Nuclear Process Heat Desalination

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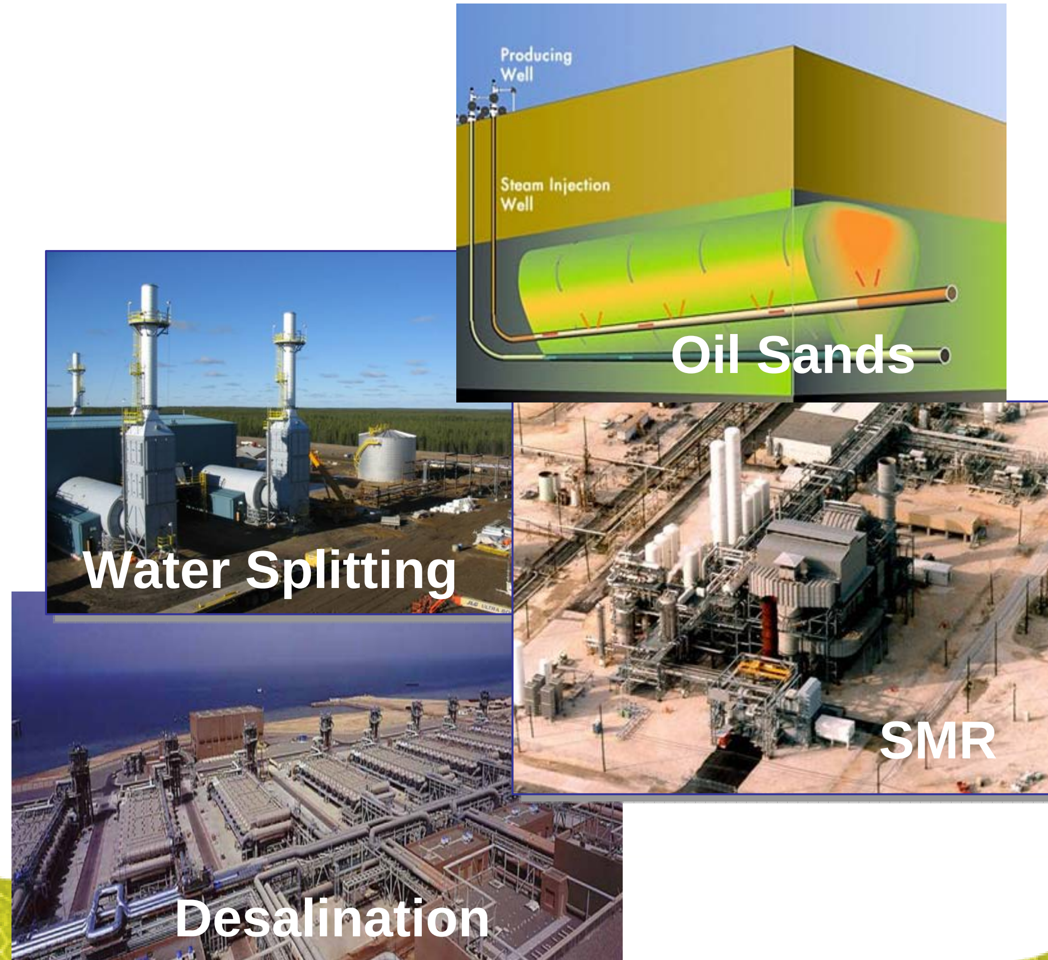
Process Heat Applications

- 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**



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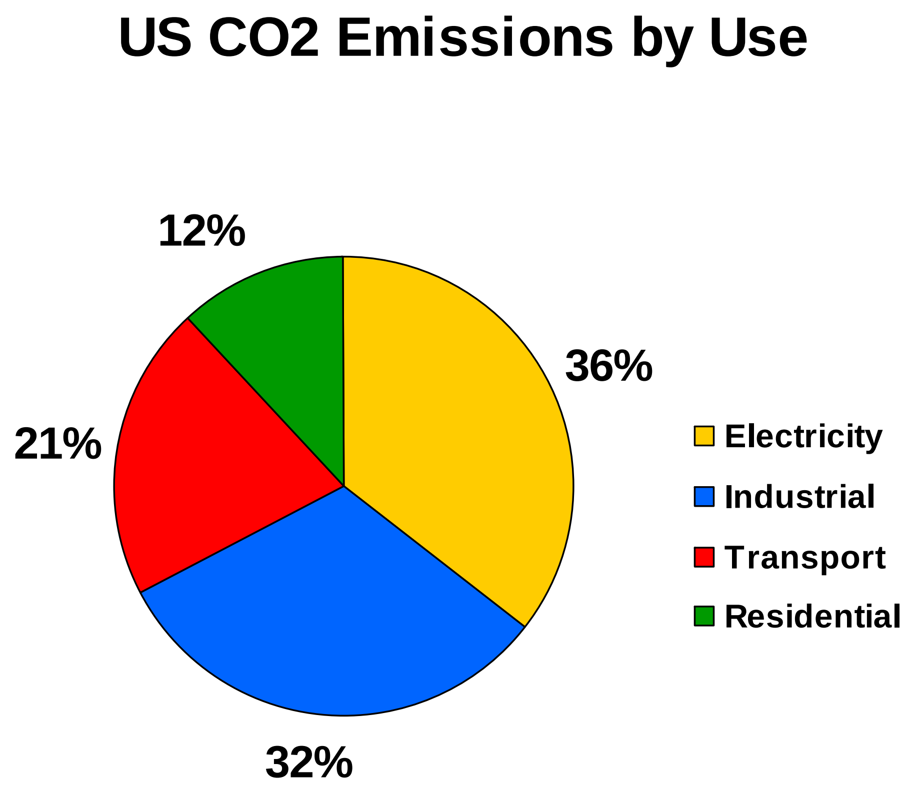
Why Nuclear Process Heat?

- Fossil sources >90% of energy use
- CO_2 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 CO_2 emissions
- Nuclear can further reduce CO_2 emissions in other energy sectors



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Water Scarcity

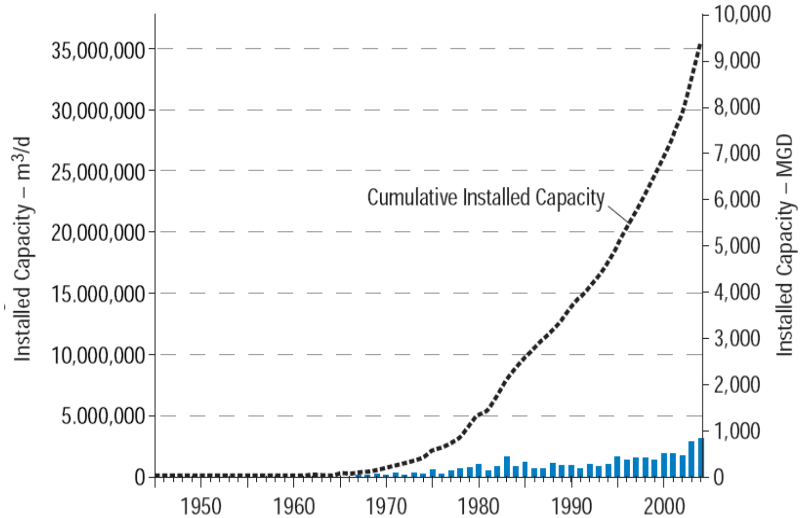
- Availability of fresh water supply for agricultural, industrial and domestic uses is reaching critical limits.
- Increased fresh water demands will exceed existing supply capability
  - Growing population
  - Industrialization

- 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[1]

[1] 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 m^3/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 gasses

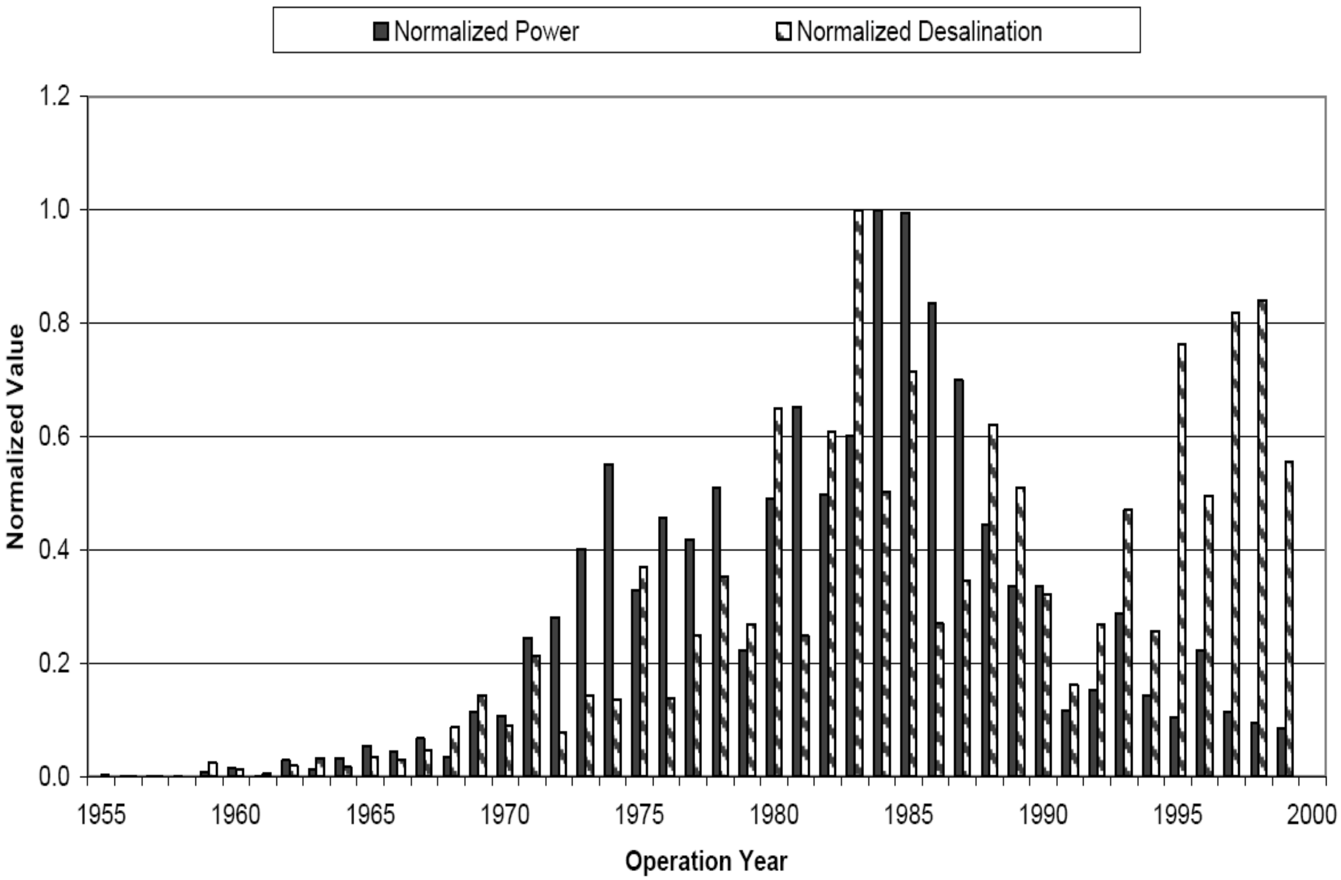


[2] Wangnick/GWI 2005.

[3] IAEA Technical Report Series 400 – Introduction to Nuclear Desalination, A Guidebook (2000).

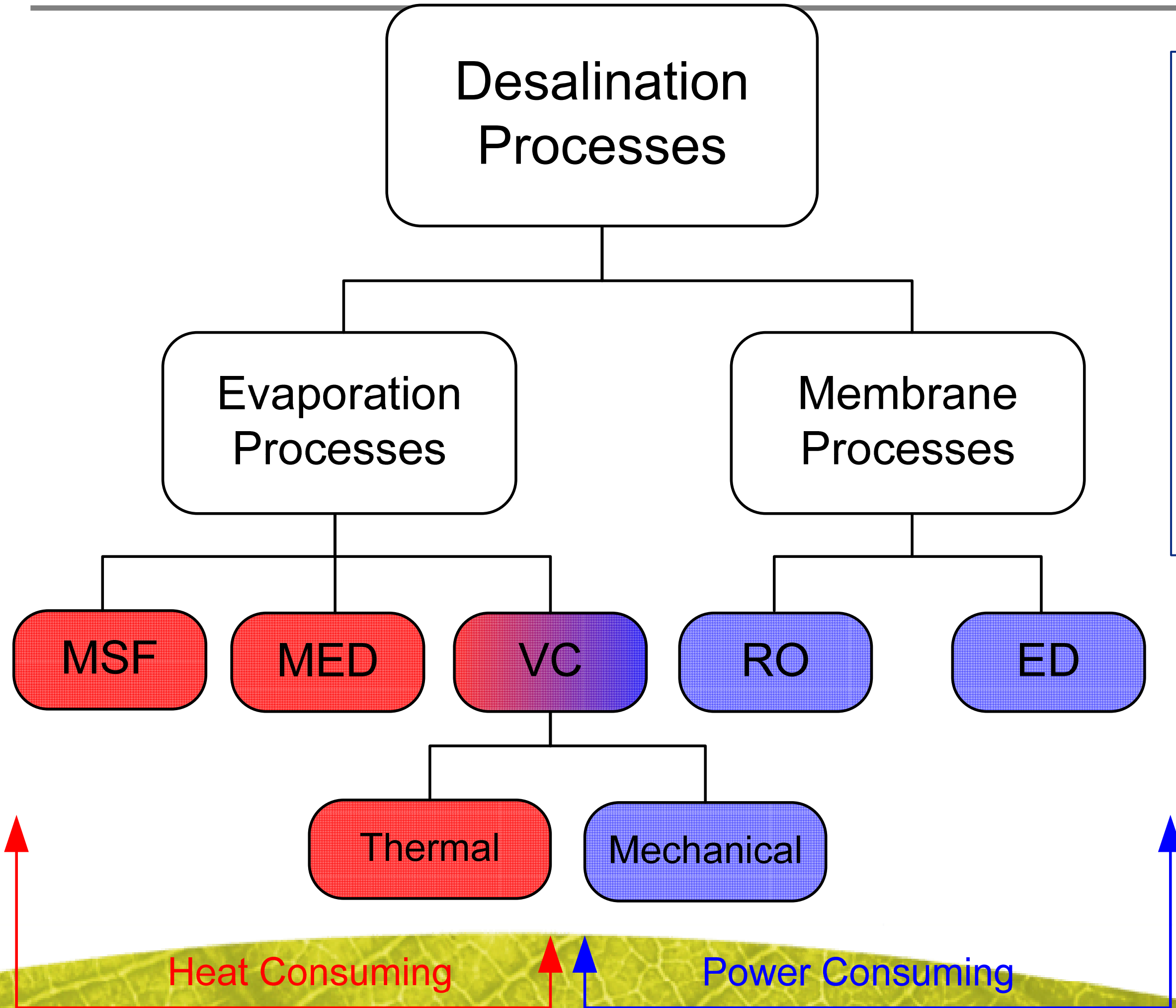
Increased Desalination Installations

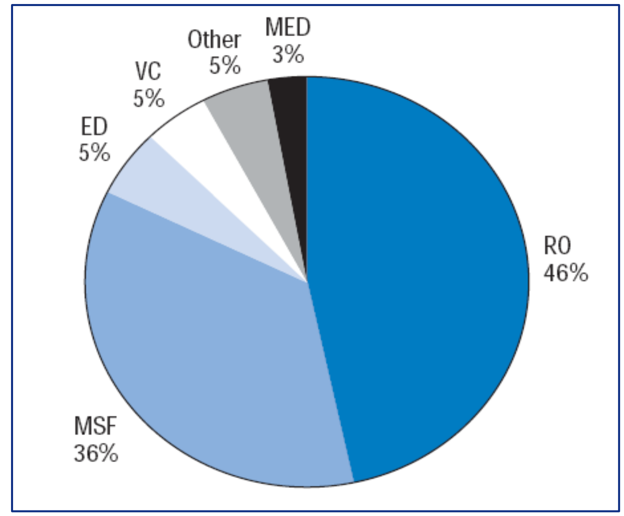
- Nuclear Power vs. Desalination Installations



Graph Source: MEGAHED, M.M., "An Overview of Nuclear Desalination: History and Challenges", International Journal of Nuclear Desalination, Vol. 1, No. 1, pp. 2–18, (2003).

Desalination Technologies





ED – Electrodialysis

MED – Multi Effect Distillation

MSF – Multistage Flash Distillation

RO – Reverse Osmosis

VC – Vapor Compression

Graph Source: Wangnick/GWI 2005.

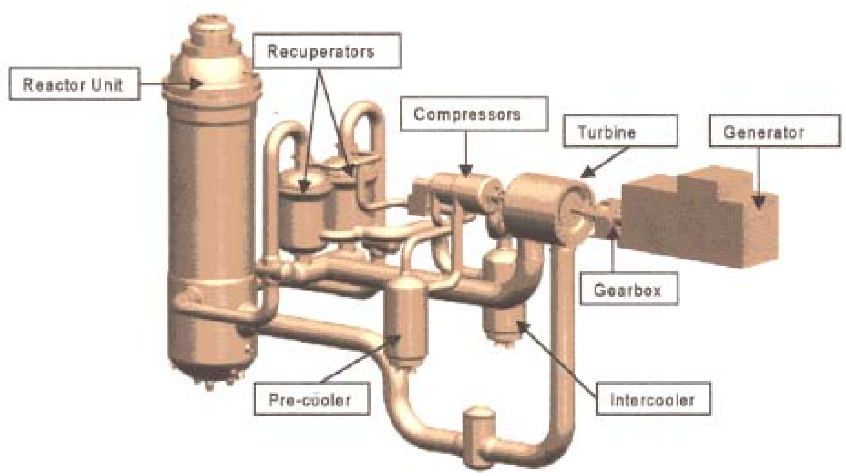
A Strong Case for Nuclear Desalination

- 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



Pebble Bed Modular Reactor (PBMR)
165 MWe

International Reactor Innovative and Secure (IRIS)
335MWe

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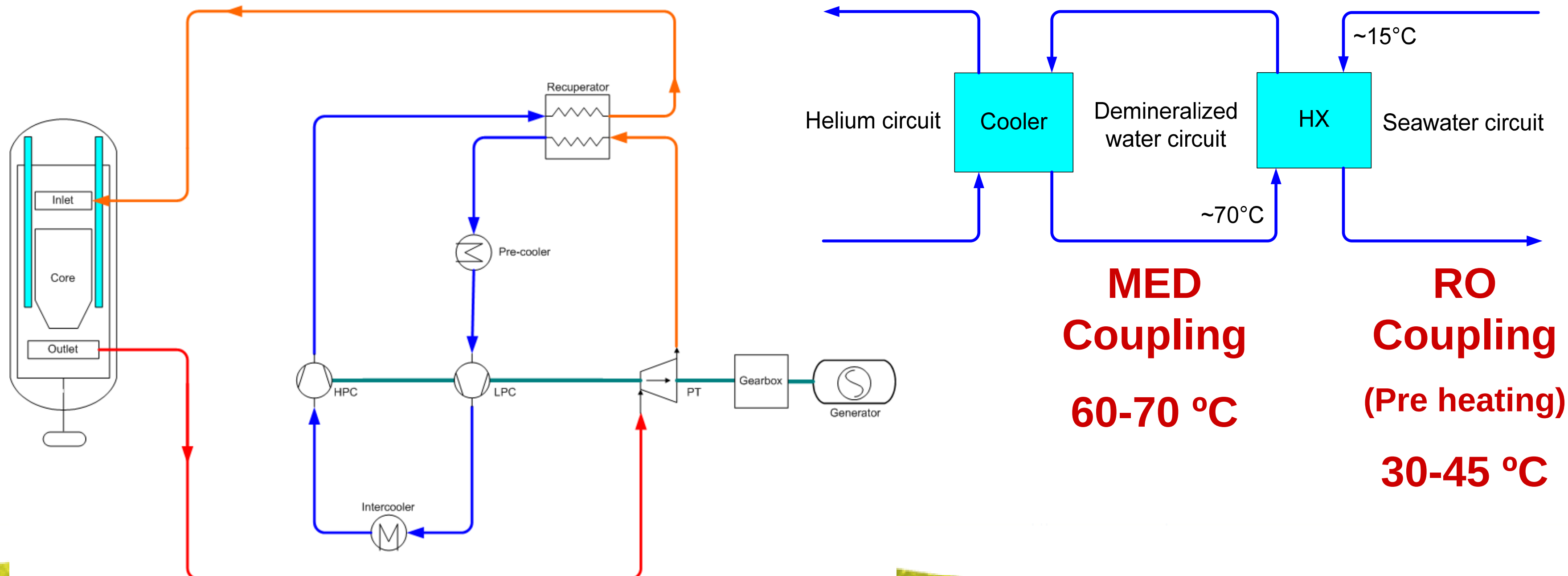
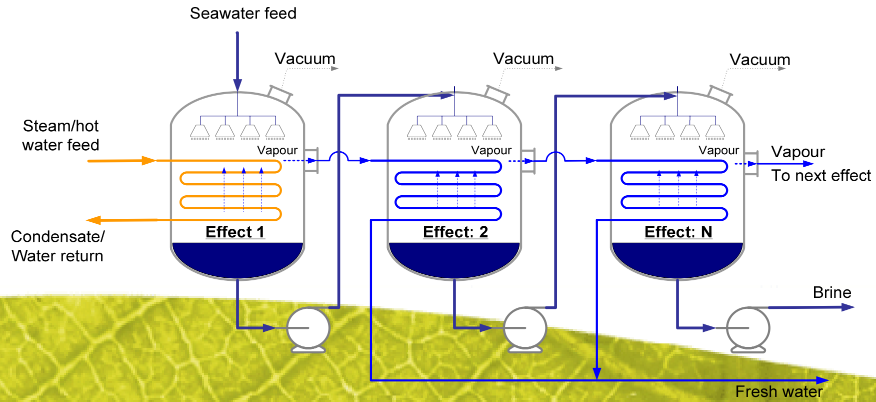
PBMR Waste Heat

- 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)

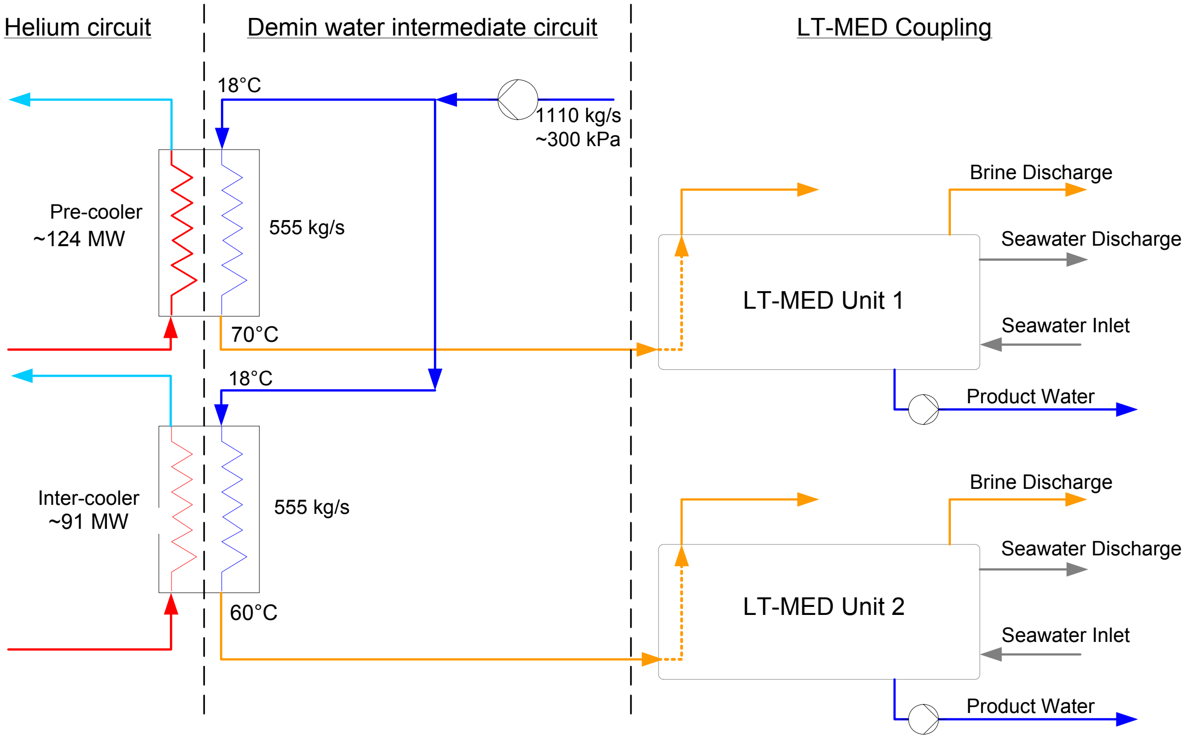
- Multi Effect Distillation (MED)
  - Thermal driven process
  - More efficient evaporation heat transfer than MSF
  - Proven technology
  - Growing Popularity
- Low Temperature Application (LT-MED)
  - Requires low temperature hot water > 55°C
  - Lower cost materials, less pretreatment required (less scaling problems)



[6] Wangnick/GWI 2005.

LT-MED for PBMR

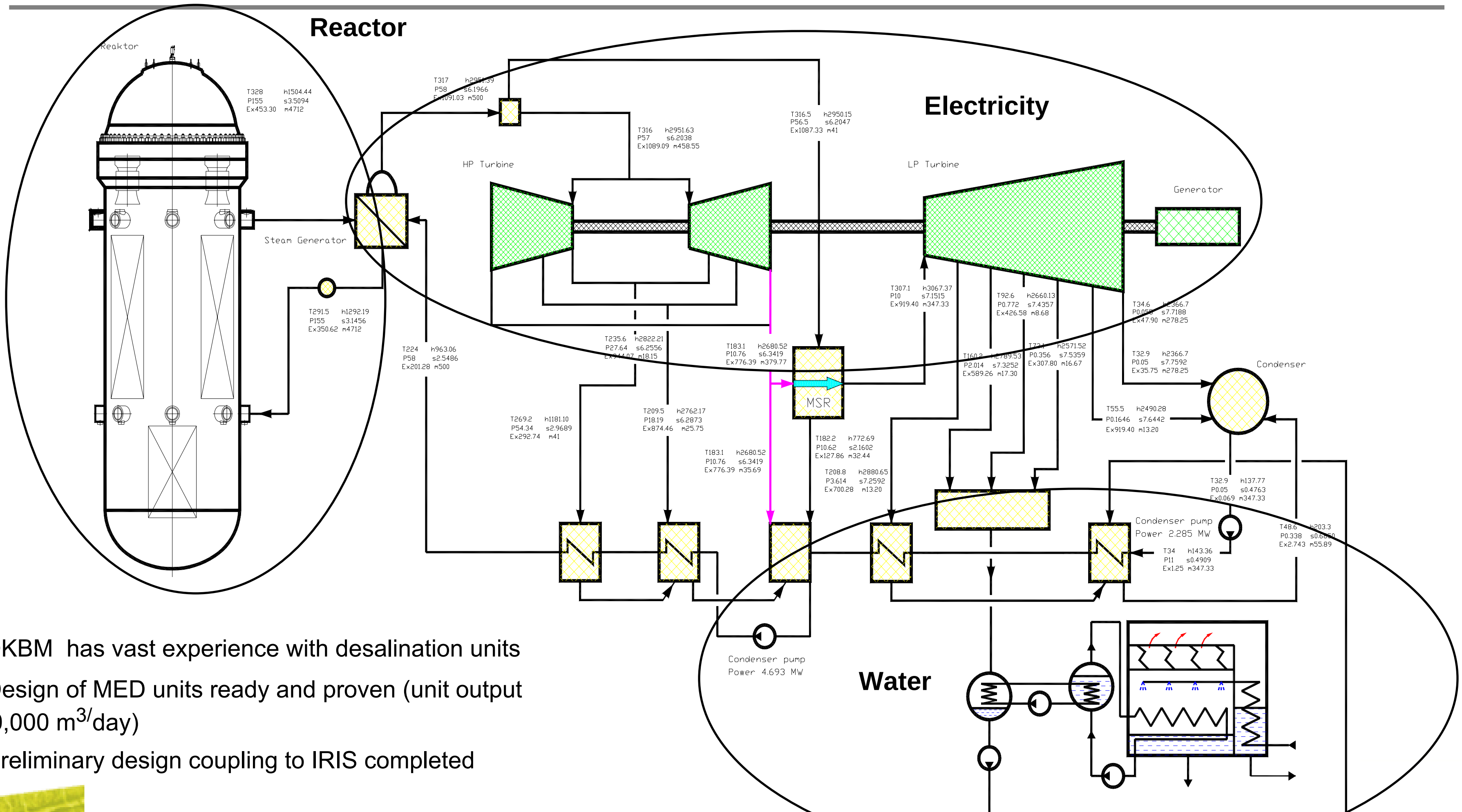
- LT-MED coupling with PBMR



~25 000 m3/day

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

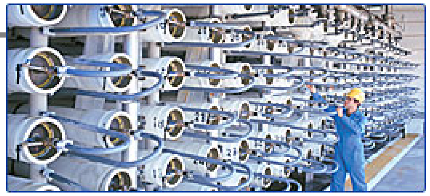
IRIS Coupled to MED Plant (OKBM Design)



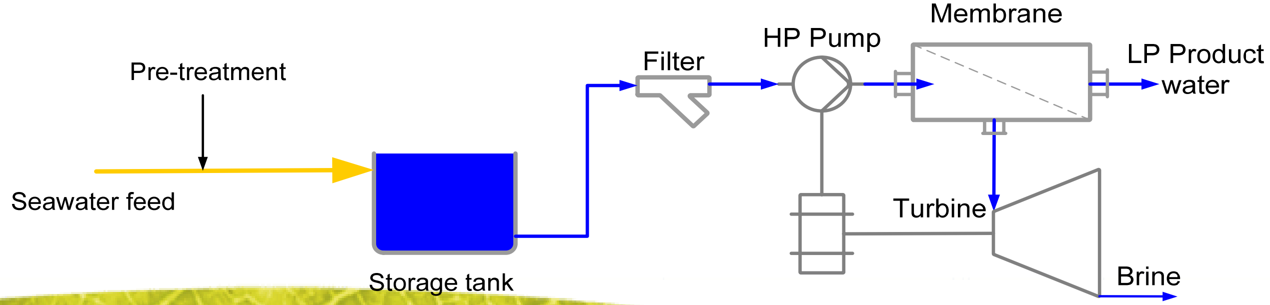
- OKBM has vast experience with desalination units
- Design of MED units ready and proven (unit output 20,000 m^3/day)
- Preliminary design coupling to IRIS completed

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



IAEA Technical Report Series 400 – Introduction to Nuclear Desalination, A Guidebook (2000).

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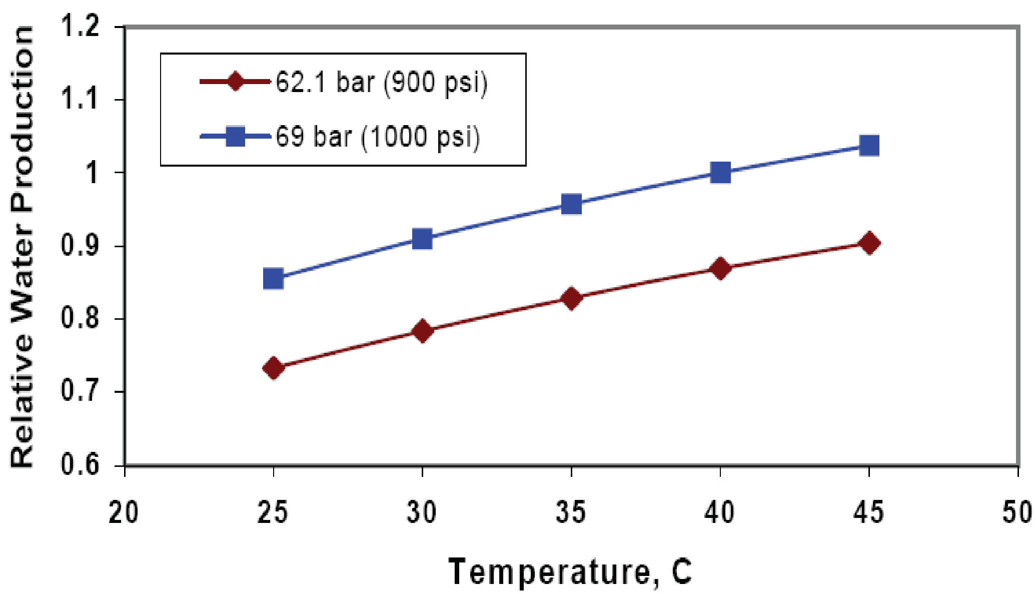
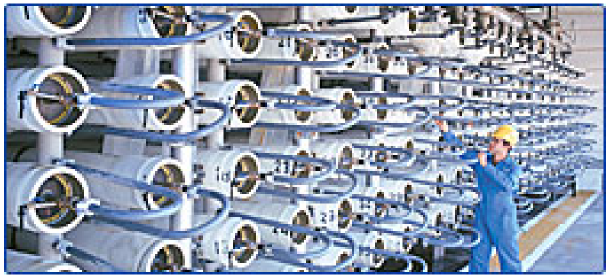
Desalination RO Process – Increases in Temperature Increase Water Production

- 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.





Graph source: IAEA-TECDOC-1524, Status of Nuclear Desalination in IAEA Member States, 2007.

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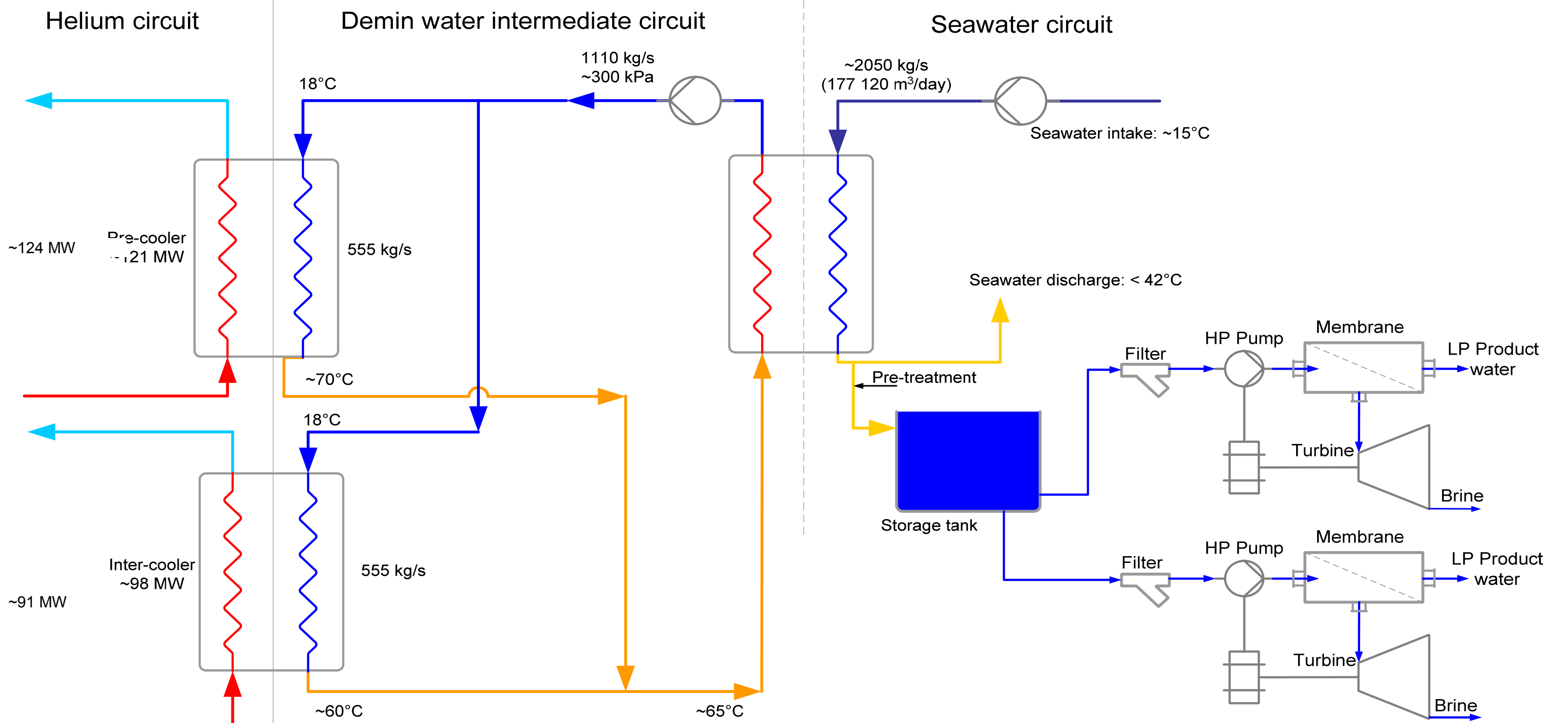
PBMR – RO Coupling

- PBMR rejects ~ 177,120 m^3/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

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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

Nuclear Desalination – IAEA

- Current activities on nuclear desalination in IAEA member states

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

Table source: IAEA-TECDOC-1524, Status of Nuclear Desalination in IAEA Member States, 2007.

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