Nuclear Process Heat Desalination

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Process Heat Applications

- **Steam Generation**
  - Oil Sands / Enhanced Oil Recovery / Shale Oil
  - Cogeneration

- **Steam Methane Reforming**
  - Hydrogen
  - Ammonia
  - Methanol

- **Water-Splitting ($H_2$ & $O_2$)**
  - Bulk Hydrogen
  - Coal-to-liquids
  - Coal-to-methane

- **Desalination**
Why Nuclear Process Heat?

- Fossil sources >90% of energy use
- CO₂ emissions continue to rise proportionally to total energy use
- Nuclear power supplies about 20% of the electric market and none of the remaining markets
- Greater role by nuclear in the electricity sector would have positive impact on CO₂ emissions
- Nuclear can further reduce CO₂ emissions in other energy sectors
**Water Scarcity**

- Availability of fresh water supply for agricultural, industrial and domestic uses is reaching critical limits.
- Increased fresh water demands will exceed existing supply capability
  - Growing population
  - Industrialization
- Worldwide limitations in the availability of fresh water
  - 97.5% of all water is represented by the oceans
  - Bulk of the remaining 2.5% is locked up in the ice caps
  - Less than 1% is available for human use
  - It is forecasted that two thirds of world population will face water shortages by 2025

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IAEA-TECDOC-1524, Status of Nuclear Desalination in IAEA Member States, 2007
Increased Interest in Desalination

- The worldwide installed capacity of desalination plants is ~35 million m³/day (2005) and growing by ~7% per annum\(^2\)
- More than 12,500 desalination plants exist worldwide\(^3\)
- Most of the existing plants use fossil energy sources
  - However, this presents new issues:
    - Price volatility
    - Energy security
    - Environmental concerns
      - Greenhouse gases

\(^2\) Wangnick/GWI 2005.
Increased Desalination Installations

- Nuclear Power vs. Desalination Installations

Desalination Technologies

Desalination Processes

Evaporation Processes
- MSF
- MED
- VC
- RO

Membrane Processes
- ED
- VC
- RO
- ED


ED – Electrodialysis
MED – Multi Effect Distillation
MSF – Multistage Flash Distillation
RO – Reverse Osmosis
VC – Vapor Compression

Heat Consuming
Power Consuming
A Strong Case for Nuclear Desalination

- 175 reactor-years on nuclear desalination worldwide\(^4\)
- Nuclear desalination appears to be a technically feasible, economically viable and sustainable option to meet the future water demands, requiring large scale seawater desalination
  - Nuclear desalination is economically competitive compared to desalination with fossil energy sources
  - Nuclear reactors provide heat in a large range of temperatures, which allows easy adaptation for any desalination process.
  - Some nuclear reactors furnish waste heat at ideal temperatures for desalination
  - Desalination is an energy intensive process. Desalination with fossil energy sources is less compatible with sustainable development in long term

\(^4\) IAEA-TECDOC-1524, Status of Nuclear Desalination in IAEA Member States, 2007
Advantages of Small Nuclear Power Plants as a Desalination Energy Source

- Small nuclear power plants can provide reliable economical power to produce fresh water in remote or developing regions of the world
  - Regions that may have:
    - A poorly developed infrastructure
    - Limited access to other sources of energy e.g. Coal, Oil, etc
    - and/or Require only small amounts of power
PBMR Waste Heat

- PBMR pre-cooler and inter-cooler reject ~215 MWt of waste heat through its Pre-cooler and Inter-cooler at ~70°C and ~60°C, respectively (ideally suited for thermal desalination)
Overview of Multi Effect Distillation (MED)

- Multi Effect Distillation (MED)
  - Thermal driven process
  - More efficient evaporation heat transfer than MSF
  - Proven technology
  - Growing Popularity

- Low Temperature Application (LT-MED)
  - Requires low temperature hot water > 55°C
  - Lower cost materials, less pretreatment required (less scaling problems)

\[ \text{Wangnick/GWI 2005.} \]
LT-MED for PBMR

- LT-MED coupling with PBMR

- Utilize waste heat in the form of hot water for LT-MED desalination units without a negative impact on the PBMR performance

- Pre-cooler ~123.5 MW
- Inter-cooler ~92 MW
- 18°C 71.2°C 18°C 57.8°C
- 555 kg/s 555 kg/s 1110 kg/s ~300 kPa
- Demin water intermediate circuit
- Helium circuit
- LT-MED Coupling
- LT-MED Unit 1
- LT-MED Unit 2
- ~25 000 m3/day

Demin water intermediate circuit
Helium circuit
LT-MED Coupling
LT-MED Unit 1
LT-MED Unit 2
IRIS Coupled to MED Plant (OKBM Design)

- OKBM has vast experience with desalination units
- Design of MED units ready and proven (unit output 20,000 m³/day)
- Preliminary design coupling to IRIS completed

There is a loss of thermal capacity of the main turbine as a result of steam supply to the Desalination Plant
Overview of RO

- **Reverse Osmosis (RO)**
  - Membrane separation process
  - Uses electricity rather than heat (for high-pressure pumps 70-80 bar)
  - Proven technology
  - Requires stringent feed water pre-treatment to prevent premature membrane fouling
  - Elevated feed water temperatures yield increased water flux per area of membrane
  - Waste heat can be utilized to pre-heat RO feed water
Desalination RO Process –
Increases in Temperature Increase Water Production

- Fastest growing segment of the desalination market due to improved membrane performance and reduced manufacturing cost
- An increase of ~15°C increases water production by ~13%
- Rejected heat from High Temperature Gas Reactors, such as PBMR can improve the productivity of the RO process.

PBMR – RO Coupling

- PBMR rejects ~ 177,120 m³/day @ ~40°C that can be used for preheating in RO
- PBMR RO plant can produce up to ~70 000 m³/day
- PBMR RO plant would consume ~17.5 MW
For Desalination, High Temperature Gas Cooled Reactors Offer an Advantage Over Conventional LWRs

- Using the RO process
  - A High Temperature Gas Cooled Nuclear Reactor (e.g. PBMR) - RO plant, can produce up to ~70,000 m³/day, while consuming ~17.5 MWe
  - If you consider a conventional LWR providing a 15 deg less preheat temperature to the RO plant, for the same production level, the power consumption is estimated to be ~ 20 MWe (note slide 15)

- Using the MED process (*):
  - A PBMR could produce ~24,000 m³/day without a negative impact on the PBMR performance
  - For the same level of production the loss of thermal capacity of the main turbine of a conventional LWR (e.g., IRIS) as a result of steam supply to the Desalination Plant would be approximately 8 MWe (**)

* Note: The estimated power needed to operated the MED plant is approximately 1.5 MWe
** Reference: “Nuclear Power Desalination Complex with IRIS Reactor Plant and Russian Distillation Desalinating Unit” V.I Kostin et al , 5th International Conference on Nuclear Option in Countries with Small and Medium Electricity Grids, Dubrovnik, Croatia , May 16-20, 2004
Summary

- Nuclear Desalination, especially small nuclear reactors in developing regions, provides a sustainable option to meet future water demands, requiring large scale seawater desalination
- MED and RO are mature and proven desalination technologies
- High Temperature Gas Cooled Nuclear Reactors (PBMR) provide a distinct benefit over LWRs in terms of available high temperature waste heat for desalination use, reducing the impact on the nuclear plant’s performance
Research Opportunities

- Efficient use of large LWR waste heat
  - Improved performance of evaporation processes
- Lower cost of (single unit deployment) small reactors in Nuclear developed countries
- Materials to handle increased operating temperatures of High Temperature Gas Cooled Reactors >950 C
- Developments to promote the use of Nuclear Process Heat for other applications
### Current activities on nuclear desalination in IAEA member states

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Location</th>
<th>Desalination Process</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMFR</td>
<td>Kazakhstan (Aktau)</td>
<td>MED, MSF</td>
<td>In service till 1999</td>
</tr>
<tr>
<td>PWRs</td>
<td>Japan (Ohi, Takahama, Ikata, Genkai)</td>
<td>MED, MSF, RO</td>
<td>In service with operating experience of over 125 reactor-years.</td>
</tr>
<tr>
<td></td>
<td>Rep. of Korea, Argentina, etc.</td>
<td>MED</td>
<td>Under design</td>
</tr>
<tr>
<td></td>
<td>Russian Federation</td>
<td>MED, RO</td>
<td>Under consideration (floating unit)</td>
</tr>
<tr>
<td>BWR</td>
<td>Japan (Kashiwazaki-Kariva)</td>
<td>MSF</td>
<td>Never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999.</td>
</tr>
<tr>
<td>HWR</td>
<td>India (Kalpakkam)</td>
<td>MSF/RO</td>
<td>Under commissioning</td>
</tr>
<tr>
<td></td>
<td>Pakistan (KANUPP)</td>
<td>MED</td>
<td>Under construction</td>
</tr>
<tr>
<td>NHR-200</td>
<td>China</td>
<td>MED</td>
<td>Under design</td>
</tr>
<tr>
<td>HTRs</td>
<td>France, The Netherlands, South Africa, USA</td>
<td>MED, RO</td>
<td>Under development and design</td>
</tr>
</tbody>
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Table source: IAEA-TECDOC-1524, Status of Nuclear Desalination in IAEA Member States, 2007.