ECONOMIC MERITS OF NUCLEAR DESALINATION

KHAMIS, Ibrahim

IAEA

Atoms for Peace: The First Half Century

1957–2007

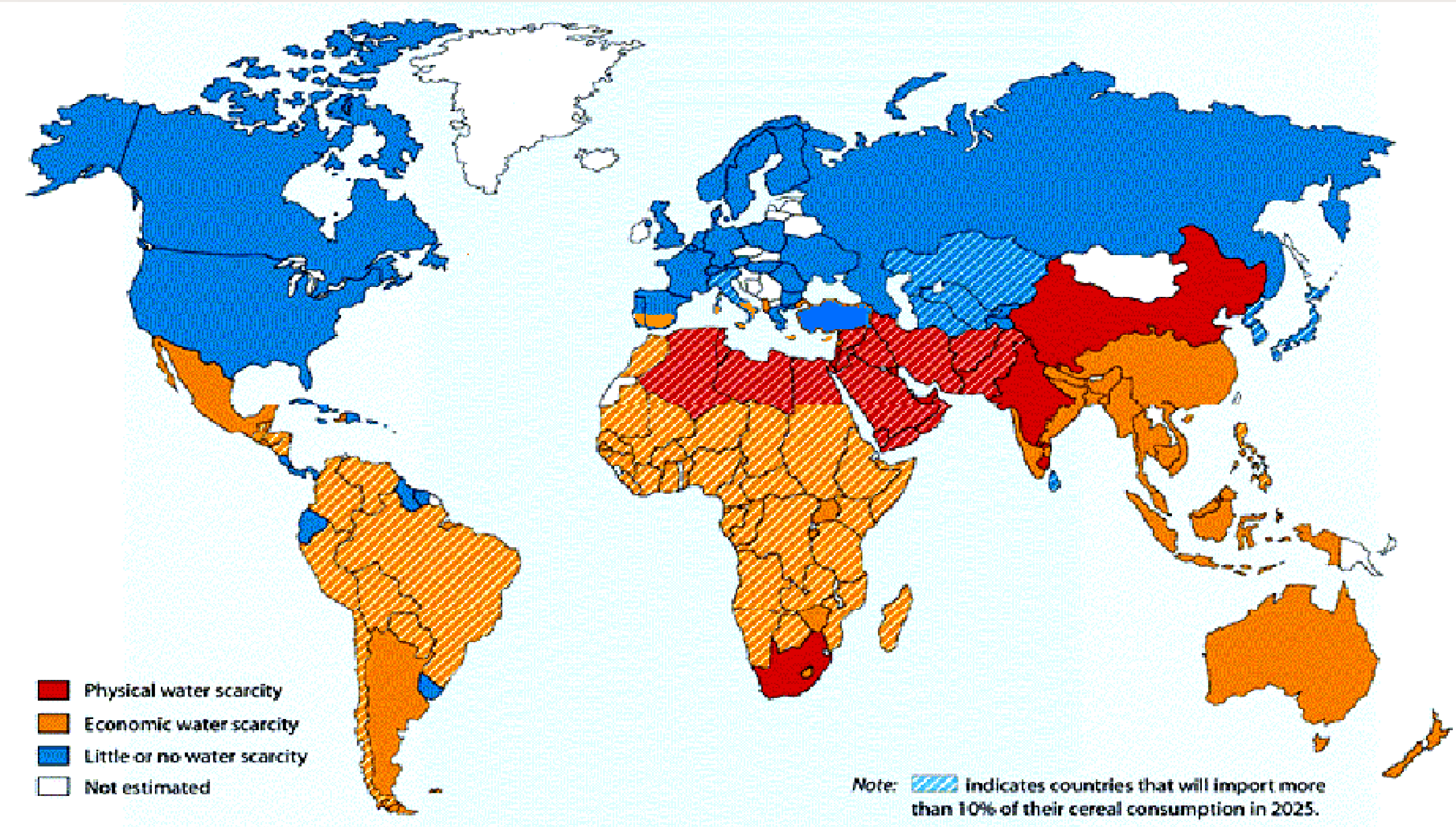
Outline

- **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



IAEA
Atoms for Peace: The First Half Century
1957–2007

Role of nuclear energy

- Increase energy and water demands necessitates increased supply
- >90% of world's primary energy will come from fossil fuels ➔ 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.

Global experience on ND

Desalination:

- More than 17 000 installed desalination units
- Total capacity is about 38 million m3/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

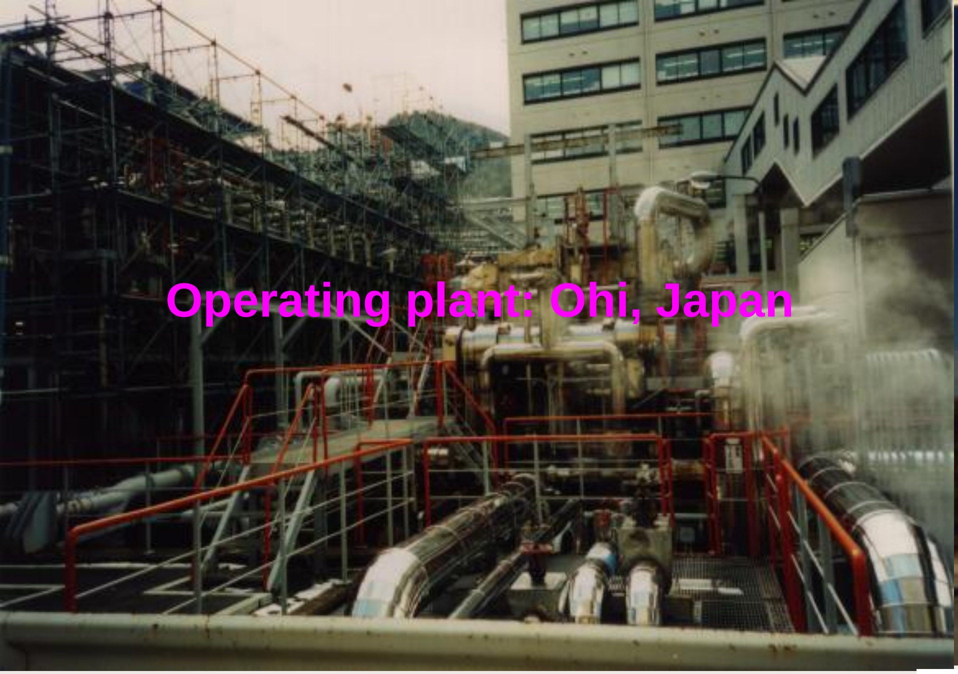
Reactor Type	Location	Desalination Process	Status
LMFR	Kazakhstan (Aktau) 80000 m3/d	MED	In service till 1999 27 y
PWR	Japan (Ohi, Takahama, Ikata, Genkai)	MED, MSF, RO	In service with operating experience of over 150 reactor-years
	Rep. of Korea, Argentina etc	MED RO	Integral SMRs of the PWR type; under design or to be constructed
	Russia	MED, RO	Under consideration (Barge mounted floating unit with KLT-40)
	USA (Diabolo Canyon)	RO	Operating

IAEA
Atoms for Peace: The First Half Century
1957–2007

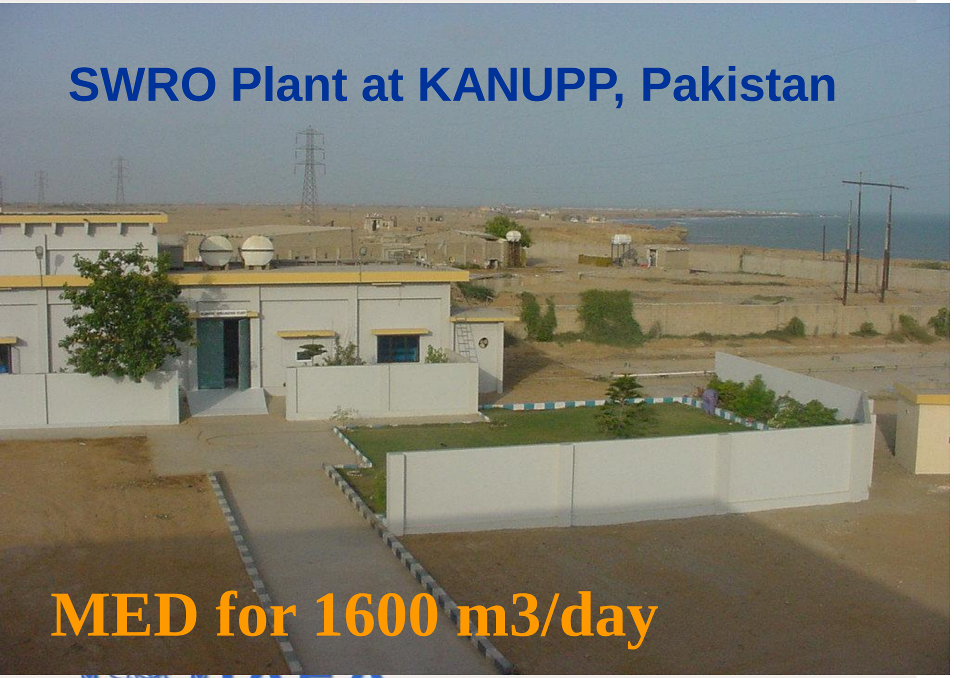
Global experience on ND- Cont.

Reactor Type	Location	Desalination Process	Status
BWR	Japan (Kashiwazaki-Kariva)	MSF	Never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999.
HWR	India (Kalpakkam) India (Trombay)	MSF/RO LT-MED	RO operating since 2002 In service since 2004
	Pakistan (KANUPP)	MED	Existing CANDU modified to be coupled to an MED plant (under construction)
NHR-200	China	MED	Dedicated heat only integral PWR; under design
HTRs	France, The Netherlands, South Africa	MED,RO	ANTARES, multipurpose reactor, GT-MHR and PBMR; under development and design.

Diablo Canyon

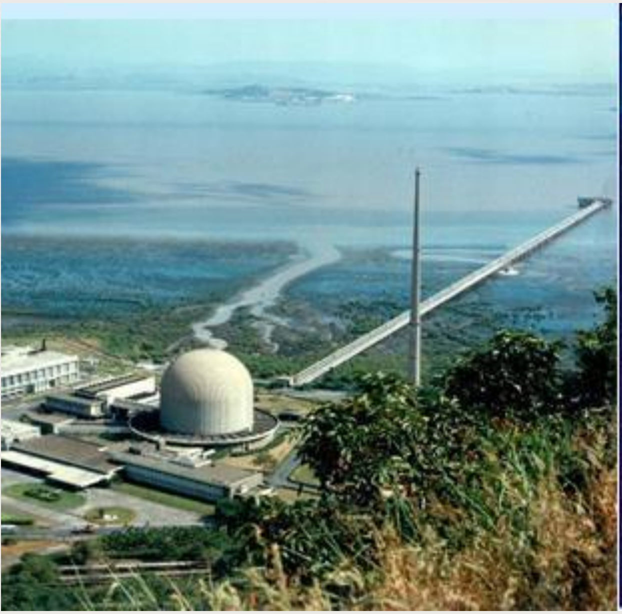

Operating plant: Ohi, Japan

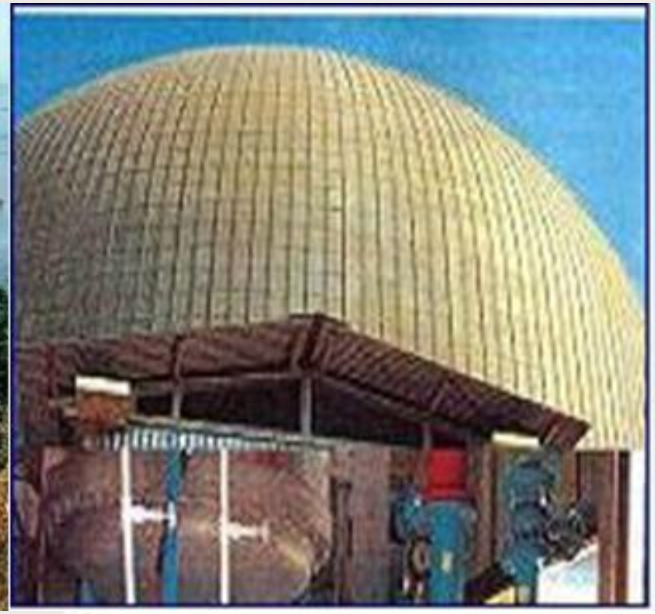

Evaporators at Aktau, Kazakhstan
80 000 m3/day for 27 years


SWRO Plant at KANUPP, Pakistan
MED for 1600 m3/day


Hybrid (MSF+RO) Kalpakkam, India
1000 m3/day desalted pure water

Integrated LTE Nuclear Desalination System, Mumbai, India

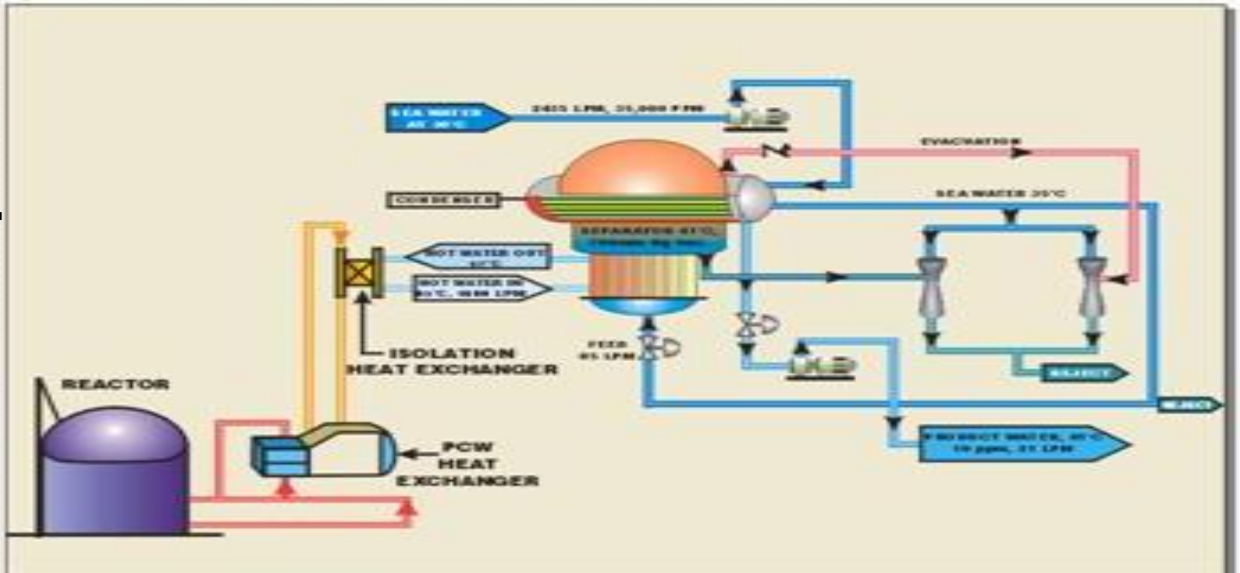




Use of waste heat

CIRUS Research Reactor

40 MWth



IAEA
Atoms for Peace: The First Half Century
1957–2007

Various types of nuclear desalination systems

Reactor type	Country	Desalination process	Status
LMFR	Kazakhstan	MED, MSF	150 reactor-years
PWRs	Japan	MED, MSF, RO	100 reactor-years
	Korea, Argentina	MED, RO	Design stage
	Russia	MED, RO	Design stage
PHWR	India	MSF, RO	Commissioning
	Canada	RO	Design stage
	Pakistan	MED	Construction
BWR	Japan	MSF	Installed
HTGR	South Africa	MED, MSF, RO	Design stage
NHR	China	MED	Design stage

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 **(Cogeneration 90% electricity +10% 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

IAEA Atoms for Peace: The First Half Century 1957–2007

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: o.75-0.88 $/m3

- MSF: 1.2-1.5 $/m3

Economic target of nuclear desalination costs:

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

Cost of new reactors (in the USA)

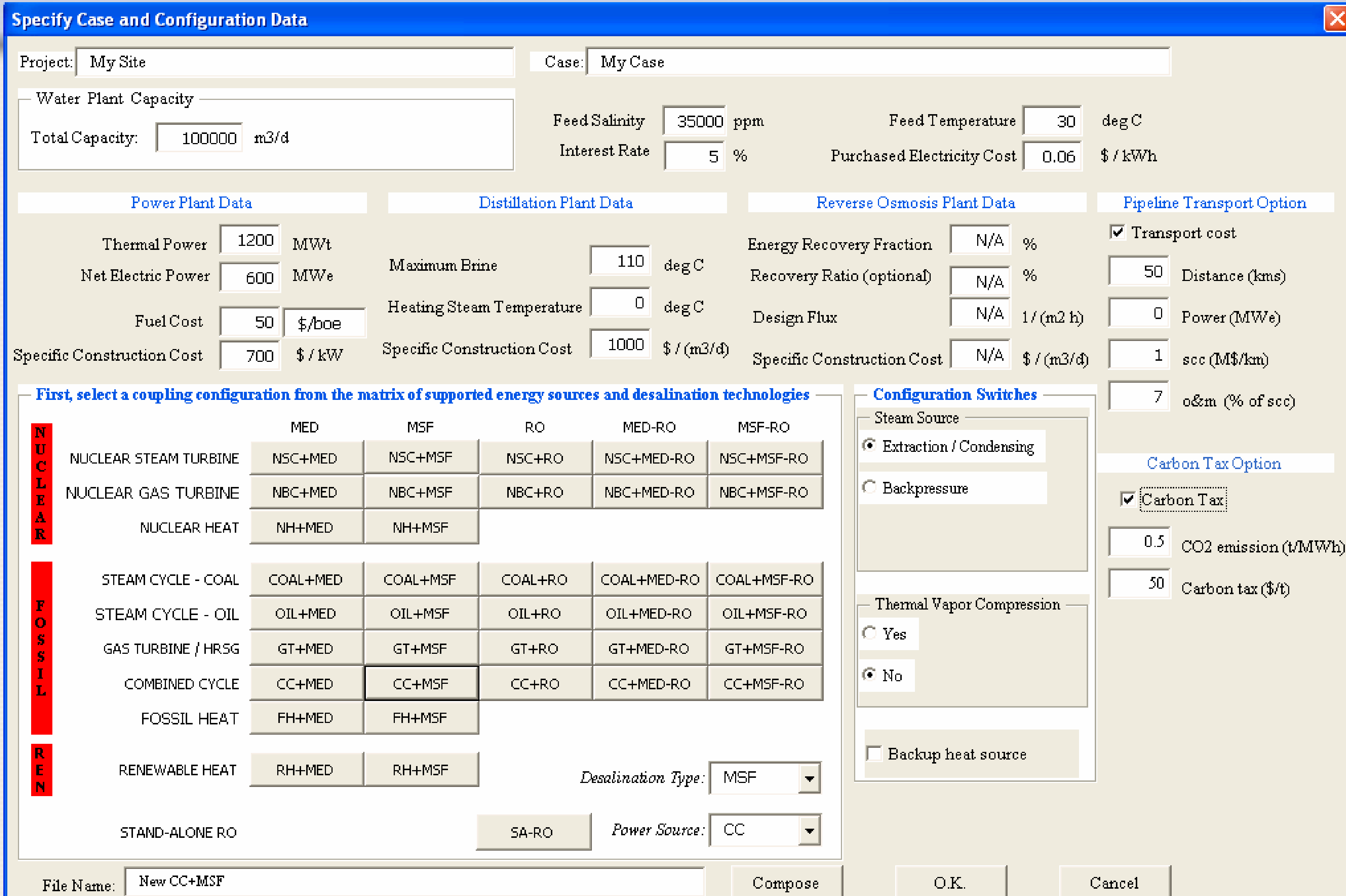
- June 2007 study (by Keystone Center):
  Overnight estimates (with interest):
  $3600 – 4000/kW
- Oct. 2007 study (by Moody's Investor Service): Estimated total costs including interest would be between: $5000 and 6000/kW
- For the **Turkey Point** in ***Florida***:
- **In 2004**: cost of ABWR ~ $1611/kW
- **In 2007 update**:
  - **$ 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



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

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

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

		Value set	
Lifetime of backup heat source *Optional*:	0.00	30	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
Factor in %	Specific nuclear fuel cost:	11	$ / MWh
1	Specific decommissioning cost:	16.72	$ / MWh
	Fossil fuel price at startup:	N/A	$/bbl ($/t)
	Nuclear fuel annual real escalation:	0.0	% / a
	Fossil fuel annual real escalation:	N/A	% / 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	m^3 / d	
Base unit cost:	1200	$ / m^3	
Optional in/outfall specific base cost:	0	$ / m^3	
Optional intermediate loop cost:	0	$ / m^3	
Distillation plant cost contingency factor:	0.100		
Distillation plant owners cost factor:	0.050		
Distillation plant lead time:	12	m	
Average management salary:	66000	$ / a	
Average labor salary:	29700	$ / a	
Optional no. of management personnel:	0		3
Optional number of labor personnel:	0		26
Specific O&M spare parts cost:	0.04	$ / m^3	
Tubing replacement cost:	0.00	$ / m^3	
Specific O&M cost for pre-treatment:	0.03	$ / m^3	
Specific O&M cost for post-treatment:	0.02	$ / m^3	
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	$ / (m^3/d)	
Optional in/outfall specific base cost:	0	$ / (m^3/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		2
Optional number of labor personnel:	0		12
O&M membrane replacement cost:	0.05	$ / m^3	
O&M spare parts cost:	0.04	$ / m^3	
Specific O&M cost for pre-treatment:	0.03	$ / m^3	
Specific O&M cost for post-treatment:	0.01	$ / m^3	
RO plant O&M insurance cost:	0.50	%	

DEEP sample input and output – part II

WATER & POWER COST SUMMARY

Case identification and site characteristics

Energy plant type:	**PWR**	Desalination plant type:	**MSF-RO**	Total required water plant capacity at site:	**350,000**	m^3/d
Energy source:	**NUCLEAR**	Backup heat source:	**N**			
Energy product form:	**H & P**	Intermediate loop (MSF):	**Y**	Capacity of distillation part:	**140,000**	m^3/d
Fuel type:	**UO2**	RO membrane type:	**SW**	Capacity of RO part:	**210,000**	m^3/d
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** \$/kW(e).h	
Discount rate:	**8.0** %	
Interest rate:	**8.0** %	
Initial year of operation:	**2005**	
Plant economic life:	**60** a	

Water and power plant cost summary

Specific construction cost: **1,672** \$ / kW → x P → Power plant total construction cost: **1,104** M \$

P = 620 MW

Power plant interest during construction: **234** M \$

Specific investment cost: **2,156** \$ / kW ← / P ← Total power plant investment: **1,338** M \$

Levelized electricity cost: **0.057** \$ / kWh

DOES THE POWER PLANT ALREADY EXIST ? **NO !** CLICK TO CHANGE

		G.O.R. :	**6.4**
Total installed water plant capacity:	**360,000** m^3/d	**Recovery ratio :**	**0.399**
Total construction cost:	**443.1** M \$		
Interest during construction:	**35.4** M \$	Net saleable power:	**508.2** MW
Total investment cost:	**478.5** M \$	Average daily water production:	**307,800** m^3/d
Specific investment cost:	**1,329.3** \$ / (m^3/d)	**Water cost:**	**0.95** \$ / m^3

IAEA
Atoms for Peace: The First Half Century
1957–2007

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

IAEA
Atoms for Peace: The First Half Century
1957–2007