ECONOMIC MERITS OF NUCLEAR DESALINATION

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Outline

• Nuclear energy and desalination
• Nuclear Desalination
• Incentives of Nuclear desalination
• Economics of Nuclear Desalination
• Summary
The need for water

- 70% of the planet is covered with water
  - Only 2.5% of that is fresh water.
    - Nearly 70% of this fresh water is frozen in the icecaps of Antarctica and Greenland.
  - Less than 0.08% of total supply is accessible for direct human use
- By the year 2025: 40% increase in water use
  - the number of people suffering from water stress or scarcity could swell to 3.5 billion,
  - 33% of would population in absolute water scarcity.
Regions facing water shortages
Role of nuclear energy

- Increase energy and water demands necessitates increased supply
- >90% of world’s primary energy will come from fossil fuels \(\Rightarrow\) increased greenhouse gas (GHG) emissions
- Nuclear power reduces GHG emissions and alleviates energy shortages
- Mid of 2007: 439 reactors in over 30 countries producing over 15.2% of world’s electricity (371.7 GW(e)) (in the US: 104 reactors = 97,411 MW(e))
Why nuclear desalination?

- “Clean” energy and minimal waste [Environment-friendly].

- Waste heat and electricity produced by nuclear plants are ideal for energy-intensive desalination processes.

- Economically competitive with conventional co-production plants, especially when a strong national grid exists and interest rates are low.

- Many years of successful operation have proved technical feasibility and reliability.
**Desalination:**
- More than 17,000 installed desalination units
- Total capacity is about 38 million m$^3$/day.

**ND:**
- The use of ND started early in the 1960s
- There are 15 ND Projects
- More than 200 reactor-years experience
## Global experience on ND

<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) 80000 m³/d</td>
<td>MED</td>
<td>In service till 1999 27 y</td>
</tr>
<tr>
<td>PWR</td>
<td>Japan (Ohi, Takahama, Ikata, Genkai)</td>
<td>MED, MSF, RO</td>
<td>In service with operating experience of over 150 reactor-years</td>
</tr>
<tr>
<td></td>
<td>Rep. of Korea, Argentina etc</td>
<td>MED, RO</td>
<td>Integral SMRs of the PWR type; under design or to be constructed</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>MED, RO</td>
<td>Under consideration (Barge mounted floating unit with KLT-40)</td>
</tr>
<tr>
<td></td>
<td>USA (Diabolo Canyon)</td>
<td>RO</td>
<td>Operating</td>
</tr>
</tbody>
</table>
Global experience on ND- Cont.

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Location</th>
<th>Desalination Process</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<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 LT-MED</td>
<td>RO operating since 2002</td>
</tr>
<tr>
<td></td>
<td>India (Trombay)</td>
<td></td>
<td>In service since 2004</td>
</tr>
<tr>
<td>NHR-200</td>
<td>Pakistan (KANUPP)</td>
<td>MED</td>
<td>Existing CANDU modified to be coupled to an MED plant (under construction)</td>
</tr>
<tr>
<td>HTRs</td>
<td>France, The Netherlands, South Africa</td>
<td>MED,RO</td>
<td>ANTARES, multipurpose reactor, GT-MHR and PBMR; under development and design.</td>
</tr>
</tbody>
</table>
Diablo Canyon
Operating plant: Ōhi, Japan

Evaporators at Aktau, Kazakhstan
80 000 m³/day for 27 years

SWRO Plant at KANUPP, Pakistan

Hybrid (MSF+RO) Kalpakkam, India

MED for 1600 m³/day

1000 m³/day desalted pure water
Integrated LTE Nuclear Desalination System, Mumbai, India

Use of waste heat

CIRUS Research Reactor

40 MWth
### Various types of nuclear desalination systems

<table>
<thead>
<tr>
<th>Reactor type</th>
<th>Country</th>
<th>Desalination process</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMFR</td>
<td>Kazakhstan</td>
<td>MED, MSF</td>
<td>150 reactor-years</td>
</tr>
<tr>
<td>PWRs</td>
<td>Japan</td>
<td>MED, MSF, RO</td>
<td>100 reactor-years</td>
</tr>
<tr>
<td></td>
<td>Korea, Argentina</td>
<td>MED, RO</td>
<td>Design stage</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>MED, RO</td>
<td>Design stage</td>
</tr>
<tr>
<td>PHWR</td>
<td>India</td>
<td>MSF, RO</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>Canada</td>
<td>RO</td>
<td>Design stage</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>MED</td>
<td>Construction</td>
</tr>
<tr>
<td>BWR</td>
<td>Japan</td>
<td>MSF</td>
<td>Installed</td>
</tr>
<tr>
<td>HTGR</td>
<td>South Africa</td>
<td>MED, MSF, RO</td>
<td>Design stage</td>
</tr>
<tr>
<td>NHR</td>
<td>China</td>
<td>MED</td>
<td>Design stage</td>
</tr>
</tbody>
</table>
Incentives of Nuclear desalination

- PBMR: Reject heat (from pre-cooler and intercooler) → 220 MW$_{th}$ at 70°C

  Clean and fresh desalinated water

  15,000 – 30,000 m$^3$/day of

  55,000 – 600,000 person
Incentives of Nuclear desalination-cont.

To produce 130,000 m³/day of desalinated water using 1000 MWe PWR

Using MED:

Total revenue \((\text{Cogeneration } 90\% \ \text{electricity} + 10\% \ \text{water})\):

- **Electricity**: 6771.6 M$
- **Water**: 888.59 M$
- **Total**: 7660 M$

Total revenue from 100% for **electricity alone**: 7166.8 M$

**Net benefit of ND**: 493.2 M$ ~ 7% more
Incentives of Nuclear desalination-cont.

Using RO even better:

• Increased availability (more water)
• No lost shaft power as in MED
• Considerable fraction of energy will be recovered.

Revenue:
- From electricity: 7026.72 M$
- From Water: 672 M$

Total: 7700 M$

Net benefit: 532 M$~ 7.5% more
Recent study on nuclear desalination

- Study started 2002-2006 (4 Years)

- Participants: 10 Countries (Argentina, China, Egypt, France, USA, India, Republic of Korea, Pakistan, Russia, Syria).
Economics of Nuclear Desalination

Estimated cost of ND: $0.40 – 1.50 / m³

- RO: 0.6-0.74 $/m³
- MED: 0.75-0.88 $/m³
- MSF: 1.2-1.5 $/m³

Economic target of nuclear desalination costs:

0.4-0.6US$/m³ depending on the region
Cost of new reactors (in the USA)

- June 2007 study (by Keystone Center): Overnight estimates (with interest):
  
  $3600 – 4000/kW

- Oct. 2007 study (by Moody’s Investor Service): Estimated total costs including interest would be between: $5000 and 6000/kW

- For the Turkey Point in Florida:

  - In 2004: cost of ABWR ~ $1611/kW
  - In 2007 update:
    - $6.5 – 8.9 billion for AP1000 (Westinghouse)
    - $8.25 – 12.15 billion for ESBWR (GE)

Materials, Labor, and equipment, had risen more than 50%
Some Major Factors that affect cost of Nuclear Projects

- Scale of Economics (The larger the better)
- Local Participations
- Rate and quality of Transfer of technology
- Modularization
- Learning curve
# Economics of Nuclear Desalination - DEEP

**Specify Case and Configuration Data**

- **Project:** My Site
- **Case:** My Case

**Water Plant Capacity**
- Total Capacity: 100,000 m³/d

**Power Plant Data**
- Thermal Power: 1,200 MWt
- Net Electric Power: 600 MWe
- Fuel Cost: 50 $/tce
- Specific Construction Cost: 700 $/kW

**Distillation Plant Data**
- Maximum Brine: 110 deg C
- Heating Steam Temperature: 0 deg C
- Specific Construction Cost: 1,000 $/(m³/d)

**Reverse Osmosis Plant Data**
- Energy Recovery Fraction: N/A %
- Recovery Ratio (optional): N/A %
- Design Flux: N/A /m² h
- Specific Construction Cost: N/A $/(m³/d)

**Pipeline Transport Option**
- Transport cost: 50 $(/kms)
- Distance (kms): 50
- Power (MWe): 1
- CO2 emission (t/MWh): 0.5
- Carbon tax ($/t): 50
- Backup heat source: Yes

**Configuration Switches**
- Steam Source: Extraction / Condensing
- Carbon Tax Option: 
  - Yes
  - No
- Thermal Vapor Compression: 
  - Yes
  - No

**Desalination Type:** MSF

**Power Source:** CC
The Various energy options considered in DEEP

<table>
<thead>
<tr>
<th>RC</th>
<th>Energy source</th>
<th>Abbreviation</th>
<th>Description</th>
<th>Plant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nuclear</td>
<td>PWR</td>
<td>Pressurised light water reactor</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>2</td>
<td>Nuclear</td>
<td>PHWR</td>
<td>Pressurised heavy water reactor</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>3</td>
<td>Fossil – coal</td>
<td>SSBC</td>
<td>Superheated steam boiler</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>4</td>
<td>Fossil oil - gas</td>
<td>SSBOG</td>
<td>Superheated steam boiler</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>5</td>
<td>Fossil</td>
<td>GT</td>
<td>Open cycle gas turbine</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>6</td>
<td>Fossil</td>
<td>CC</td>
<td>Combined cycle</td>
<td>Co-generation plant</td>
</tr>
<tr>
<td>7</td>
<td>Nuclear</td>
<td>HR</td>
<td>Heat reactor (steam or hot water)</td>
<td>Heat-only plant</td>
</tr>
<tr>
<td>8</td>
<td>Fossil</td>
<td>B</td>
<td>Boiler (steam or hot water)</td>
<td>Heat-only plant</td>
</tr>
<tr>
<td>9</td>
<td>Nuclear</td>
<td>GTMHR</td>
<td>Gas turbine modular helium reactor</td>
<td>Power plant</td>
</tr>
<tr>
<td>10</td>
<td>Fossil</td>
<td>D</td>
<td>Diesel</td>
<td>Power plant</td>
</tr>
<tr>
<td>11</td>
<td>Nuclear</td>
<td>SPWR</td>
<td>Small PWR</td>
<td>Co-generation plant</td>
</tr>
</tbody>
</table>
The desalination processes considered in DEEP

<table>
<thead>
<tr>
<th>Process</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distillation</td>
<td>MED</td>
<td>Multi-Effect Distillation</td>
</tr>
<tr>
<td></td>
<td>MSF</td>
<td>Multi-Stage Flash</td>
</tr>
<tr>
<td>Membrane</td>
<td>SA-RO</td>
<td>Stand-Alone Reverse Osmosis</td>
</tr>
<tr>
<td></td>
<td>C-RO</td>
<td>Contiguous Reverse Osmosis</td>
</tr>
<tr>
<td>Hybrid</td>
<td>MED/RO</td>
<td>Multi-Effect Distillation with Reverse Osmosis</td>
</tr>
<tr>
<td></td>
<td>MSF/RO</td>
<td>Multi-Stage Flash with Reverse Osmosis</td>
</tr>
</tbody>
</table>
## DEEP sample input and output – part I

### Economic parameters input data
- **Discount rate**: 8.0 % / a
- **Interest rate**: 8.0 % / a
- **Currency reference year**: 2003
- **Initial construction date**: 2003
- **Initial year of operation**: 2005
- **Purchased electricity cost**: 0.06 $ / kWh
- **Backup heat source input data**
  - **Lifetime of backup heat source Optional**: 0.00 % / a
  - **Backup heat source unit cost**: 0.00 $ / MW
  - **Fossil fuel price**: 20.00 $ / bbl
  - **Fossil fuel real escalation**: 2.00 % / a

### Energy plant cost input data
- **Plant economic life**: 60 a
- **Specific construction cost**: 1672 $ / kW
- **Additional site related construction cost**: 167 $ / kW
- **Construction lead time**: 60 m
- **Specific O&M cost**: 9 $ / MWh
- **Specific nuclear fuel cost**: 11 $ / MWh
- **Specific decommissioning cost**: 16.72 $ / MWh
- **Nuclear fuel price at startup**: N/A $ / bbl ($/l)
- **Fossil fuel annual real escalation**: 0.0 % / a
- **Fossil fuel annual real escalation**: 0.0 % / a

### Distillation plant cost input data
- **Plant economic life**: 30 a
- **Distillation plant lead time**: 12 m
- **Optional value (type 0 for Deep default)**: 0 m
- **Reference unit size for cost**: 48,000 m³ / d
- **Base unit cost**: 1200 $ / m³
- **Optional in/outfall specific base cost**: 0 $ / m³
- **Optional intermediate loop factor**: 0 $ / m³
- **Distillation plant cost contingency factor**: 0.100
- **Distillation plant owners cost factor**: 0.050
- **Distillation plant lead time**: 12 m
- **Average management salary**: 66,000 $ / a
  - **Average labor salary**: 29,700 $ / a
- **Optional no. of management personnel**: 0
- **Optional no. of labor personnel**: 0
- **Specific O&M spare parts cost**: 0.04 $ / m³
- **Tubing replacement cost**: 0.00 $ / m³
- **Specific O&M cost for pre-treatment**: 0.03 $ / m³
- **Specific O&M cost for post-treatment**: 0.02 $ / m³
- **Distillation plant O&M insurance cost**: 0.50 %

### RO plant cost input data
- **Plant economic life**: 30 a
- **RO plant lead time**: 24 m
- **Optional value (type 0 for Deep default)**: 0 m
- **Hybrid plant lead time**: 24 m
- **Optional value (type 0 for Deep default)**: 0 m
- **Base unit cost**: 800 $ / (m³/d)
- **Optional in/outfall specific base cost**: 0 $ / (m³/d)
- **Membrane equipment cost to total cost ratio**: 0.10
- **RO plant cost contingency factor**: 0.100
- **RO plant owners cost factor**: 0.050
- **RO plant lead time**: 24 m
- **Average management salary**: 66,000 $ / a
  - **Average labor salary**: 29,700 $ / a
- **Optional no. of management personnel**: 0
- **Optional no. of labor personnel**: 0
- **O&M membrane replacement cost**: 0.05 $ / m³
- **O&M spare parts cost**: 0.04 $ / m³
- **Specific O&M cost for pre-treatment**: 0.03 $ / m³
- **Specific O&M cost for post-treatment**: 0.01 $ / m³
- **RO plant O&M insurance cost**: 0.50 %
# DEEP sample input and output – part II

## WATER & POWER COST SUMMARY

### Case identification and site characteristics

<table>
<thead>
<tr>
<th>Energy plant type:</th>
<th>PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy source:</td>
<td>NUCLEAR</td>
</tr>
<tr>
<td>Energy product form:</td>
<td>H &amp; P</td>
</tr>
<tr>
<td>Fuel type:</td>
<td>UO2</td>
</tr>
<tr>
<td>Desalination plant type:</td>
<td>MSF-RO</td>
</tr>
<tr>
<td>Backup heat source:</td>
<td>N</td>
</tr>
<tr>
<td>Intermediate loop (MSF):</td>
<td>Y</td>
</tr>
<tr>
<td>RO membrane type:</td>
<td>SW</td>
</tr>
<tr>
<td>Total required water plant capacity at site:</td>
<td>350,000 m³/d</td>
</tr>
<tr>
<td>Capacity of distillation part:</td>
<td>140,000 m³/d</td>
</tr>
<tr>
<td>Capacity of RO part:</td>
<td>210,000 m³/d</td>
</tr>
</tbody>
</table>

### Case: Case X  
### Assumed site location: Site Y

### General input data

- Seawater TDS: 38,500 ppm
- Average annual seawater temperature: 21.0 °C
- Distillation plant design cooling water temperature: 21.0 °C
- Stand-alone RO design cooling water temperature: 21.0 °C
- Purchased electricity cost: 0.060 $/MW(h)
- Discount rate: 8.0 %
- Initial year of operation: 2005
- Plant economic life: 60 a
- Interest rate: 8.0 %

### Water and power plant cost summary

- Specific construction cost: 1.672 $/kW
- Power plant total construction cost: 1,104 M $
- Power plant interest during construction: 234 M $
- Total power plant investment: 1,338 M $
- Specific investment cost: 2.156 $/kW
- Levelized electricity cost: 0.057 $/kWh
- Total installed water plant capacity: 360,000 m³/d
- Total construction cost: 443.1 M $
- Interest during construction: 35.4 M $
- Total investment cost: 478.5 M $
- Specific investment cost: 1,329.3 $/(m³/d)
- G.O.R.: 6.4
- Recovery ratio: 0.399
- Net saleable power: 508.2 MW
- Average daily water production: 307,800 m³/d
- Water cost: 0.95 $/m³
Challenges facing nuclear desalination

• 1) **Disparity**: Countries vs. nuclear energy technology.

• 2) **Public perception**: Product water is not radioactively contaminated.

• 3) **Economics**: competitive if nuclear electricity is competitive.
Conclusion

- Nuclear desalination is feasible, safe, and economically competitive.

- Compared to the most economical fossil fuelled based option (the gas turbine Combined Cycle), cost of ND is 30-60% lower depending on gas prices.

- Net revenues for cogeneration (electricity and water) is better than electricity generation alone:
  - at least by 7% (as much as 20% in some studies for specific cases of cogeneration plants)
...Thank you for your attention