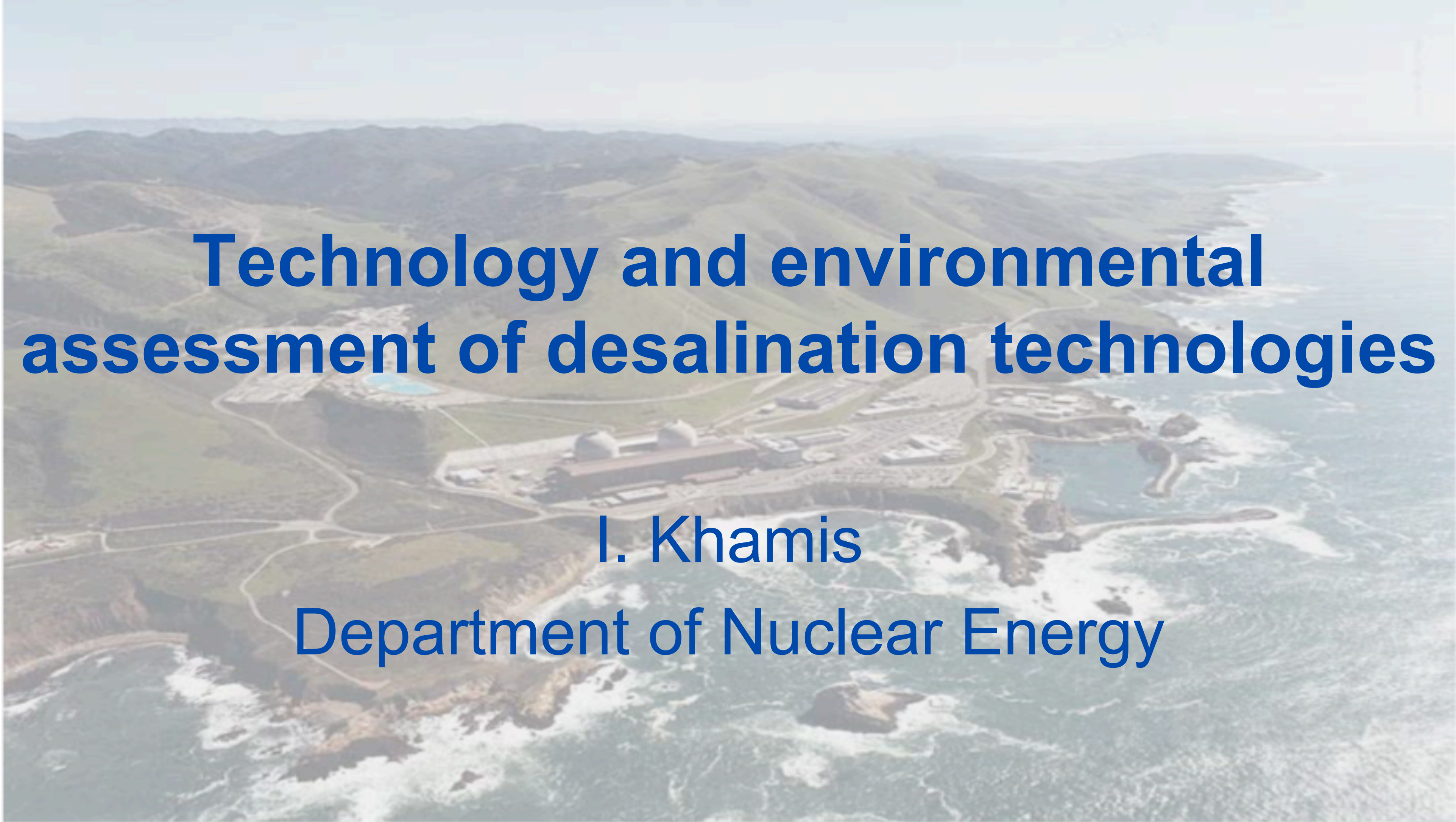

Technology and environmental assessment of desalination technologies

I. Khamis
Department of Nuclear Energy

IAEA
International Atomic Energy Agency

Contents

- Environmental impacts of nuclear desalination
- Economics
- Safety aspects
- Water quality and monitoring
- Conclusion

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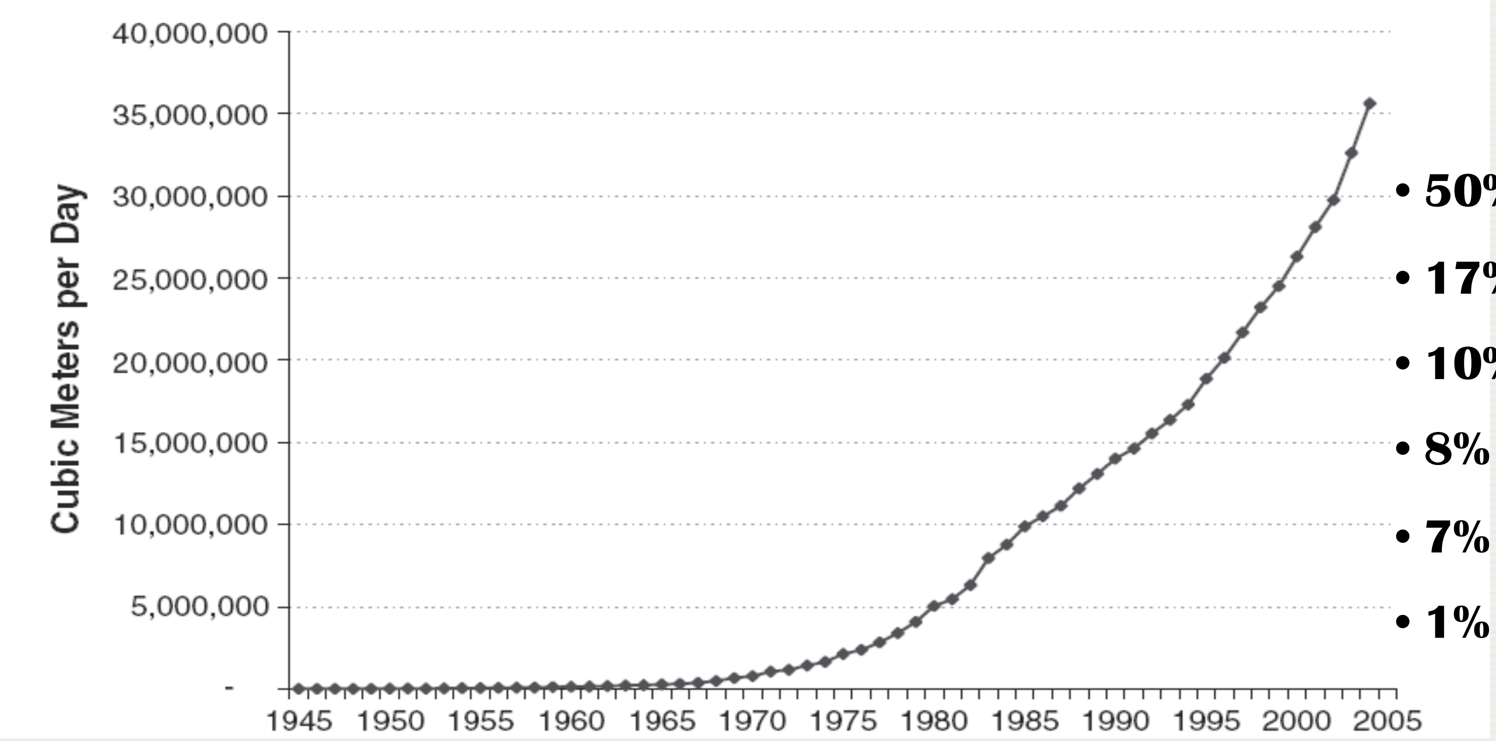
Growing interest in Environmental performance of desalination systems

- Desalination capacity is growing exponentially
- Current estimates are 50 million cubic meters of water production per day

+ 60 Newcomer



- 50% Gulf region
- 17% N. America
- 10% Asia
- 8% N. Africa
- 7% Europe
- 1% Australia

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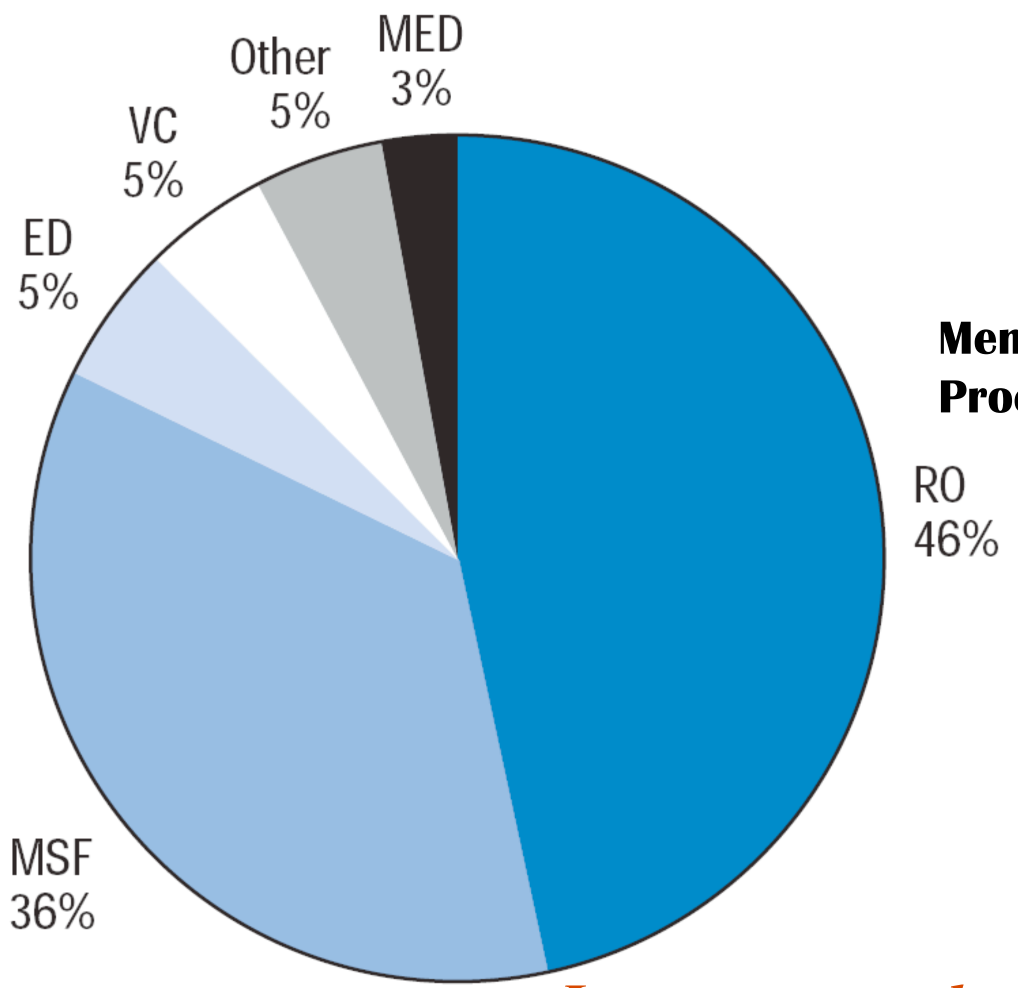
Source: Wangnick/GWI. 2005.

Desalination Technologies



Membrane Processes 51%

Distillation Processes 49%

Large systems lead to major adverse impacts

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Source: Wangnick/GWI. 2005.

Main Environmental Issues

Despite major improvement,

- **Marine**
- **Coastal**
- **Atmospheric**
- **Socio-economic**

'60s artist's rendering of a nuclear desalination plant. Source: ORNL

Co-location reduces impacts

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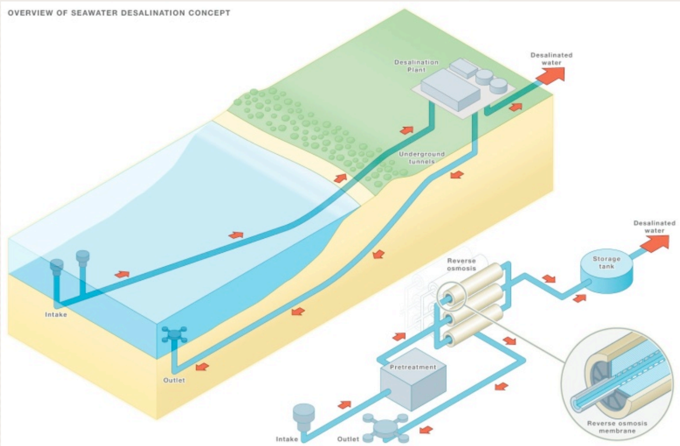
Desalination's impact is complex



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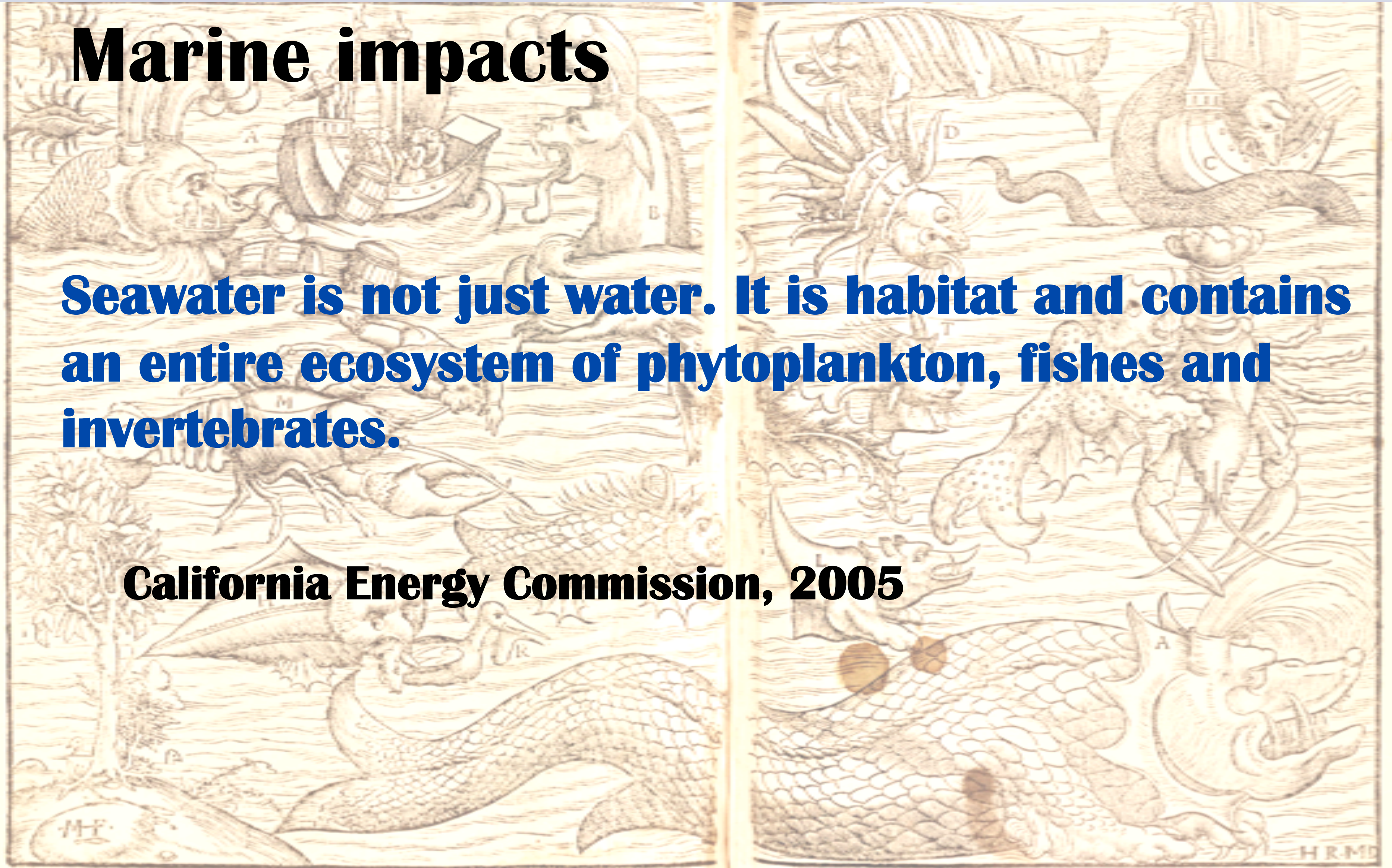
Marine impacts

Seawater is not just water. It is habitat and contains an entire ecosystem of phytoplankton, fishes and invertebrates.

California Energy Commission, 2005

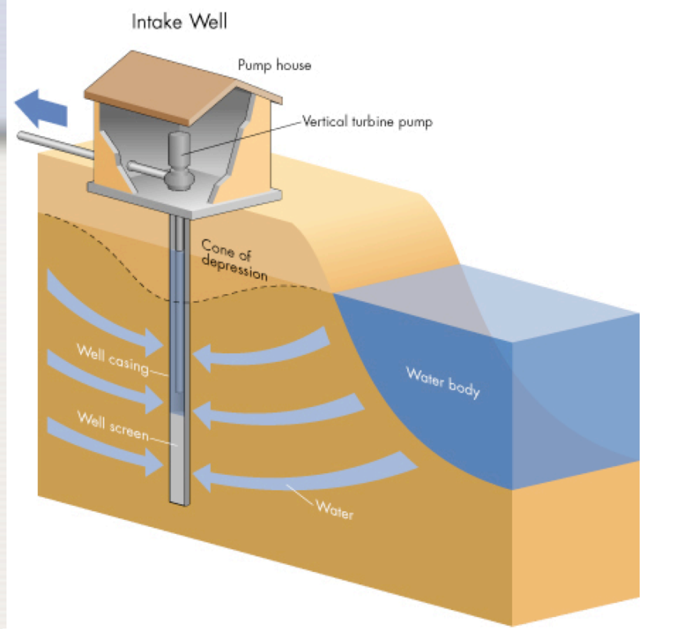


Source: S. Münster, *Cosmography*. 1598.

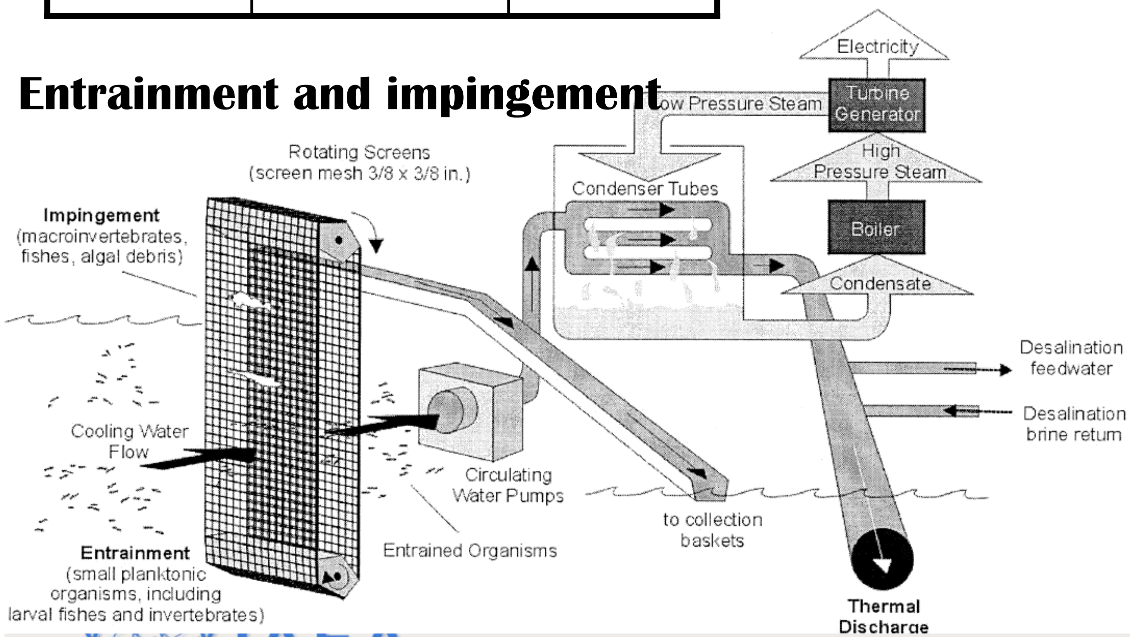
Direct and Indirect Intake systems

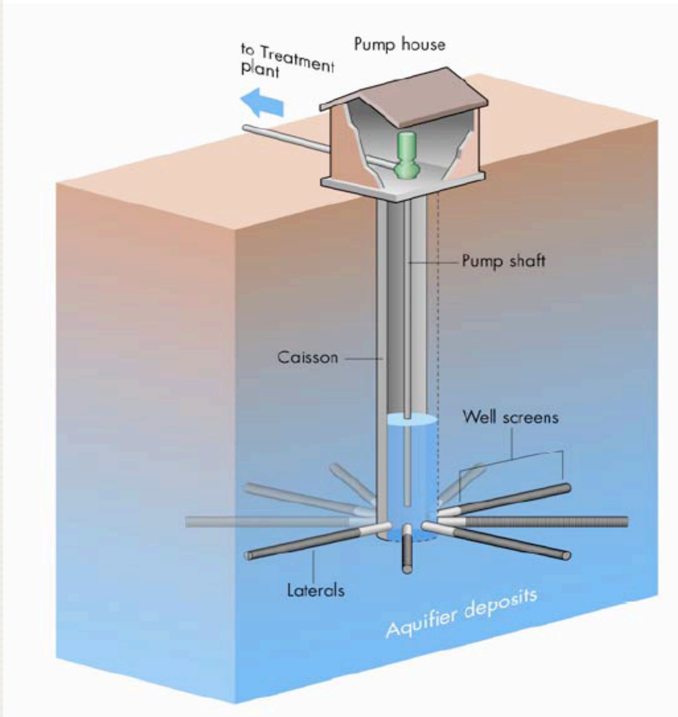
	OTC	Cooling towers
Nuclear	95 – 230	3 – 4
Fossil	76 – 190	2
NG/Oil CC	29 - 76	1

Once-through cooling needs for Nuclear is the highest



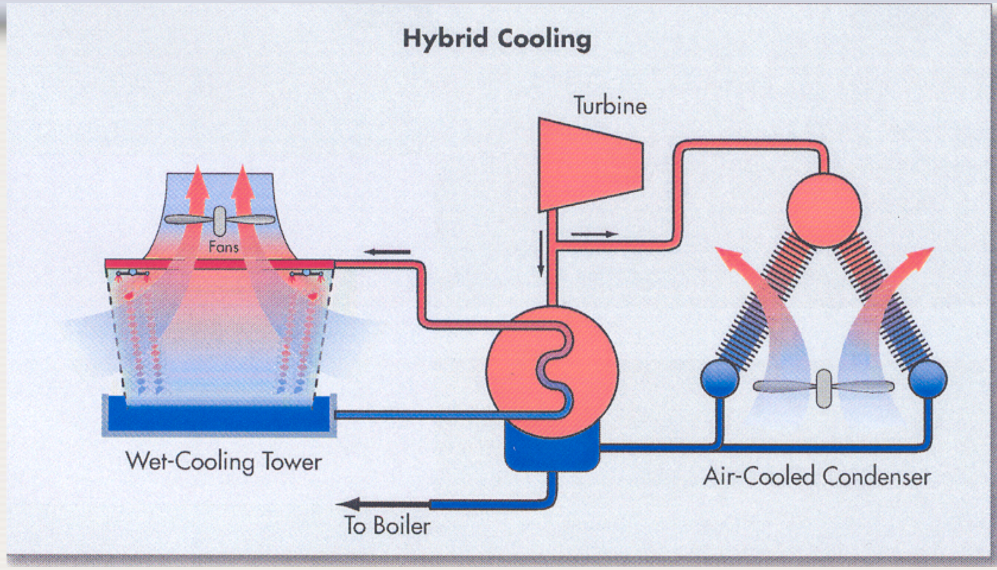
Entrainment and impingement





- Mitigation recommendation

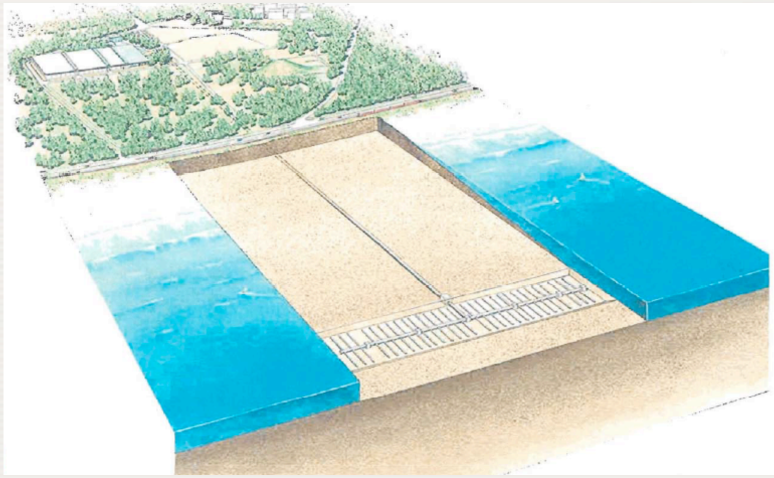
Dry- and/or wet-cooling
for Nuclear, and



Source: Barker, 2007

Indirect intake systems
for desalination, or

Intake from areas with
low biological activity



Source: Fukuoka District Waterworks Agency

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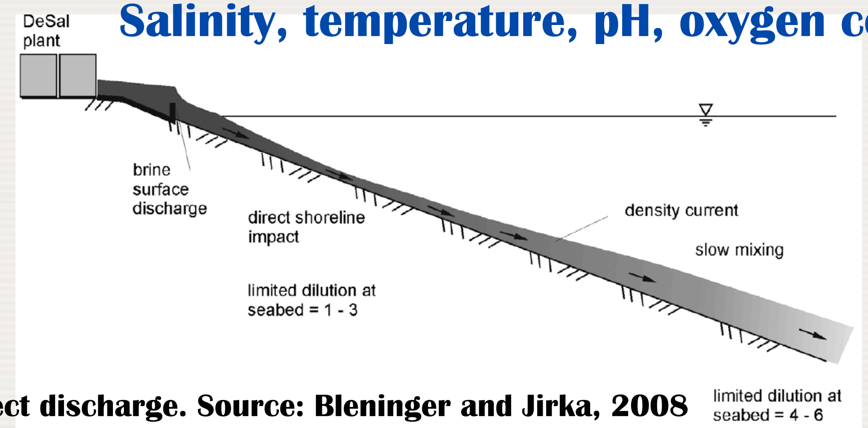
Discharge

- Regulations

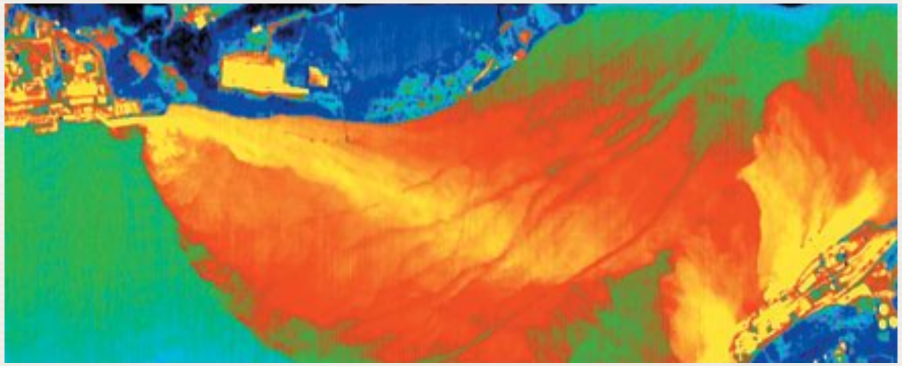
US Clean Water Act Section 403(c), Barcelona Convention, IAEA Safety Guide No. NS-G-3.2

- Discharge characteristics

Salinity, temperature, pH, oxygen content, toxicity



Direct discharge. Source: Bleninger and Jirka, 2008



Thermal discharge. Source: IGER Archive Collection, 1988

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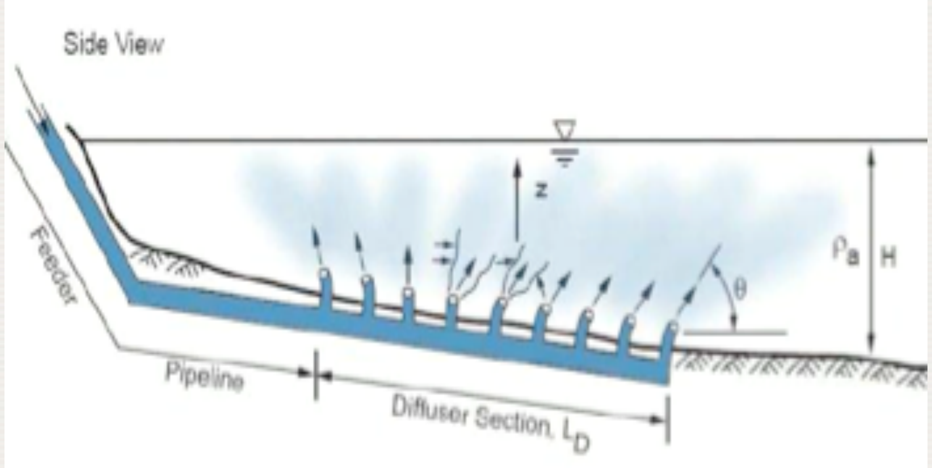
Mitigation recommendations

Commercial use of the discharged brine,

Dilution with multi-port diffusers in biologically insensitive areas…



Discharge diffusers. Source: USEPA 1991

…and environmentally sound intakes!

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Marine Impacts

- All energy options are similar
- Mitigation schemes are easily installed
- Once-through cooling has to be abandoned

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Coastal Impact

- Land use and visual impacts
- Aquifer contamination
- Construction impact
- Noise impact

Land Use

Method	Area needed for a 1GW power plant
Solar (photo voltaic)	20 – 50 km^2
Windmill	50 – 150 km^2
Biomass (including bio-alcohol/oil)	4000 – 6000 km^2
Nuclear	1 - 4 km^2

Source: IAEA; WEC, 2007

Desalination facilities of 100 000 m3/day would require

- 0.2 km^2
- 12 to 510 MW of installed power – requiring co-located power generation

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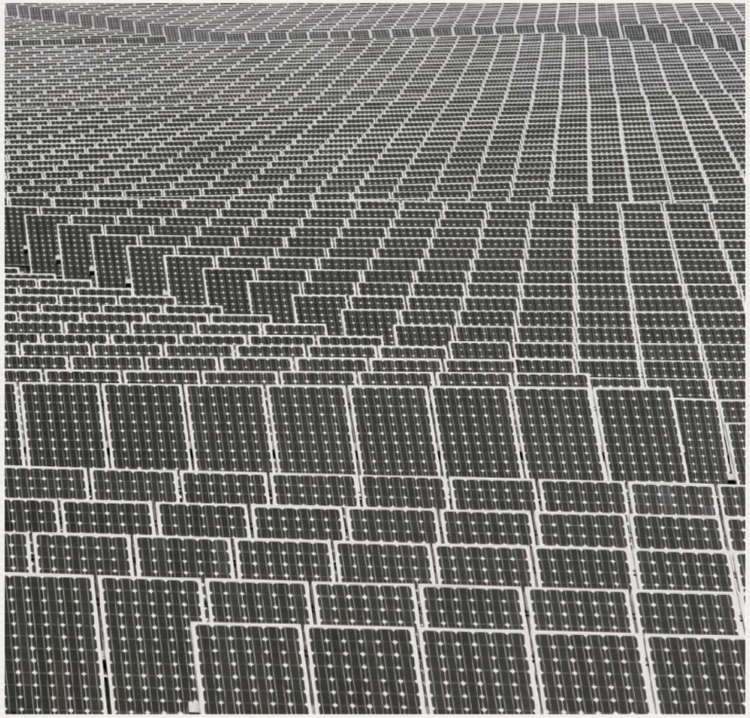
Visual Impacts

Paluel (F) nuclear power plant

Serpa (P) solar power plant



Palm Springs (US) wind farm

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In conclusion of Coastal Impacts

- Nuclear Desalination
  - is best for large water production
  - economy of scale is a big advantage
- Coastal impact for large-capacities nuclear desalination is lower than any other option

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Atmospheric Impacts

Carbon Dioxide Release

- for 100,000 m3/day desalination plant

Power Source	CO_2 Released (tons)
Coal	200 to 900
Natural Gas	100 to 200
Wind	0.02 to 0.2
Nuclear	0.02 to 0.2

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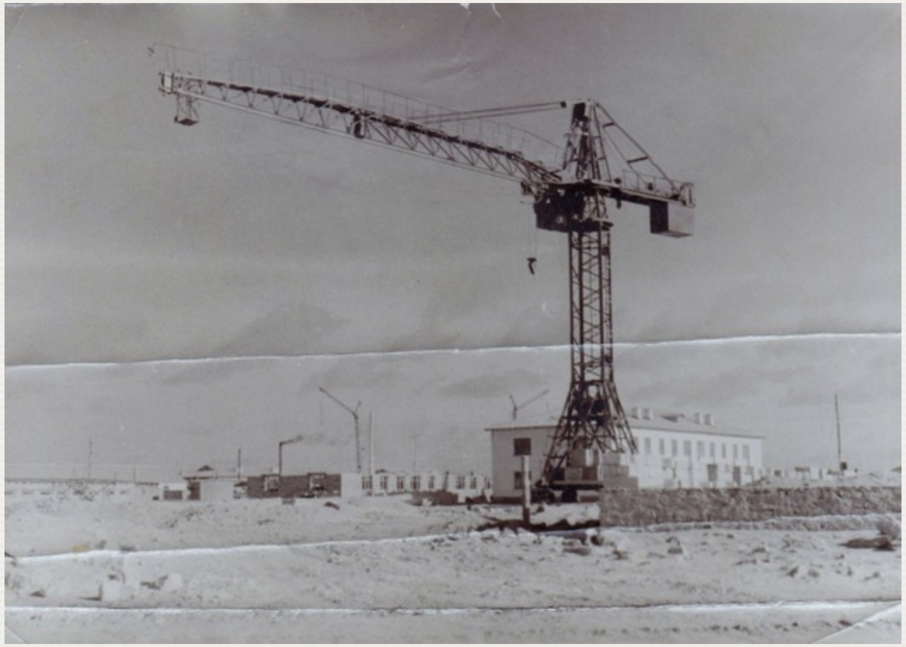
Socio-economic Impacts

Development stimulus

- energy availability
- water availability



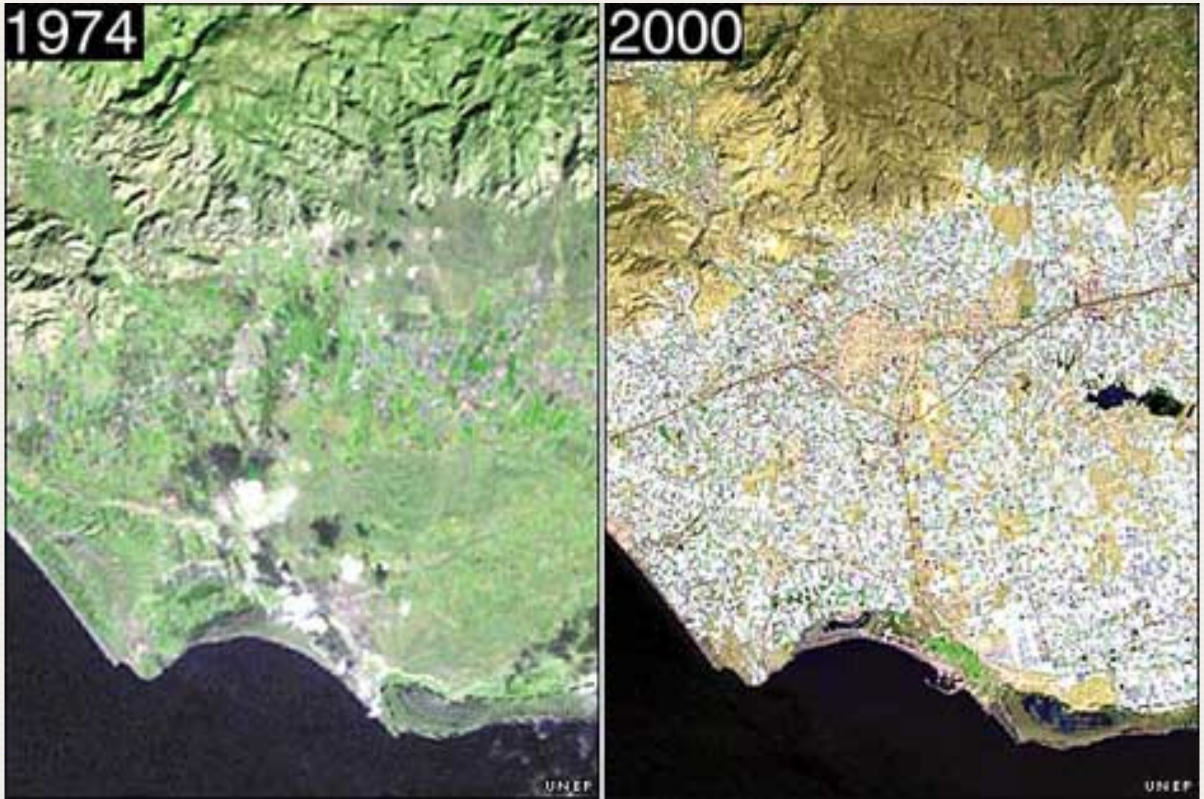
Aqtau, 1961

Aqtau, 1975

Source: www.aqtau.kz

Changes in the land use, development of new industries

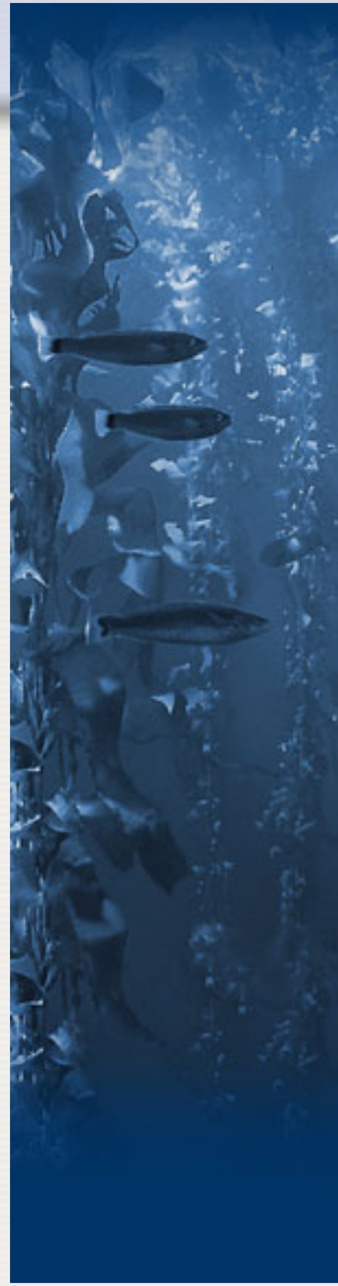
- population relocation, social disturbance
- environmental justice



Source: UNEP

Public acceptance

- safety
- public health
- environmental impacts



Economics of Nuclear Desalination

- Demonstrated competitiveness of nuclear power for desalination compared with fossil-fueled energy sources
- % Contribution to overall cost:

  Capital (35-45%), energy (25-55%), O&M (10-25%)
- Capital cost relatively insensitive to the desalination component
- Desalination costs range: \$0.40 – 1.90 / m^3

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Economics of Nuclear Desalination

- MSF costs systematically higher than RO or MED
- RO economically favorable for less stringent drinking standards (e.g. WHO, <1000 ppm TDS)
- Costs higher with smaller reactors (“economy of scale” effect)
- RO and MED costs are, in general, comparable

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Economics of nuclear desalination

- Results are site specific.
- Nuclear desalination costs:
  - RO: 0.5 to 0.94 $/m3
  - MED: 0.6 to 0.96 $/m3
  - MSF: 1.18 to 1.48 $/m3

- Comparing to current prices of oil:

all nuclear options are economically competitive.

Economic target of nuclear desalination costs:

0.4-0.6US$/m^3 depending on the region

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Electricity cost (US cent/kWh) in Europe

	MIT 2003	France 2003	UK 2004	Chicago 2004	Canada 2004	EU 2007
Nuclear	4.2	3.7	4.6	4.2 - 4.6	5.0	5.4 - 7.4
Coal	4.2		5.2	3.5 - 4.1	4.5	4.7 - 6.1
Gas	5.8	5.8- 10.1	5.9, 9.8	5.5 - 7.0	7.2	4.6 - 6.1
Wind onshore			7.4			4.7 - 14.8
Wind offshore			11.0			8.2 - 20.2

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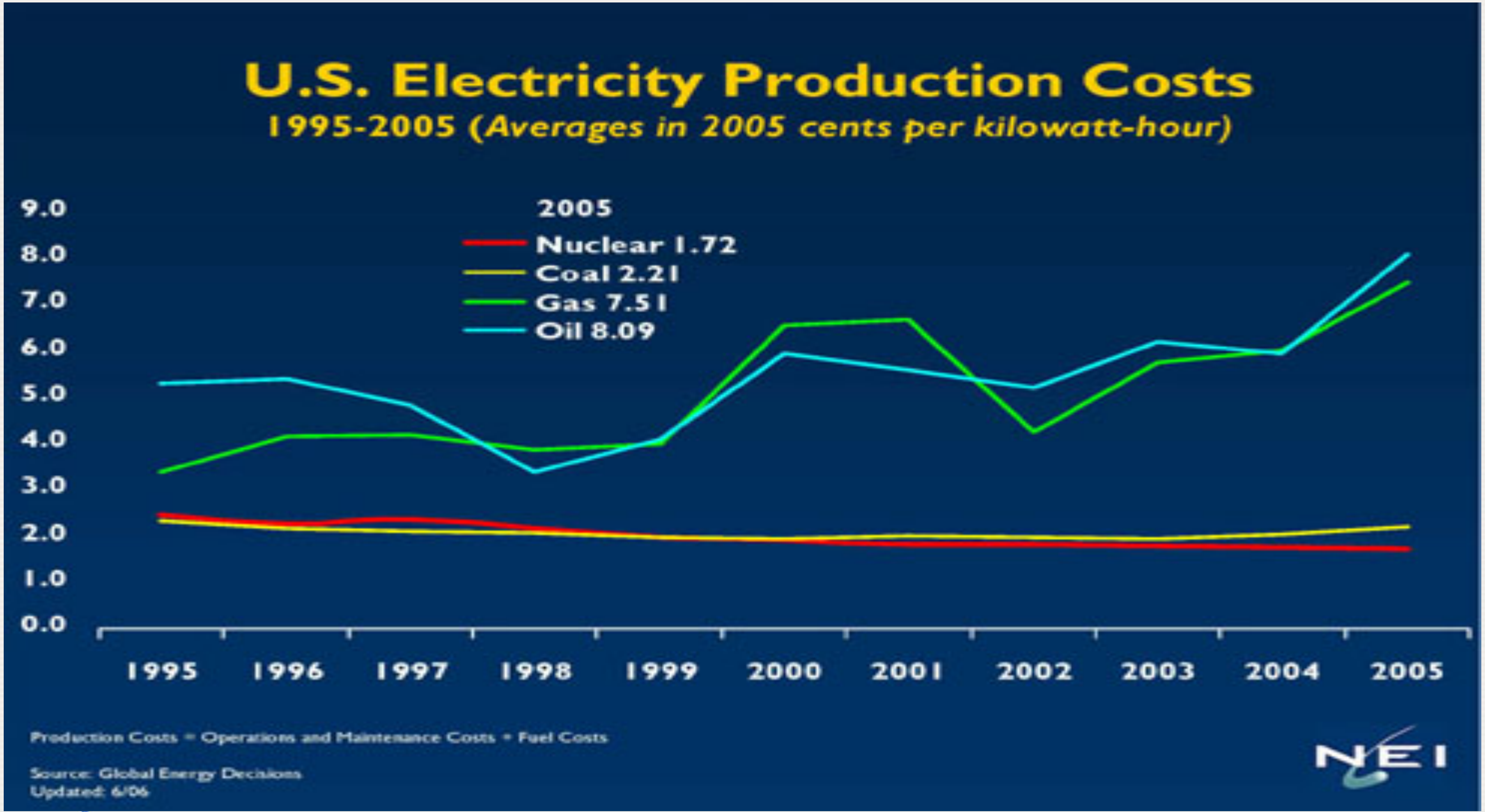
Costs of Fuel & OM in the US



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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

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Incentives of Nuclear desalination-cont.

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

Total revenue (**Cogeneration 90% electricity +10% water)** :

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

Using MED

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

Net benefit of ND: 493.2 M$ ~ 7% more

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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

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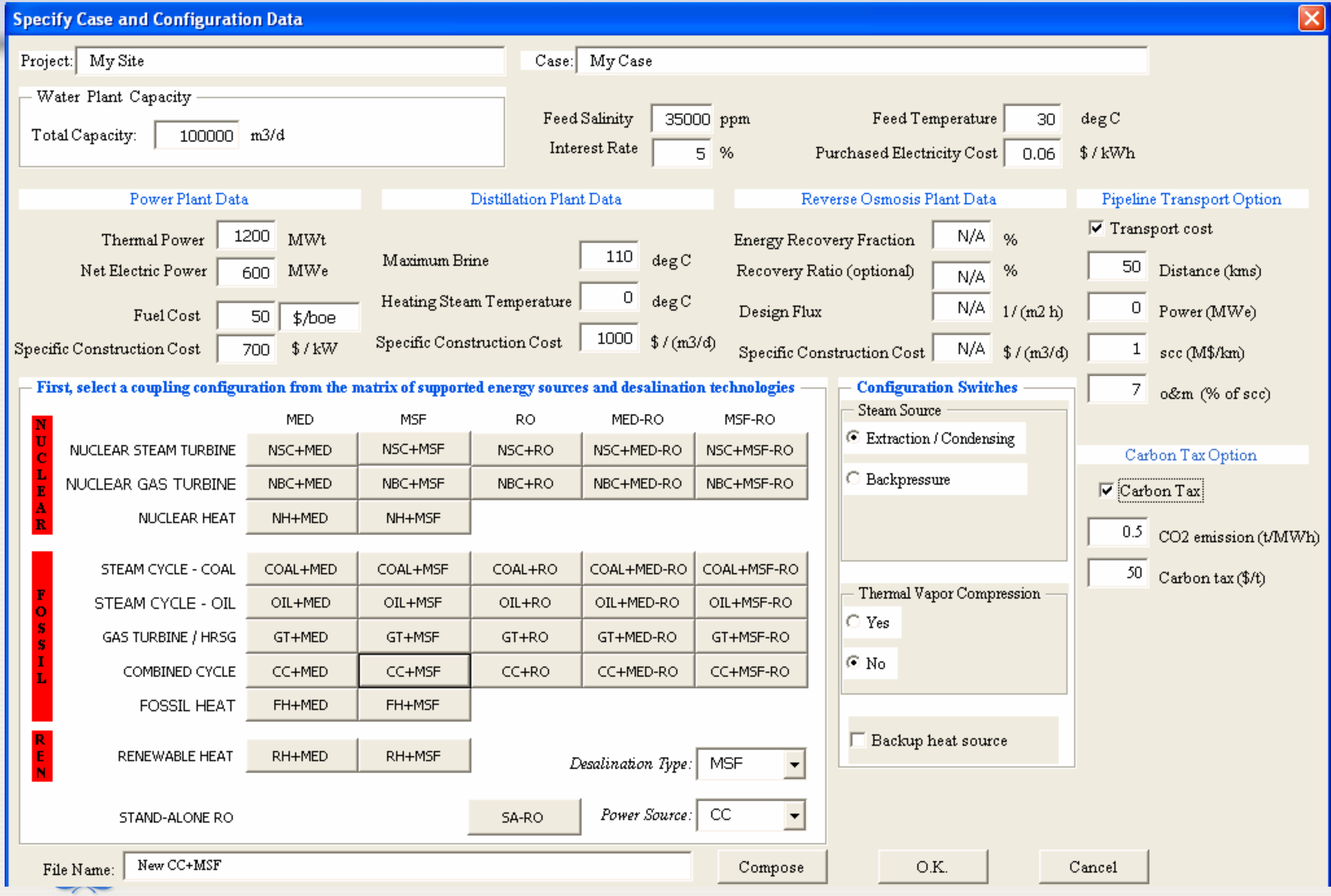
Economics of Nuclear Desalination-DEEP



INPUT to DEEP

Case identification and site characteristics
Required water plant capacity at site
Desalination plant type
Performance Input
Cost Input
Economic parameters input data
Performance Calculation
Cost Calculation
Economic Evaluation

The Various energy options considered in DEEP

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

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The desalination processes considered in DEEP

Process	Abbreviation	Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

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Safety of Nuclear Desalination

Safety level of ND

- **Safety issues of ND are similar to NPP.**

- Safety: mainly dependent of nuclear plant, the design of coupling technology, and transient interactions between the two plants.

- Additional **specific safety considerations** for the coupling schemes between the reactor and the desalination plant (DP):

- Issues related to environment, shared resources, and siting…etc.

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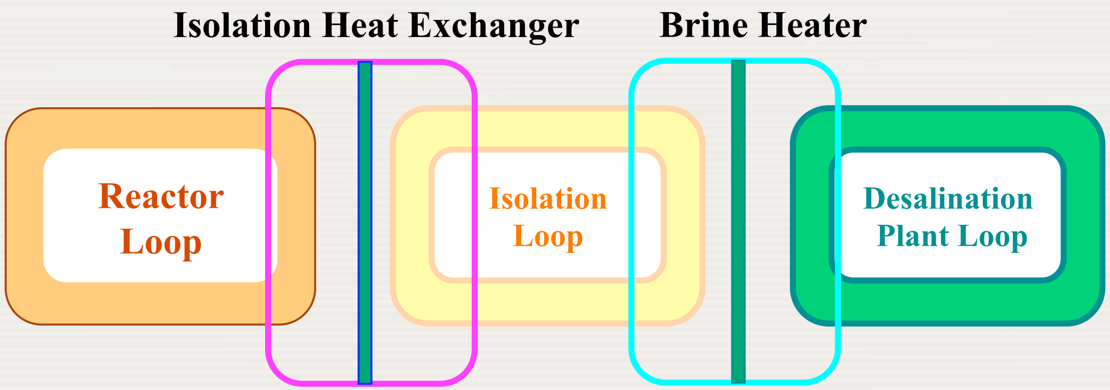
Safety in nuclear desalination

Usual safety barriers are:

- Fuel matrix
- Fuel cladding
- Primary circuit
- Reactor containment system

- Coupling through ***additional HX*** i.e. increase in the number of usual safety barriers that are standard in a NPP.

COUPLING



- Coupling dictates **specific safety considerations** :
  - **Prevent the transfer of radioactive materials from NPP to DP**
  - **Minimize the impact of thermal desalination system on the nuclear reactor**
  - **Protect the public and environment against radiation hazards that may be released from the ND system.**
  - **Specific requirements as dictated by the National Regulatory Body.**
  - **Backup heat or power source (NPP in refuelling).**

Safety implications of Coupling of NP to DP

- Thermal (MSF, MED): NP and DP have effect on each other.
- Contiguous (RO, VC): No thermal coupling, only electric from the grid
- If contiguous system draws part or all of its feedwater from the condenser cooling water discharge of NP (as in preheat of RO), Safety should be evaluated.

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Additional Safety concern

- Resist pressure from the ND on the NP
- Safety culture is to exist and to be placed above production capability.
- Availability of alternate sources of thermal or electrical energy in case of reactor shutdown

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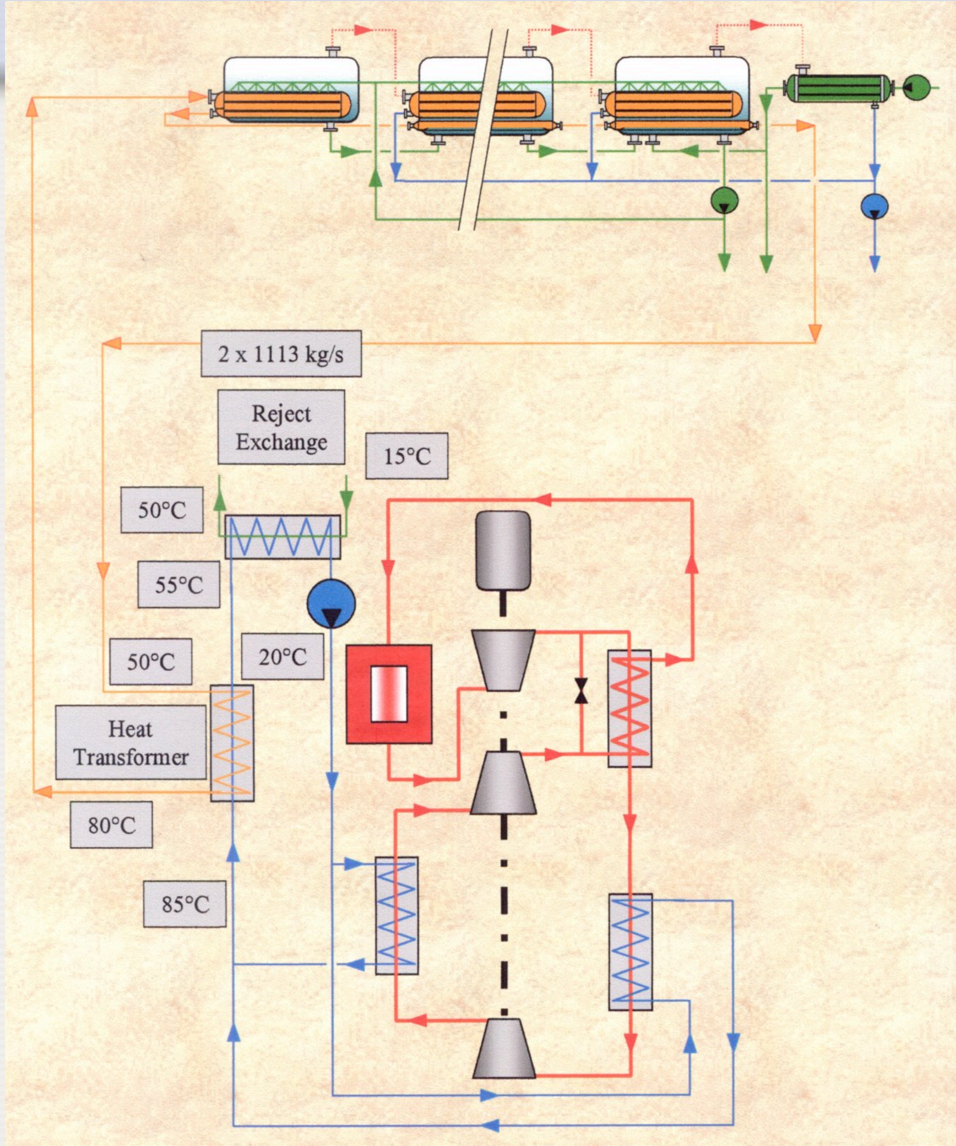
How can Nuclear Power Plants be used for the production of fresh water?

- Existing and planned nuclear power stations could be used to produce fresh water using the surplus of
  - Waste heat
    - MED desalination plants
      - GT-MHR, through a flash tank using intercoolers reject heat
      - HRT, using steam extractions
      - PWR, using low pressure steam extraction
      - AP1000, using condenser reject heat
      - FPU, using condenser reject heat
    - through MSF desalination plants
      - BWR, through a flash tank using turbine steam extractions
  - Electricity
    - though RO desalination plants
      - Any plant (e.g., CANDU-6)
  - A combination of heat and electricity
      - PHWR: steam extraction to MSF and electricity to RO

Coupling of the GT-MHR to a plant MED



- The higher the temperature of the circuit extraction of heat, more water can be produced
- Coupling Alternatives:
  - ➢ through a flash tank
  - ➢ using hot water
- For 1 single MED, coupling through a flash tank is more efficient
- For 2 MED, coupling through hot water is more efficient

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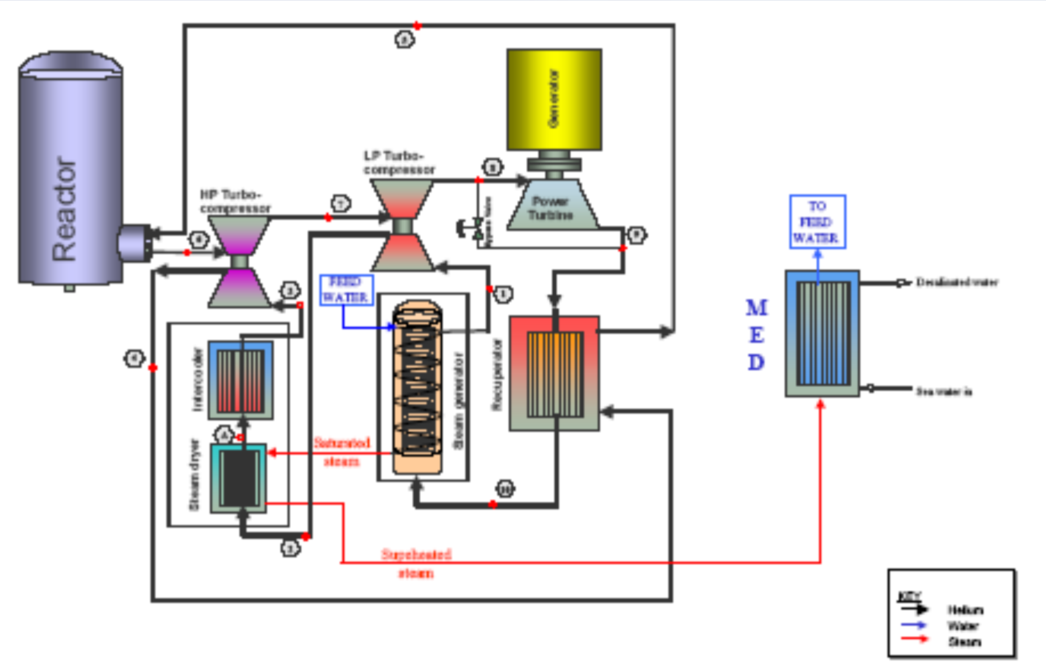
HTR – MED (Micanet)



HTR / Desalination Process Coupling Scheme

HTR coupled to MED Results (similar results for MSF)			
Steam interface data HTR to MED	35.8 kg/s	70ºC	0.3 bar
Desalinated water produced	27200 m^3/day (~ 90 Hm^3/year)		
Electric power produced	122 MWe		

Water Demand

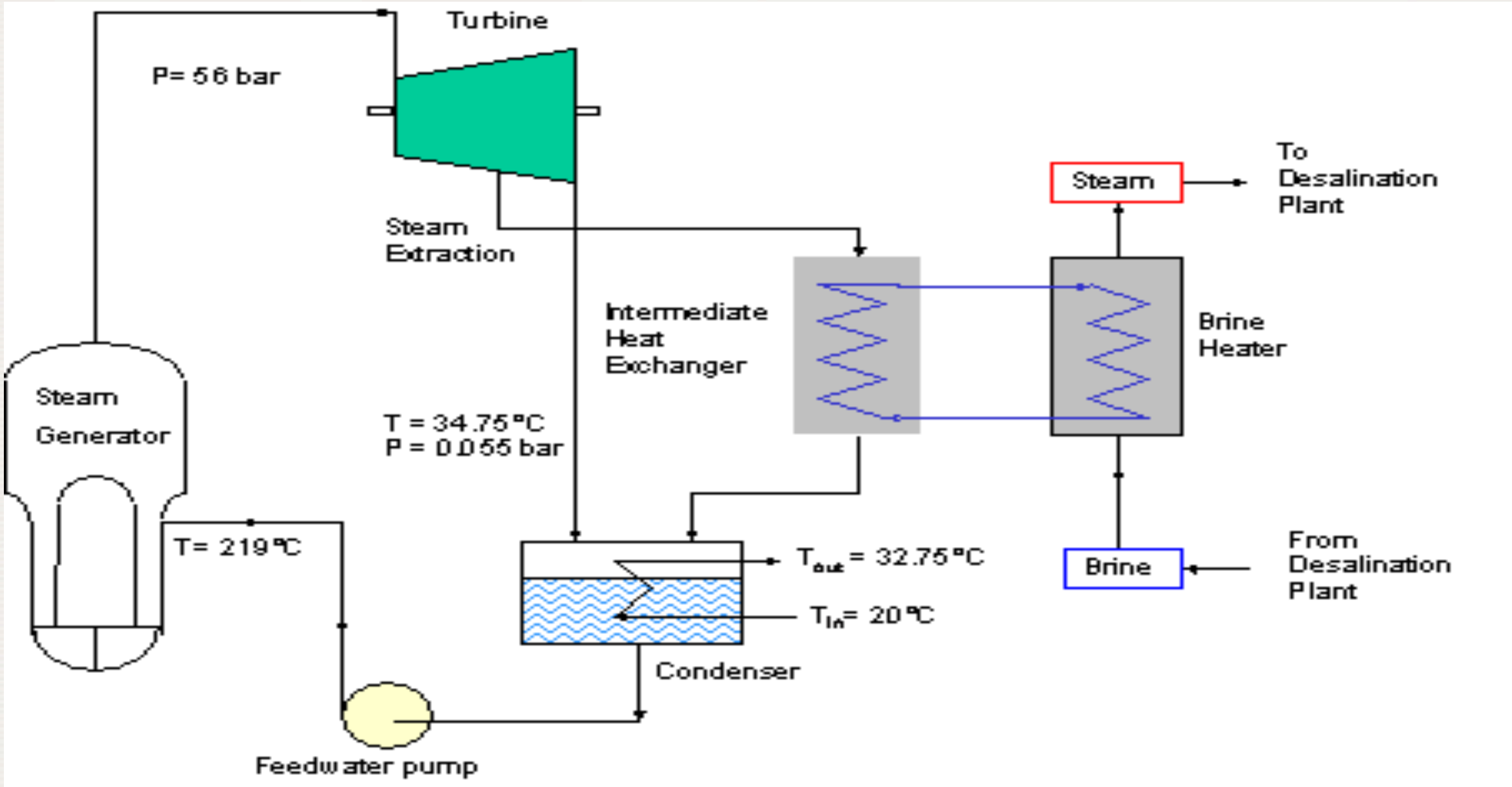
- Estimated water shortage in the Mediterranean region ≈ 3700 Hm^3/year
- Current desalination projects in Spain: more than 600 Hm^3/year

Proposed Scheme

1 HTR unit coupled with MED or MSF plant

- Typical water and electricity demand for a middle-sized town (population ≈ 50.000)
- Water production and efficiency improves using excess of electricity for RO plant

Conventional coupling of PWR NPP with MED



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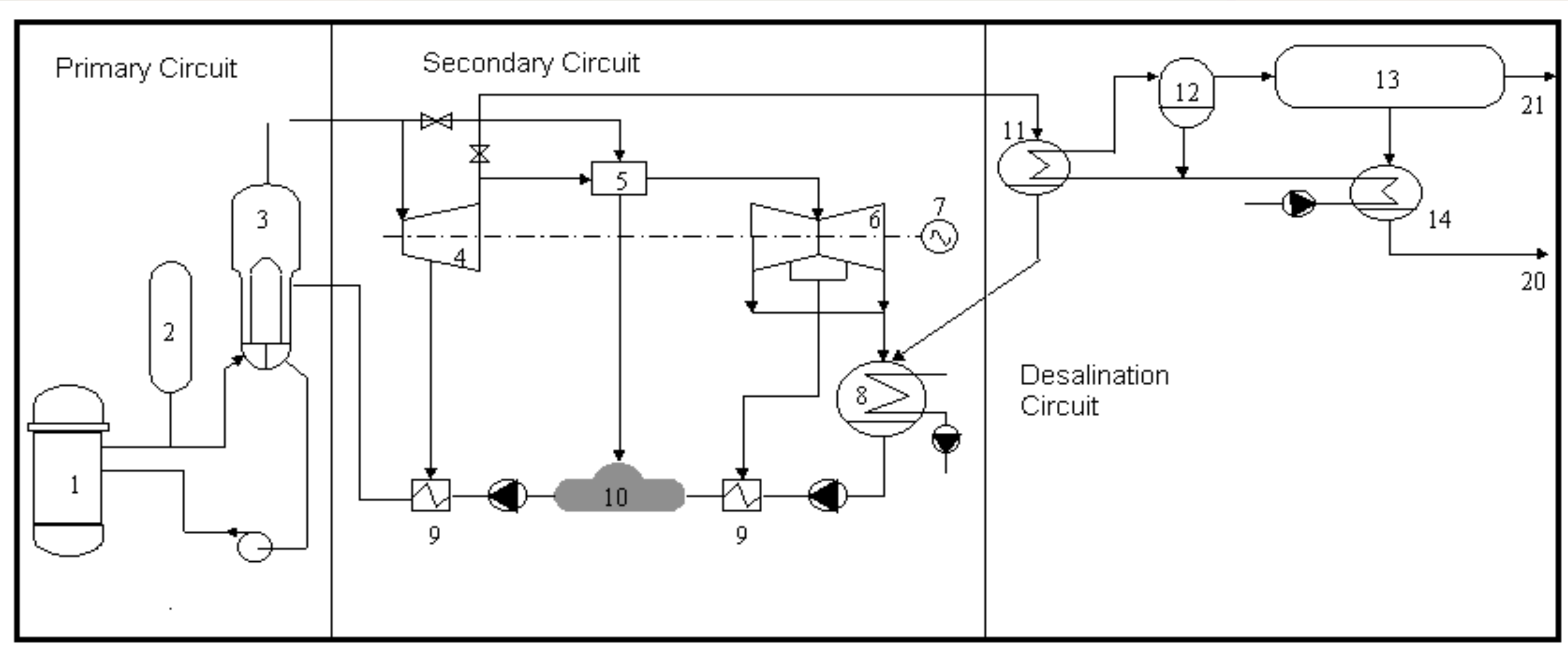
AP1000 coupled to the MED through the condenser



The higher the pressure in the condenser, the greater amount of water can be produced, but power generation is reduced.

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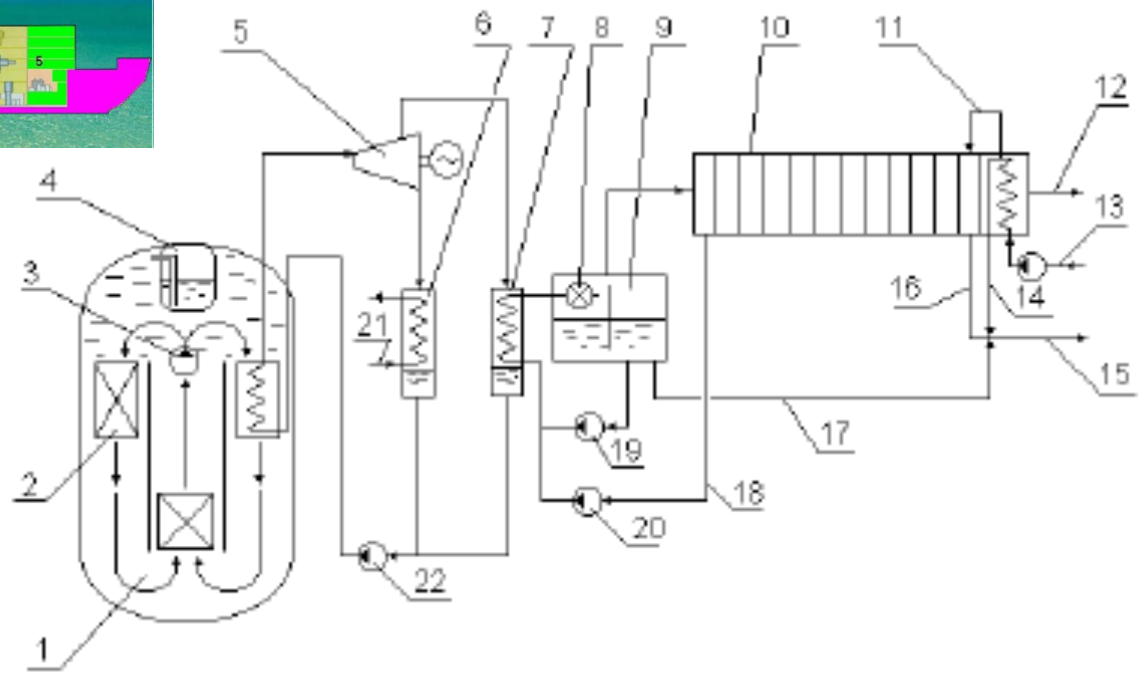
Coupling of Floating Power unit FPU and MED



1 – nuclear reactor; 2 – steam generator; 3 – primary pump; 4 – pressurizer; 5 – turbogenerator; 6 – turbine condenser; 7 – condenser-heat exchanger of distillation plant; 8 – throttle; 9 – flash tank; 10 – multi effect distillation plant; 11 – feed makeup; 12 – product water; 13 – seawater intake; 14 – reject cooling water; 15 – brine outfall; 16 – brine discharge; 17 – flash tank blowdown; 18 – preheated water makeup; 19 – intermediate recirculation pump; 20 – makeup pump; 21 – cooling seawater; 22 – feed pump

*Floating Power Unit, Modular Reactor Russian pressurized water of 2 x 150 MW

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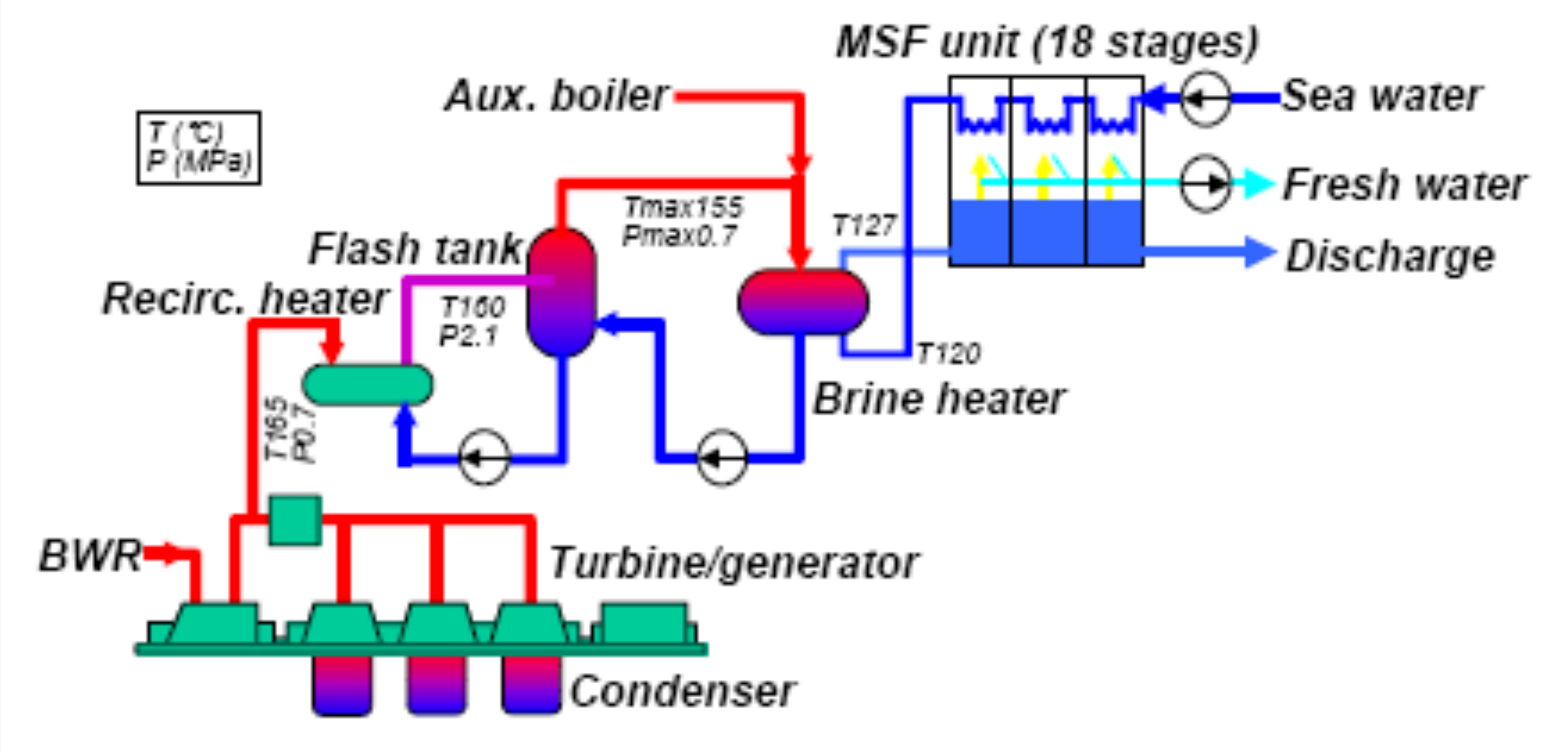
BWR coupled to MSF (*Kashiwazaki-Kariwa Unit 1)*



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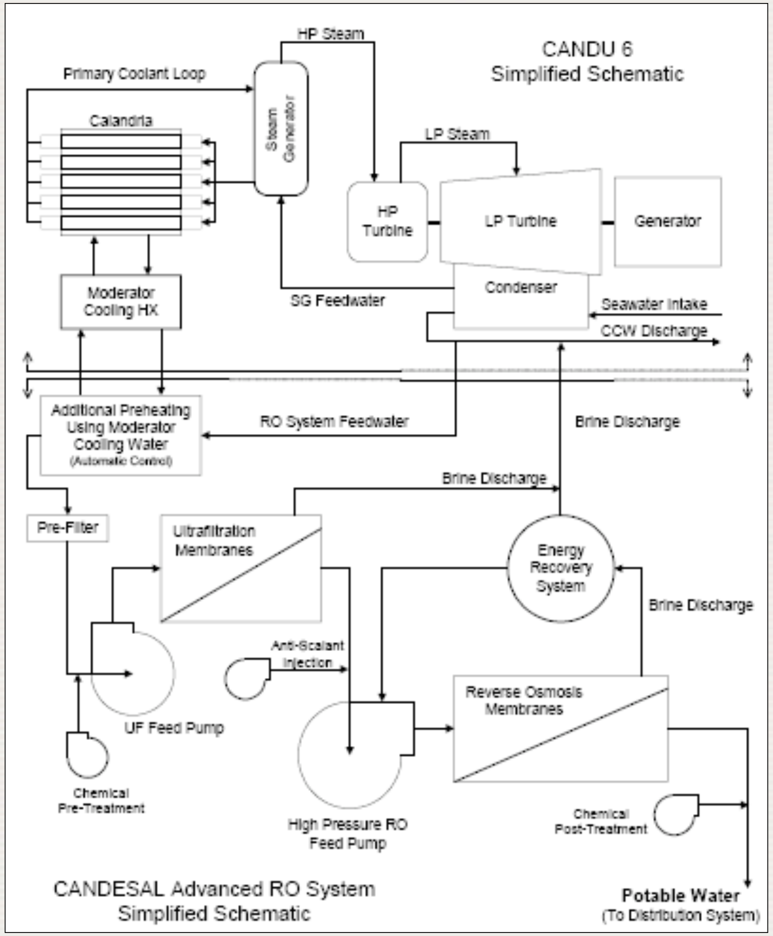
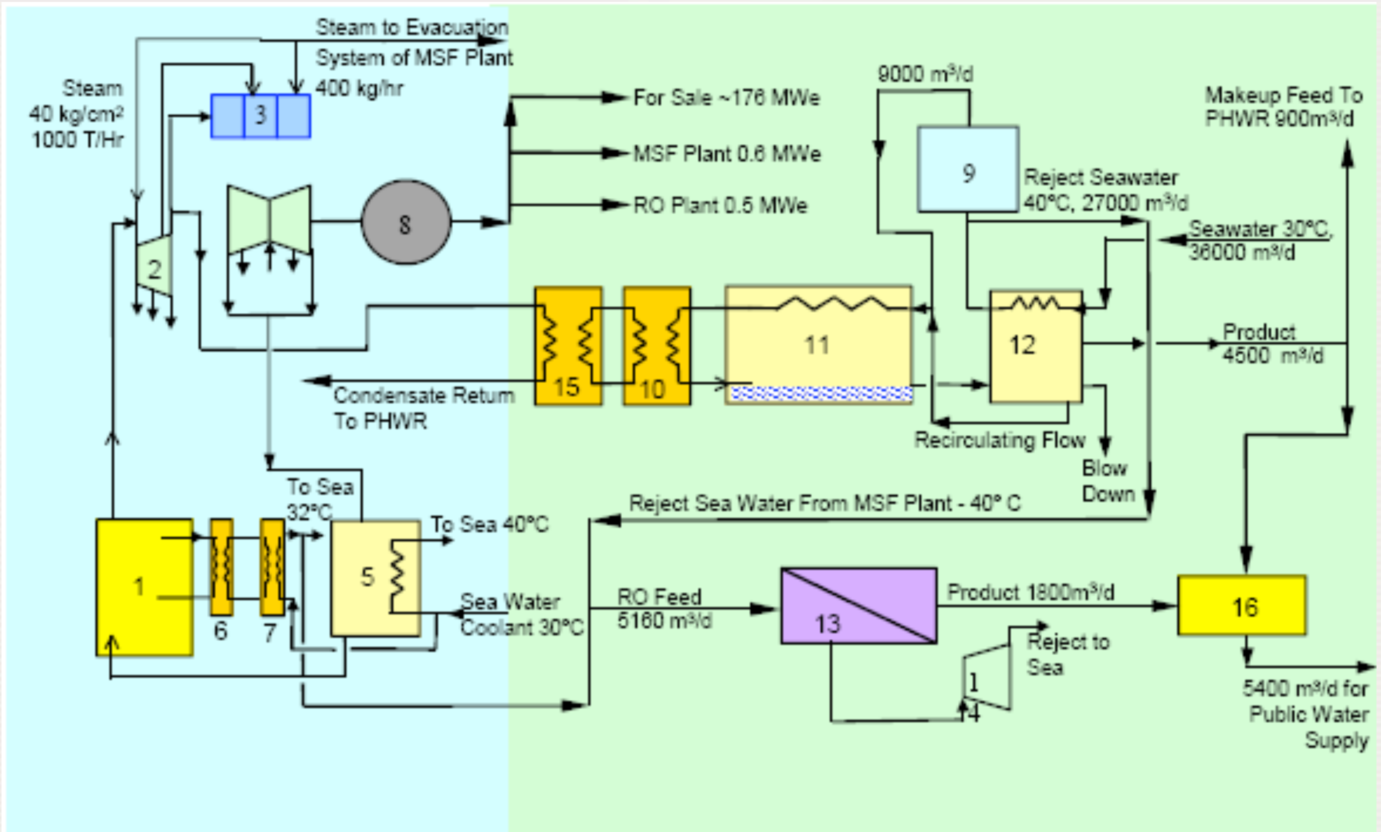
Coupling in CANDU-6 * and RO

* Canadian Reactor of 600 MW pressurized water moderated by heavy water



Coupling PHWR* with MSF- RO (Kalpakkam, India)



* Indian Reactor of 170 MW pressurized water moderated by heavy water

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Water quality and monitoring

WHO Guideline for Drinking-Water Quality (Vol. 1, Chapter 9, page198, 2004)

Recommended annual dose limit from radionuclides present in the drinking water = **0.1 mSv/year**

- Estimated lifetime risk of stochastic health effect: 10E-5
- Average global background radiation exposures : 2.4

Populations in areas with 10 times naturally high background radiation are without any health consequences

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Water quality and monitoring

ALLOWED TRITIUM LEVELS IN DRINKING WATER

Country	Tritium limit (Bq/l)
Finland	30000
Australia	76103
Canada	7000
EU	100
Kazakhstan	7700
Switzerland	10000
United States	740
WHO	10000

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Water quality and monitoring

- ***Desalinated water quality:*** in compliance with national and international regulations (WHO)
- ***Radiological limits for drinking water:*** based on consumption of ~2 litres per day
- ***Standards:*** according to the ALARA principle
- ***Monitoring*** for radioactivity and conductivity: batch monitoring, intermediate loop and product stream water.

Water quality and monitoring-cont.

National regulatory body:

- Closed loop between NPP and DP with pressure boundary.
- Limits on discharge of radioactivity to environment.
- Continuous monitoring of leakages
- Criteria for environmental release of desalted water
- Protection against radiation hazards due to discharge of brine and cooling water.

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Conclusion

Nuclear desalination is:

Feasible, safe, economically competitive, and benign to environment.

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…Thank you for your attention