Nisan Desalination Services

Training workshop on the technology and the performances of desalination systems

ICTP, Trieste, 11 –15 May 2009

DEEP: Structure, models and coupling schemes

1- General background, models, options

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Agenda

- Mutual presentation
- A little bit of history (background)
- Desalination processes
- Some notions on coupling schemes
- Nuclear desalination (DEEP) economics

Dr. Simon Nisan

- Chief Engineer and Research Director at CEA, CEN Cadarache; chargé d'affaire Nuclear Desalination (1971-2009)
- IAEA expert on nuclear reactors, economics, nuclear desalination etc (since 1989)
- Expert/evaluator for the Italian gouvernment and the EU Commission (since 2002)
- CEO, NDS from 01/04/09

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Nuclear Energy and Nuclear Desalination

MOTIVATION -1

- Nearly all countries have opted for, or have been led to choose, the Western economic model of development

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- Energy consumption
  - Growth of economic activity
  - comfort and higher standards of living

- There is at present a considerable disparity in the enrgy consumption of DC's and IC's.
  - in the US, with 5% of the world population, energy consumption is 25%
  - the entire third world, with 75% of the population, also consumes 25%
  - per capita US energy consumption 8 toe/y
  - per capita DC energy consumption 0.6 toe/y

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- World energy demands would thus consistently increase in the future decades
- The rate of energy consumption in the DC's would be much higher (population growth and increased industrialisation)

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- Doubling of the world energy demands in 2020, tripling by 2050

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- Projections regarding the choice of energy to meet this tremendous demand are being hotly debated, leading to large uncertainties
- It would thus be a very irresponsible attitude to exclude a given type of energy
- No sustainable developement without making use of all possible energies that human mind is capable of developing
- Energy in all its forms would be required, fossil, renewables and nuclear

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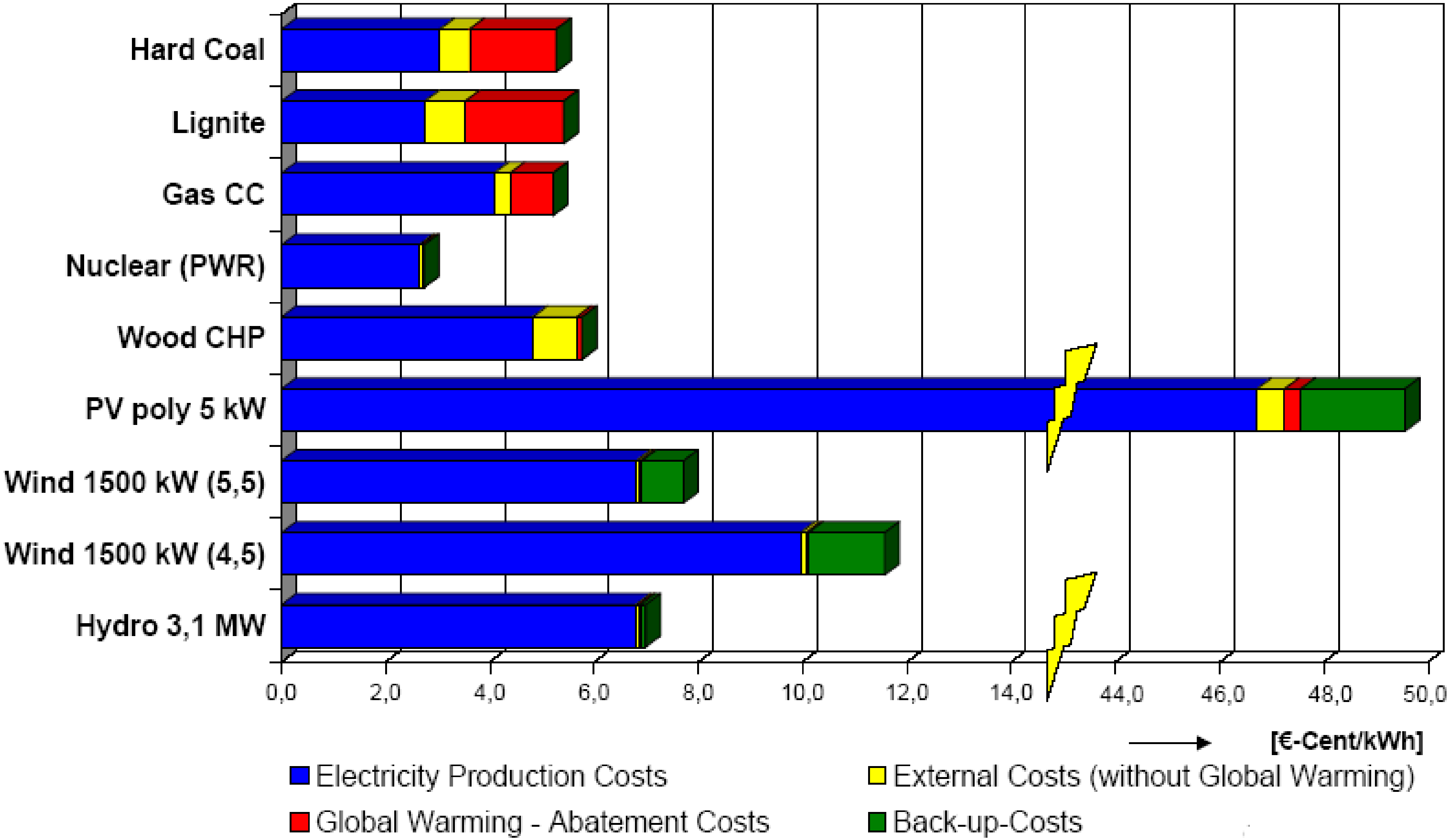
Motivation-2

- Fossil fuels need to be preserved for more important uses in the future
- Burning fossil fuels has strong negative impact on the environment: global warming, acid rains, particulate emissions..
- The biggest threat is global warming caused by CO_2. 55 % of GHG today, 75% tomorrow, if nothing is done

- Renewables, such as wind and solar power, have the greatest potential in the future
- They are handicapped by their very low power density, huge spaces, large amounts of materials for construction
  - 1 GW → 20 km^2 of solar cells, 50 km^2 of wind farm, 4000 km^2 of forestation
- Intermittent nature very costly
- Future research will enhance efficiency but still applications would be for small consumers

Internalisation in Germany



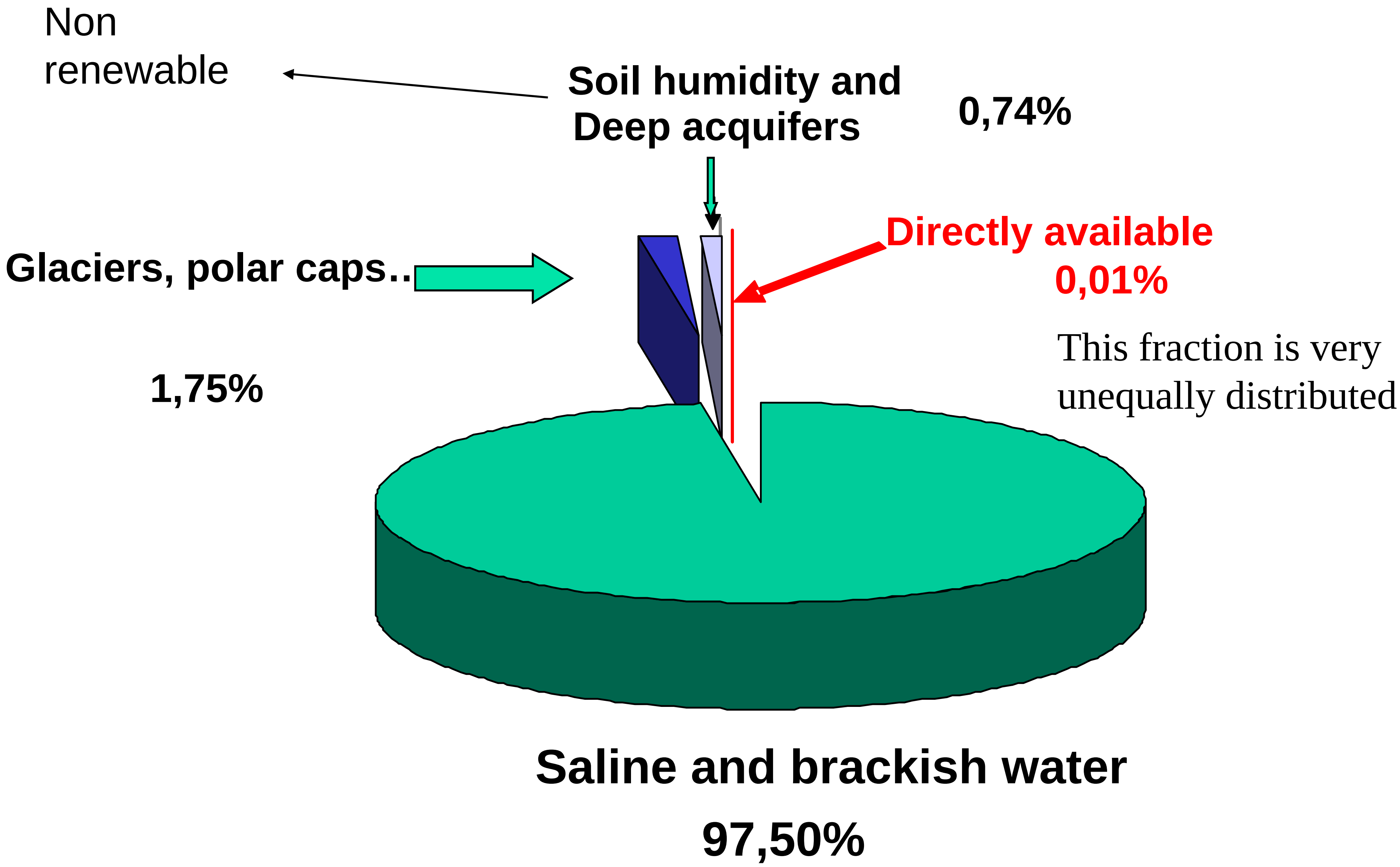
- Nuclear energy is a clean, economic source already providing 17% of worlds electricity.
  - e.g. the French case
- Several reasons have overshadowed its advantages
  - Chernobyl, high capital cost, competition
- To be truly sustainable, it has to respond to some challenges
  - Safety, security of supply, economics, waste management, non-proliferation

→ GEN III and Gen IV nuclear reactors

World Water resources

- If all the water on earth could be put in a gallon jug, then available water resources would be hardly more than one quarter of a table spoon!

Distribution of water resources on earth



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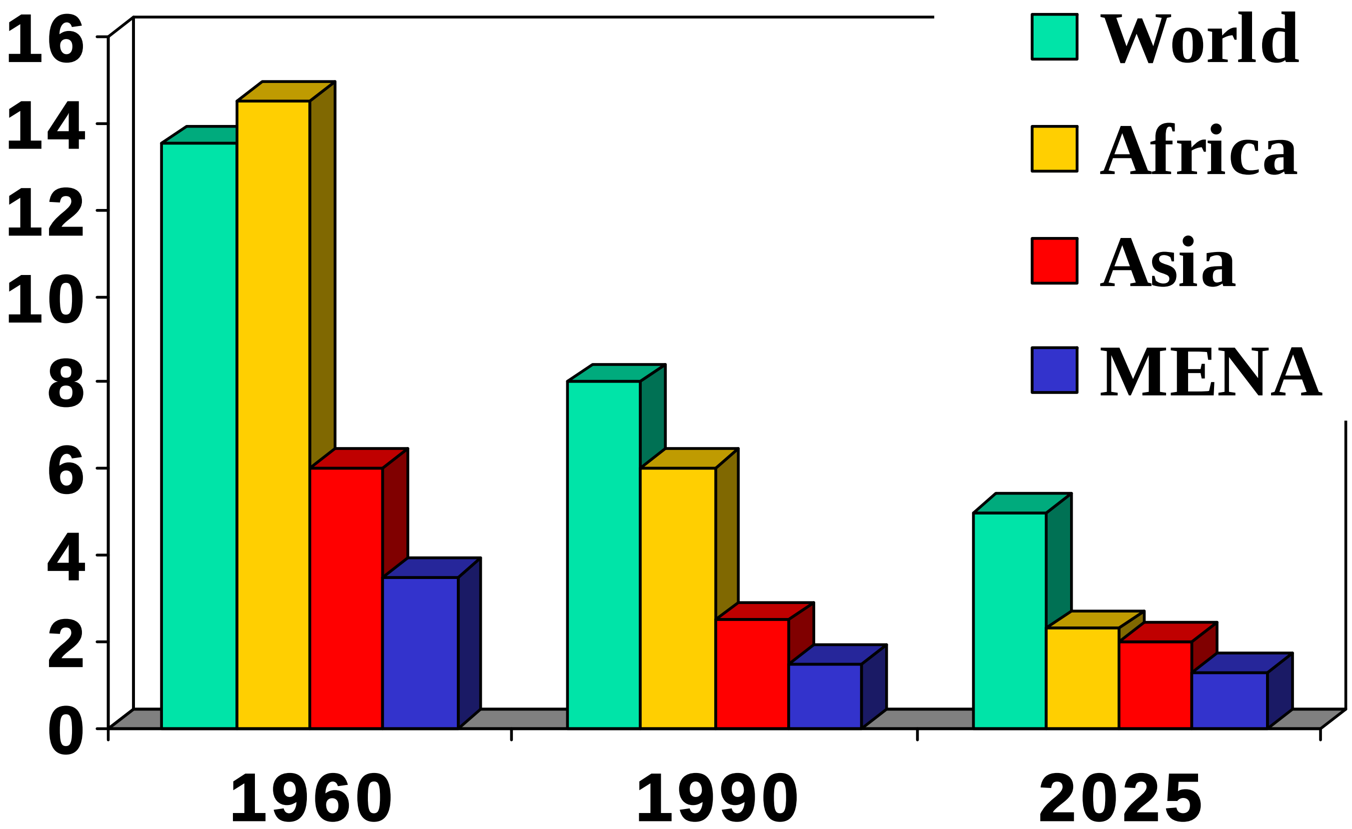
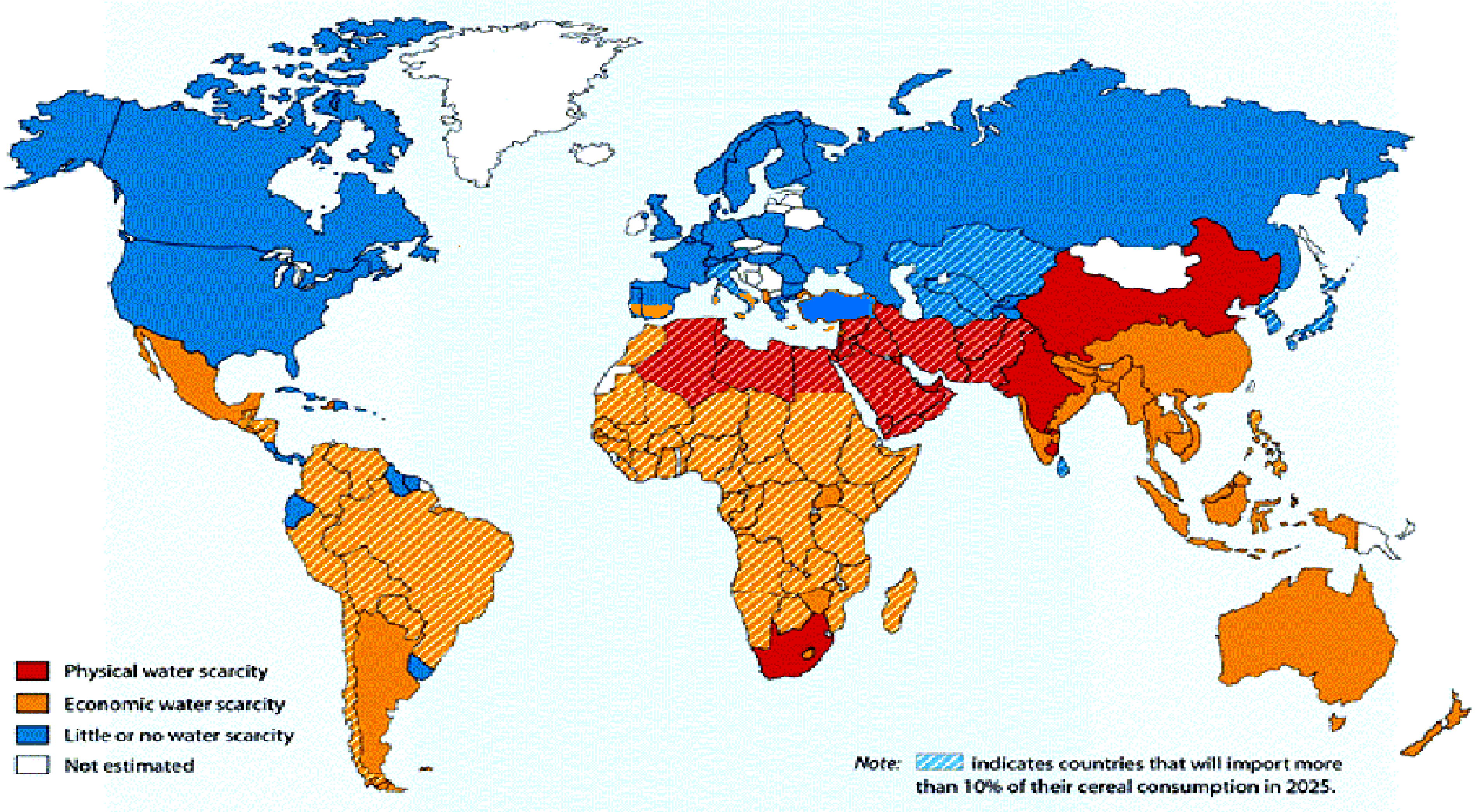
- The limited, but easily accessible freshwater ressources in rivers, lakes and shallow ground water acquifers are rapidly dwindling because:
  - Over-exploitation and consequent water quality degradation
  - Increasing population and standards of living
  - Increasing industrial activities ⟹ Climate change



Available Renewable Water Ressources
(in X 1000 m^3/capita/anum) are Limited … and Declining



Water shortage in different regions of the world (2020-2025)

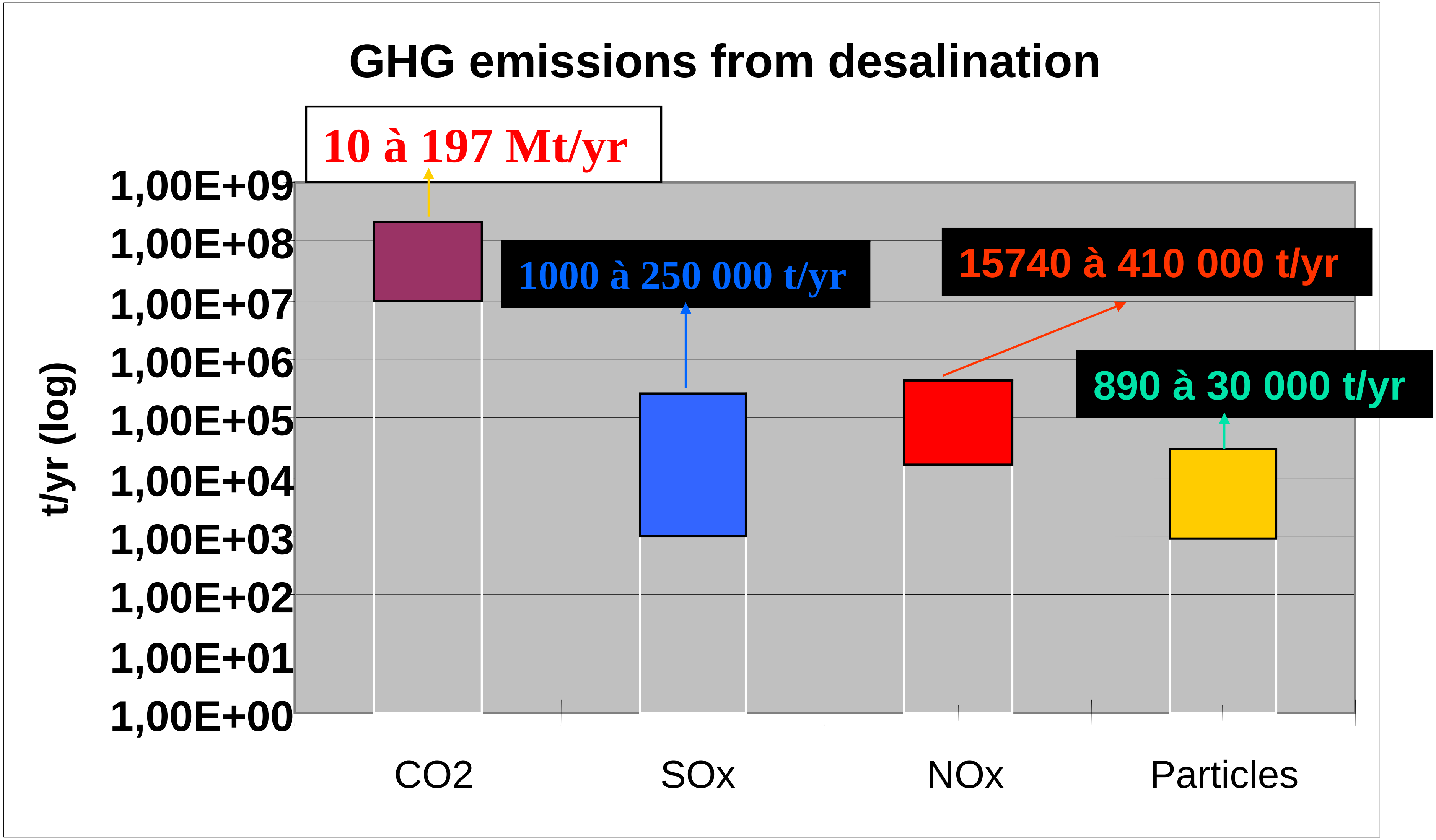
Why Seawater Desalination?

- Seawater is the most abundant source
- Desalination, once an expensive process, is now a an economically viable technology thanks to the considerable progress made during the past 10 years.
- Desalination is a multipurpose solution, addressing the domestic, industrial and agricultural uses.
- Global desalination market will double to more than US $ 80 billion in the next 20 years.

Why Nuclear Sea Water Desalination?

- Desalination is an energy intensive process. A future desalination strategy based solely on fossil fuel sources is not sustainable:
  - Fossil fuel reserves need to be conserved for other important applications
  - They will be increasingly costly in the future.
  - The energy dependence?

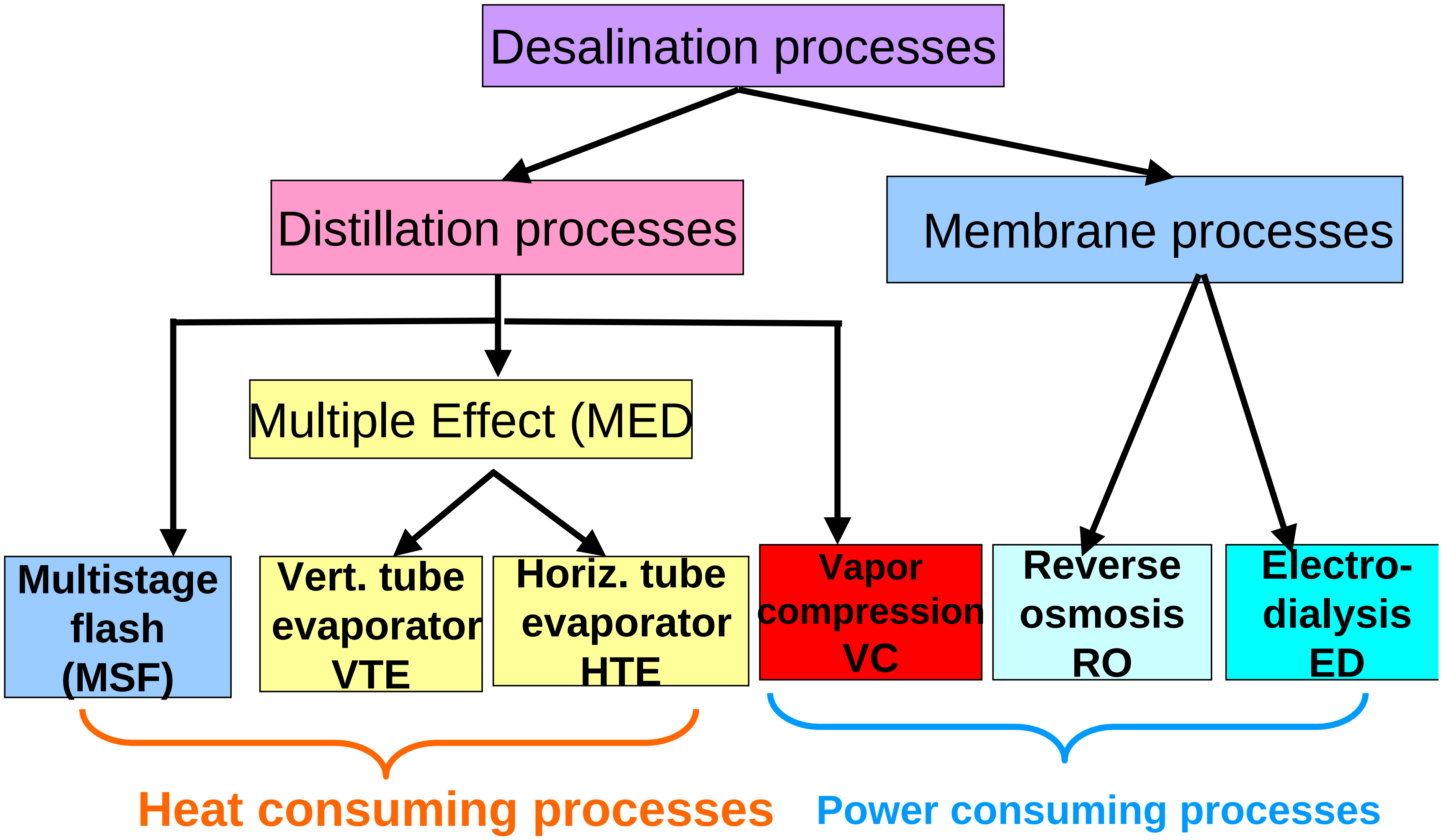
- The most important impact of fossil fuel based desalination is on the environment. Take an example:
  - It can be shown that, in 2020, for the Mediterranean region alone, one would require about 20 million m3/day of desalting capacity.
  - This is a pessimistic assumption, because it is assumed that only 2.5% of the needs would be covered by desalination.
  - However, ...:


GHG emissions from desalination
10 à 197 Mt/yr
1000 à 250 000 t/yr
15740 à 410 000 t/yr
890 à 30 000 t/yr
t/yr (log)
1,00E+09
1,00E+08
1,00E+07
1,00E+06
1,00E+05
1,00E+04
1,00E+03
1,00E+02
1,00E+01
1,00E+00
CO2
SOx
NOx
Particles

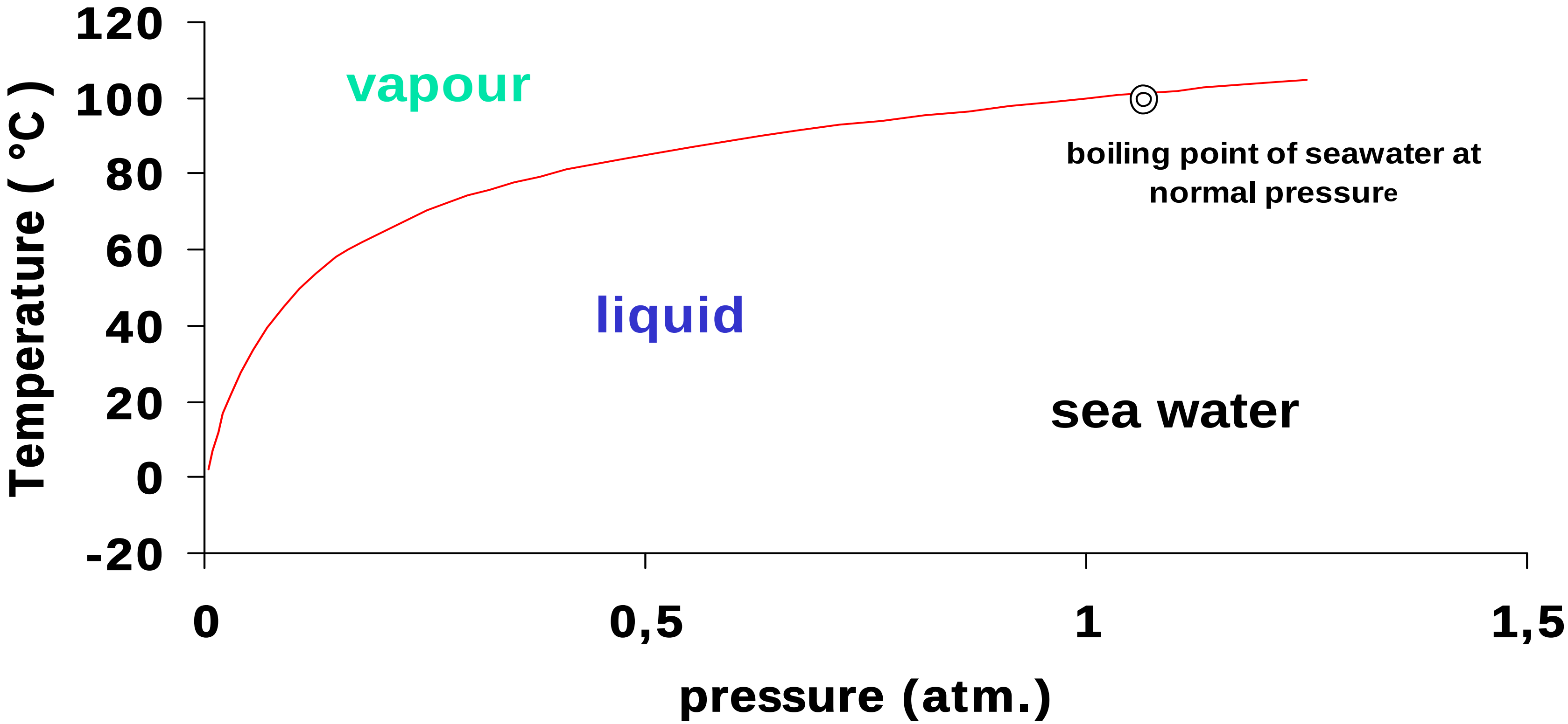
Background

- First general conference resolution in 1989
- TECDOC 574 (1990) [status report]
- 2nd GC resolution in 1990
- Formation of an expert group to develop an « approximate » economic evaluation tool to guide the decision makers in the choice of nuclear desalination options
- IAEA contract to GA for CDEE development
- 5 nation study
- TECDOC 666 (1992); first economic evaluation

→ DEEP 2.0 (2000); TECDOC 1186 (2000)

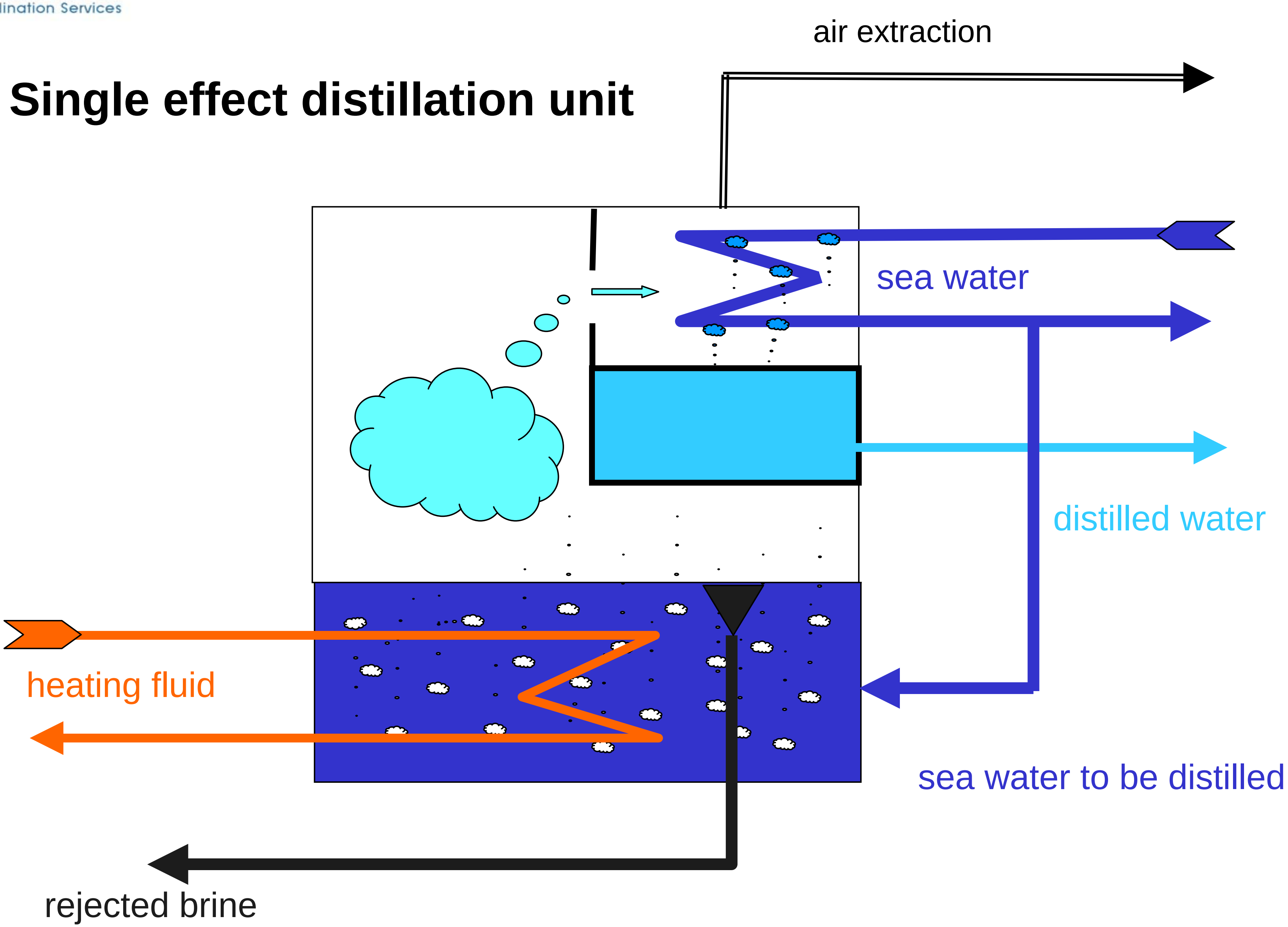

Desalination processes
Distillation processes
Membrane processes
Multiple Effect (MED
Multistage flash (MSF)
Vert. tube evaporator VTE
Horiz. tube evaporator HTE
Vapor compression VC
Reverse osmosis RO
Electro-dialysis ED
Heat consuming processes
Power consuming processes

Boiling point of water as a function of pressure

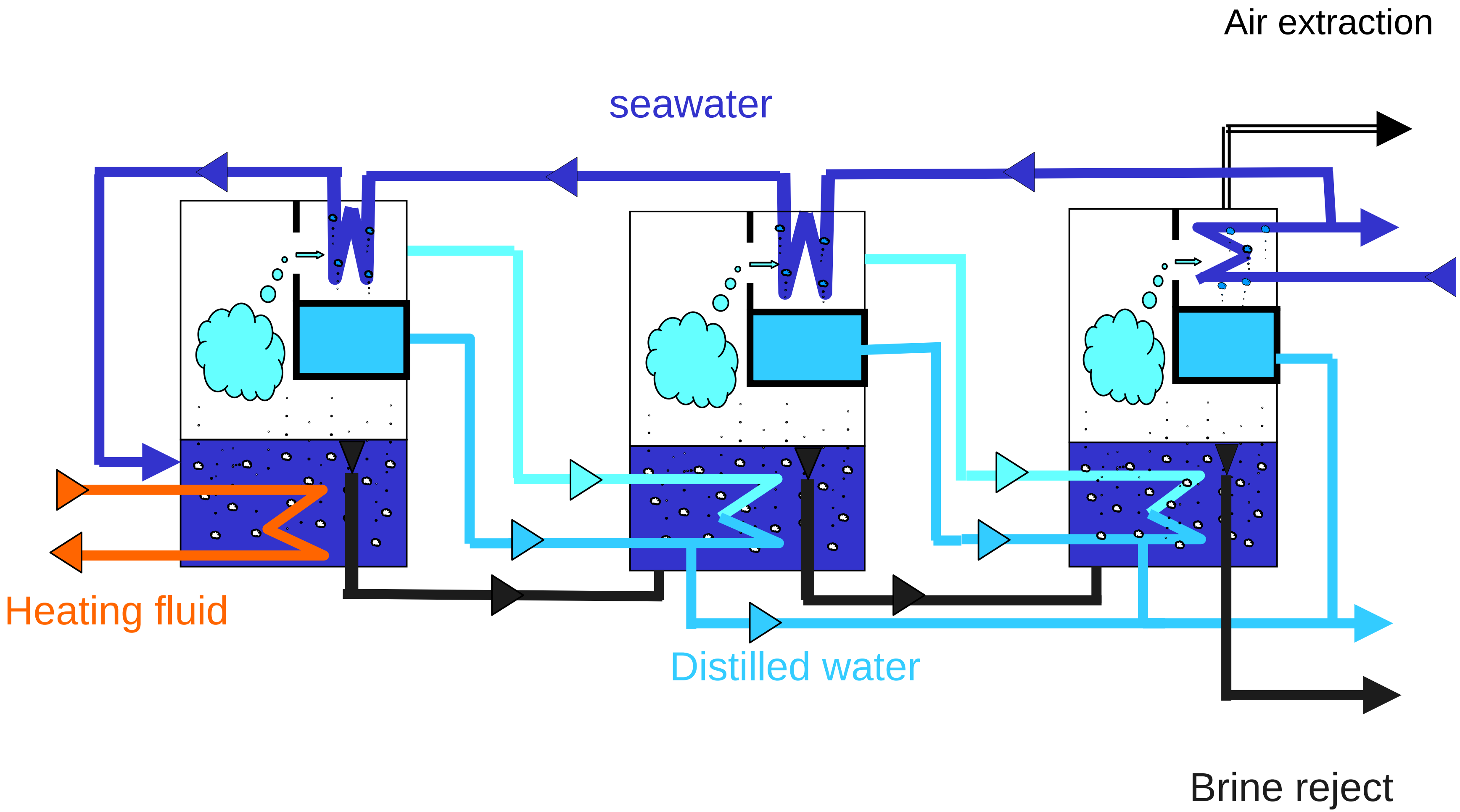


The boiling point of water is reduced If the pressure in the vessel is lowered,

Single effect distillation unit



Multi- effect distillation, MED



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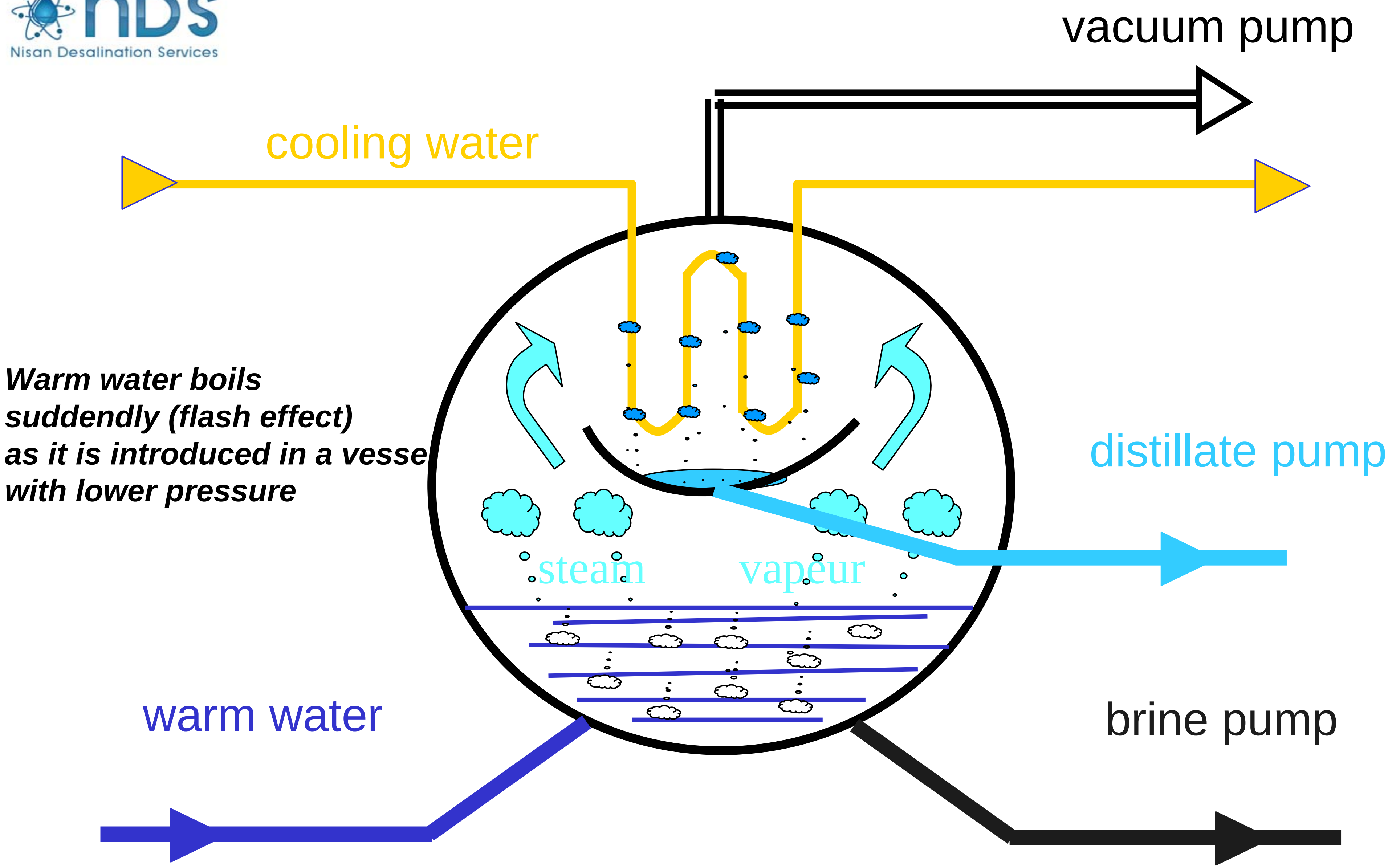
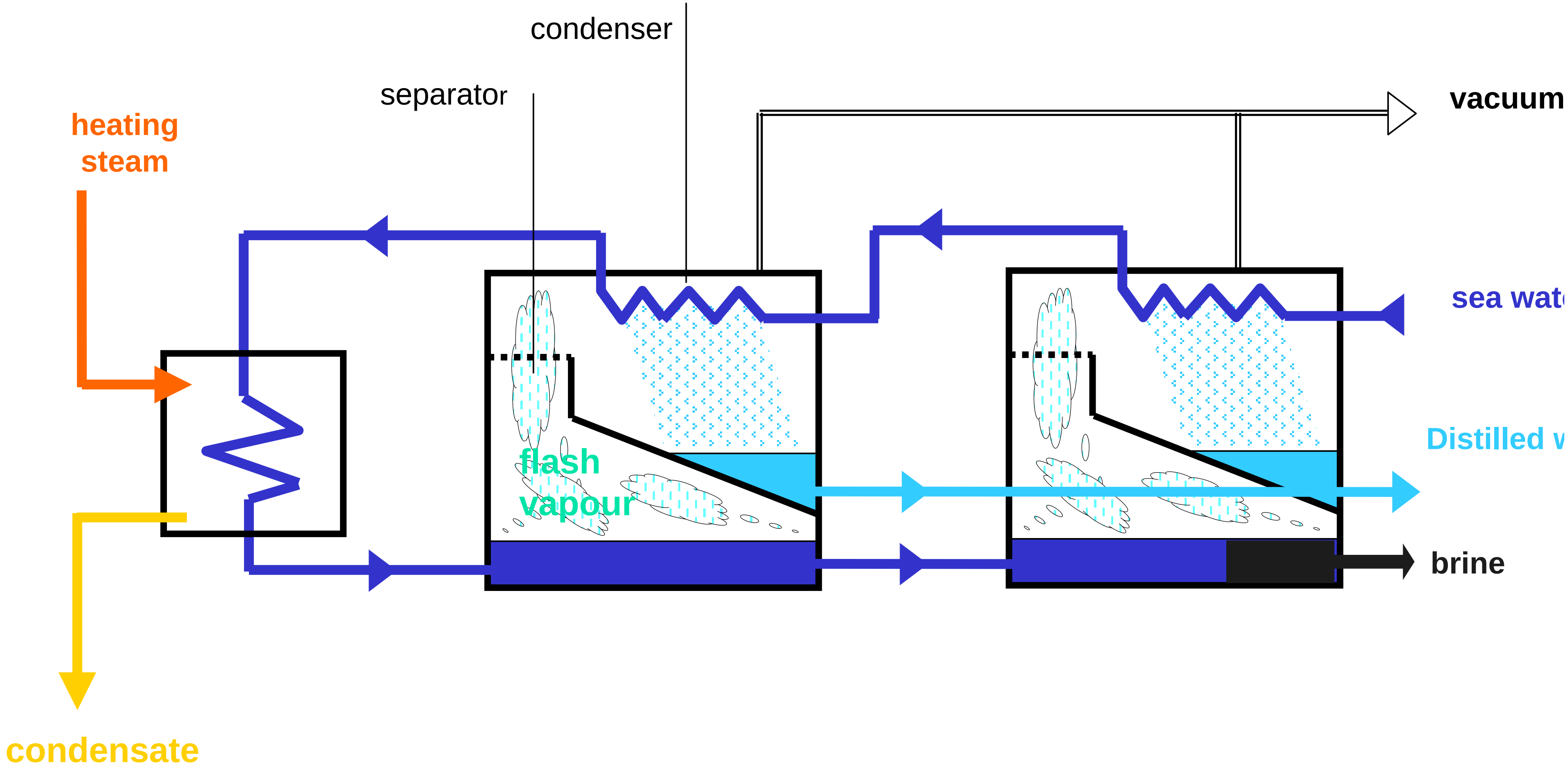
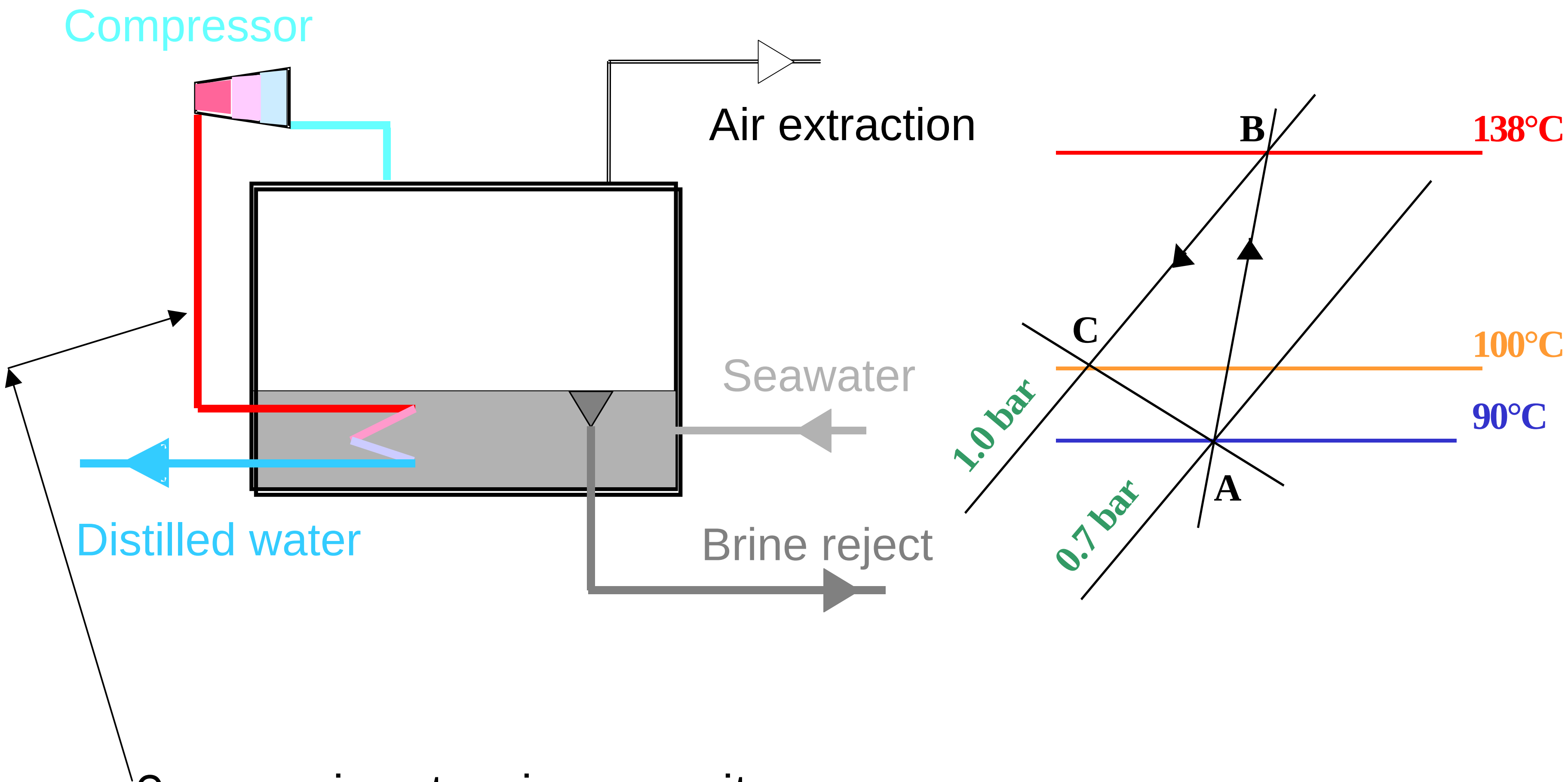


Single stage flash evaporator : schematic flow diagram

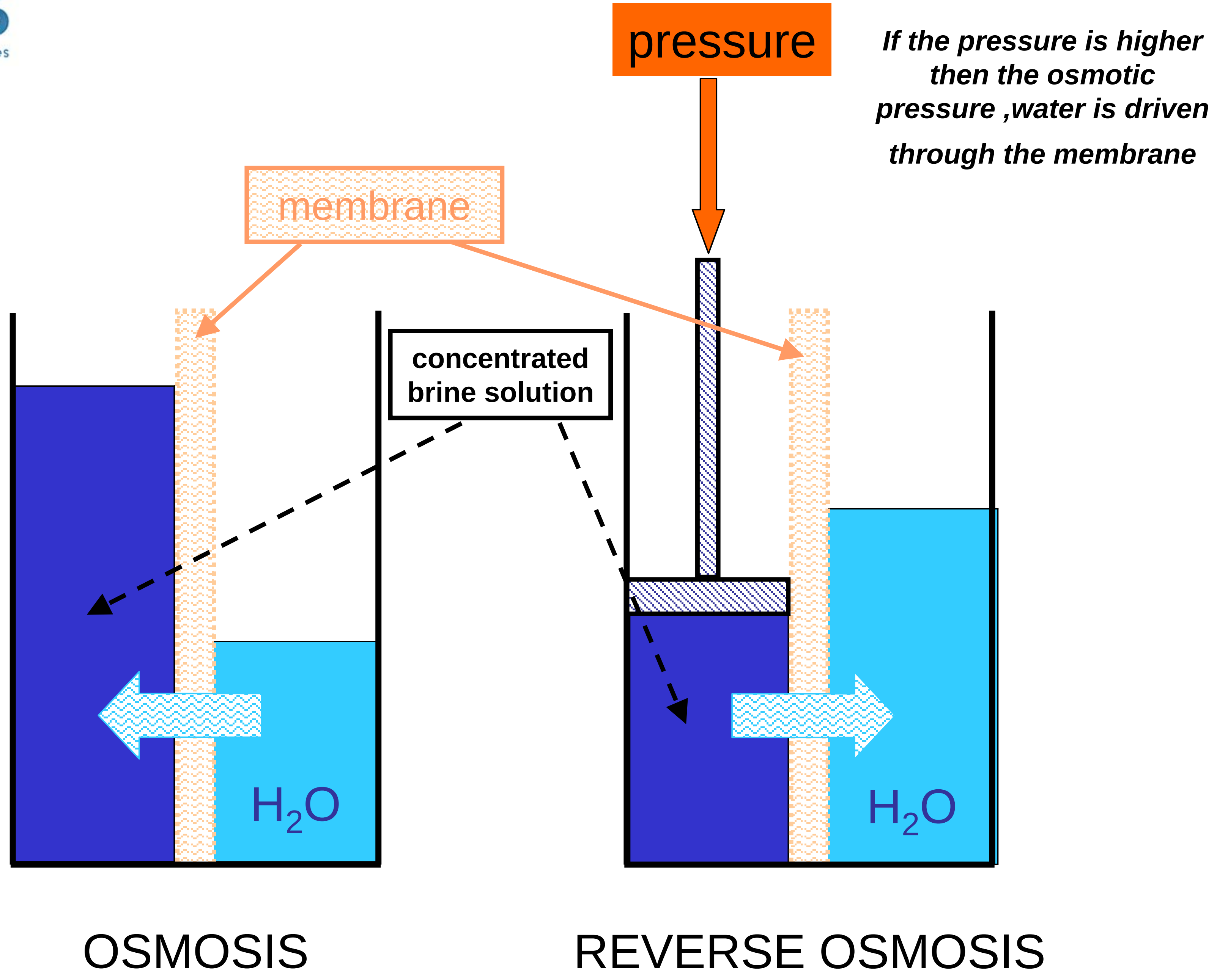


MULTISTAGE FLASH DISTILLATION (MSF)

VAPOUR COMPRESSION DISTILLATION UNIT

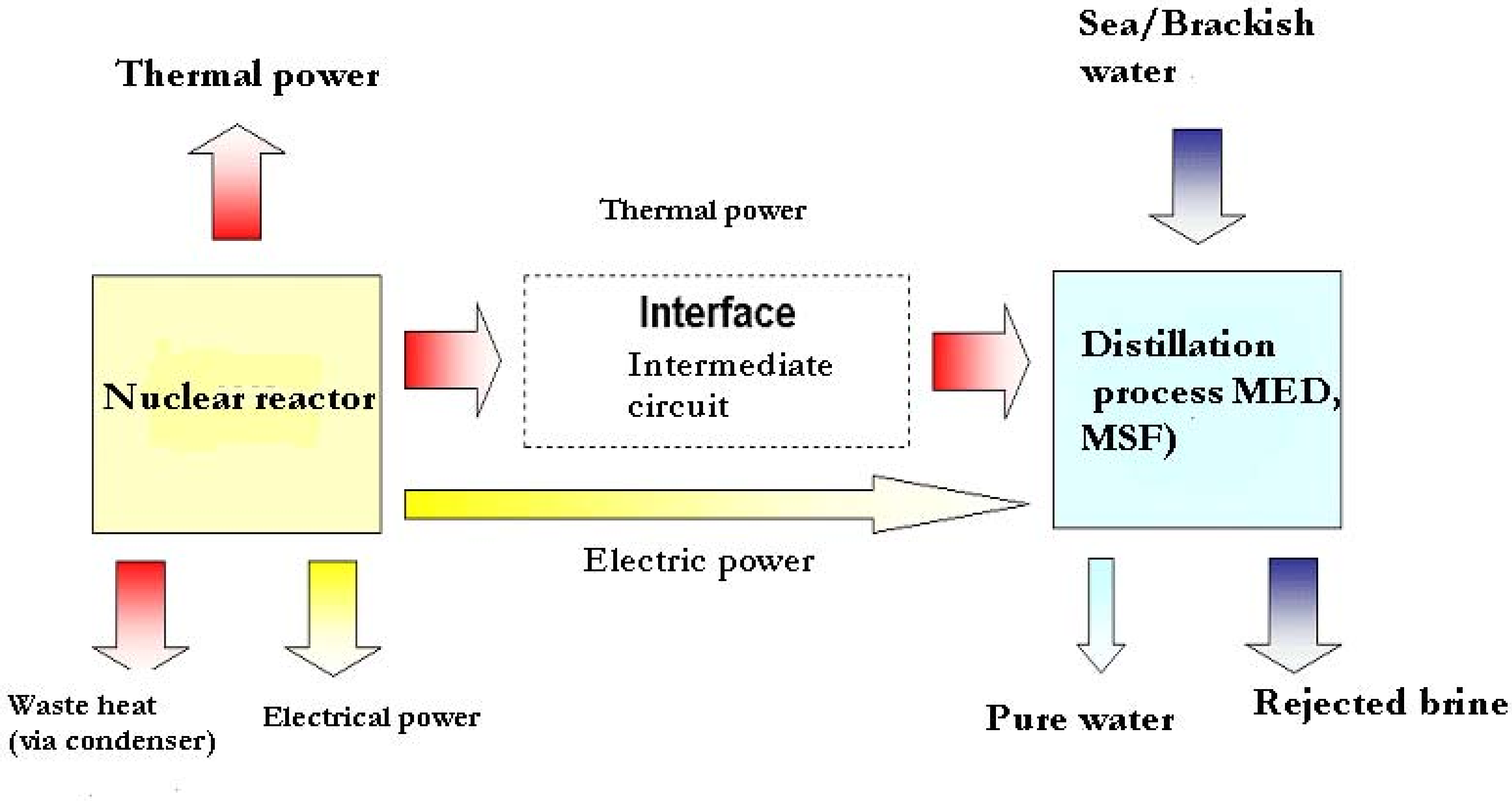


Compressing stem increases its temperature

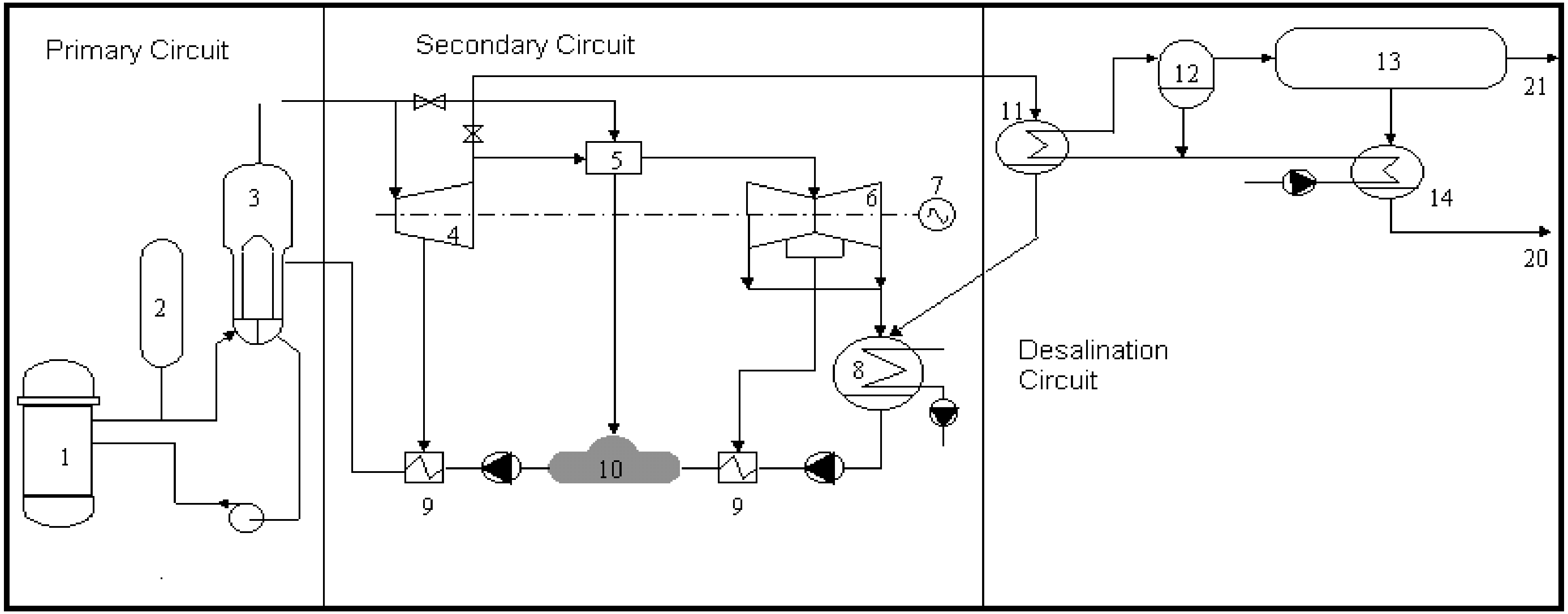


pressure
If the pressure is higher then the osmotic pressure ,water is driven through the membrane
membrane
concentrated brine solution
H_2O
H_2O
OSMOSIS
REVERSE OSMOSIS

The principle of coupling (Nuclear reactor + distillation process)



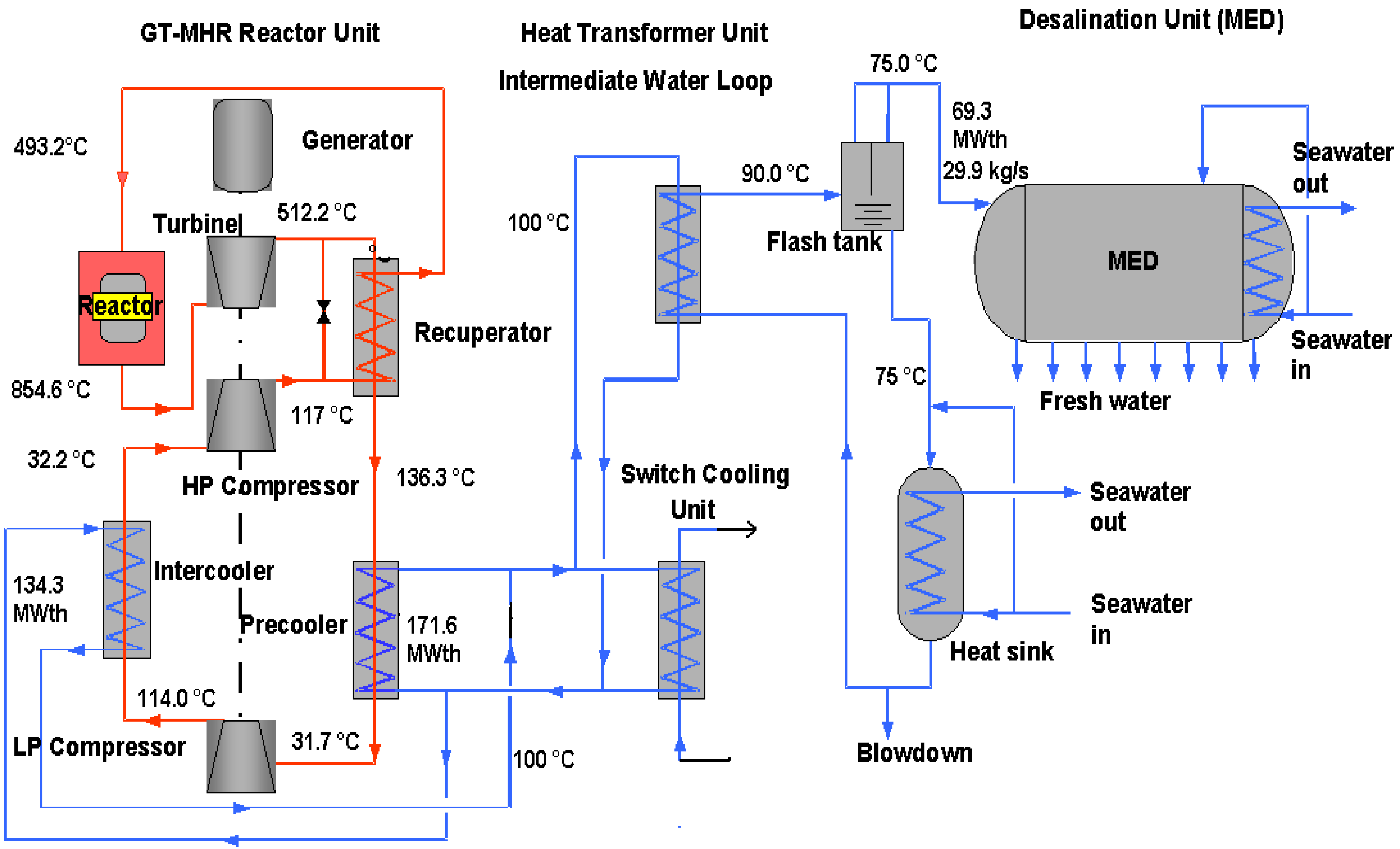
Coupling with a PWR, PHWR …



The coupling requires bleeding of vapour from in between the turbine stages. Hence some loss of power

With MED, 89.3 MWth, 42 kg/s (90°C), 11.3 MWe lost to produce 48 000 m³/jour.

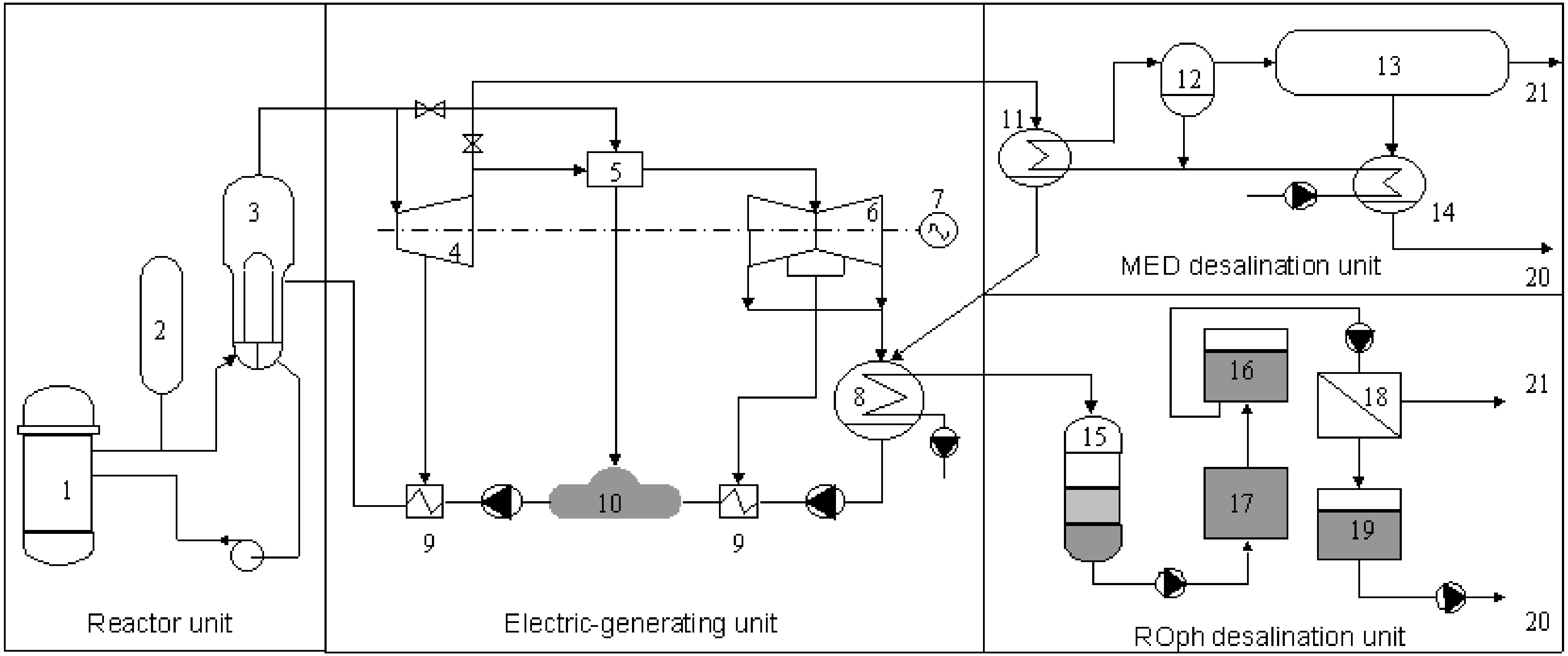
Innovation: utilise the waste heat from nuclear reactors



Optimised GT-MHR + MED coupling, utilising waste heat

Coupling with a PWR

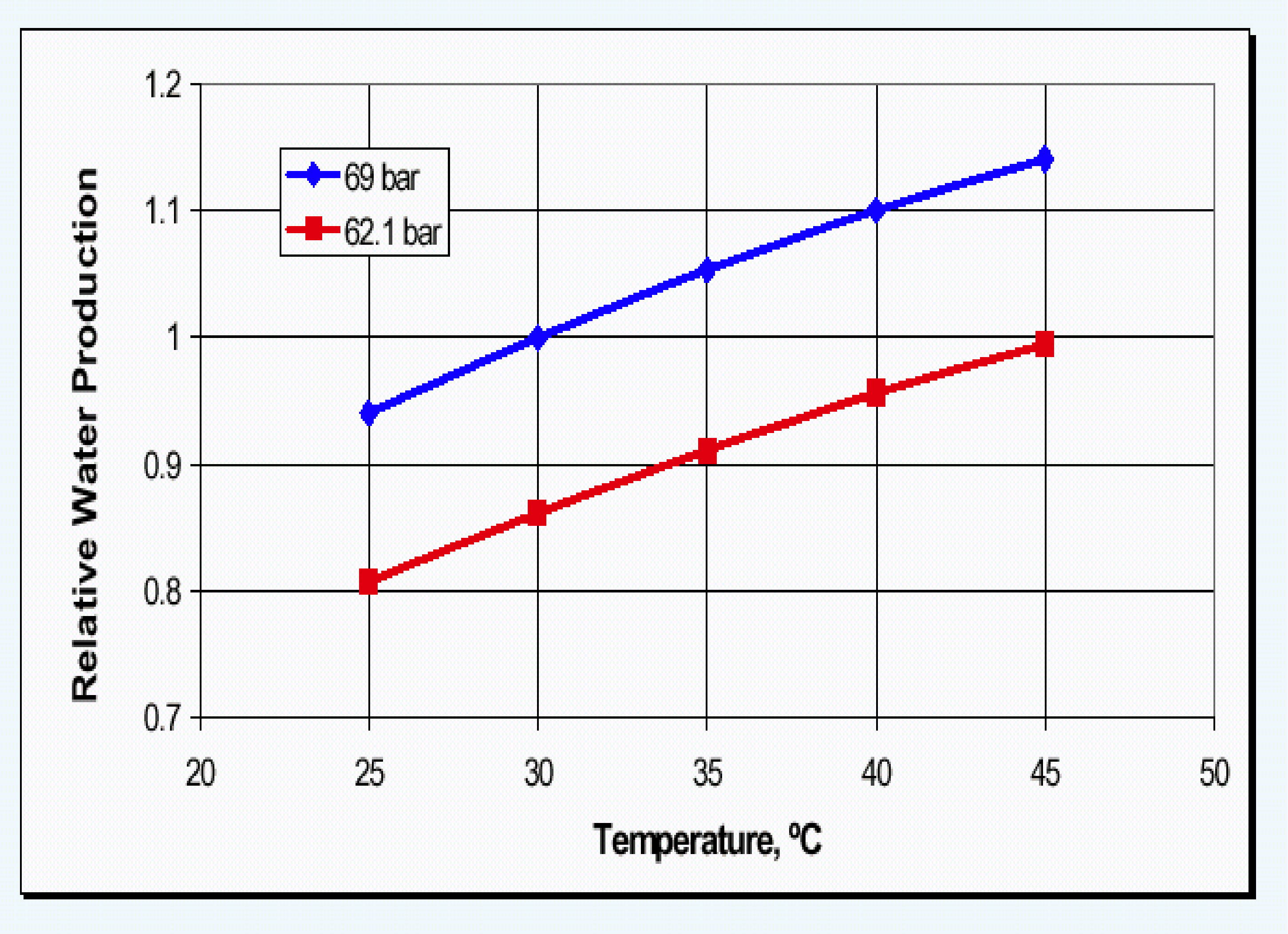
The waste heat lost via the condenser can be used to preheat RO feedwater



Relative water production in RO (ROph process)

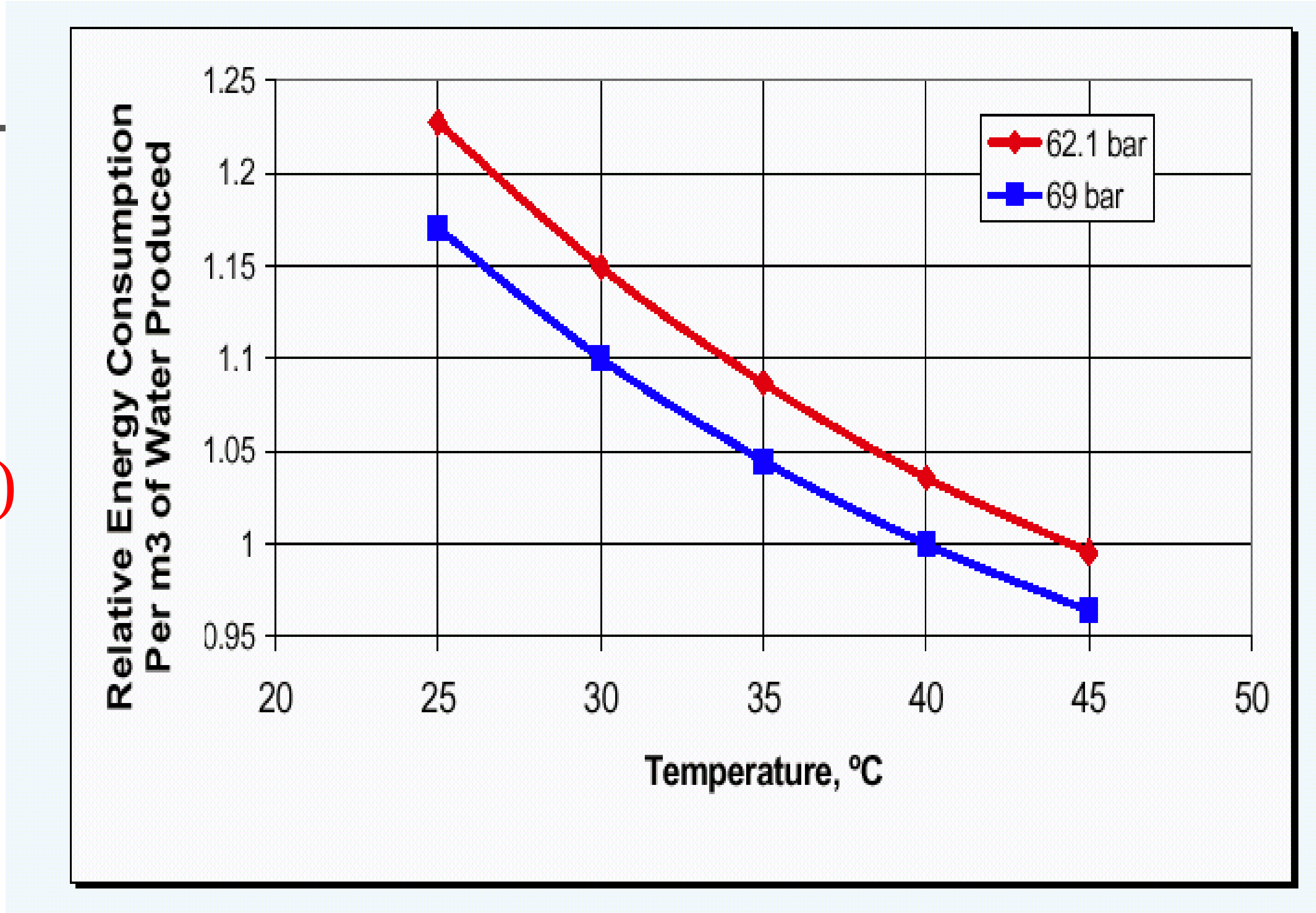
$$\mu \propto \frac{1}{T}$$

$$Q_p \propto \frac{1}{\mu}$$



Specific energy consumption (ROph process)

NDP=(ΔP-Δπ)



The two effects could reduce desalination cost by 7 to 30%

The Roph process

- We obtained correlations of the type:

  Recovery ratio = f(**x**, **e**, **m**)

  Feed pressure = f(**x**, **e**, **m**)

  Feed flow= f(**x**, **e**)

  Permeate TDS = f(**x**, **e**, **m**)

- We integrated them in a new version of DEEP, which has now two options:

  1: CEA: calculation with « NISAN » correlations

  2: IAEA: calculations as before

Desalination, 182 (2005) 483-495

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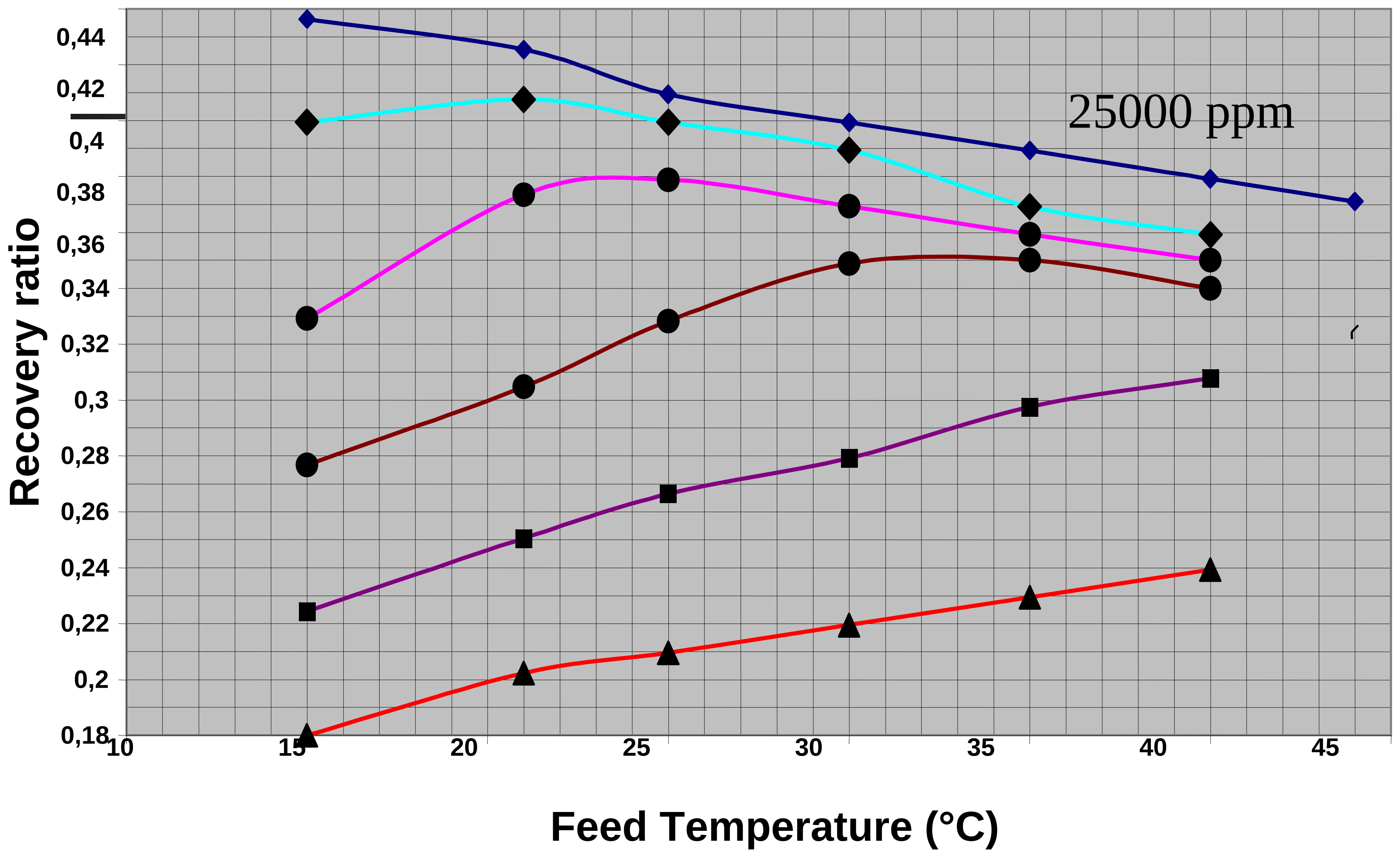

Energy consumption of desalination processes

Process	kWth.h/m^3	kWe.h/m^3
MSF	100	3
MED	50	2
RO	-	4.5 (3)

- To produce 130 000 m^3/day, MED would require 276 MW_{th} and 11 MW_e, and RO only 16 to 24 MW_e.
- Process operating temperatures : MSF 100-130°C; MED 60 à 100 °C ; RO 15 – 44°C
- No direct coupling with the reactor for RO ; necessary for MED, MSF

Economics of Desalination

- The main role of the economic assessment of an engineering project is to assist in making decisions
    - Technical choice of options
    - Financial, managerial or administrative
    - Near future or long term
- Criteria?
    - **Cost of the product** (\$/m^3)
    - **Percentage of local currency**
    - **The price of the product**
    - **The value of the product to the customer**
- See TECDOCS 666 and 1561

Key factors

- The single most useful criterion to measure the performance of a given combination of an energy source and desalination plant is the lifetime levelised unit cost of the water produced ($/m3).

$$\$/m3 = \frac{Total\ water\ production\ cost}{Total\ amount\ of\ water\ produced}$$

- Total water cost = the cost of energy (heat or electricity or both) + capital cost of desalination + O&M costs +..

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Nuclear Power Options in DEEP

- Medium sized PWR, Westinghouse (AP-600)
- Medium sized PHWR, AECL (CANDU 3)
- Small PWR, Russian KLT-40
- GT-MHR, (General Atomics)
- Nuclear heat only reactor, Chinese HR-200

Fossil Power Options in DEEP

- Superheated steam boiler for coal
- SSB for oil or gas
- Open cycle gas turbine,
- Combined cycle gas turbine
- Diesel, power plant
- Boiler (steam or hot water), heat-only plant

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Desalination Options in DEEP

- Multi-effect distillation (MED) [+VC]
- Multi-stage flash (MSF) [+VC]
- Reverse osmosis (spiral wound) R/O-sp
- Reverse osmosis (hollow fibre) R/O-hf [X]
- All hybrid combinations of the above

Calculation Routine of DEEP

- Input of capacity etc., input of technical parameters or default
- Power plant performance
- Power plant modification: heat extraction
- Desalination plant performance
- Power and desalination plant cost
- Economic evaluation: water and power cost
- Graphic output

Capital cost

- Base cost = Direct cost + Indirect cost + owners cost
  + spare parts + contingency
- Total cost = Base cost + Escalation + IDC

- Total capitalised Investment , *I*

$$I = \sum I_m (1 + d)^{D - D_m}$$

$\sum$ = summation of all the direct & indirect expenditure, I_m a specific expenditure, D, reference date for capitalisation, D_m date of expenditure, d discount rate

Cost Allocation Methods

Prorating Methods

Allocation according to given criteria

- Proportional Method
  - two single purpose plants

Credit Methods

- Power Credit Method
  - ***DEEP***

See TECDOC 666 or 1561

The proportional method

- Divides the total plant cost between the two products: electricity and heat in a certain ratio, selected on the basis of various criteria.
- e.g. comparison of the dual purpose plant with alternative single purpose plant to establish a ratio of heat to electricity costs
- difficulty of accurately defining the costs of equivalent single purpose plants
- market distortions (direct or hidden subvenntions..)

Cost Evaluation Methodology in DEEP

- ***Single purpose plant***
  - Levelised cost of energy is the discounted cost of all expenditures associated with the design, construction, operation, maintenance, fuel cycle costs divided by the discounted values of the quantities of energy produced
  - water cost is similarly obtained by charging to water all water plant investments (plus energy production costs) and dividing by total water production

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The Power Credit Method for Dual Purpose Plants

- The energy cost is set to be the cost obtained from an imaginary single purpose power plant, generating net energy E with total expenses, C
- Determine the net saleable kWh cost, C_{kwh} = C/E
- Calculate the amounts of desalted water (W) and the net saleable power E2 produced by the plant at a total expense C2. (E2 < E; C2>C)
- The desalted water cost is credited by the net Saleable Power Cost = C2-E2* C_{kwh}
- Cwater = (C2-E2* C_{kwh})/W