passive Single-Phase Heat-Removal Systems

Retrofit Concepts for Operation and Post-Closure Phase

► Crown shaped RB frame

► Stand-alone support frame

Concept of modular “heat transfer units” offers flexible and plant specific design possibilities

Stand-alone passive cooling system implies independency from decommissioning activities
## 2. Passive Single-Phase Heat-Removal Systems

### Feasibility Study of 10 MW Wet Storage

<table>
<thead>
<tr>
<th>Total heat to be removed 10 MW</th>
<th>OPERATION MODE 1</th>
<th>OPERATION MODE 2</th>
<th>OPERATION MODE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>operation mode active (pumps and / or fans)</td>
<td>passive</td>
<td>passive</td>
<td></td>
</tr>
<tr>
<td>( T_{\text{pool}} )</td>
<td>( \leq 45^\circ C )</td>
<td>( \leq 60^\circ C )</td>
<td>(&lt; 80^\circ C )</td>
</tr>
<tr>
<td>( T_{\text{ambient}} )</td>
<td>( 26^\circ C )</td>
<td>( 28^\circ C )</td>
<td>( 32^\circ C )</td>
</tr>
<tr>
<td>( \Delta T = T_{\text{pool}} - T_{\text{ambient}} )</td>
<td>( 19^\circ C )</td>
<td>( 32^\circ C )</td>
<td>( 48^\circ C )</td>
</tr>
<tr>
<td>dry cooling tower available</td>
<td>2 groups</td>
<td>2 groups</td>
<td>1 group</td>
</tr>
<tr>
<td>available footprint area inside the cooling towers</td>
<td>1045 m² (2 groups available maintenance not considered)</td>
<td>1045 m² (2 groups available maintenance not considered)</td>
<td>523 m² (only 1 group available e.g. due to airplane crash)</td>
</tr>
<tr>
<td>required footprint area inside the cooling towers</td>
<td>734 m²</td>
<td>918 m²</td>
<td>525 m²</td>
</tr>
<tr>
<td>ratio: area ( \text{ITT} ) divided by area ( \text{Gösgen} )</td>
<td>4.2</td>
<td>5.3</td>
<td>6.0</td>
</tr>
</tbody>
</table>

It is possible to handle a heat load of approx. 10 MW in a passive way for abnormal and accidental conditions.

Active components are required under the nominal load of 10 MW during normal operation.
Evolution of Passive Wet Storage Facilities

Design study 10 MW

Cooling capacity increases by a factor of 10, footprint area only by a factor of approx. 5

Goesgen 1 MW
3. Passive Two-Phase Heat-Removal Systems
3. Passive Two-Phase Heat-Removal Systems

**Principle of a Two-Phase Heat-Removal System**

\[ \dot{Q}_{HX} = R^{-1} \Delta T_{HX} \]

- Increased temperature gradients over the HXs
- Increased heat transfer coefficients due to boiling and condensation
- Higher driving pressure difference due to higher density differences
3. Passive Two-Phase Heat-Removal Systems

Comparison of a Single- and a Two-Phase Heat Removal Process

Two-phase heat removal systems increase performance especially at low driving temperature differences
4. Hybrid Systems
AREVA Cooling Tube (ACT) and
KERENA SFP Cooler
Motivation for the ACT Development

► For retrofit measures the fixation of the coolers is an ambitious task
  • Penetration of the liner
  • Welding of mounts
  • Fuel inside pool
  • Re-certification of the pool
  • Expensive measures

Solution: use existing structures e.g. fuel racks
Due to very small driving forces on pool water side an overall optimization is essential. A lot of experience is needed to design passive systems – changes during commissioning are impossible.
4. Hybrid Systems

KERENA Spent Fuel Pool Cooler
INKA Test Facility

Load case | Unit | #1 | #2
--- | --- | --- | ---
Mass flow rate cooling fluid | $\dot{m}_{CF} / \text{kgs}^{-1}$ | 40 | 75
Cooling fluid temperature | $T_{C_{in}} / ^\circ C$ | 15 | 25
Pool temperature | $T_{P_{in}} / ^\circ C$ | < 60 | < 75
Discharged heat | $\dot{Q} / MW$ | 5.1 | 10

Hybrid cooling solution for small pools and high heat loads
($>>$ 2MW, unloaded core) are also possible with immersed design
5. Conclusion
More than 20 years of R&D activities generate a wide portfolio of technical concepts for spent fuel pool cooling

First-of-a-kind wet spent-fuel storage with a passive single-phase heat-removal system of 0.5 MW in 2008 (extension to 1.25 MW in 2016)

Further technical solutions have been developed, especially retrofit measures for diversified cooling systems

- Product development periods have been decreased by a factor of 0.5 to provide individual solutions in an adequate financial framework
- AREVA started different product development cycles to provide evolutionary heat-removal system for low driving temperature applications, e.g. the first-of-a-kind ACT technology

Individual pool cooling solutions for individual requirements
AREVA’s Spent Fuel Pool Solutions

- AREVA is able to provide **active** and **passive** spent fuel pool cooling solutions for **new builds** and **retrofit measures**

- Our **integrated tailor-made solutions** cover a broad variety of:
  - regulatory requirements
  - technical requests
  - different commercial boundary conditions

More information: AREVA’s Spent Fuel Pool Solutions
www.areva.de
Editor and Copyright April 2016: AREVA GmbH – Paul-Gossen-Straße 100 – 91052 Erlangen, Germany. It is prohibited to reproduce the present publication in its entirety or partially in whatever form without prior written consent. Legal action may be taken against any infringer and/or any person breaching the aforementioned prohibitions.

Subject to change without notice, errors excepted. Illustrations may differ from the original. The statements and information in this brochure are for advertising purposes only and do not constitute an offer of contract. They shall neither be construed as a guarantee of quality or durability, nor as warranties of merchantability or fitness for a particular purpose. These statements, even if they are future-orientated, are based on information that was available to us at the date of publication. Only the terms of individual contracts shall be authoritative for type, scope and characteristics of our products and services.
New Technical Concepts of Spent Fuel Pool-Cooling and Implementation

Dr. Thomas Fuchs
Section Leader Numerical Methods and Ageing Management in PWR System Engineering
Hamburg, 2016/05/12

Weitere Fragen? Besuchen Sie uns am AREVA-Stand
Further questions? Visit us at the AREVA booth