Water Conservation Type Cooling Systems for Nuclear Power Plants

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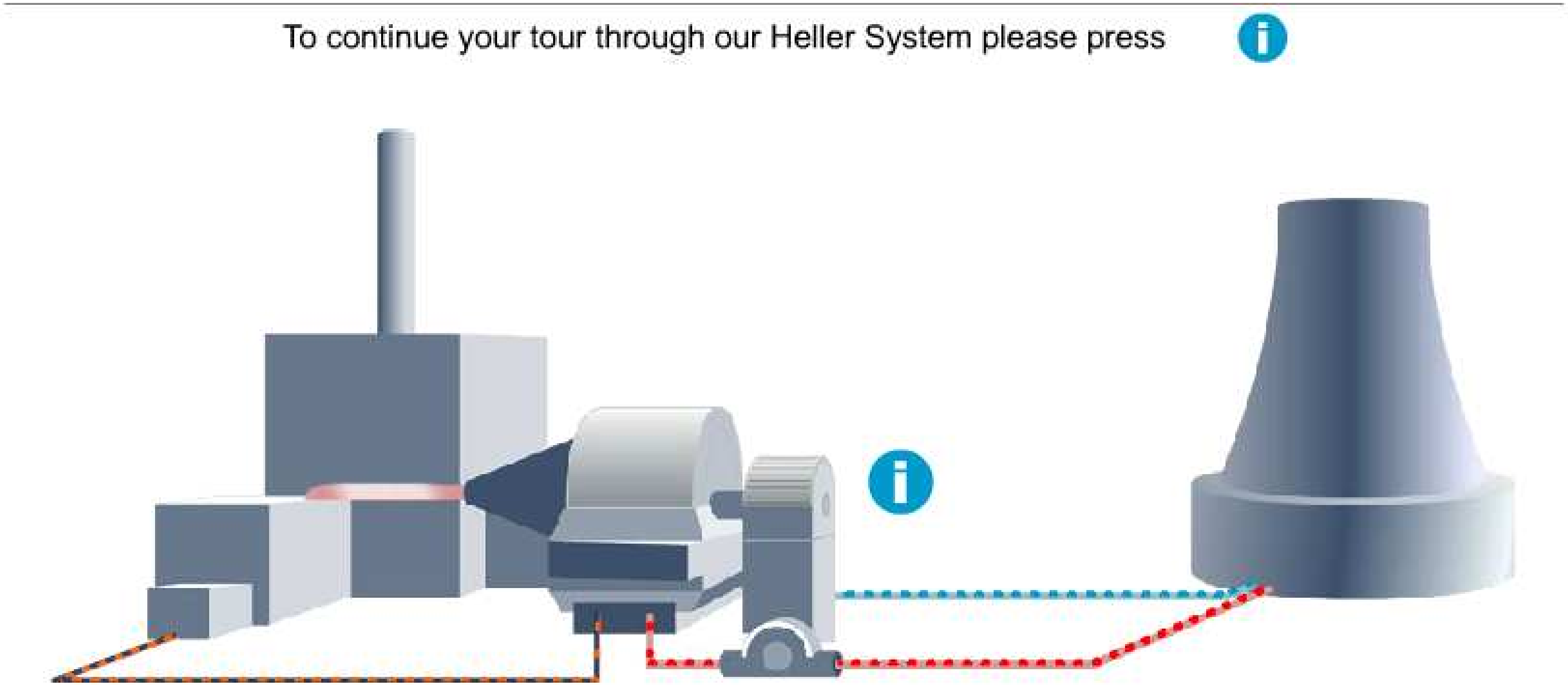
GEA Heat Exchangers / **GEA EGI Contracting/Engineering Co. Ltd.**

Contents

page

1. Indirect dry cooling (HELLER System) and its dry/wet derivatives

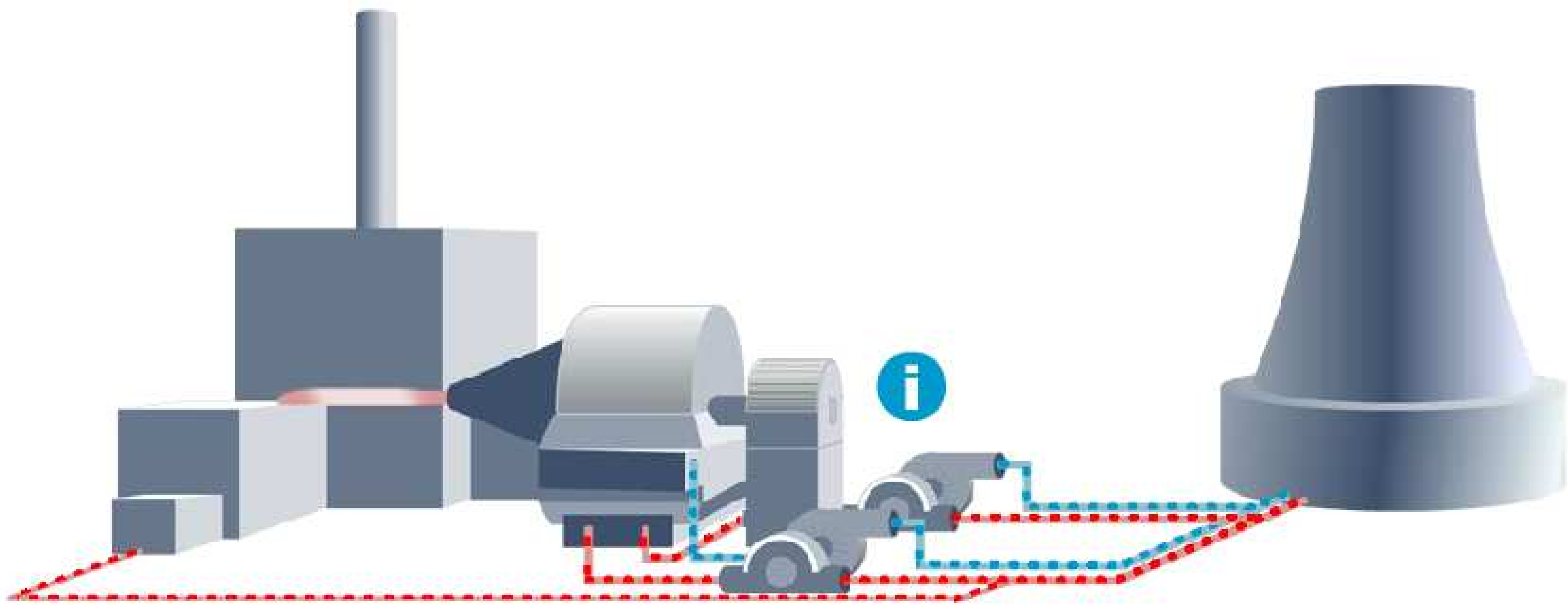
➢ **HELLER System with surface condenser**



1. Indirect dry cooling (HELLER System) and its dry/wet derivatives

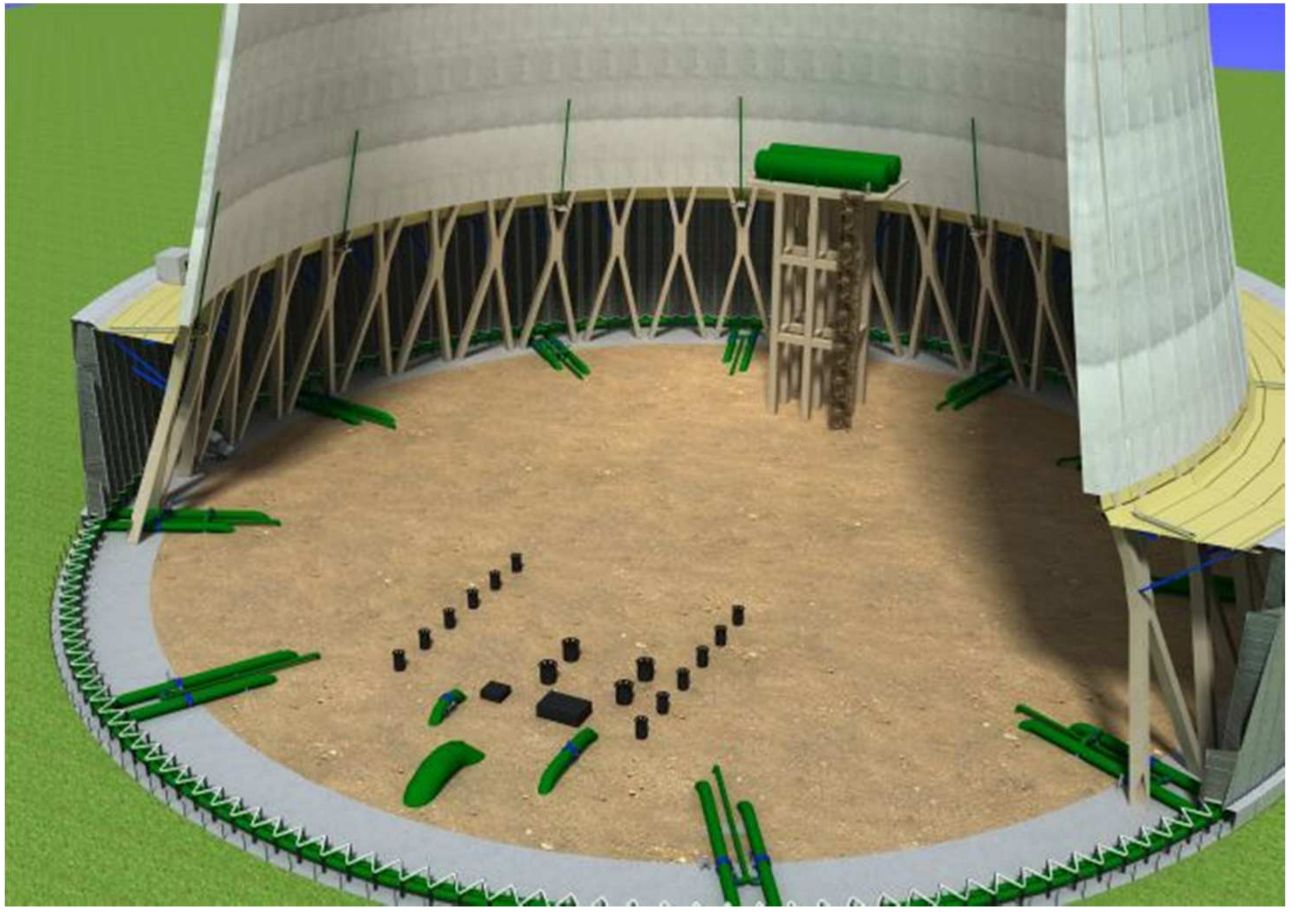
➢ HELLER System with DC condenser

To continue your tour through our Heller System please press

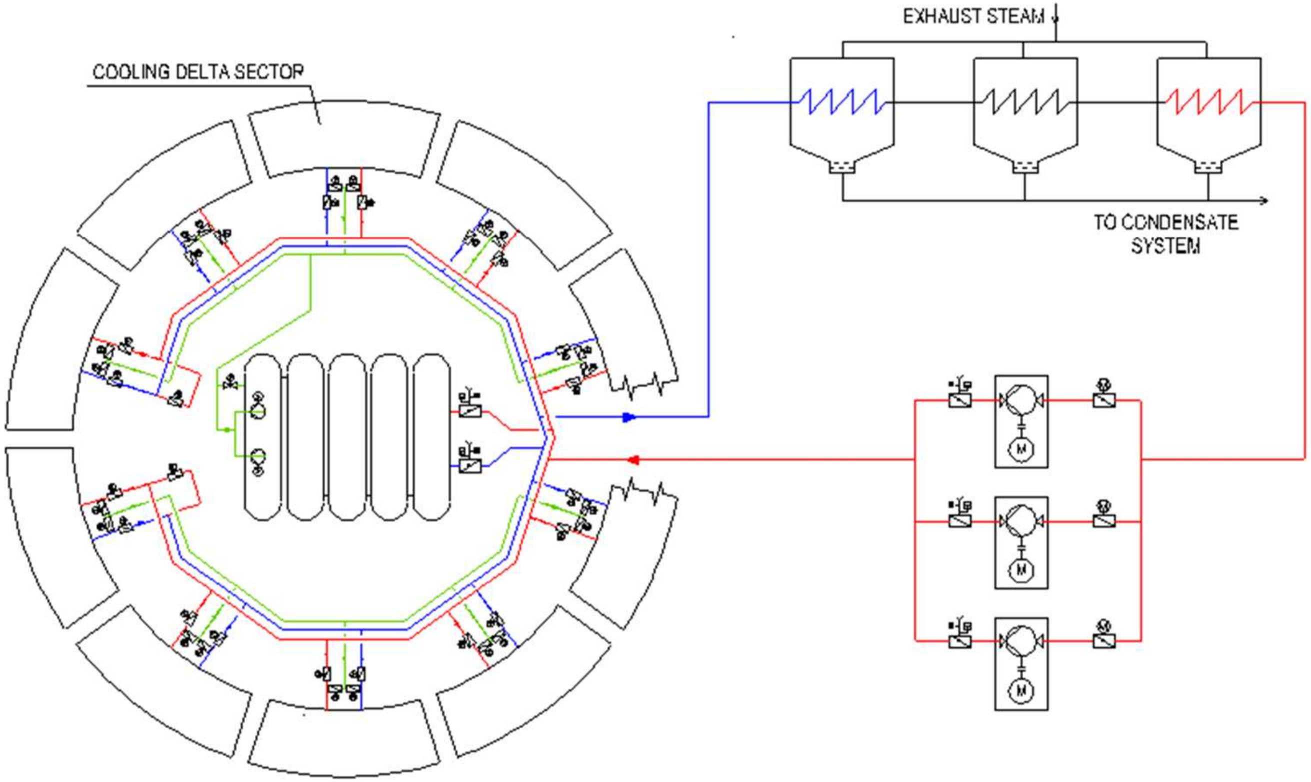


HELLER System is an indirect dry cooling plant. The power plant waste heat is initially exchanged in a condenser (preferably a direct contact one) to a closed cooling water circuit. The heat absorbed by the water is rejected to ambient air in fin tube type heat exchangers. Air moving can be either by natural or mechanical draft.

➢ Dry cooling tower arrangement



➢ Simplified flow diagram for a HELLER System with surface condenser



2. GEA EGI's HELLER System References

- **GEA EGI (the center of excellence for indirect HELLER Systems) has more than 55 years of experience - resulting in a total of 30,000 MW_e power plant capacity in service and under construction with the HELLER System and its derivatives**

- **GEA EGI's references located in 20 countries, cover all types of power cycles and climatic conditions:**

  - units operating under extreme ambient conditions: *air temperature as cold as -62°C (-79.6°F) or as hot as +50°C (+122°F) (incl. areas over the arctic circle and in desert belt) and sites located at sea shore or at high altitudes (up to 2000 m / 6000 ft)*

  - indirect dry cooling plants either with DC or surface condenser

  - the largest dry cooled Combined Cycle Plant in the world

  - **the only dry-cooled nuclear power plant in the world**

  - natural draft dry cooling towers through which flue gases are exhausted

  - cost efficient, environmentally compatible dry/wet derivatives of HELLER System: *2200 MW_e equipped with supplemental spraying (incl. units under constructions) and 4300 MW_e with parallel wet assisting or delugable cooler cells*

The only one dry cooled nuclear power plant in the world:

Bilibino Nuclear Power Plant 4×12 MW_e Russia (located over the Arctic Circle)
– cooling system supplied by EGI

The plant has been operating successfully since mid. of 1970s.

- The design minimum temperature considered for the complete plant, thus also for the cooling system was: - 62 ºC
- The mechanical draft HELLER Systems have:
  - ✓stainless steel surface condensers
  - ✓triangular shape vertically arranged Forgó-type all-aluminum air coolers
  - ✓ warm air re-circulation possibility is applied to protect the air coolers against extreme low winter temperatures

  - ✓since the ambient temperature in July and August may exceed 30-33°C, after a period of operation a supplemental spraying system has been installed to be used for this short period (approx. 100 hours/year).

Air Moving: either natural (concrete or steel) or mechancal draft

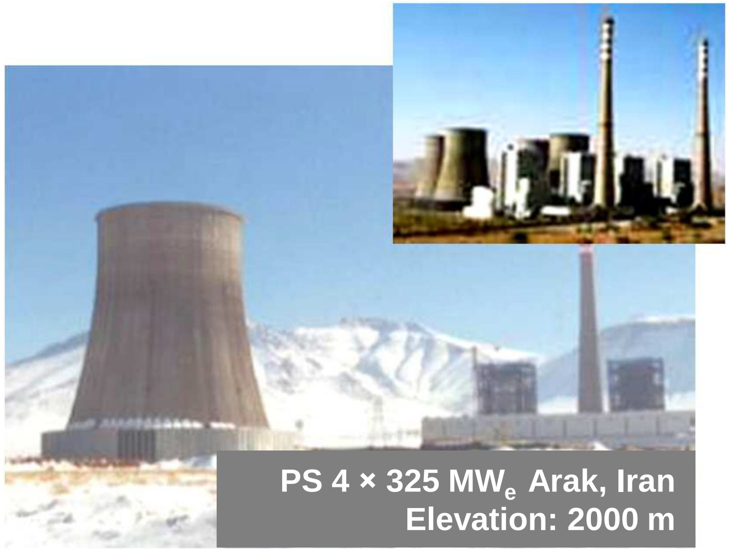
3 × 220 MW$_e$ Al Zara TPP, Syria; EPC: MHI

2 × 600 MW$_e$ Yangcheng TPP
HELLER System with surface condenser

800 MW$_e$ Modugno CCPP, Italy; EPC: ALSTOM
Induced draft, low noise, near sea shore

260 MW$_e$ Moscow City 2. Co-gen CCPP
winter proof up to -42°C

HELLER Systems in Extreme Cold Climate



PS 4 × 325 MW_e Arak, Iran
Elevation: 2000 m

2 × 310 MW_e & 4 × 200 MW_e Razdan PS, Armenia
Elevation: 1760 m

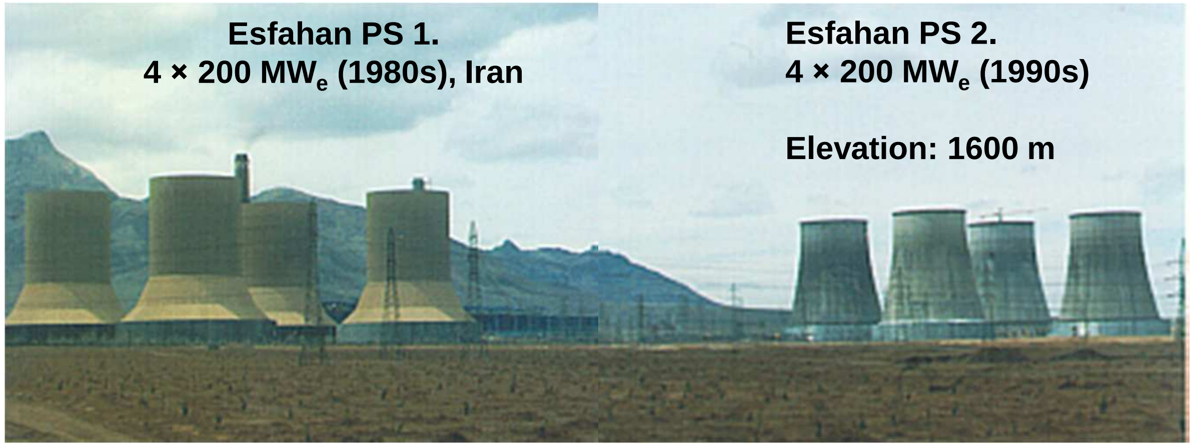
2 × 180 MW_e Pervomajsk CHP, Russia
freeze proof up to -42°C

340 MW_e Thereshkovo CHP, Russia
freeze proof up to -42°C

HELLER Systems in Sizzling Deserts

540 MW_e Nasserieh CCPP, Syria, EPC: Siemens

750 MW_e Deir Ali CCPP, Syria
EPC: Siemens



Esfahan PS 1.
4 × 200 MW_e (1980s), Iran

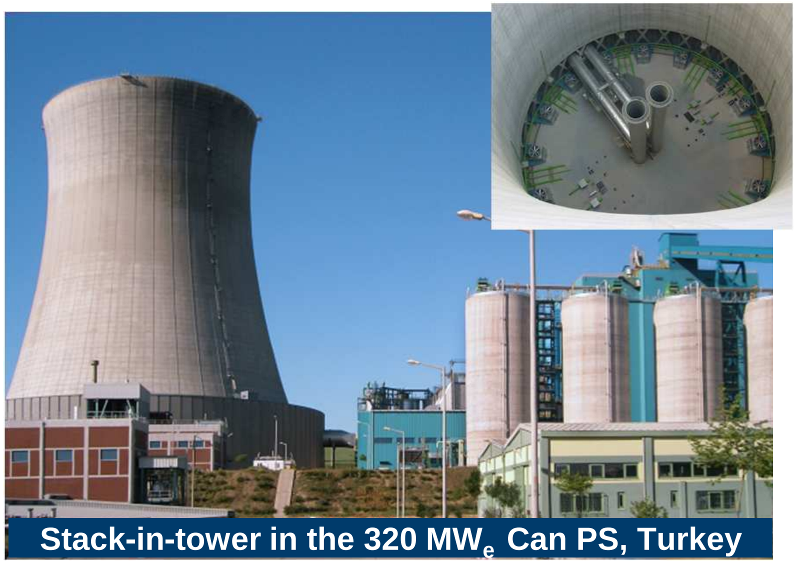
Esfahan PS 2.
4 × 200 MW_e (1990s)

Elevation: 1600 m

World's largest dry cooled combined cycle power plant

Cool for Coal – a greener & cheaper flue gas exhausting

2 × 700 MW$_e$ BaoJi SC PS, China, FGD-in-tower

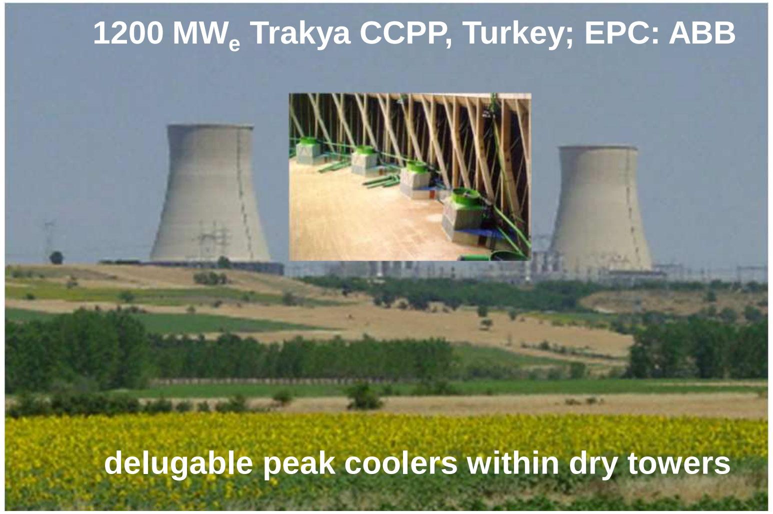


Stack-in-tower in the 320 MW$_e$ Can PS, Turkey

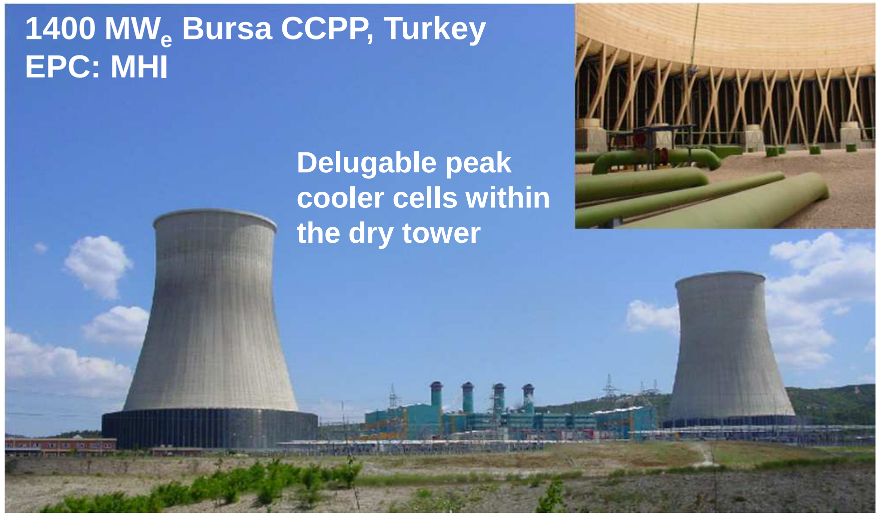
FGD-in-tower
2 × 300 MW$_e$ in a single tower
Shan Yin SC PS, China

Dry/wet HS Derivatives: supplemental spraying

Dry/wet HS Derivatives: wet enhanced peak coolers

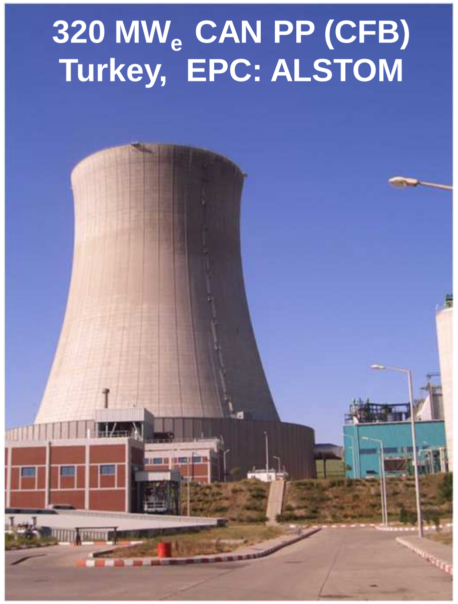

1200 MW_e Trakya CCPP, Turkey; EPC: ABB

delugable peak coolers within dry towers


1400 MW_e Bursa CCPP, Turkey
EPC: MHI

Delugable peak cooler cells within the dry tower


4 × 250 MW_e Shahid Rajai TPP, Iran; EPC: MHI


320 MW_e CAN PP (CFB)
Turkey, EPC: ALSTOM

delugable peak coolers within the tower

Dry/wet HELLER derivatives: separate circuit dry/wet system

860 MW_e lignit fired Mátra PS, Hungary owned by RWE, of which

2×230 MW_e units are equipped with separate circuit HELLER dry/wet system

(combined DC & surface condenser) – additionally the air coolers may have also possibility for supplemental spraying

Assisting wet cells located outside the dry cooling towers

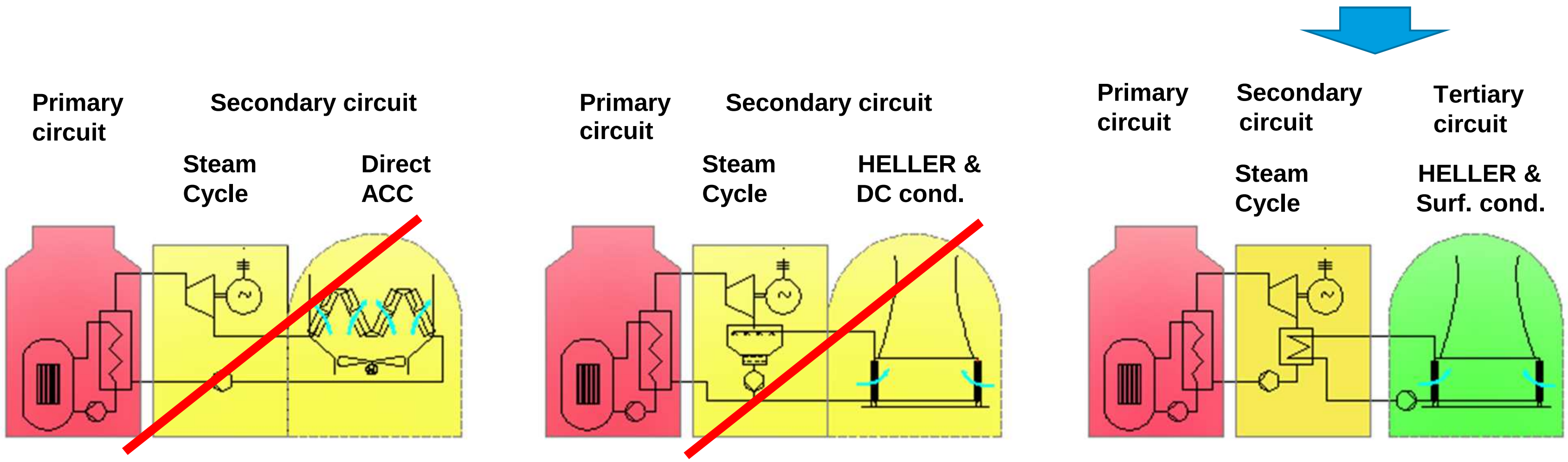
3. Adapting HELLER System and its dry/wet derivatives to NPP cooling

3.1 Basic aspects for matching water conserving cooling systems to NPPs

❖ **Safety first!**

✓Only those cooling systems are to be considered which are able to establish at least the same isolation between the primary nuclear circuit and the environment as it is maintained by an all-wet cooling system – including also avoiding the extension of the steam cycle space; independently if it is part of the primary circuit (BWR) or that of the secondary one (PWR) - SAFETY FIRST!

✓Though natural draft HELLER System with direct contact condenser is the most economical solution, but **for nuclear plants the dry HELLER System & its dry-wet derivatives are considered with surface condenser only. It can even improve the NPP safety by implementing a further closed circuit between the primary nuclear circuit and the environment.**



❖ Large unit capacity NPPs with saturated steam cycles

✓ The reduced steam cycle efficiency (due to its saturated steam cycle) combined with large unit capacities (applied for economic reasons) require extra-large cooling systems as well as high CW flow rates compared to the fossil fueled power plants.

✓ Since heat rejection by dry cooling is made through sensible temperature increase of the ambient air, the cooling air flow is approx. 3-4 times larger than that of a wet cooling tower. Taking into account the extreme large heat-to-be-dissipated the natural draft has significant advantage over the mechanical draft.

✓ An efficient dry cooling system for NPPs in the output range of 1000-1700 MW_e need two or three large natural draft cooling towers per unit.

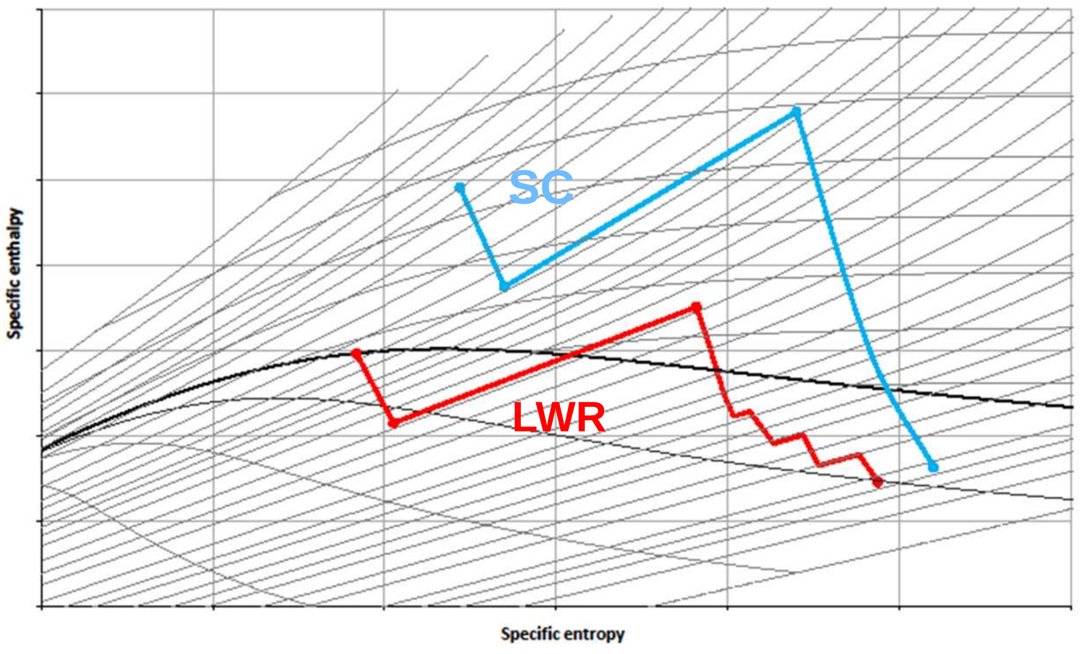


Fig 3.1 Expansion lines of a saturated steam cycle (LWR) compared to that of a supercritical steam cycle

❖ Strong dependence of dry cooling capability on ambient air DBT

✓ At dry cooling the condenser temperature – thus the turbine backpressure – thoroughly follows the increase in ambient temperature. Indirect dry cooling in winter time is capable to establish even lower backpressure than allowed by the turbine choking point, whereas it leads to elevated backpressures in hot summer hours.

✓ Thus water conservation type cooling systems – depending on climatic conditions – may require LP turbines operable at wider backpressure range and having markedly higher maximum allowable backpressure than required for wet cooled NPPs.

✓ To improve operational conditions the following solutions - as well as their combinations - can be considered:

- applying 3D designed LSB for LP turbines - allowing a wider backpressure range
- selecting smaller exhaust area LP turbines, which allow higher MAB (e.g. for a large LWR unit instead of 6F LP turbine only 4F may be justified with the same last stage blading)
- increasing the capacity of the dry cooling system (i.e. applying lower cooling tower ITD)
- to use water enhancement, i.e. applying dry/wet cooling system
- adapting the saturated steam cycle to the high condenser temperatures imposed by dry cooling in summer.

✓ In general, it is important to carefully match the LP turbine and the cooling system (together they constitute the **cold-end**) to avoid substantial operational limitations and power losses.

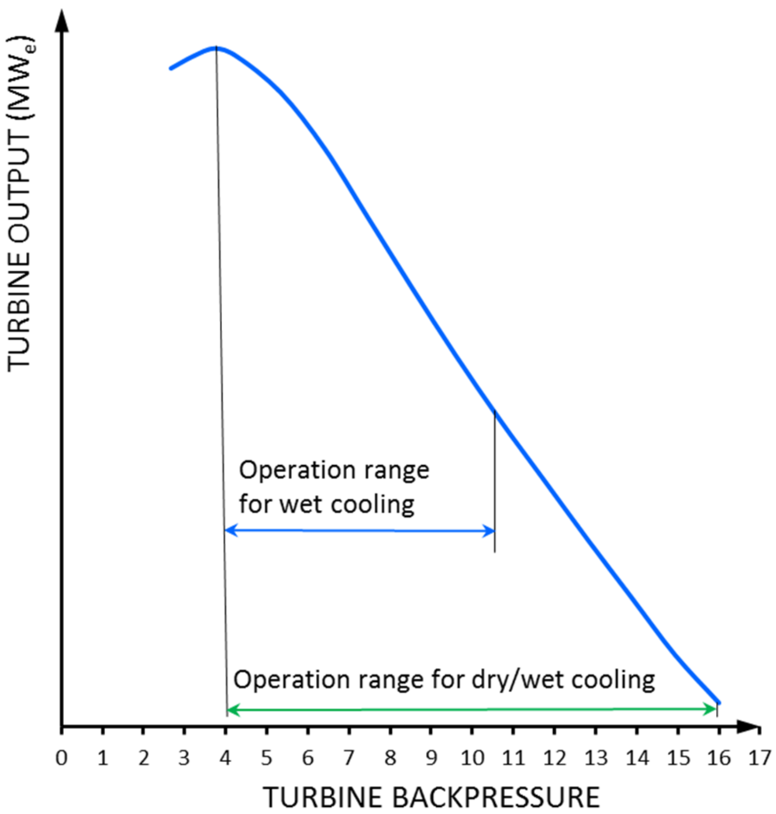


Fig 3.2.a
Backpressure operation ranges for a wet and a dry/wet cooling

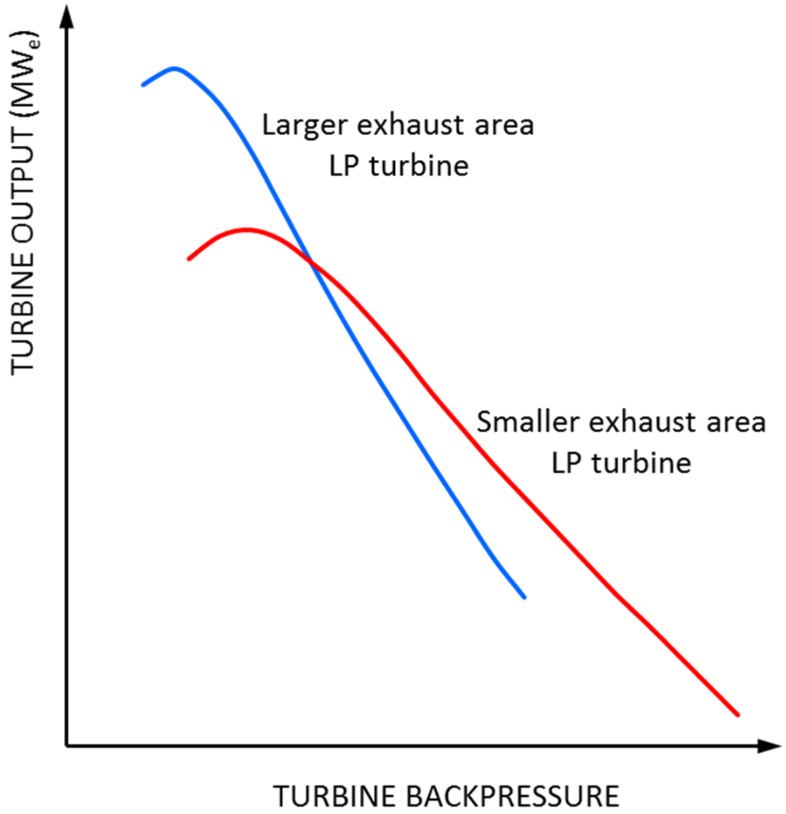
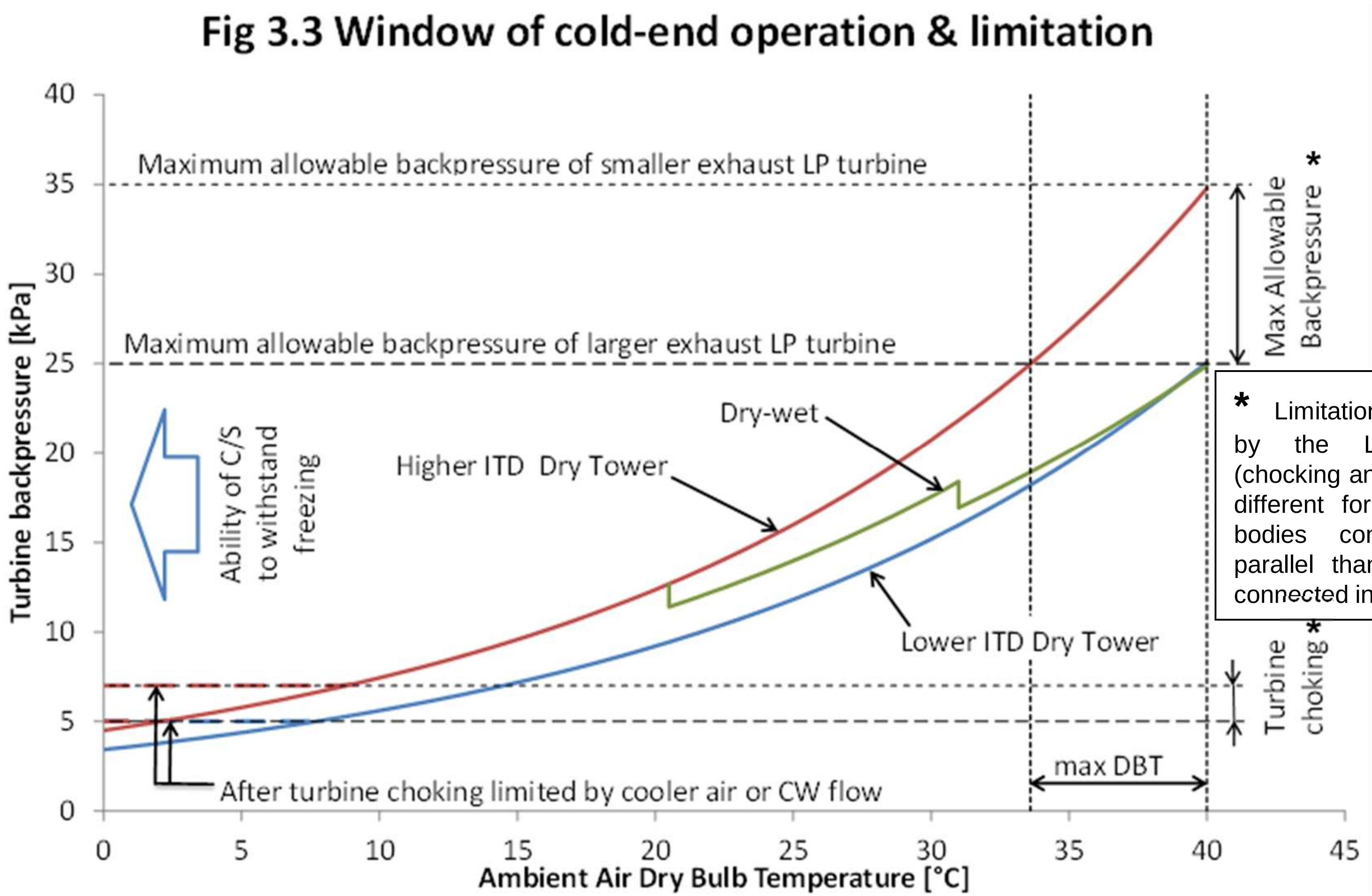


Fig 3.2.b
Effects of reduced LP exhaust area on chocking-point, MAB and output



* Limitations imposed by the LP turbine (chocking and MAB) are different for condenser bodies connected in parallel than for those connected in series!

Selecting a performance and cost effective water conservation type cooling system necessitates to investigate and evaluate together the cooling system and LP turbine options with due regard to site conditions and the decisive economic factors.

❖ Classifying cooling systems by their water consumption

- ✓ Derived from the all dry HELLER System GEA EGI has developed several dry/wet combinations. Their water conservation features can be classified best by their annual and daily maximum water consumptions - referred to those of an all-wet cooling system (the hourly maximum is not a representative value since within the daily maximum it shall be bridged by reserving).

- ✓ The actual division of heat rejection between the dry and the wet sections can be changed seasonally, daily and even hourly within certain limits. The selection of the capacity ratio - either for the plant investment or for the operational schedule - depends on the make-up water availability & cost, the power demand & the electricity price as well as on investment and environmental costs, fees & limitations.

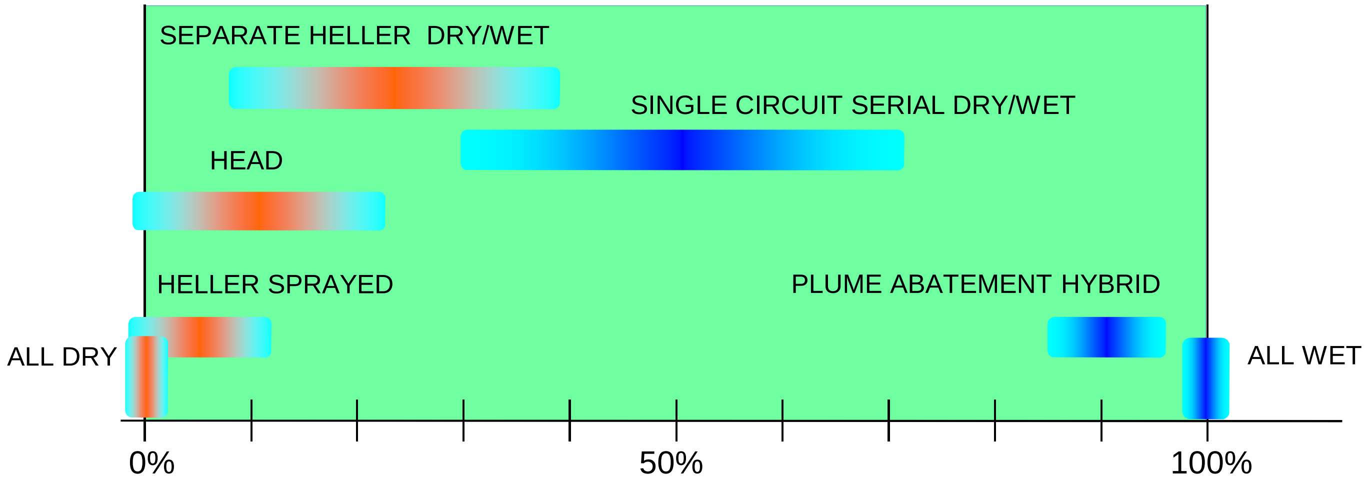
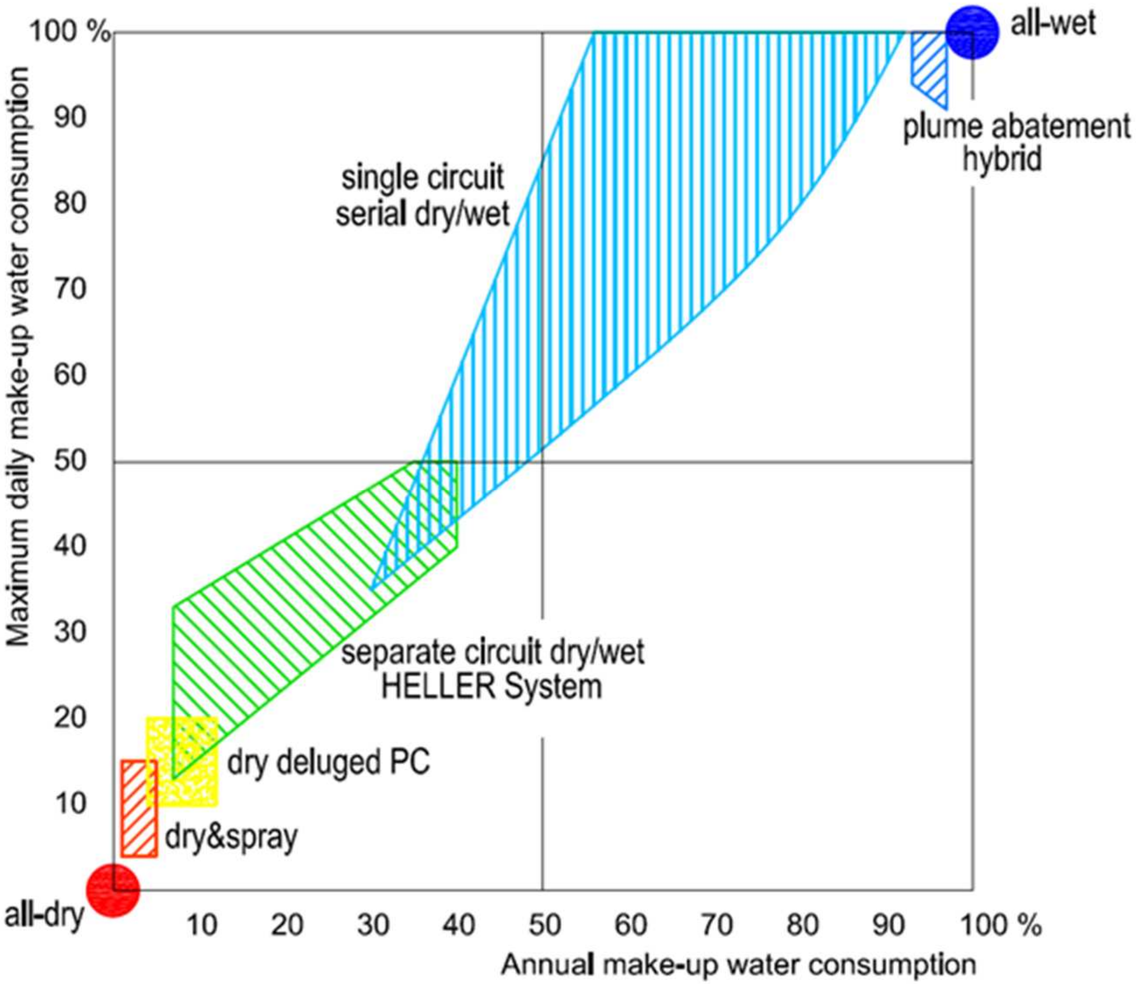


Fig. 3.4 Classification by annual water consumption relative to that of an all wet cooling

Fig 3.5 Classification by annual and maximum daily (hottest day) water consumptions relative to those of all wet coolings

- ✓ Based on optimization and case studies, GEA EGI suggests to consider real water conservation type dry/wet systems in a broader range with 1-40% annual (targeted range of 1-20%) and 10-50% maximum daily water consumption
(i.e. in Fig.3.5 the operation should preferably remain within the bottom left quarter of the chart).

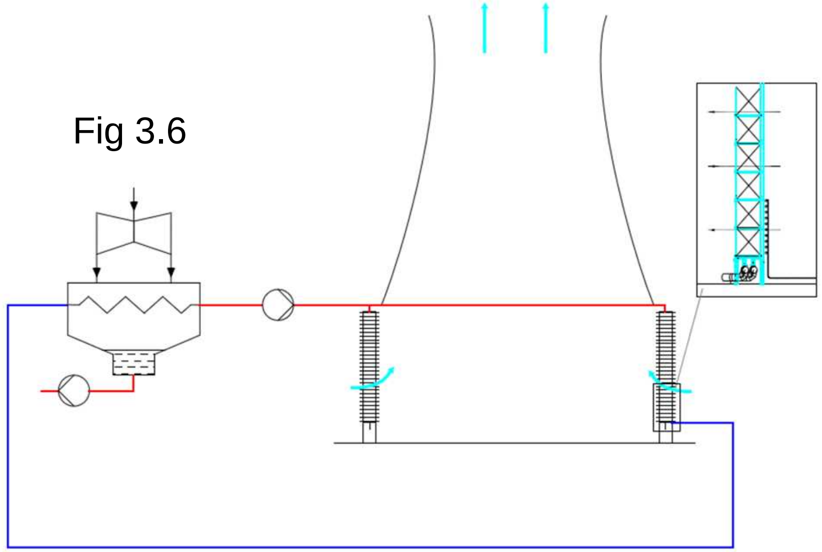


❖ Some basic dry/wet cooling system solutions

✓ Dry cooling with supplemental spraying

It is essentially an indirect dry HELLER System with surface condenser operating throughout most of the year in all-dry mode. The bottom sections of the vertically arranged air coolers are equipped with sprayers. Spraying is activated only in the hottest summer hours (approx. 100-800 hours/year).

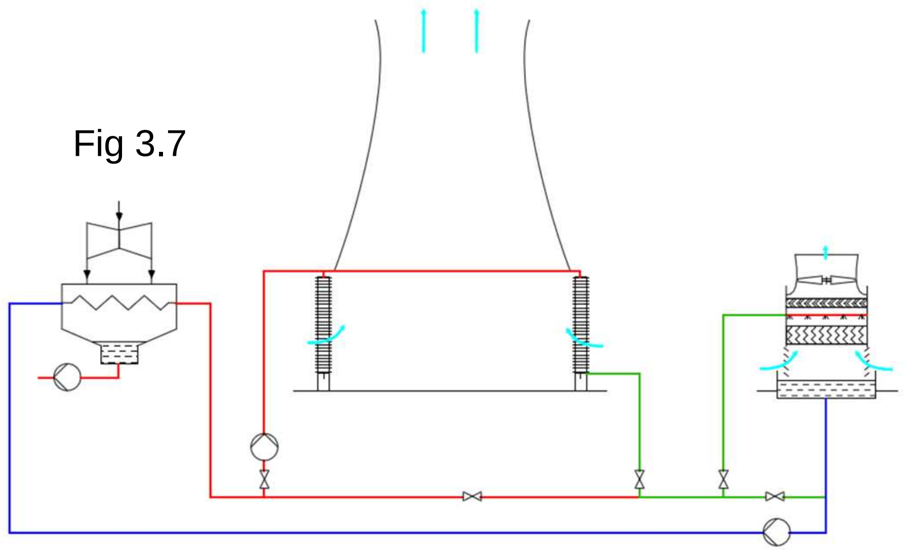
Fig 3.6



✓ Single circuit serial dry/wet cooling

CW is circulated in a single circuit, comprising serially connected dry air coolers and wet fills. Dry and wet sections can be bypassed and operated separately. This seemingly simple system has a major disadvantage: high maintenance costs related to depositions within air cooler tubes – which may limit water conserving capability.

Fig 3.7



✓ HELLER-based separate circuit dry/wet cooling system

An all-dry HELLER System (natural or mechanical draft) is integrated with a wet cooling system, however maintaining separate circuits for both.

Integration of the dry and wet circuits can be made via water-to-water heat exchangers (connected in series or parallel with the air coolers) or trough the surface condenser – in which there is a separate segment assigned for the dry circuit and another separate one for the wet circuit. The two kinds of integration can also be combined with each other.

These system variants can favorably be used if high level of water conservation is targeted. Its auxiliary power consumption and maintenance cost are significantly less than those of single circuit serial dry/wet cooling systems.

Fig 3.8

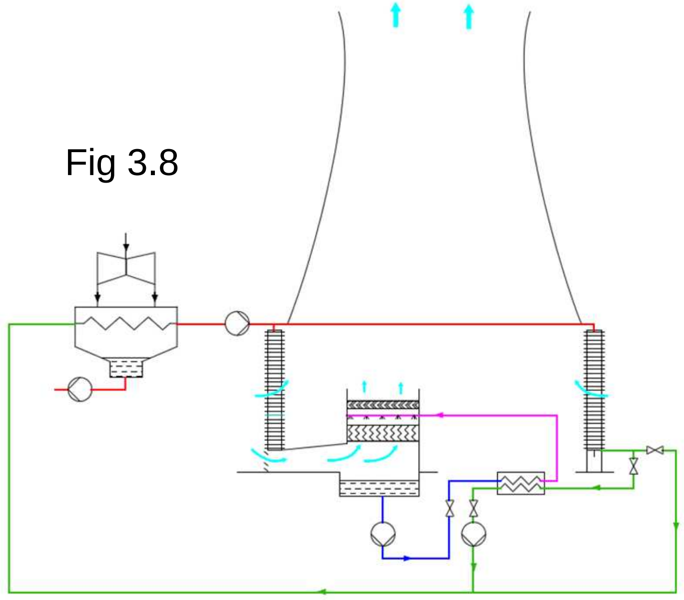
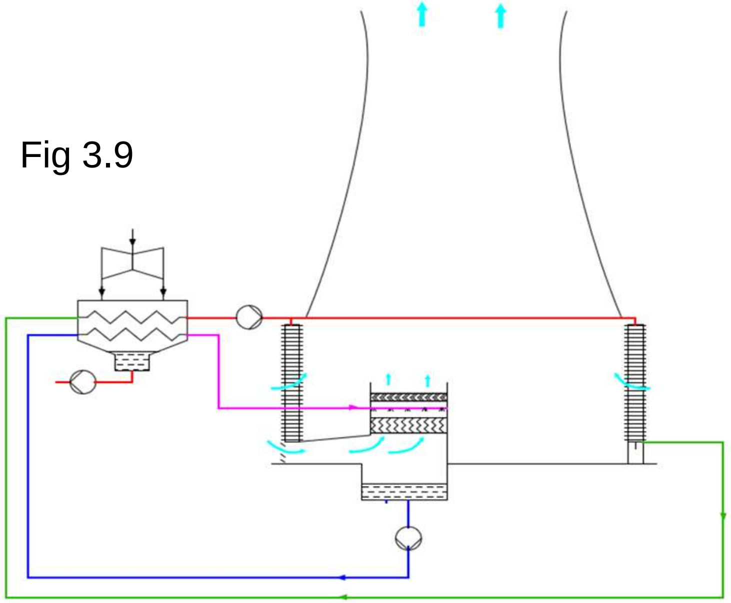


Fig 3.9



- ✓ In addition to the circuitry & configuration options, a number of dry/wet sub-variants are available differing in:

  - draft: natural/natural; natural/mechanical; mechanical/natural; mechanical/mechanical;
  - extent of wet assistance;
  - existing opportunity or not to operate the cooling system solely as dry one, depending on ambient temperature
  - location of the dry and wet sections (e.g. wet part outside or within the dry tower);
  - the applied materials.

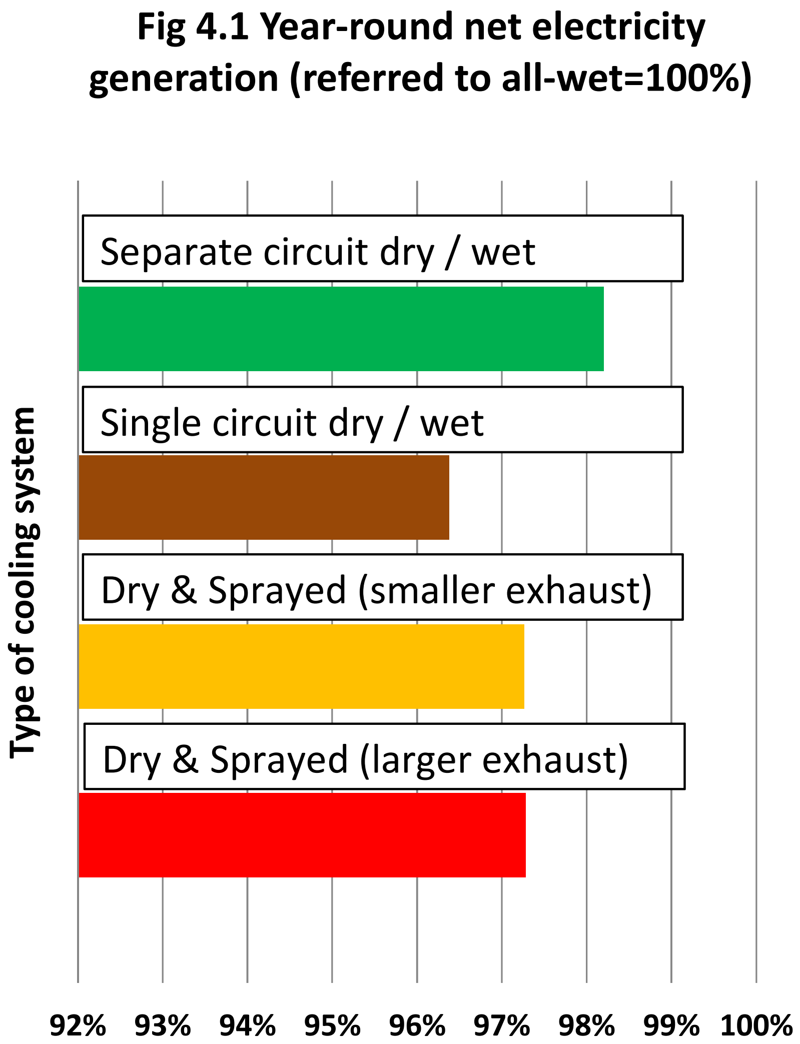
4. Impact of cooling systems on NPP performance, water need & economics

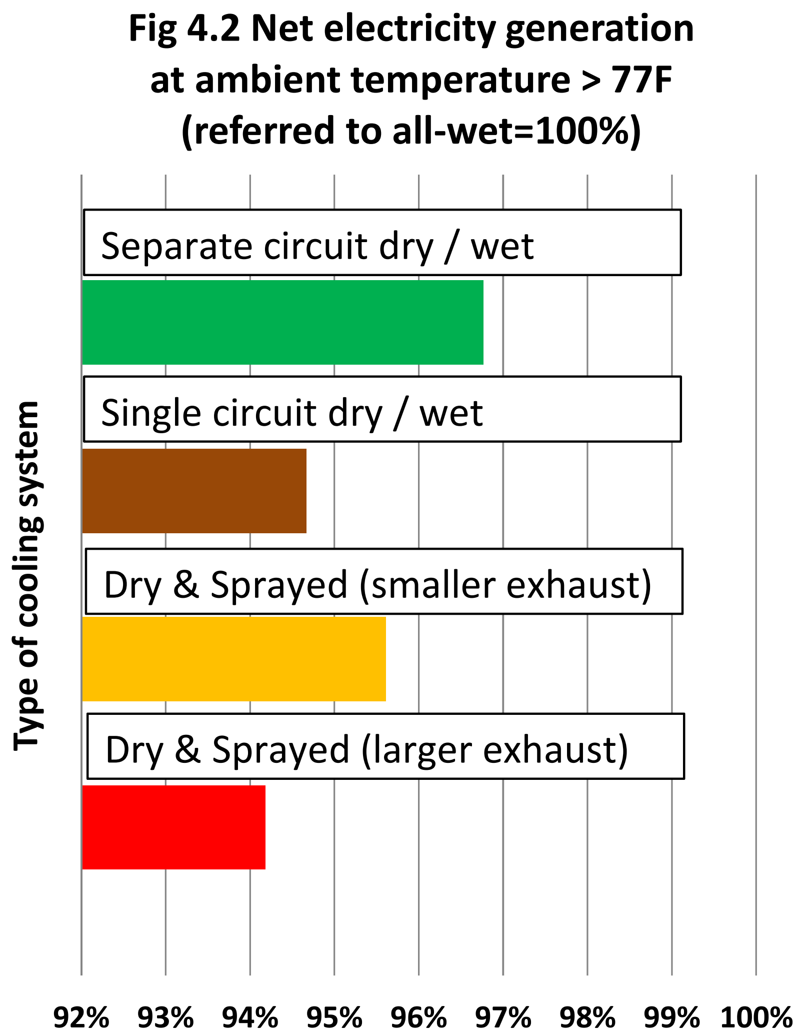
- ❖ Deciding on the cooling system of a future nuclear power plant is a decision for more than half a century and inflicts lasting effects (benefits or drawbacks) on a large region. Therefore, it is important to base the selection on a comprehensive analysis.

- ❖ The choice of a cooling system is significantly influenced by several sets of conditions and features, which are interdependent on each other:
  - ✓ the climatic & site conditions (e.g. dry bulb temperatures and humidity as well as water availability and quality, site elevation, distance from load center, geological properties etc.)
  - ✓ the environmental and permitting regulations
  - ✓ the impact of cooling system on
  - ✓ - power plant characteristics, performance, water need
  - ✓ - power plant economics – with special emphasis on the present value costs (including capital, operational & maintenance costs as well as cost consequences of differences in electricity production and plant equivalent unavailability)

- ❖ GEA EGI has made several concept and case studies for potential nuclear power plant owners and suppliers, aiming at investigating the impact of cooling systems on nuclear power plants. The investigated sites had different climatic conditions from the extreme cold to extreme hot.
- ❖ Results of the case study through which the impact of cooling systems on water need, electricity generation and the economics are introduced herein is related to an 1200 MW_e class NPP planned for a warm climate (yearly mean DBT 71°F and max. DBT 105°F).

❖ **Impact of cooling systems on electricity generation (referred to that of all-wet cooled NPP)**





✓**It is remarkable, that at the rather warm climate of the specific case, the best scoring water conservation variant (separate circ. dry/wet) remained only by abt. 1.8% under the annual electricity generation of the wet cooled one and by 3.7% less in the peak period (DBT ≥ 25°C = 77°F).**

❖ **Impact of cooling systems on make-up water consumption (referred to that of all-wet cooled NPP)**

Fig 4.3 Year-round make-up water consumption (referred to all-wet=100%)

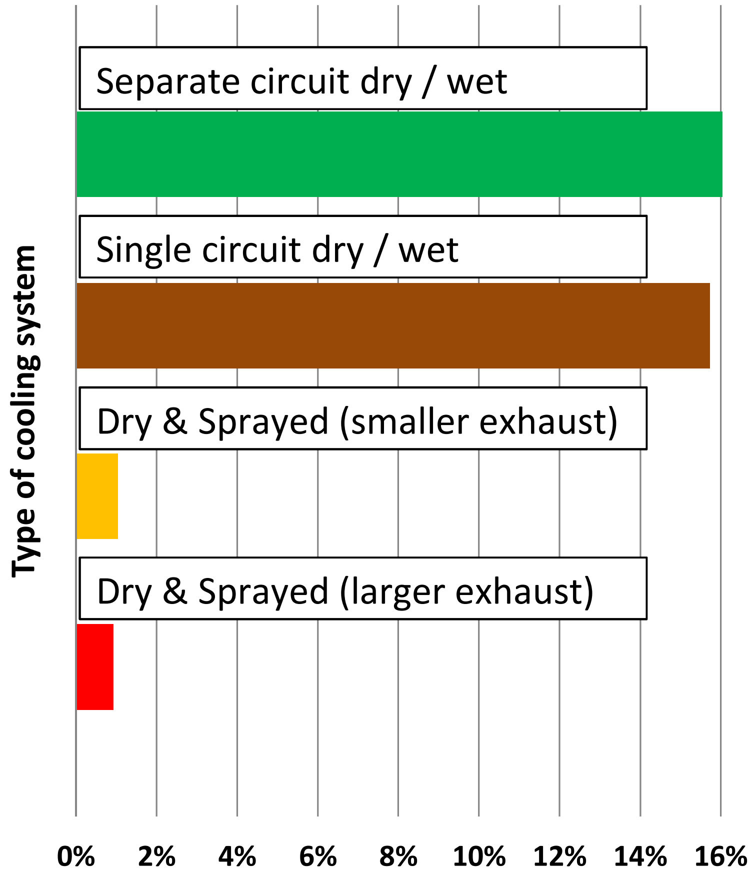
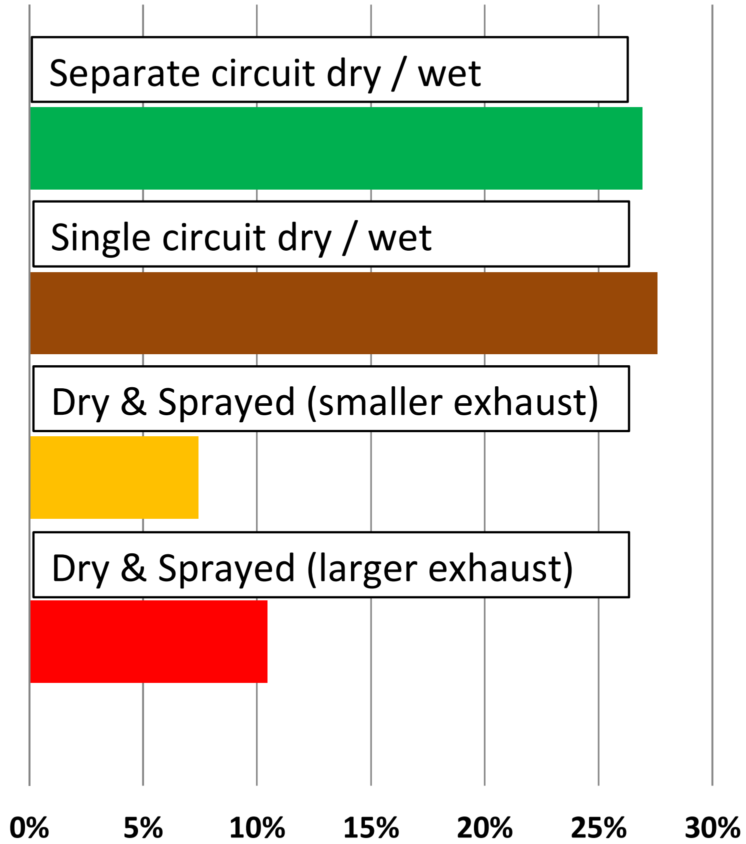


Fig 4.4 Max daily make-up water consumption (referred to All-wet=100%)

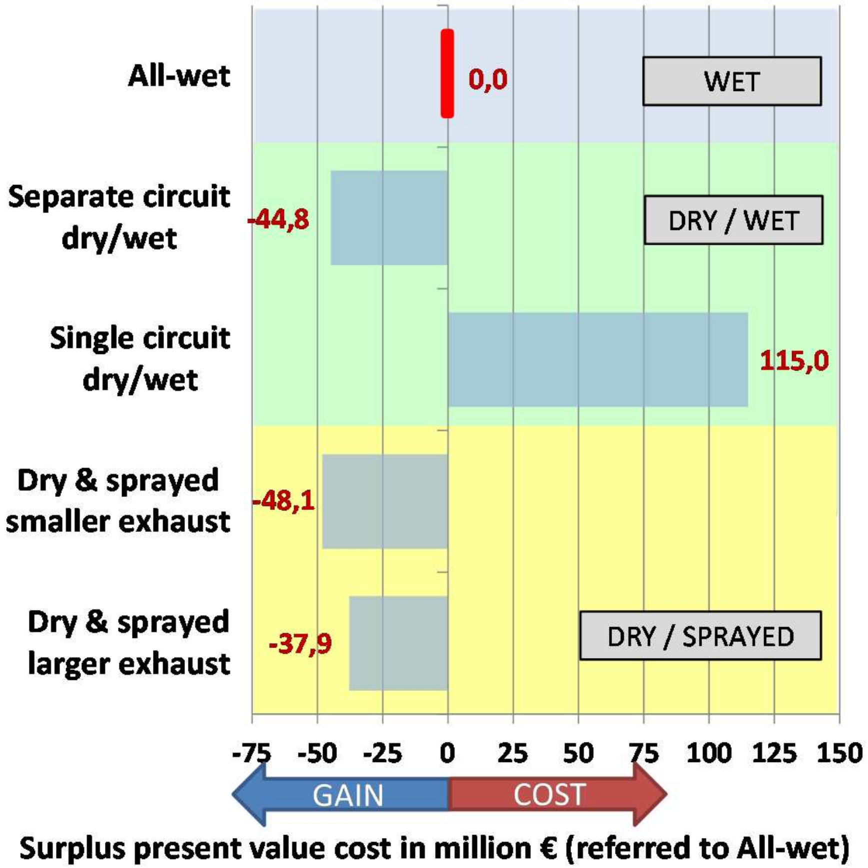


✓**The annual water need of the dry HELLER Systems with supplemental spraying is abt. 1%, and that of the dry/wet variants is abt. 16% compared to the natural draft wet cooling.**

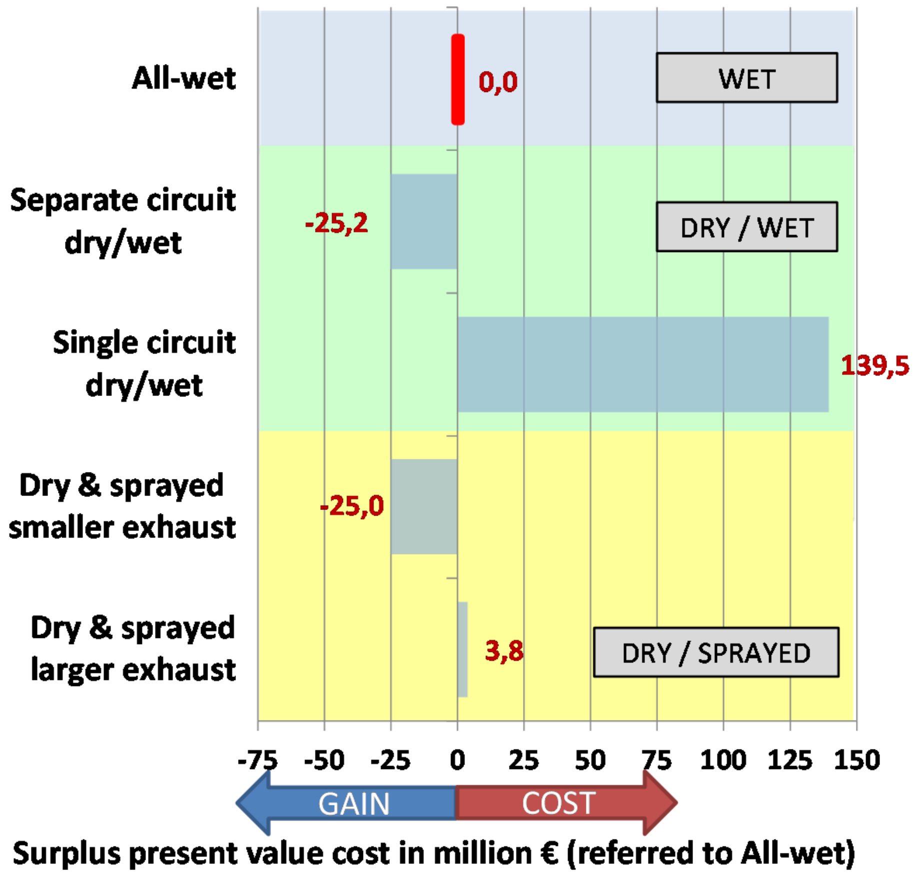
✓ **The wet cooling system uses approx. 2.76 m^3 make-up water for 1 MWh electric energy in average; it is 0.03 m^3/MWh for the sprayed dry cooled variants and abt. 0.45 m^3/MWh for the dry/wet systems.**

Fig 4.5 Relative present value cost/gain referred to All-wet cooling

a. at 45 €/MWh average electricity and 0.75 €/m³ make-up water cost



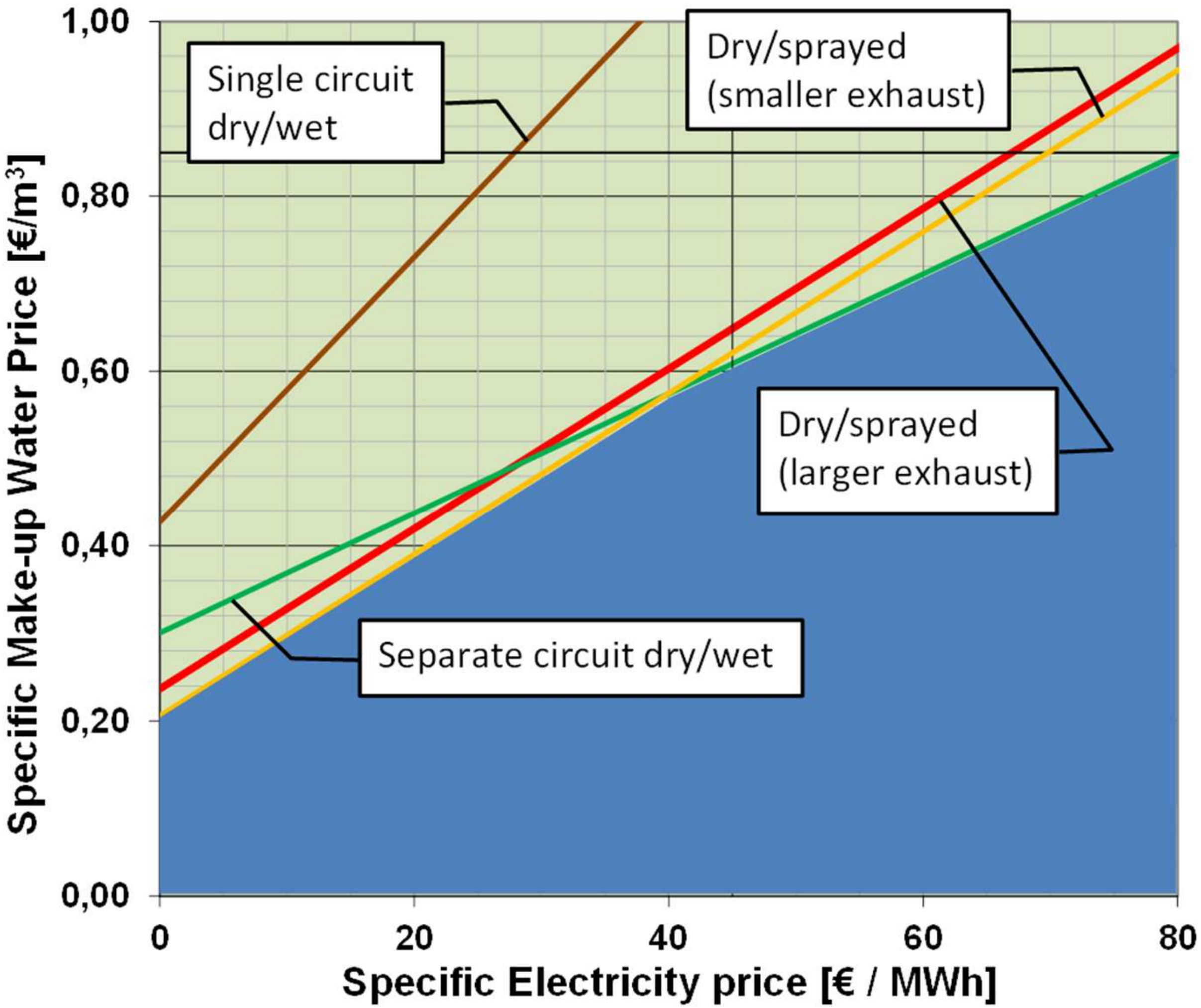
b. at 36 €/MWh off peak & 66 €/MWh peak (above 25°C) tariff and 0.75 €/m³ make-up water cost



✓ Comprehensive information can be provided for the same case study (a warm site with 71°F yearly mean and 105°F max. DBT) about the economic viability of different cooling systems compared to the all-wet one by a so-called economic viability envelope.

In Fig. 4.6 boundary lines of economic equivalence separately between each variant and the natural draft wet cooling are plotted against coordinates of water and electricity prices.

Fig 4.6 Economic viability envelope



5. Conclusions

The site and economic conditions as well as environmental & permitting regulations can significantly influence the economics of competing cooling systems. Though, the case study introduced herein related to a warm site, considering also several other investigations made by GEA EGI for different sites, some trends may be realized:

❖ At medium (> 0.6 $/m^3) or higher make-up water costs the water conservation type HELLER cooling systems (sprayed dry and separate circuit dry/wet) may provide the best economics on present value basis (their capital cost is significantly higher than those of wet cooling systems, whereas they score better when considering all cost items and impact on NPP).

❖ Therefore, water conservation type cooling systems can open route for economic installation of nuclear power plants – practically in the vicinity of any load center (independently on potential water constraint). Thus, they can be instrumental in widening the siting opportunities for NPPs, without making notable economic sacrifices.

❖ It is remarkable that among the dry and dry/wet cooling options natural draft versions perform definitely better than the mechanical draft ones, sometimes not only on present value basis, but even if ranking them by their capital costs.

- Certain LP turbines designed originally for wet cooling can be used economically also with dry/wet cooling especially at moderate and cold climates. It is worthwhile to investigate also alternative LP turbine with smaller exhaust area for warm climates (inevitable for extreme warm climates). Avoiding excessive water consumption is important to maintain the real water conservation features of a cooling system.

- If there are no constraints on make-up water availability, no or negligible fee on raw water entitlement and the make-up water cost is low, the natural draft wet cooling systems tend to provide better economics than the water conservation type cooling systems.

- During site selection for a NPP and prior to deciding on its cooling system, it is worthwhile to make a comprehensive evaluation.

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