IAEA 60 Years
Atoms for Peace and Development

Nuclear Desalination

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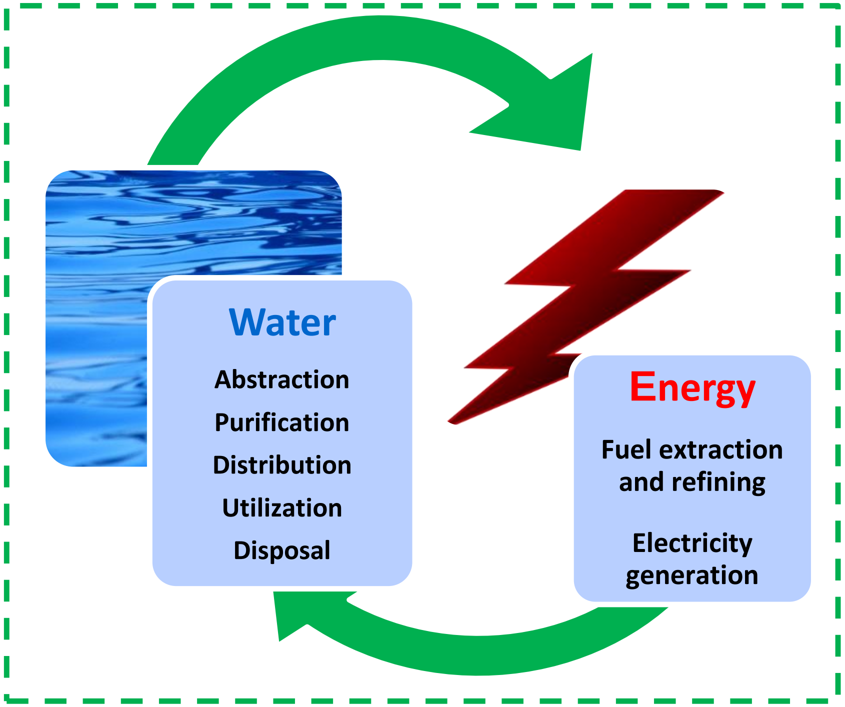
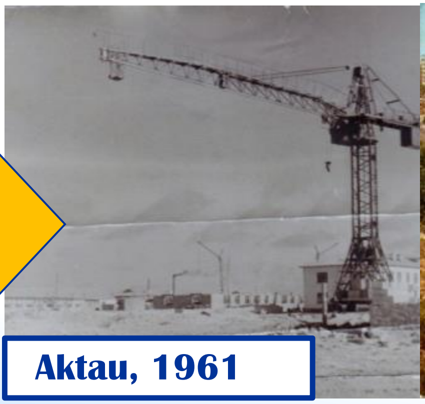
Success Story on Nuclear Desalination:



SUSTAINABLE DEVELOPMENT

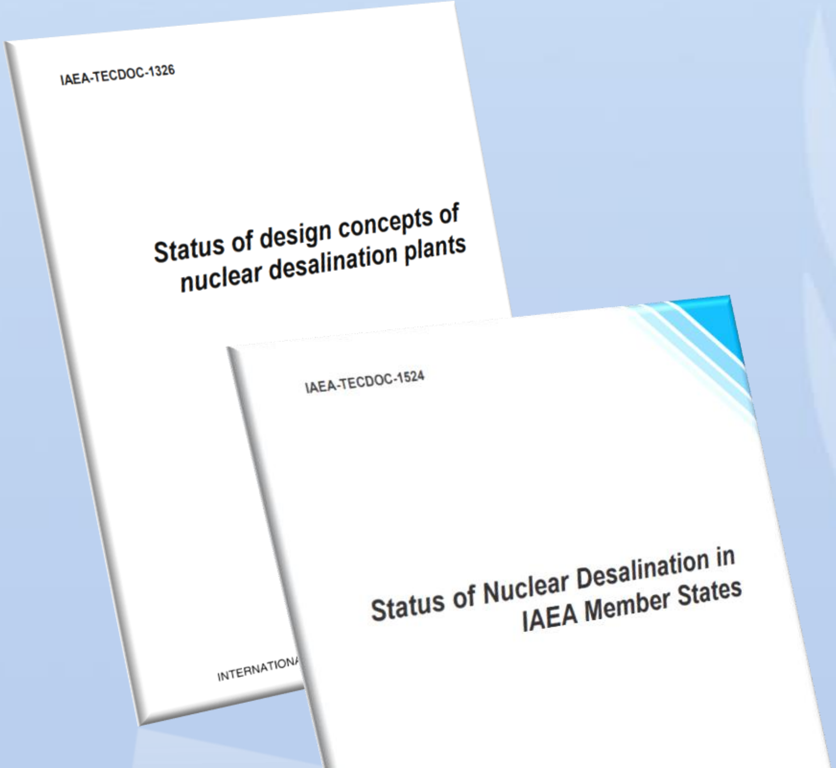
Synergies in Nuclear desalination are a catalyst for sustainable development



Aktau, 1961

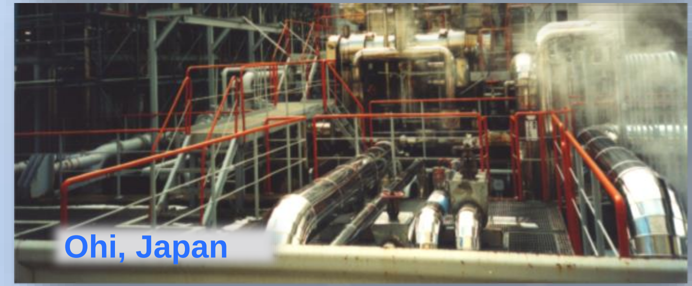
Aktau, 1975

Introduction & Status




Kalpakkam, India


Karachi, Pakistan


Ohi, Japan


Aktau, Kazakhstan

Nuclear Desalination

What is it?

Any co-located desalination plant that is powered with nuclear energy

Why?

Viable option to meet:

- Increasing global demand for water & energy
- Concerns about climate change
- Volatile fossil fuel prices
- Security of energy supply → 1+1=~~2~~ 1½

How?

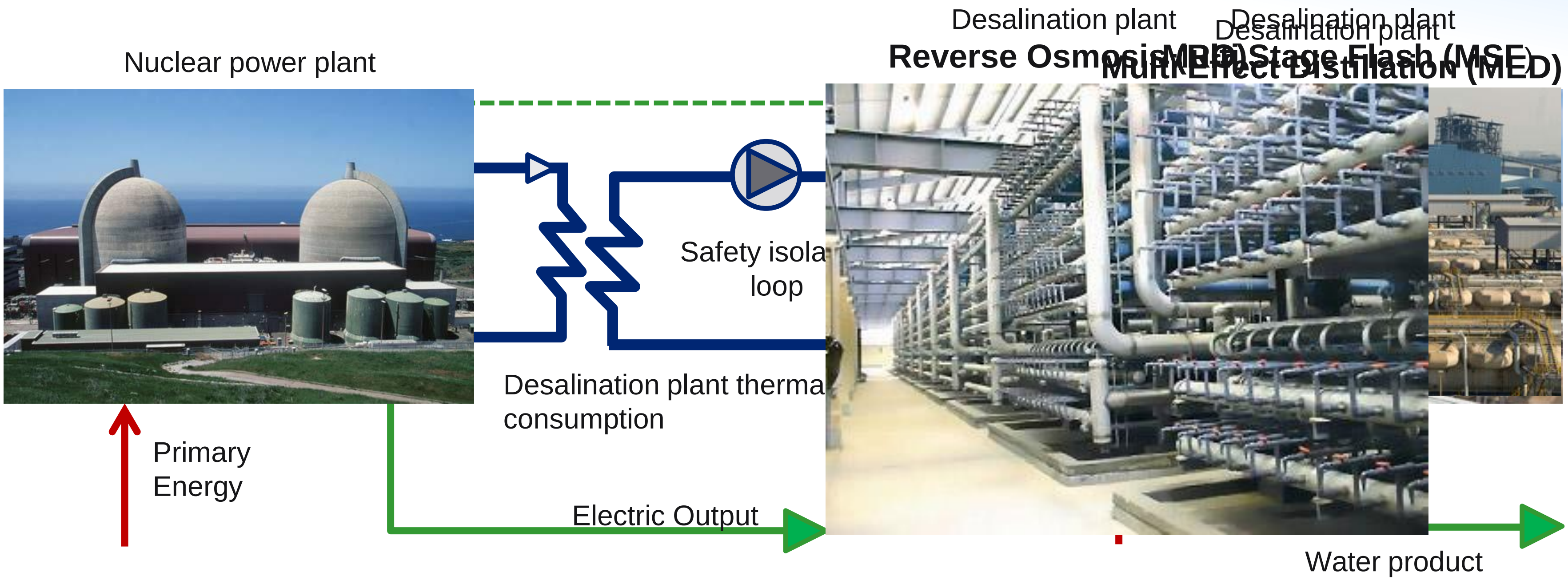
- Cogeneration concept
- Extra safety barriers

Nuclear Desalination

- Nuclear desalination is defined to be the production of potable water from seawater in a facility in which a nuclear reactor is used as the source of energy (electrical and/or thermal) for the desalination process.
- All of the technologies currently in use for desalination require significant amounts of energy, either as low-temperature process heat or electricity.
- Nuclear power plants can provide residual heat, low temperature steam and electricity.

Nuclear Desalination Technology

Sea water desalination with nuclear power



The coupling of two different technologies in a way that ensures the safe operation and the economic excellence of the overall plant→ **Complex plant engineering and design**

Main Parameters in Desalination Processes

- **Capacity** → Production of water (usually in m^3/d)
- **Quality** → Water quality expressed by amount of total dissolved solids (TDS) in the product (in ppm)

Specific for thermal

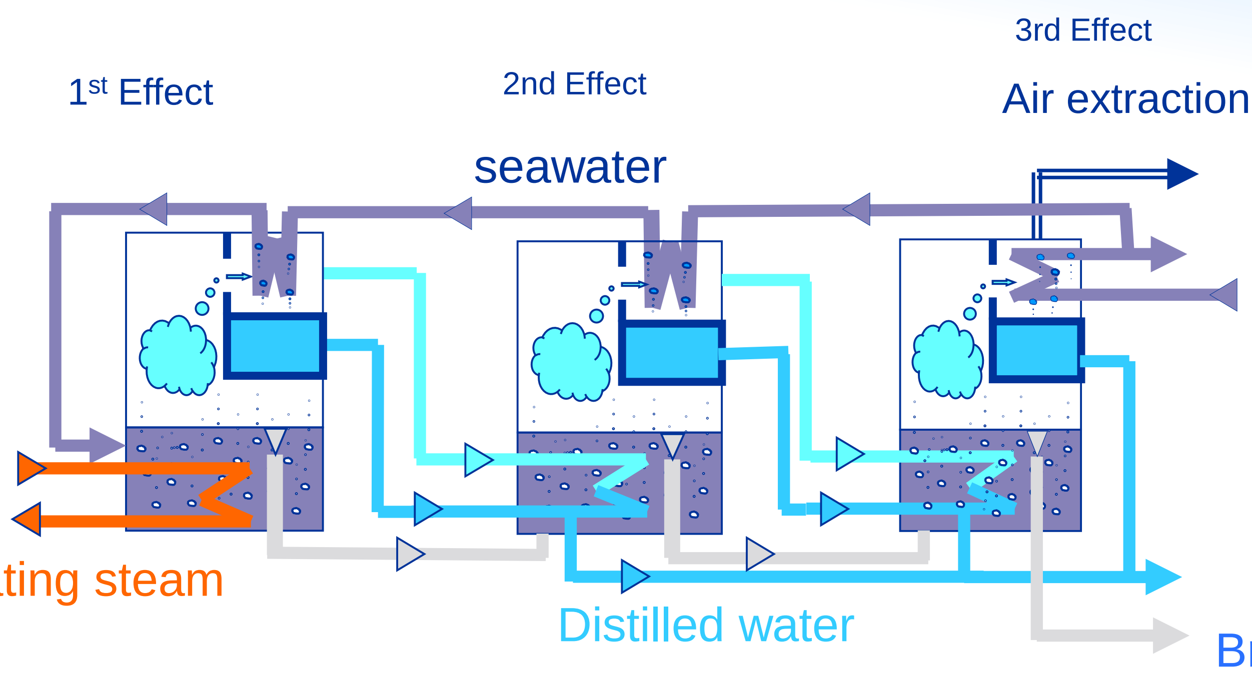
- **Gain Output Ratio GOR** → The ratio of the mass of water product per mass of steam needed. It is used as a measure of efficiency (the bigger the better)
- **Top Brine Temperature** → The maximum temperature of the brine in the first stage/effect. Defines the quality of heat needed and affects GOR.

Specific for membrane

- **Pressure** → The feedwater pressure used to pump the feedwater through the membrane. Usually related with the membrane type and mechanical properties.

Main Desalination Technologies

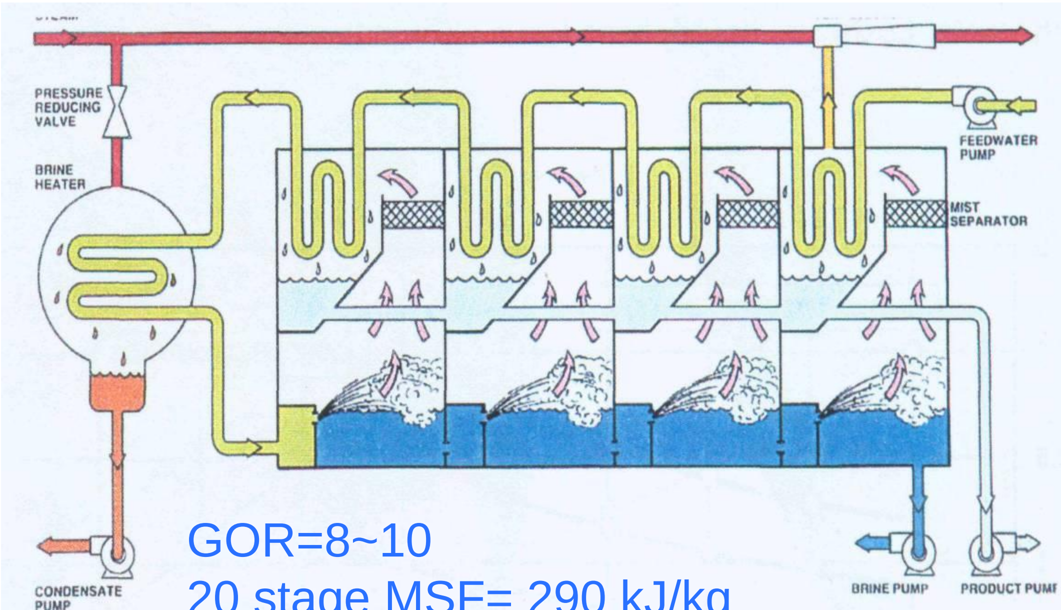
Multiple Effect Distillation (MED) Plant



In the MED process, vapor produced by an external heating steam source is multiplied by placing several evaporators (effects) in series under successively lower pressures, and using the vapor produced in each effect as a heat source for the next one.

Main Desalination Technologies

Multi-Stage Flash (MSF) Distillation Plant



GOR=8~10

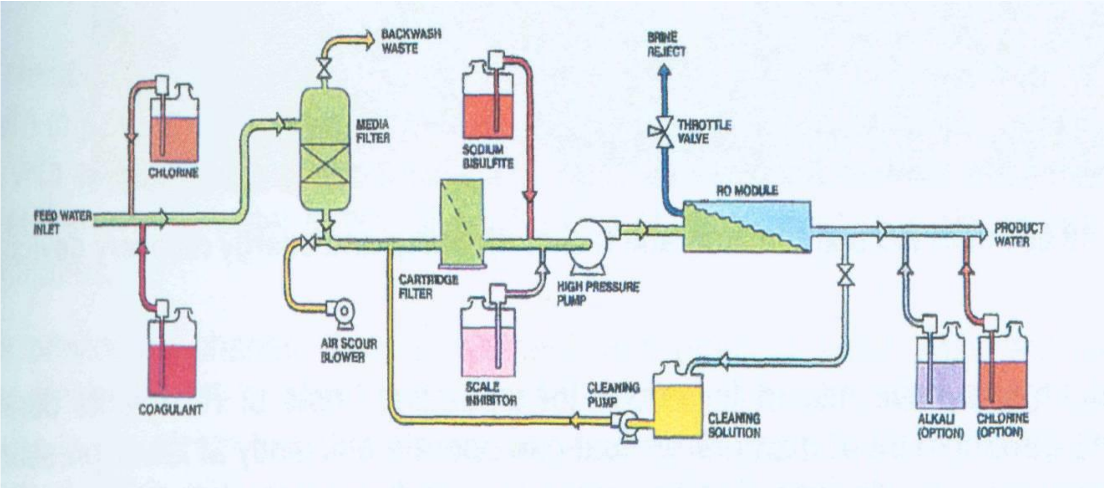
20 stage MSF= 290 kJ/kg

MSF= evaporation and condensation of water

In the MSF process, vapor is produced by heating the seawater close to its boiling temperature and passing it to a series of stages under successively decreasing pressures to induce flashing. The vapor produced is then condensed and cooled as distillate in the seawater tubes of the following stage.

Main Desalination Technologies

Reverse Osmosis (RO)



- Seawater is forced to pass under pressure through special semi-permeable membranes: pure water is produced & brine is rejected.
- The differential pressure must be high enough to overcome the natural tendency of water to move from the low salt concentration side to the high concentration side, as defined by osmotic pressure.

- Operating pressure: 54 to 80 bar for seawater systems (Osmotic pressure ~ 25 bar for seawater)
- The water recovery rate of RO systems tends to be low ~ 40%

Main Desalination Technologies

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	Advantages	Weaknesses
MSF	• Simplicity, reliability, long track record • Minimum pretreatment • Large unit sizes • On-line cleaning	• High energy requirements • Not appropriate for single purpose plants
MED	• Minimum pretreatment • Low TDS product water • Less electrical energy than MSF • Lower capital cost than MSF	• Complex to operate • Small unit sizes
RO	• Less energy needed than thermal • Less feed water needed • Lower capital costs	• Extremely dependent on effectiveness of pretreatment • More complex to operate than thermal • Low product purity • Boron issues to be addressed

Coupling Nuclear Reactors with Desalination

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
- MSF desalination plants
  - BWR, through a flash tank using turbine steam extractions

Electricity

- RO desalination plants
  - Any plant (e.g., CANDU-6)

Hybrid (combination of heat and electricity)

- PHWR: steam extraction to MSF and electricity to RO

Experience on Nuclear Desalination

Plant name	Location	Gross power [MW(e)]	Water capacity $[m^3/d]$	Reactor type/ Desal. process
Shevchenko	Aktau, Kazakhstan	150	80000 – 145000	FBR/MSF&MED
Ikata-1,2	Ehime, Japan	566	2000	LWR/MSF
Ikata-3	Ehime, Japan	890	2000	LWR/RO
Ohi-1,2	Fukui, Japan	2 x 1175	3900	LWR/MSF
Ohi-3,4	Fukui, Japan	1 x 1180	2600	LWR/RO
Genkai-4	Fukuoka, Japan	1180	1000	LWR/RO
Genkai-3,4	Fukuoka, Japan	2 x 1180	1000	LWR/MED
Takahama-3,4	Fukui, Japan	2 x 870	1000	LWR/RO
Diablo Canyon	San Luis Obispo, USA	2 x 1100	2180	LWR/RO
NDDP	Kalpakkam, India	2 x 170	1800	PHWR/RO
Karachi	Karachi, Pakistan	[illegible]	[illegible]	MED

Commissioned in 2010

Types of Nuclear Power Plants & Desalination Technologies used for Nuclear Desalination

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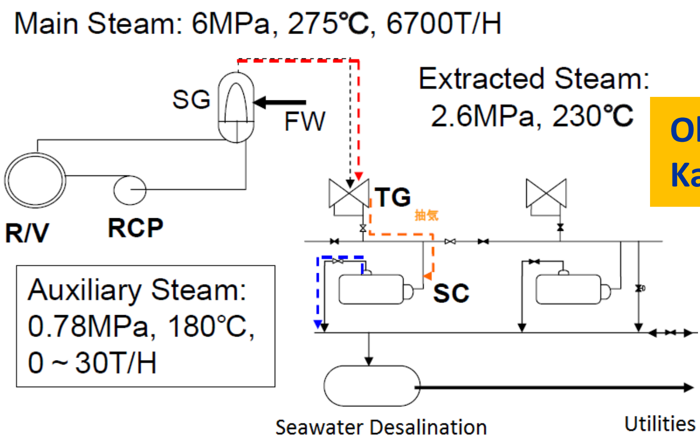
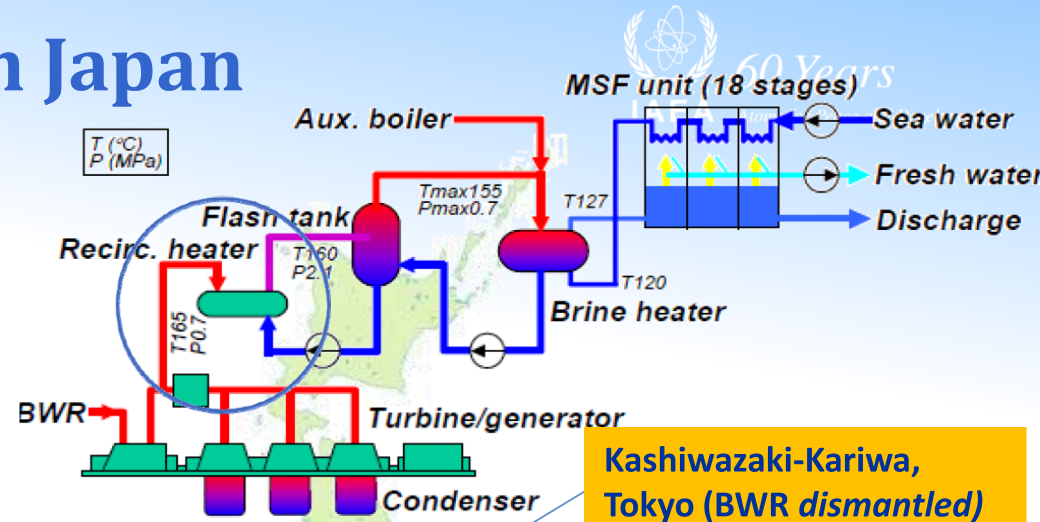
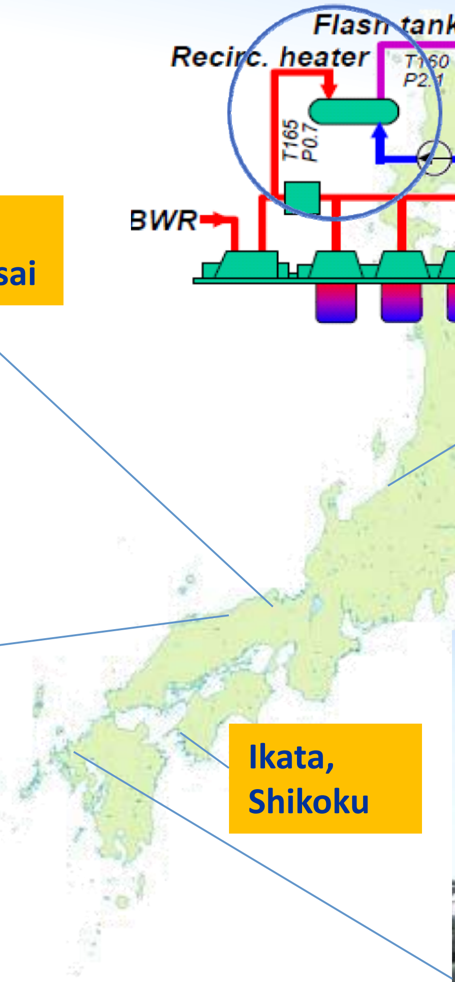
Reactor type	Country	Desalination process	Status
LMFR	Kazakhstan	MED, MSF	Decommissioned (1999)
PWRs	Japan	MED, MSF, RO	Operating > 150 reactor-years
	Korea, Argentina	MED, RO	Design stage
	Russia	MED, RO	Design stage
PHWR	India	MSF, RO	Operating since (2002+2010)
	Canada	RO	Design stage
	Pakistan	MED	Operating since (2010)
BWR	Japan	MSF	Installed
HTGR	South Africa	MED, MSF, RO	Design stage
NHR	China	MED	Design stage

Nuclear Desalination in Japan (8 units)







MED for two PWR units
1,000 m³/d (each of 4 desalination units)

MED for in-plant water makeup
(1,000 m³/d)

Photos are courtesy of EPCO

Nuclear Desalination in Pakistan

1600 m^3/day MED Nuclear Desalination Demonstration Plant coupled with KANUPP(137MWe CANDU Reactor) commissioned in December, 2009.

First Phase:

- MED : one-third capacity, first battery (1600 m^3/day)

- ICL & Sea water intake circuits: Full capacity

Second Phase:

- Second battery of MED plant (1600 m^3/day) to be added(Locally designed and manufactured)

Nuclear Desalination in India

NDDP: 6.3 MLD Sea water Desalination Plant at MAPS, Kalpakkam (Hybrid System)

Reverse Osmosis (RO): Commissioned in 2003

Capacity (MLD): 1.8

Product water quality (ppm): 500

Multi-Stage Flash (MSF):Commissioned in 2008-9

Capacity (MLD): 4.5

Product water quality (ppm): 10

Desalination plants coupled to a nuclear power plant(NPP).

One part follows RO with electricity from NPP.

Other part follows MSF distillation uses low grade heat from NPP.

Two qualities of water are available which is blended for human or industrial consumption.

Presence of Radioactive Contaminants in product water: Nil

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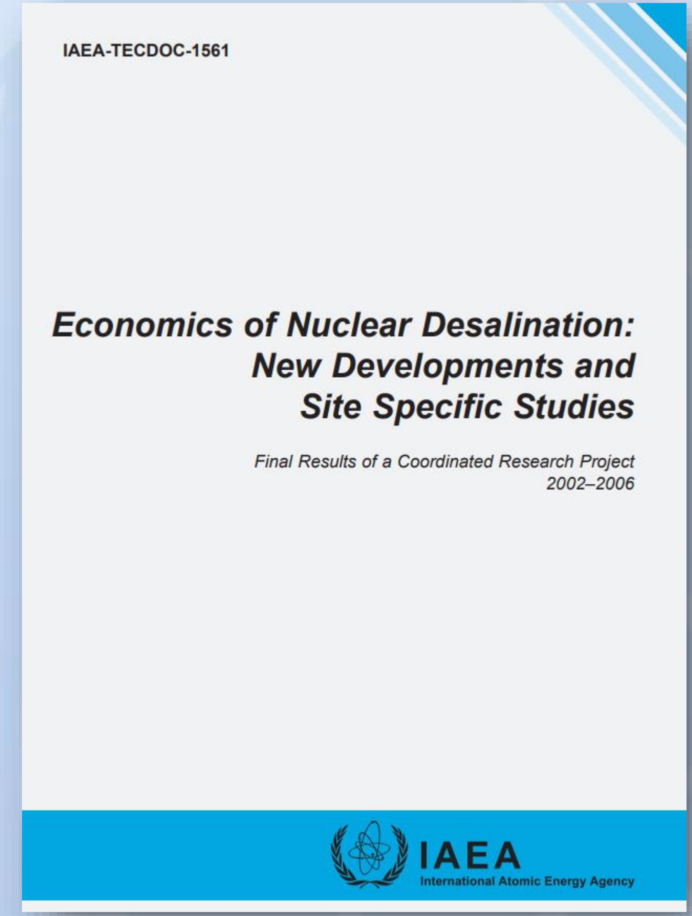
Economics


IAEA-TECDOC-1561

Economics of Nuclear Desalination: New Developments and Site Specific Studies

Final Results of a Coordinated Research Project 2002–2006

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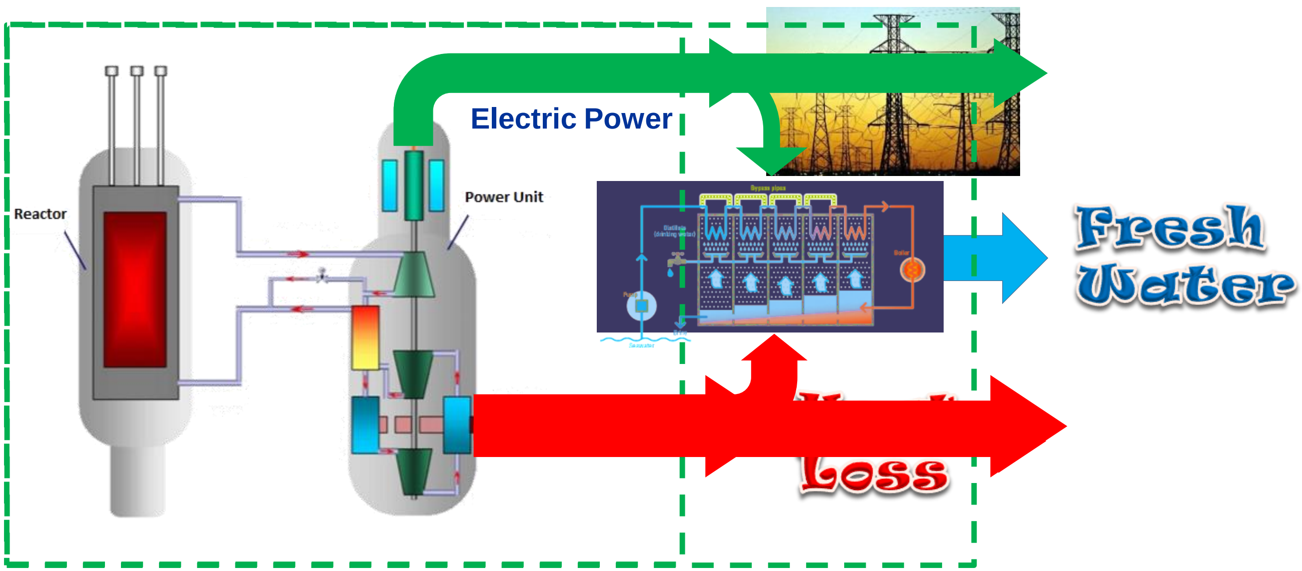
Harnessing Waste Heat for Nuclear Desalination

Waste heat: Heat extracted from NPP with no penalty to the power production



Nuclear Desalination?

- *Improves overall efficiency*
- *Improve economics*
- *Can be used as Off-Peak Power*

Harnessing Waste Heat
PBMR for desalination

Using reject heat from the pre-cooler and intercooler of PBMR = 220 MWth at 70 °C + MED desalination technology

↓

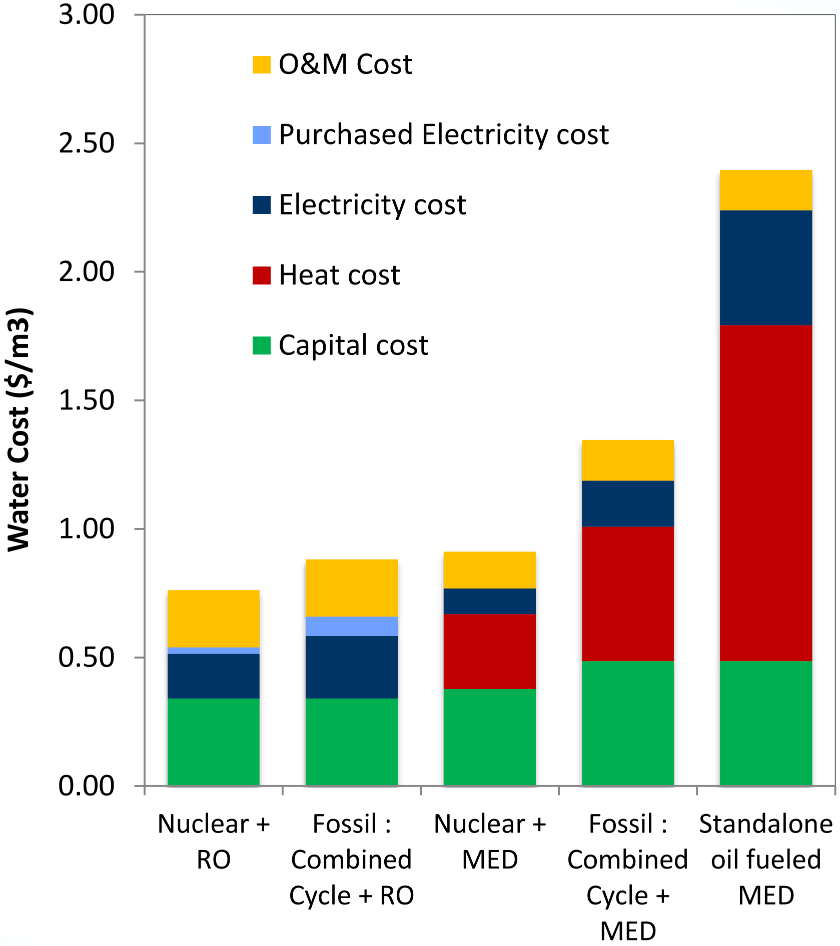
Desalinated water 15,000 – 30,000 m3/day

↓

Cover the needs of 55,000 – 600,000 people

Waste heat can also be recovered from PWR and CANDU type reactors to preheat RO seawater desalination

Cost of Nuclear Desalination



It is important to incorporate enviro-economics when evaluating water and energy options → a combination of environmental and economic objectives

	Capital Costs ($/kWe)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Fuel ($/MWh)
Nuclear	4500	70	4	8
Coal	2400	40	7	40
CCGT	850	15	5	80
Wind	2000	30	0	0
PV	4000	25	0	0

Cost assumptions:

optimal coupling between NPP and DP

Lifetime: 20 yrs

Discount rate : 6%

Electricity needs

SWRO : 5 kWh/m^3

MSF : 3.0 kWh/m^3

MED : 1.25 kWh/m^3

WNA (2010), The Economics of Nuclear Power
EIA (2010), Annual Energy Outlook 2011
Du and Parsons, (2009), Update on the cost of Nuclear Power, EIA, Annual Energy Outlook
MIT, (2009), Update of the MIT 2003 Future of Nuclear Power Study
Economic Modelling Working Group (EMWG) of the GIF (2007), Cost Estimating Guidelines for Generation IV nuclear energy systems Rev 4.2
Global Water Intelligence (2010), Desalination Markets 2010 : Global Forecasts and analysis
Global Water Intelligence (2011), IDA Desalination Plant Inventory

Improvement of economics using Cogeneration 10% of 1000 MWe PWR for desalination

To produce 130 000 m^3/day of desalinated water using 1000 MWe PWR

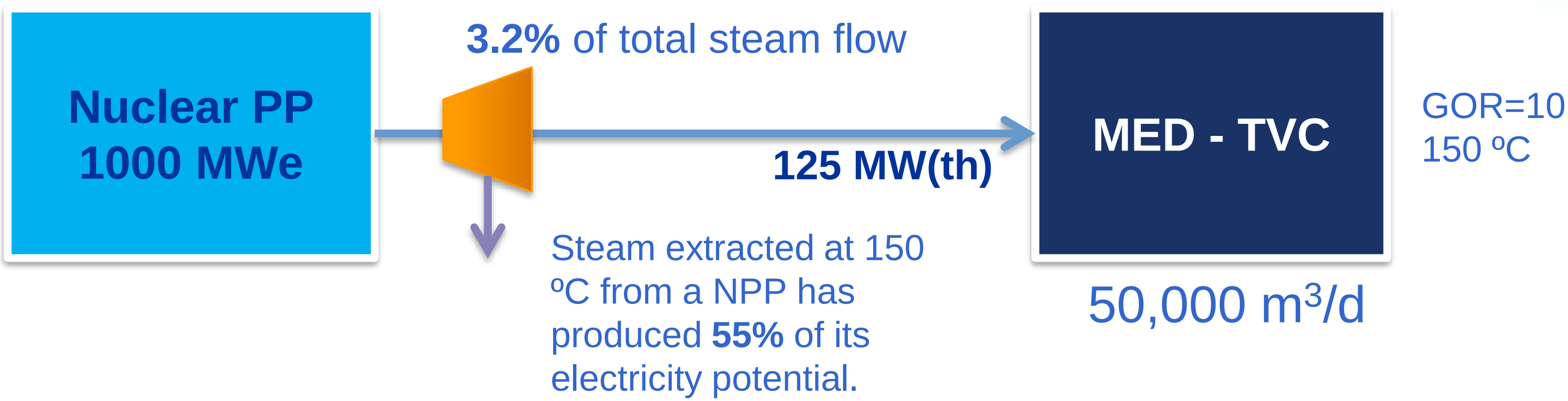
Total revenue (Cogeneration 90% electricity +10% water):

	Standalone	MED	RO
Electricity	7166 M$	6771 M$	7062 M$
Water	0	888 M$	672 M$
Total	7166 M$	7660 M$	7700 M$
		+7%	**+7.5%**

Using MED:
- Easier maintenance & pretreatment
- Industrial quality water

Using RO :
- Increased availability
- No lost power as in MED
- Using waste heat to preheat feed water by 15°C increases water production by ~13%

Water cost of small desalination plants



3.2% x 45%= 1.4% more steam needed in order to compensate the power lost

- The energy costs of nuclear desalination ~15% of total electricity costs
- Virtual free water

Safety Aspects

Safety level of Nuclear Desalination

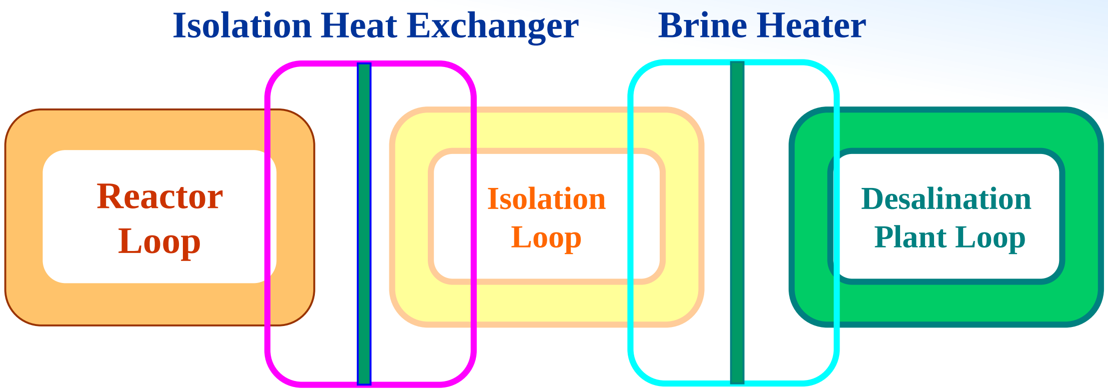
Safety issues of ND are similar to NPP

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.

Coupling

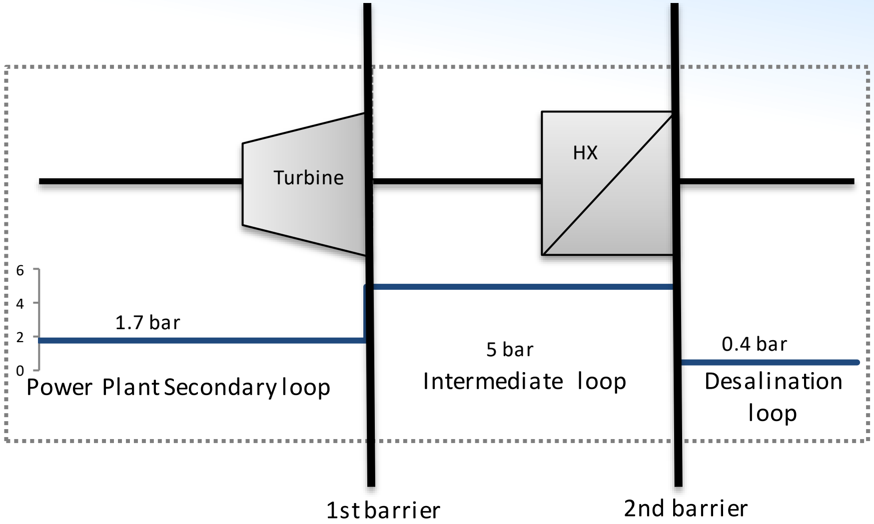


Coupling dictates **specific safety considerations** :

- Prevent the transfer of radioactive materials from NPP to Desalination plant.
- 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 Desalination plant system.
- Specific requirements as dictated by the National Regulatory Body.
- Backup heat or power source (NPP in refuelling).

Safe coupling

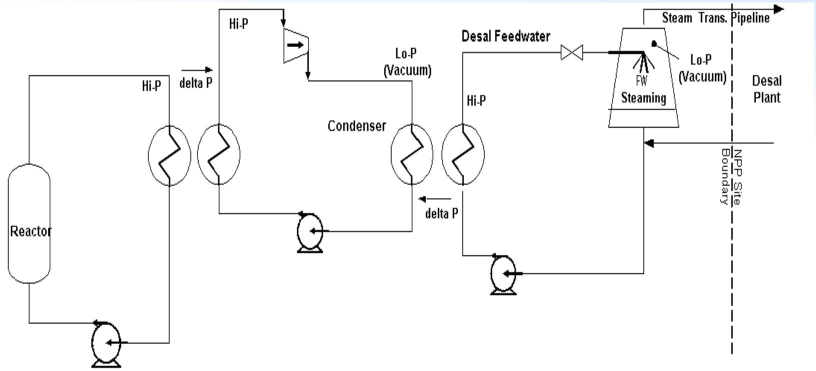
- 3 physical safety barriers with the use of an intermediate heat exchanger loop
- Pressure Reversal
- Online and batch monitoring of water radiation levels



- Experience has showed that radiation levels are orders of magnitudes below WHO specifications

Coupling between NP and DP: Specific Safety Considerations

In case of coupling through the condenser, additional non-safety grade barriers are established (the main condenser tubes).



In normal operation: main condenser at lower pressure than its surroundings (dynamic barrier) → No leakage

Radioactive releases to potable water can be prevented by design and operational provisions

IN CASE OF ACCIDENT CONDITIONS AT THE NP

ND is to be shut down → Prevent potential contamination

Water produced by ND can be stored and monitored for radiological contamination before distribution

Coupling between NP and DP: *general considerations*

Selection of proper technology

Required product quality & amount: power-to-water ratio

Specific national requirements

Site selection

In-depth feasibility studies

Coupling between NP and DP: technical considerations

Power vs. heating reactor

Parallel vs. series cogeneration

- Parallel cogen: part of steam to NP and part to DP
- Series cogen: expanded steam from NP turbine continues to DP

At least 2 mechanical barriers between primary coolant and brine

DP→ backup heat source if NP is down

NP→ backup steam condenser if DP is down

Additional considerations

- Seawater Intake
  - Open intakes or sea wells
- Concentrate disposal
  - temperature, salinity, chemicals
- “Hybrid” systems
  - Combination of several desalination technologies
  - RO plus pure distillation water

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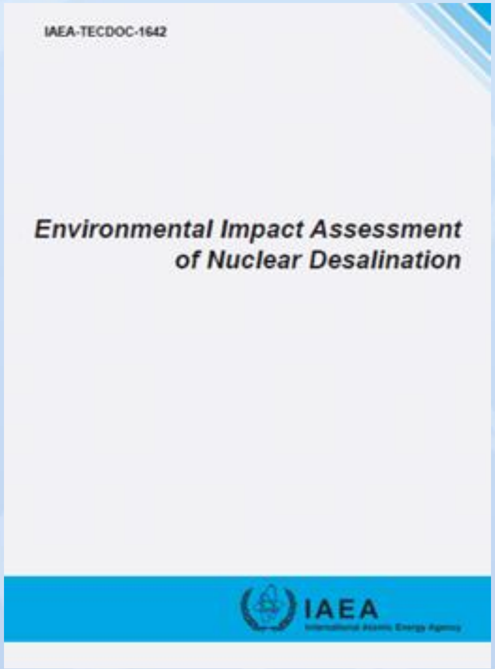
Environmental Impact



Site Selection
Coastal Impact
Marine impacts
Atmospheric Impacts

Environmental Consideration

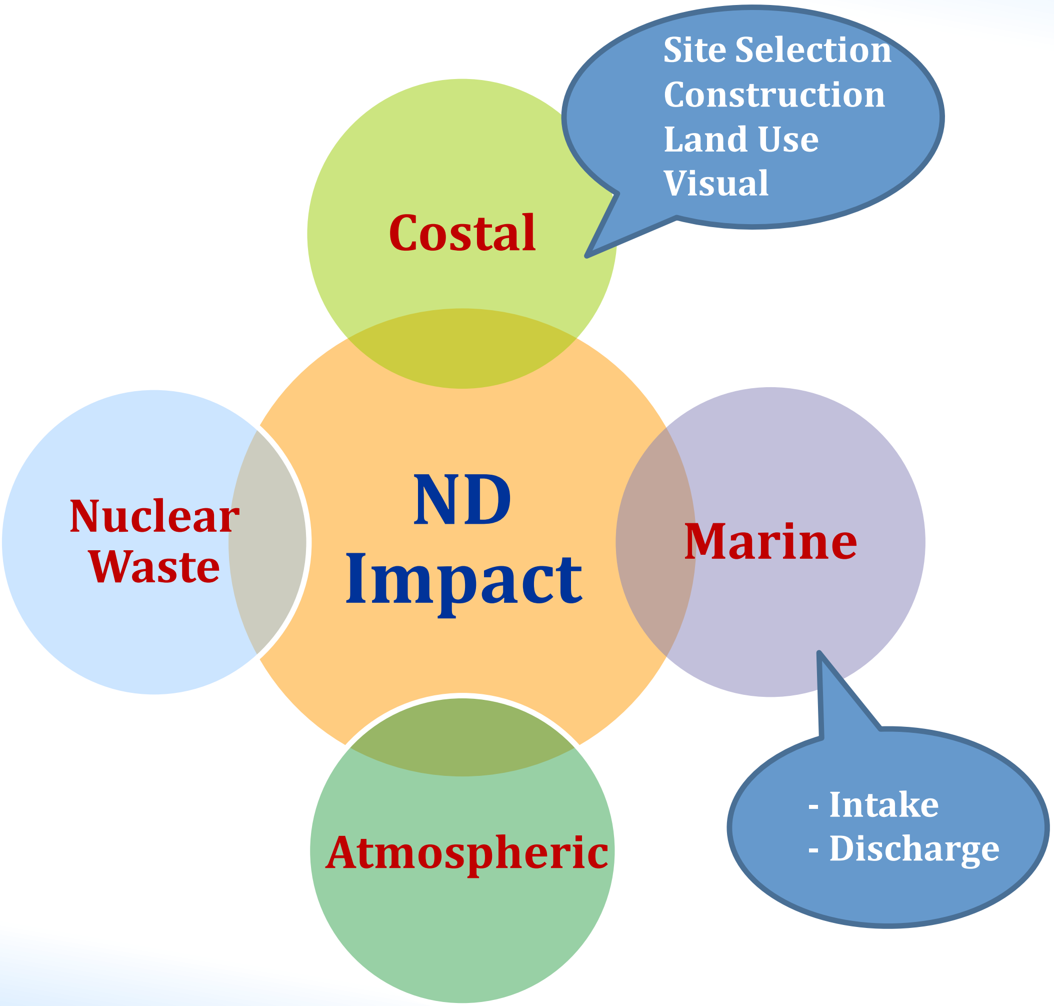
For ***Nuclear Desalination:***

- ❖ **Environmental issues related to desalination are a major factor in the design and implementation of desalination technologies.**
- ❖ **For DP, major environmental issues are related to the disposal and management of the concentrate.**

Typically a desalination plant concentrate consists of the following components or groups of components, respectively :

- high salinity (depends on the recovery rate);
- heat (in thermal desalination);
- Anti-scaling additives (poly-carbonic acids, polyphosphates);
- antifoaming additives;
- antifouling additives (mainly chlorine and hypochlorite);
- halogenated organic compounds formed after chlorine addition;
- acid;
- corrosion products (metals).

Environmental Aspects for Nuclear Desalination



Site Selection

First step in planning a desalination plant is the selection of site, <u>Among many factors affecting siting:</u> Available energy, costs, transport of product water, discharge of brine, but also: the environmental impact of construction and operation of desalination plant.

Co-location with nuclear power offers partial mitigation of desalination's impacts on the marine and coastal environment, increased economic competitiveness, and offers waste heat from the power plant as an energy source for the desalination process, thus reducing its global warming impact.

Co-location involves additional issues: e.g. high salinity and the chemical composition of the brine discharge.

Coastal Impact

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Construction Impact

Smaller specific use of materials (tons/MW) + Smaller construction area,

Yet, Potential for longer construction period.

Land Use

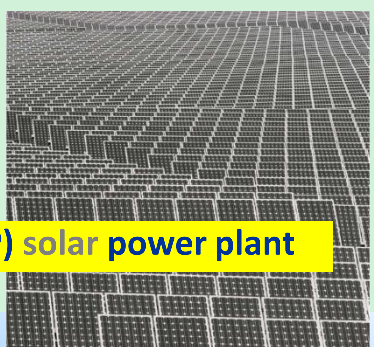
Example: **Nuclear Desalination facilities of 100 000 m^3/day would require 0.2 km^2**

12 to 510 MW of installed power – requiring co-located power generation

Method	Land use (km^2) for 1 GWe power plant
Solar (photovoltaic)	20 – 50
Wind	50 – 150
Biomass (+ bio-alcohol/oil)	4000 – 6000
Nuclear	1 - 4

Source: IAEA; WEC, 2007

Visual Impacts



Serpa (P) solar power plant

Palm Springs (US) wind farm

Paluel (F) NPP

Marine impacts

Desalination impacts the marine environment through two major operation phases: seawater intake and effluent discharge.

Possible environmental impacts of discharge

Elevated temperature and salinity are aggravating marine life

- Increased mortality or incapacitation of marine organisms
- Habitat deterioration or undesirable changes in species composition

Strategies for Mitigation

Commercial use of the discharged brine

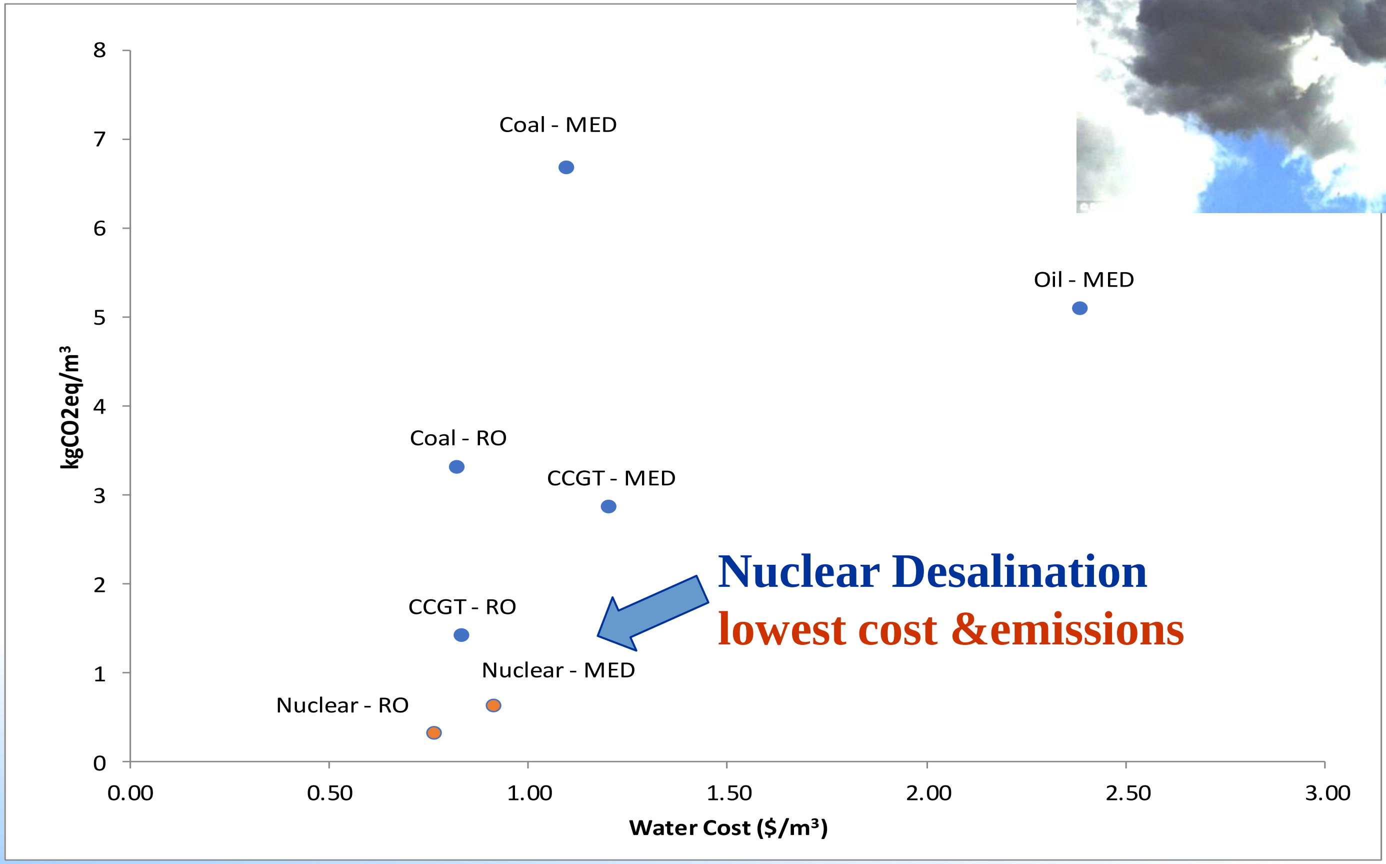
Dilution with multi-port diffusers in biologically insensitive areas…

…and environmentally sound intakes!

Atmospheric Impacts

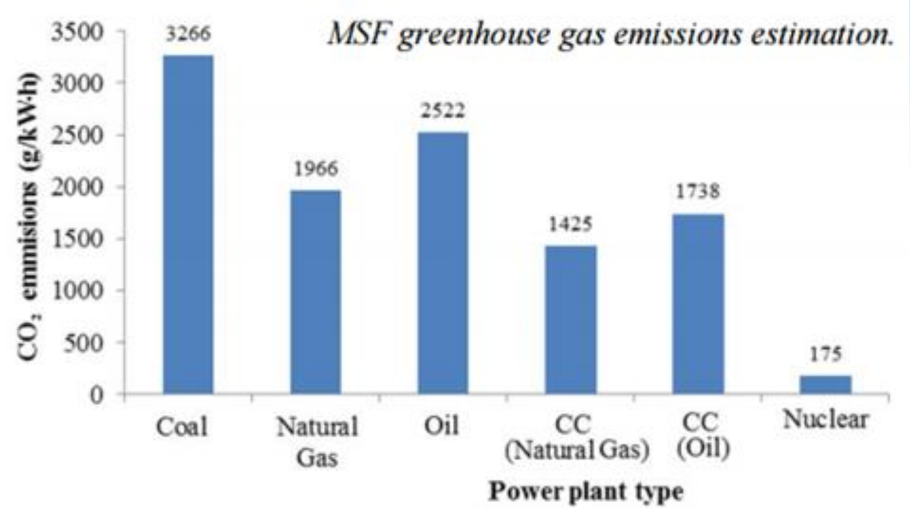
It is important to incorporate enviro-economics when evaluating water and energy options

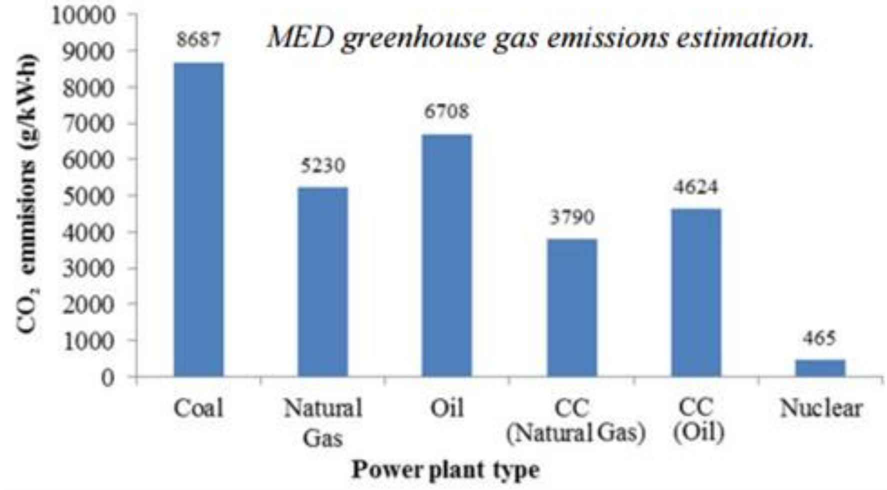
→ a combination of environmental and economic objectives

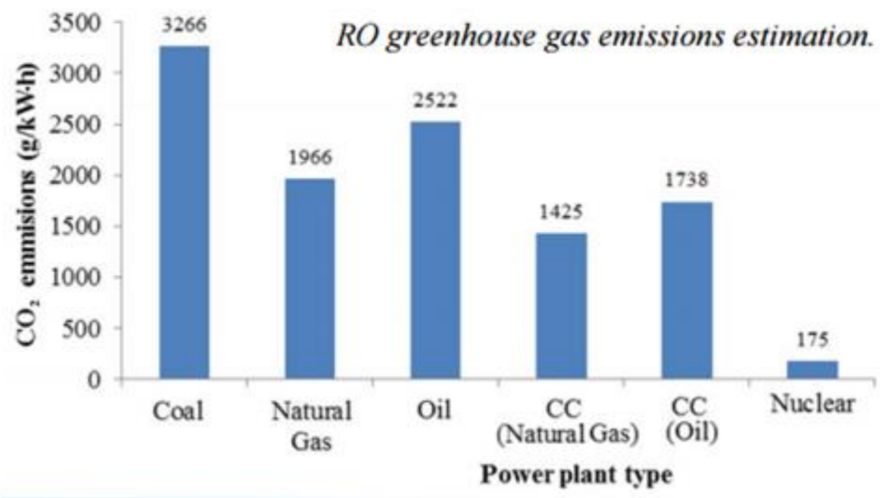


Source: Analysis based on Primary Cost data from MIT (2009), EIA (2010), and GWI (2010)

GHG Emissions of ***Nuclear Desalination:***







Questions & Discussion!

Thank you!