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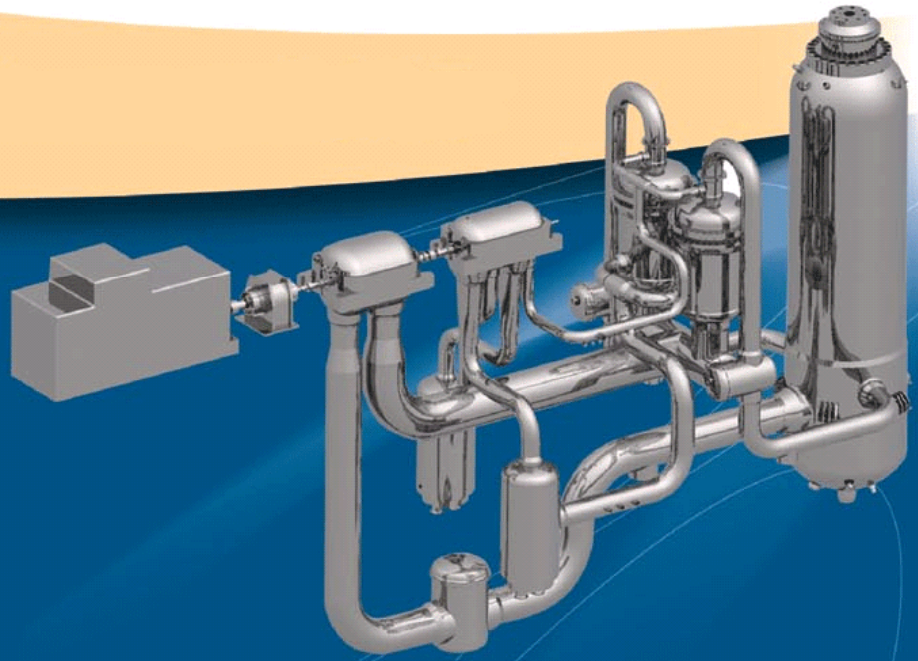

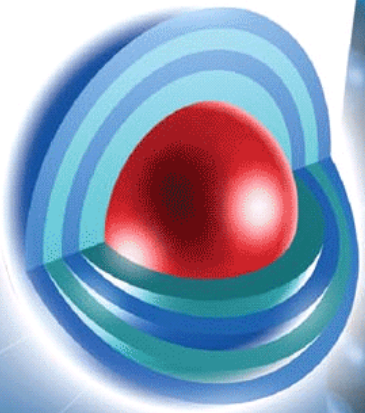

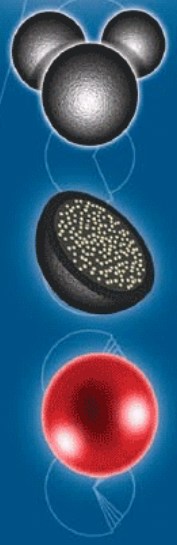

Desalination using the PBMR DPP as heat source

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Presented by Willem Kriel

Outline

- **Introduction**
  - Water Scarcity
  - Desalination
- **PBMR**
- **Desalination Overview**
  - Multistage Flash Distillation (MSF)
  - Multi Effect Distillation (MED)
  - Reverse Osmosis (RO)
- **Desalination with the PBMR Demonstration Power Plant (DPP)**
  - Multi Effect Distillation (MED)
  - Reverse Osmosis (RO)
- **Challenges**
- **Summary**

Introduction - Water Scarcity

- **Fresh water is a key element to all societies**
  - Agricultural use
  - Drinking water
  - Process water for industrial use
- **World wide 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

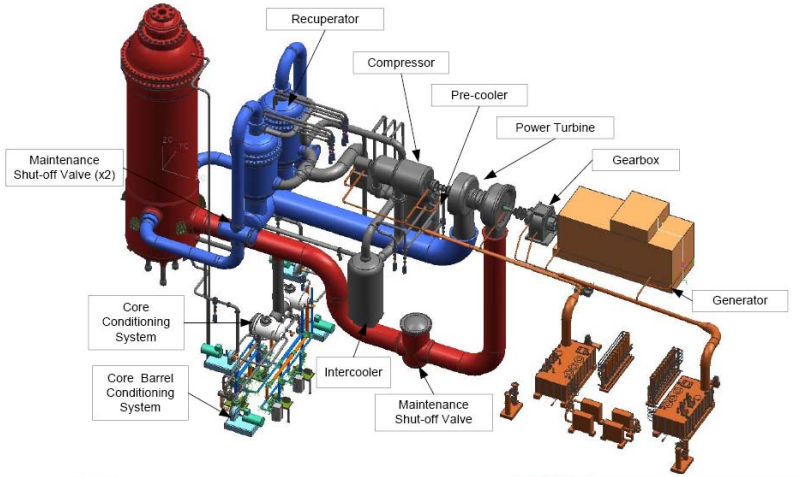
Introduction – Desalination

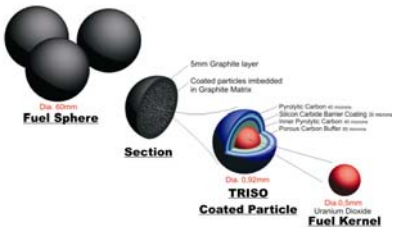
- **A total of approximately 34 million m^3/day of desalted water is produced by 12,500 plants world wide**
- **Capacity is increasing annually by 1 million m^3/day**
- **Most of the existing plants use fossil energy sources**
- **Interest in nuclear desalination has grown worldwide in the past decade for a variety of reasons:**
  - Increased water scarcity
  - Economic competitiveness
  - Energy supply diversification
  - Environmental protection – carbon emissions

- **No commercial HTR desalination plant exist**
- **PBMR DPP very well suited for desalination**

PBMR DPP

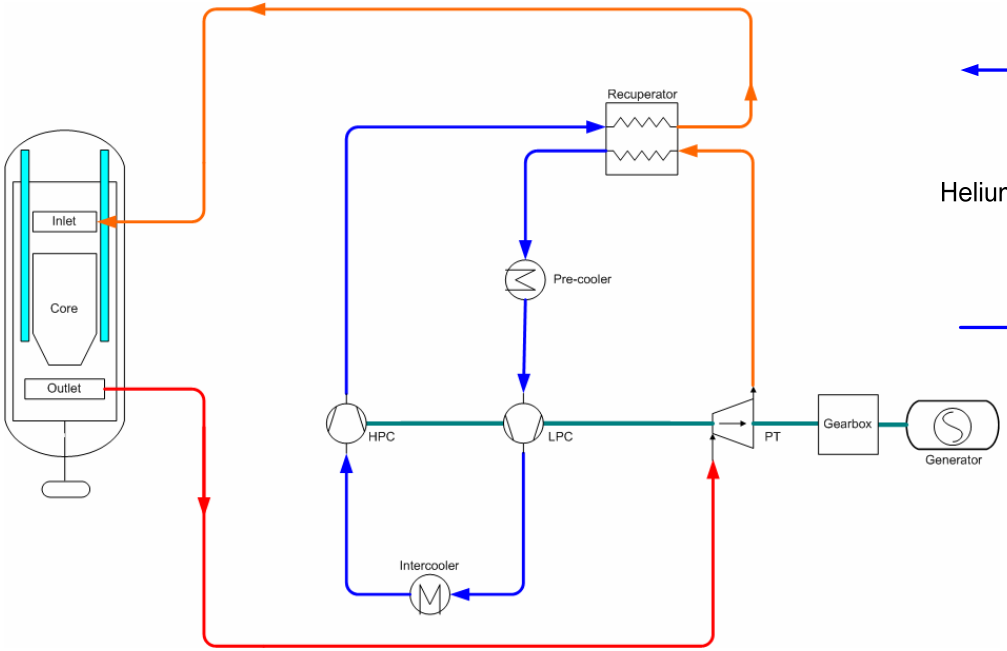
- South Africa, Western Cape, Koeberg
- Construction starts during 2008
- Commissioning 2012/13
- 400 MWt (900°C ROT)
- 165 MWe
- η = ~41%
- German based fuel design
- Helium as working fluid
- Direct recuperative Brayton cycle

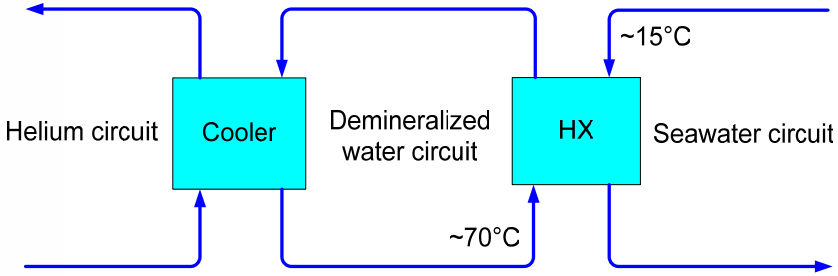




PBMR DPP Waste Heat

- PBMR DPP pre-cooler and inter-cooler reject ~220 MWt of waste heat at ~70°C (suited for thermal desalination)
- LWRs reject waste heat at ~35°C (not suited for thermal desalination)



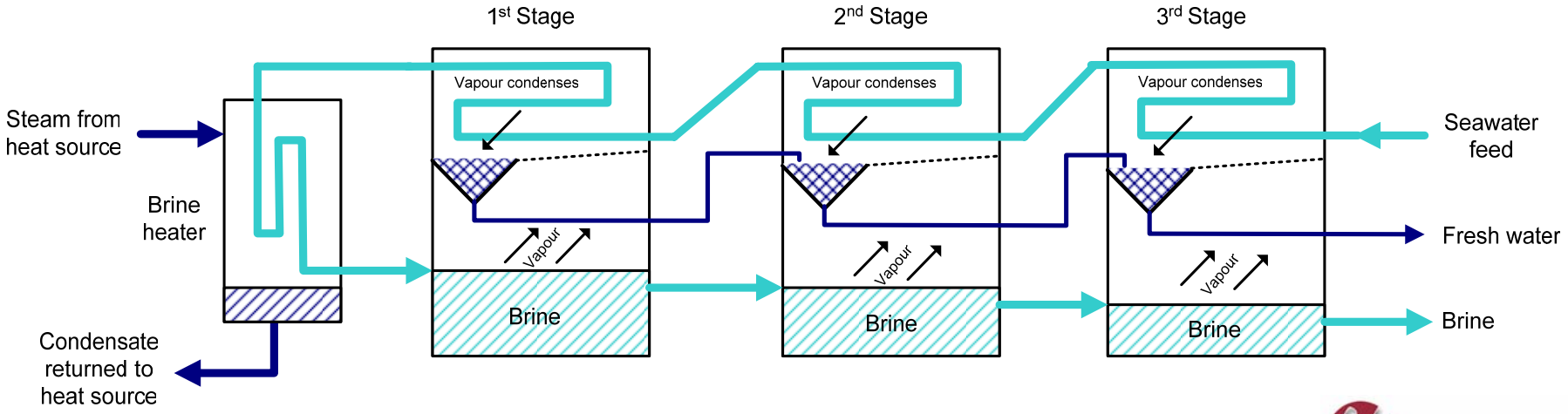


Current status of desalination

- **Thermal desalination**
  - Multistage Flash Distillation (MSF) (from 1950s)
  - Multi Effect Distillation (MED) (from 1960s, gained wide acceptance during the 1990s)
  - Vapor Compression (VC) (not common for large scale commercial applications)
- **Membrane Filtration**
  - Reverse Osmosis (RO) (started to gain momentum during 1970s)
  - Consumes electricity rather than heat
  - Fastest growing desalination technology world-wide
- **Nuclear desalination experience**
  - Nuclear desalination plants in Japan and Kazakhstan operating for ~20 years
  - Nuclear desalination experience exceeds 150 reactor-years with an exceptional safety record as of 2000

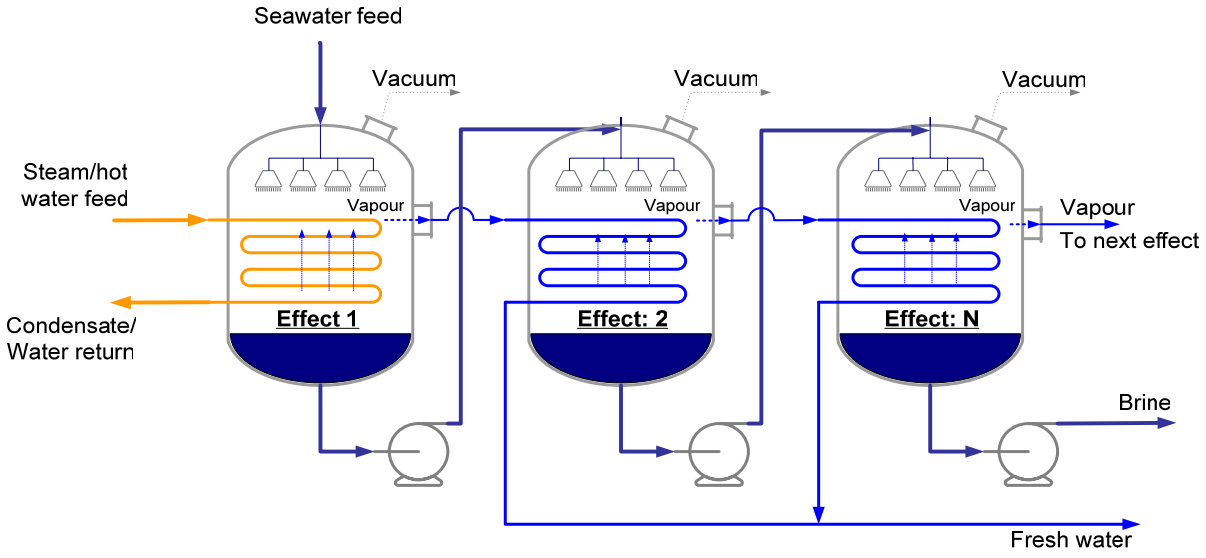
Desalination Technologies - MSF

- **Multistage Flash Distillation (MSF)**
  - Thermal driven process
  - Leading thermal desalination process
  - Proven technology
  - Requires steam as heat source at ~110°C
  - Can produce water with 5-25 ppm TDS
  - $1,000 to $3,000 per m^3/day installed capacity [1]
  - Units of up to 60,000 m3/day have been built

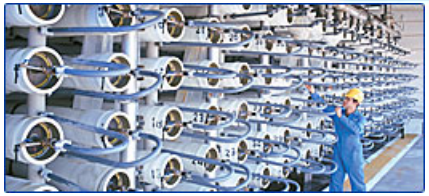


Desalination Technologies - MED

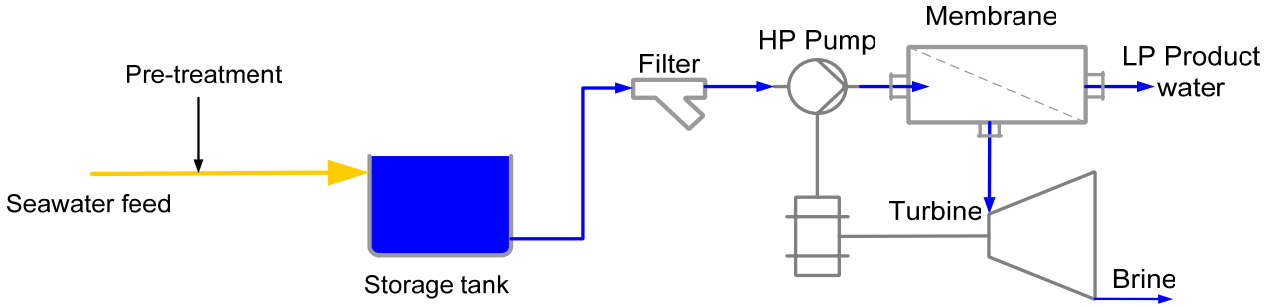
- **Multi Effect Distillation (MED)**
  - Thermal driven process
  - More efficient evaporation heat transfer than MSF
  - Proven technology
  - Requires low temperature steam/ hot water ~65°C
  - Can produce water with 5-25 ppm TDS
  - $900 to $2,000 per m^3/day installed capacity [1]



Desalination Technologies - 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 pretreatment to prevent premature membrane fouling
  - Large scale plant can recover 30-40% of the energy from high pressure reject brine by pelton wheels and hydro turbines
  - RO plants with energy recovery requires 4-6 kWeh/m^3 product water
  - Elevated feed water temperatures yield increased water flux per area of membrane
  - Waste heat can be utilized to pre-heat RO feed water
  - Can produce water with ~400 ppm TDS
  - \$900 to \$1,700 per m^3/day installed capacity [1]



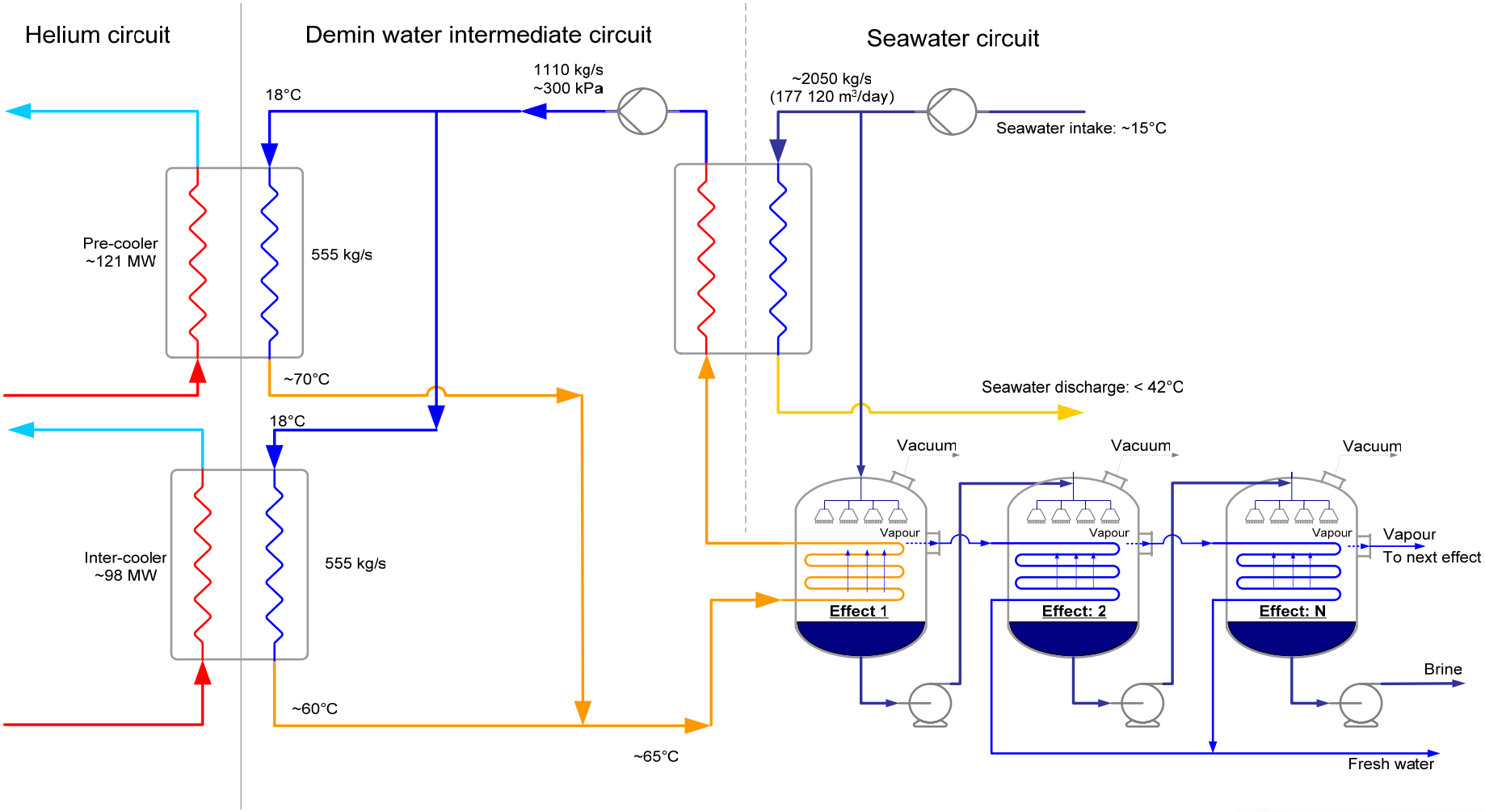
Desalination for PBMR DPP - MSF

- **Multistage Flash Distillation (MSF)**
  - Advantageous where heat is available as low temperature steam at 100-110°C
  - Delivers product water with high levels of purity 5-25 ppm TDS from seawater containing 35,000 - 45,000 ppm TDS
  - Requires extensive pre-treatment of feed water
  - PBMR DPP rejects waste heat at lower temperature ~70°C
  - MSF process therefore not ideally suited for coupling with the PBMR DPP

Desalination for PBMR DPP - MED

- **Multi Effect Distillation (MED)**
  - Recently increased application around the world
  - Uses 33% less electric energy than MSF process
  - Delivers product water with high levels of purity 5-25 ppm TDS from seawater containing 35,000-45,000 ppm TDS
  - In contrast with MSF, MED plants can operate at lower feed water temperatures of ~65°C (LT-MED)
- **LT-MED (Low Temperature MED)**
  - PBMR DPP rejects heat at ~70°C through pre-cooler and intercooler
  - LT-MED plant can be coupled to PBMR DPP with only minor modifications
  - The amount of waste heat utilized by the LT-MED plant can be varied
  - The ultimate heat sink of the PBMR DPP can reject any unutilized waste heat
  - The pre-cooler rejects ~120 MWt at ~70°C
  - The inter-cooler rejects ~100 MWt at ~60°C

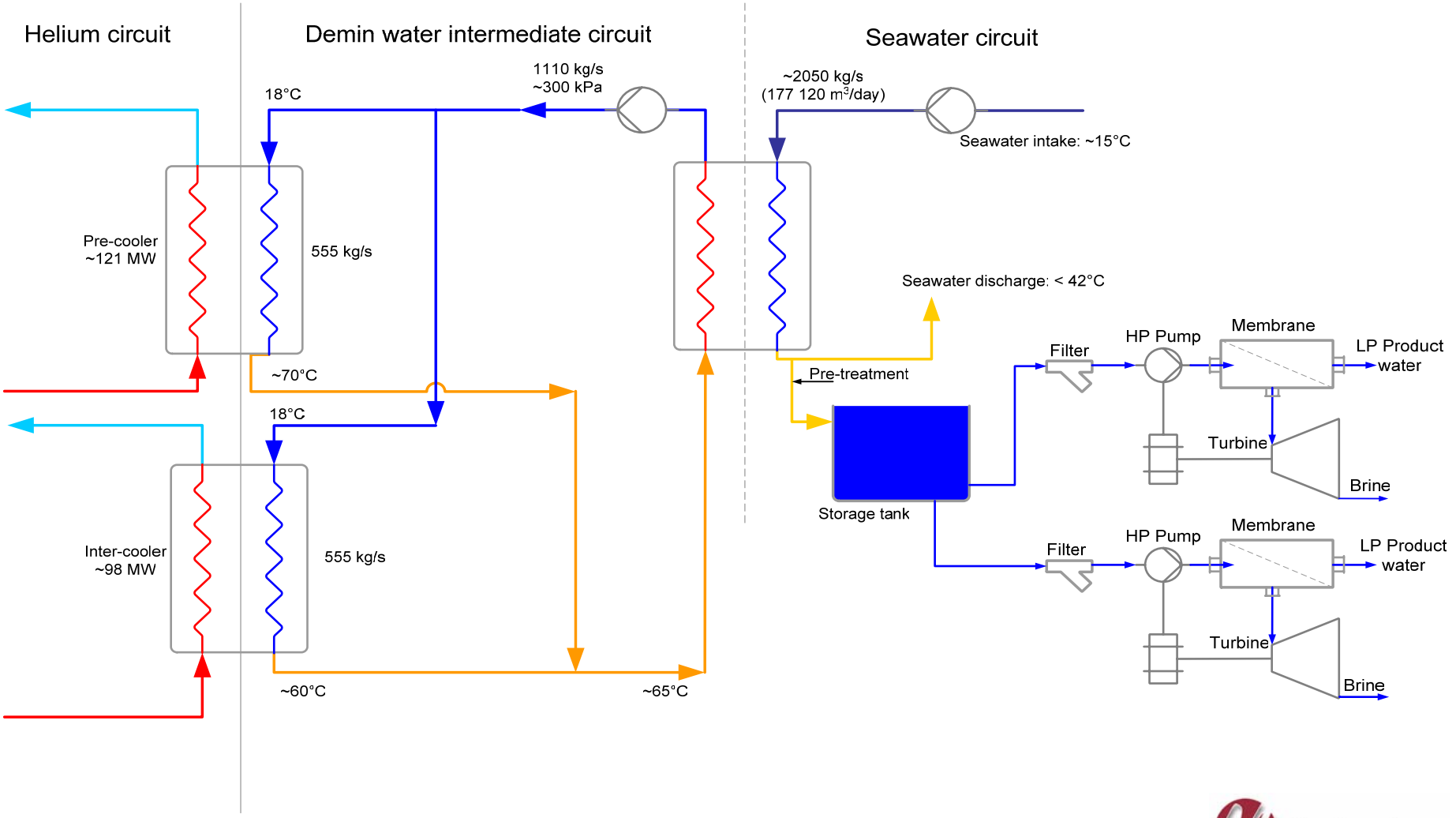
PBMR DPP – MED Coupling



Desalination for PBMR DPP - RO

- Fastest growing segment of the desalination market due to improved membrane performance and reduced manufacturing cost
- Rejected seawater can be used for RO feed water
- PBMR DPP provides the RO plant with the required electricity
- RO plant can consist of a number of modules, which can be expanded as the market for water grows
- RO plant with a 15,000 m^3/day capacity would require ~3.8 MWe
- Almost no modifications required to PBMR DPP ultimate heat sink

PBMR DPP – RO Coupling



PBMR DPP with MED vs. RO

Performance indicator	MED (15,000 m^3/day)	RO (15,000 m^3/day)
Daily water sales	$8,550	$8,550
PBMR DPP electricity sales (based on 165 MWe)	$95,040	$95,040
Electricity sales lost	$0	$2,189
Capital cost	~M$21.75	~M$19.5
Additional revenue/day	$8,550	$6,361
Straight payback	7 years	8.4 years

Assumptions:

- Water production of 15,000 m^3/day assumed
- RSA electricity price $24/MWh (6% growth over the next 6 years)
- MED and RO capital cost assumed to be $1450 and $1300 per m^3/day capacity, respectively
- Western Cape water sale price $0.57/$m^3$ (6% growth over the next 6 years)
- Straight payback does not include time value of money

Challenges

- **MED and RO options for the PBMR DPP remains to be assessed in terms of feed water pre-treatment requirements**
- **A detailed economic trade-off study needs to be performed to determine the best suited option**
- **The fresh water market in the surrounding areas of the Koeberg Nuclear Site needs to be assessed**
  - The market will have a significant influence on the choice of the desalination option
  - MED produces industrial quality water
  - RO produces lower quality fit for human use

Summary

- PBMR DPP can address water scarcity concerns through desalination
- MED and RO are mature and proven desalination technologies
- PBMR DPP waste heat is ideally suited for the LT-MED process
- LT-MED utilizing 220 MWt waste heat could produce 15,000-30,000 m^3/day*
- Rejected seawater can serve as pre-heated feed water for a RO plant
- Size of RO plant a function of electricity available for desalination

*To be confirmed with detailed thermal-hydraulic model and economic evaluation

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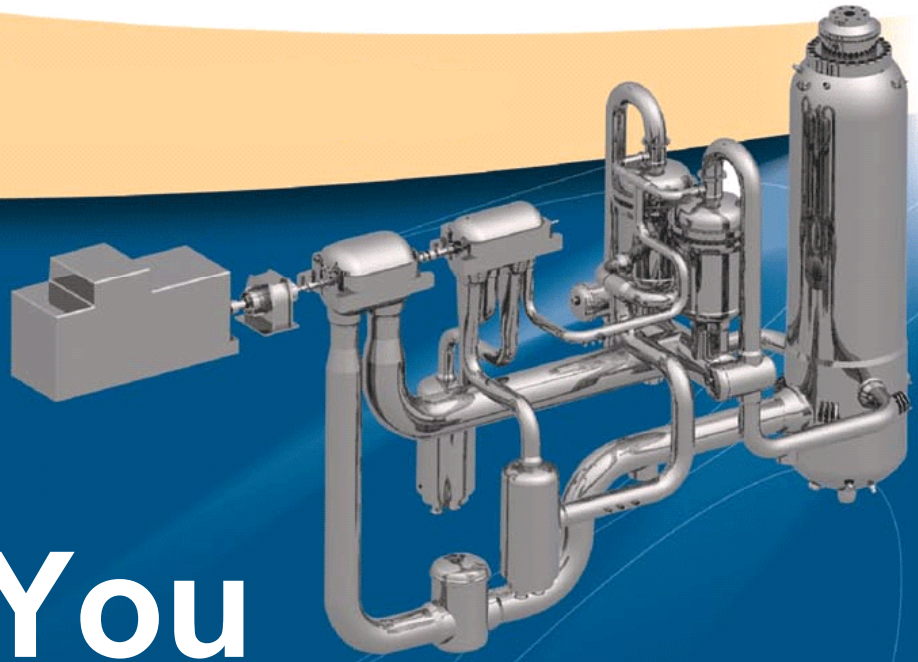

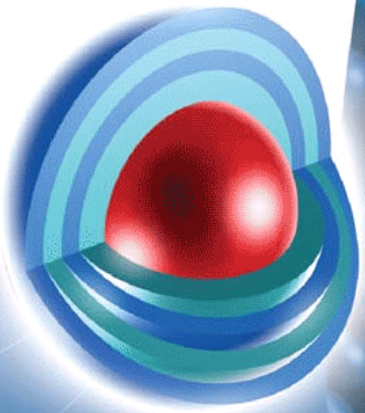

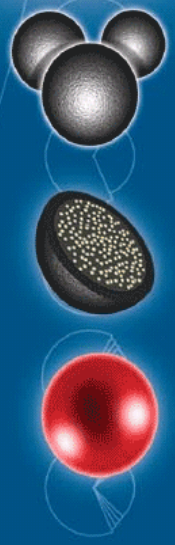

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