EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Prospective Technological Studies (Seville)
Technologies for Sustainable Development
European IPPC Bureau

Integrated Pollution Prevention and Control (IPPC)

Reference Document on the application of Best Available Techniques to Industrial Cooling Systems

November 2000

Executive Summary

World Trade Center, Isla de la Cartuja s/n, E-41092 Seville - Spain
Telephone: direct line (+34-95) 4488-284, switchboard 4488-318. Fax: 4488-426.
Internet: http://eippcb.jrc.es

EXECUTIVE SUMMARY

This reference document on the application of best available techniques to industrial cooling systems (BREF) reflects the information exchange carried out according to Article 16 (2) of Council Directive 96/61/EC on IPPC. The document has to be seen in the light of the preface that describes the objective of the document and its use.

In the framework of IPPC, industrial cooling has been identified as a horizontal issue. It means that "Best Available Techniques"(BAT) in this document is assessed without an in-depth assessment of the industrial process to be cooled. Notwithstanding, BAT for a cooling system is considered within the cooling requirements of the industrial process. It is acknowledged that BAT for cooling a process is a complex matter balancing the cooling requirements of the process, the site-specific factors and the environmental requirements, which allows implementation under economically and technically viable conditions.

The term "industrial cooling systems" refers to systems to remove excess heat from any medium, using heat exchange with water and/or air to bring down the temperature of that medium towards ambient levels.

In this document, BAT is described for cooling systems that are considered to work as auxiliary systems for the normal operation of an industrial process. It is acknowledged that reliable operation of a cooling system will positively affect the reliability of the industrial process. However, the operation of a cooling system in relation to process safety is not covered in this BREF.

This document presents an integrated approach to arrive at BAT for industrial cooling systems acknowledging that the final BAT solution is mainly a site-specific matter. With respect to the selection of a cooling system, this approach can only discuss which elements are linked to the environmental performance of the cooling system, rather than select and (dis) qualify any of the applied cooling systems. Where reduction measures are applied, the BAT approach attempts to highlight the associated cross-media effects thus emphasising that reduction of the different emissions of cooling systems needs balancing.

The five chapters of the main document describe the BAT approach, its key issues and principles, the cooling systems and their environmental aspects, the key BAT findings and the conclusions and recommendations for further work. Eleven annexes give background information addressing specific aspects of designing and operating cooling systems and examples to illustrate the BAT approach.

1. Integrated approach

The integrated BAT approach considers the environmental performance of the cooling system in the context of the overall environmental performance of an industrial process. It aims at minimisation of both the indirect and direct impacts of the operation of a cooling system. It is based on the experience that the environmental performance of cooling of a process largely depends on selection and design of the cooling system. Therefore, for new installations the approach focuses on prevention of emissions by selection of an adequate cooling configuration and by proper design and construction of the cooling system. Additionally, reduced emissions are achieved by optimization of daily operation.

For existing cooling systems there is on a short term less potential for prevention by technological measures and emphasis is on emission reduction by optimized operation and systems control. For existing systems a large number of parameters, such as space, availability of operating resources and existing legislative restrictions, may be fixed and leave few degrees of freedom to change. However, the general BAT approach in this document can be considered as a long-term goal, which fits with equipment replacements cycles for existing installations.

The BAT approach acknowledges that cooling is an essential part of many industrial processes and should be seen as an important element in the overall energy management system. The efficient use of energy in industrial processes is very important from the environmental and cost-efficiency points of view. First of all, BAT means that attention must be paid to the overall energy efficiency of the industrial or manufacturing process, before measures are taken to optimize the cooling system. To increase overall energy efficiency, industry aims to reduce the amount of non-recoverable heat by applying proper management of energy and by adopting a range of integrated energy-saving programmes. This includes energy exchange between different units inside the cooled industrial or manufacturing process as well as links outside this process with adjacent processes. There is a tendency towards a concept of heat recovery for industrial regions when industrial sites are interlinked or are linked with district heating or greenhouse farming. Where no further recovery and re-use of this heat is possible, it may have to be released into the environment.

Distinction is made between low level (10-25ºC), medium level (25-60ºC) and high level (60ºC) non-recoverable heat. In general, wet cooling systems are applied for low level heat and dry cooling systems for high level heat. For the medium level no single cooling principle is preferred and different configurations can be found.

After optimization of the overall energy efficiency of the industrial or manufacturing process a given amount and level of non-recoverable heat remains and a first selection for a cooling configuration to dissipate this heat can be made balancing:

- the cooling requirements of the process,
- the site limitations (including local legislation) and
- the environmental requirements.

The cooling requirements of the industrial or manufacturing process must always be met to ensure reliable process conditions, including start-up and shut down. The required minimum process temperature and the required cooling capacity must be guaranteed at all times so as to enhance the efficiency of the industrial or manufacturing process and reduce the loss of product and emissions to the environment. The more temperature sensitive these processes, the more important this will be.

Site conditions limit the design options and the possible ways a cooling system can be operated. They are defined by the local climate, by the availability of water for cooling and discharge, by the available space for constructions and by the sensitivity of the surrounding area to emissions. Depending on the process demands on cooling and the required cooling capacity, site selection for a new installation can be very important (e.g. large cold water source). Where the choice for a site is driven by other criteria or in the case of existing cooling systems, the cooling requirements of the process and the site characteristics are fixed.

For cooling, the local climate is important, as it affects the temperature of the ultimate coolant water and air. The local climate is characterised by the pattern of wet and dry bulb temperatures. In general, cooling systems are designed to fulfil the cooling requirements under the least favourable climatic conditions that can occur locally, i.e. with highest wet and dry bulb temperatures.

The next step in the selection and design of the cooling system aims to meet the BAT requirements, within the requirements of the process to be cooled and the site limits. This means that emphasis here is on the selection of adequate material and equipment to reduce maintenance requirements, to facilitate operation of the cooling system and the realisation of environmental requirements. Besides the release of heat into the environments other environmental effects can occur such as the emission of additives used for conditioning of

cooling systems. It is emphasized that where the amount and level of heat to be dissipated can be reduced, the resulting environmental impact of the industrial cooling system will be lower.
The principles of the BAT approach can also be applied to existing cooling systems. Technological options may be available, such as a change of cooling technology, or a change or modification of existing equipment or chemicals used, but they can only be applied to a limited extent.

2. Applied cooling systems

Cooling systems are based on thermodynamic principles and are designed to promote the heat exchange between process and coolant and to facilitate the release of non-recoverable heat into the environment. Industrial cooling systems can be categorized by their design and by the main cooling principle: using water or air, or a combination of water and air as coolants.
The exchange of heat between process medium and coolant is enhanced by heat exchangers. From the heat exchangers the coolant transports the heat into the environment. In open systems the coolant is in contact with the environment. In closed systems the coolant or process medium circulates inside tubes or coils and is not in open contact with the environment.

Once-through systems are commonly applied to large capacity installations in locations where sufficient cooling water and receiving surface water are available. If a reliable water source is not available, recirculating systems (cooling towers) are used.

In open recirculating towers, cooling water is cooled down by contact with a airstream. Towers are equipped with devices to enhance the air/water contact. The airflow can be created by mechanical draught using fans or by natural draught. The mechanical draught towers are used widely for small and large capacities. Natural draught towers mostly are applied for large capacities (e.g. power industry).

In closed circuit systems the tubes or coils in which the coolant or process medium circulates are cooled, in turn cooling the substance they contain. In wet systems an airflow cools by evaporation the tubes or coils which are sprayed with water. In dry systems only an airflow passes the tubes/coils. In both designs coils can be equipped with fins, enlarging the cooling surface and thus the cooling effect. Closed circuit wet systems are widely used in industry for smaller capacities. The principle of dry air-cooling can be found in smaller industrial as well as in large power plant applications in those situations where sufficient water is not available or water is very expensive.

Open and closed hybrid cooling systems are special mechanical tower designs, which allows wet and dry operation to reduce visible plume formation. With the option of operating the systems (in particular small cell-type units) as dry systems during periods of low ambient air temperatures, a reduction in annual water consumption and visible plume formation can be achieved.

Table 1: Example of technical and thermodynamic characteristics of the different cooling systems for industrial (non-power plant) applications

Cooling system	Cooling medium	Main cooling principle	Minimum approaches (K)[4]	Minimum achievable end temperature of the process medium[5] (°C)	Capacity of industrial process (MW_{th})
Open once-through system - direct	Water	Conduction/ Convection	3 – 5	18 – 20	<0.01 - > 2000
Open once-through system - indirect	Water	Conduction/ Convection	6 – 10	21 – 25	<0.01 - > 1000
Open recirculating cooling system - direct	Water[1] Air[2]	Evaporation[3]	6 – 10	27 – 31	< 0.1 – >2000
Open recirculating cooling system - indirect	Water[1] Air[2]	Evaporation[3]	9 – 15	30 – 36	< 0.1 - > 200
Closed circuit wet cooling system	Water[1] Air[2]	Evaporation + convection	7 – 14[7]	28 – 35	0.2 – 10
Closed circuit dry air cooling system	Air	Convection	10 – 15	40 – 45	< 0.1 – 100
Open hybrid cooling	Water[1] Air[2]	Evaporation + convection	7 – 14	28 – 35	0.15 - 2.5 [6]
Closed hybrid cooling	Water[1] Air[2]	Evaporation + convection	7 – 14	28 – 35	0.15 - 2.5 [6]

Notes:
1) Water is the secondary cooling medium and is mostly recirculated. Evaporating water transfers the heat to the air
2) Air is the cooling medium in which the heat is transferred to the environment.
3) Evaporation is the main cooling principle. Heat is also transferred by conduction/convection but in a smaller ratio.
4) Approaches relative to wet or dry bulb temperatures
Approaches of heat exchanger and cooling tower must be added
5) End temperatures depend on the site's climate (data are valid for average middle European climate conditions 30°/21°C dry / wet bulb temperature and 15°C max. water temperature
6) Capacity of small units – with a combination of several units or specially built cooling, systems higher capacities can be achieved.
7) Where an indirect system applies or convection is also involved the approach in this example increases with 3-5K leading to an increased process temperature

The table shows the characteristics of the applied cooling systems for a given climatic situation. The end temperature of the process medium leaving the heat exchanger after cooling depends on the coolant temperature and on the design of the cooling system. Water has a higher specific heat capacity than air and therefore is the better coolant. The temperature of the coolant air and water depend on the local dry and wet bulb temperatures. The higher the bulb temperatures the more difficult it is to cool down to low end temperatures of the process.

The end temperature of the process is the sum of the lowest ambient (coolant) temperature and the minimum required temperature difference between coolant (entering the cooling system) and process medium (leaving the cooling system) over the heat exchanger, which is also called the (thermal) approach. Technically the approach can be very small by design, but costs are inversely proportional to the size The smaller the approach the lower the process end temperature can be. Each heat exchanger will have its approach and, in the case of additional heat exchangers, in series, all approaches are added to the temperature of the coolant (entering the cooling system) to calculate the achievable end temperature of the process. Additional heat exchangers are used in indirect cooling systems, where an extra cooling circuit is applied. This secondary circuit and the primary cooling circuit are linked by a heat exchanger. Indirect cooling systems are applied where leakage of process substances into the environment must be strictly avoided.

For the cooling systems commonly applied in the power industry, minimum approaches and cooling capacities are somewhat different from non-power plant applications because of the special requirements of the steam condensation process. The different approaches and relevant power generating capacities are summarized below.

Table 2: Examples of capacity and thermodynamic characteristics of different cooling systems for applications in power industry

Cooling system	Applied approaches (K)	Capacity of power generating process (MW_{th})
Open once-through systems	13-20 (terminal difference 3-5)	< 2700
Open wet cooling tower	7-15	< 2700
Open hybrid cooling tower	15-20	< 2500
Dry air-cooled condenser	15-25	< 900

3. Environmental aspects of the applied cooling systems

The environmental aspects of cooling systems vary with the applied cooling configuration, but the focus is predominantly on increasing the overall energy efficiency and reduction of emissions to the aquatic environment. The consumption and emission levels are very site-specific and where it is possible to quantify them they show large variation. In the philosophy of an integrated BAT approach, cross-media effects must be taken into account in the assessment of each environmental aspect and the associated reduction measures.

- **Energy consumption**

The specific direct and indirect consumption of energy is an important environmental aspect relevant for all cooling systems. The specific indirect energy consumption is the energy consumption of the process to be cooled. This indirect energy consumption can increase due to a sub-optimal cooling performance of the applied cooling configuration, which may result in a temperature rise of the process (ΔK) and is expressed in $kW_e/MW_{th}/K$.
The specific direct energy consumption of a cooling system is expressed in kW_e/MW_{th} and refers to the amount of energy consumed by all energy consuming equipment (pumps, fans) of the cooling system for each MW_{th} it dissipates.

Measures to reduce the specific indirect energy consumption are:
- to select the cooling configuration with the lowest specific indirect energy consumption (in general once through systems),
- to apply a design with small approaches and
- to reduce the resistance to heat exchange by proper maintenance of the cooling system.

For example, in case of power industry a change from once through to recirculating cooling means an increase in energy consumption for auxiliaries, as well as a decrease of efficiency in the thermal cycle.

To reduce the specific direct energy consumption, pumps and fans with higher efficiencies are available. Resistance and pressure drops in the process can be reduced by design of the cooling system and by application of low resistance drift eliminators and tower fill. Proper mechanical or chemical cleaning of surfaces will maintain low resistance in the process during operation.

- **Water**

Water is important for wet cooling systems as the predominant coolant, but also as the receiving environment for cooling water discharge. Impingement and entrainment of fish and other aquatic organisms occur with large water intakes. Discharge of large amounts of warm water can also influence the aquatic environment, but the impact can be controlled by suitable location of intake and outfall and assessment of tidal or estuarine flows to insure adequate mixing and advective dispersion of the warm water.

Consumption of water varies between 0.5 $m^3/h/MW_{th}$ for an open hybrid tower and up to 86 $m^3/h/MW_{th}$ for an open once-through system. Reduction of large water intakes by once-through systems requires a change towards recirculating cooling at the same time it will reduce the discharge of large amounts of warm cooling water and may also reduce emissions of chemicals and waste. The water consumption of recirculating systems can be reduced by increasing the number of cycles, by improving the water make up quality or by optimizing the use of waste water sources available on or off site. Both options require a complex cooling water treatment programme. Hybrid cooling, which allows dry cooling during some periods of the year, with a lower cooling demand or with low air temperatures and so can reduce water consumption in particular for small cell-type units.

Design and positioning of the intake and various devices (screens, barriers, light, sound) are applied to reduce the entrainment and impingement of aquatic organisms. The effect of the devices depends on the species. Costs are high and measures are preferably applied in a greenfield situation. Lowering the required cooling capacity if possible by increasing the reuse of heat may reduce emissions of warm cooling water to the receiving surface water.

- **Emissions of heat into the surface water**

As mentioned before the emissions of heat into surface water can have environmental impact on the receiving surface water. Factors of influence are e.g. the available cooling capacity of the receiving surface water, the actual temperature and the ecological status of the surface water. Emissions of heat can result in the exceeding the EQS for temperature during warm summer periods as a consequence of heat discharges into the surface water resulting from cooling water. For two ecological systems (Salmonid waters and Cyprinid waters) thermal requirements have been taken up in Directive 78/659/EEC. Relevant for the environmental impact of heat emissions is not only the actual temperature in the water, but also the temperature rise at the boundary of the mixing zone as a consequence of the heat discharge into the water. The amount and level of the heat discharged into the surface water related to the dimensions of the receiving surface water are relevant to the extent of the environmental impact. In situations where heat discharges at relatively small surface waters and the hot water plume reaches the opposite side of the river or canal this can lead to barriers for the migration of Salmonides.
Besides these effects high temperature as a consequence of heat emissions can lead to increased respiration and biological production (eutrophication) resulting in a lower concentration of oxygen in the water.
When designing a cooling system the above aspects and the possibilities to reduce the heat dissipated into the surface water have to be taken into account.

- **Emissions of substances into surface water**

Emissions into the surface water from cooling systems caused by:
- applied cooling water additives and their reactants,
- airborne substances entering through a cooling tower,
- corrosion products caused by corrosion of the cooling systems’ equipment, and
- leakage of process chemicals (product) and their reaction products.

Proper functioning of cooling systems may require the treatment of cooling water against corrosion of the equipment, scaling and micro- and macrofouling. Treatments are different for open once-through and recirculating cooling systems. For the latter systems, cooling water treatment programmes can be highly complex and the range of chemicals used can be large. As a consequence, emission levels in the blowdown of these systems also show large variation and representative emission levels are difficult to report. Sometimes the blowdown is treated before discharge.

Emissions of oxidizing biocides in open once-through systems, measured as free oxidant at the outlet, vary between 0.1 [mg FO/l] and 0.5 [mg FO/l] depending on the pattern and frequency of dosage.

Table 3: Chemical components of cooling water treatments used in open and recirculating wet cooling systems

	Water quality problems					
Examples of chemical treatment*	**Corrosion**		**Scaling**		**(Bio-)fouling**	
	Once-through systems	**Recircu-lating systems**	**Once-through systems**	**Recircu-lating systems**	**Once-through systems**	**Recircu-lating systems**
Zinc		X				
Molybdates		X				
Silicates		X				
Phosphonates		X		X		
Polyphosphonates		X		X		
Polyol esters				X		
Natural organics				X		
Polymers	(X)		(X)	X		
Non-oxidizing biocides						X
Oxidyzing biocides					X	X
* chromate is not widely used anymore due to its high environmental effect						

Selecting and applying cooling equipment that is constructed of material suitable for the environment in which it will operate can reduce leakage and corrosion. This environment is described by:
- the process conditions, such as temperature, pressure, flow speed,
- the media cooled, and
- the chemical characteristics of the cooling water.

Materials commonly used for heat exchangers, conduits, pumps and casing are carbon steel, copper-nickel and various qualities of stainless steel, but titanium (Ti) is increasingly used. Coatings and paints are also applied to protect the surface.

- **Use of biocides**

Open once-through systems are predominantly treated with oxidizing biocides against macrofouling. The amount applied can be expressed in the yearly used oxidative additive expressed as chlorine-equivalent per MW_{th} in connection with the level of fouling in or close to the heat exchanger. The use of halogens as oxidative additives in once-through systems will lead to environmental loads primarily by producing halogenated by-products.

In open recirculating systems, pretreatment of water is applied against scaling, corrosion and micro-fouling. With the relatively smaller volumes of recirculating wet systems alternative treatments are successfully applied, such as ozone and UV light, but they require specific process conditions and can be quite costly.

Operational measures reducing harmful effects of cooling water discharge are the closing of the purge during shock treatment and the treatment of the blowdown before discharge into the receiving surface water. For treatment of blowdown in a wastewater treatment facility the remaining biocidal activity must be monitored as it may affect the microbial population.

To reduce the emissions in the discharge and to reduce the impact on the aquatic environment, biocides are selected which aim to match the requirements of the cooling systems with the sensitivity of the receiving aquatic environment.

- **Emissions to air**

The discharged air from dry circuit cooling towers is usually not considered as the most important aspect of cooling. Contamination may occur if there is a leak of product, but proper maintenance can prevent this.
The droplets in the discharge of wet cooling towers can be contaminated with water treatment chemicals, with microbes or with corrosion products. The application of drift eliminators and an optimized water treatment programme reduce potential risks.
Plume formation is considered where the horizon-marring effect occurs or where risk exists of the plume reaching ground level.

- **Noise**

The emission of noise is a local issue for large natural draught cooling towers and all mechanical cooling systems. Unattenuated sound power levels vary between 70 for natural draught and about 120 [dB(A)] for mechanical towers. Variation is due to differences in equipment and to place of measurement as it differs between air inlet and air outlet. Fans, pumps and falling water are the major sources.

- **Risk aspects**

Risk aspects of cooling systems refer to leakage from heat exchangers, to storage of chemicals and to microbiological contamination (such as legionnaire’s disease) of wet cooling systems.

Preventive maintenance and monitoring are applied measures to prevent leakage as well as microbiological contamination. Where leakage could lead to discharges of large amounts of substances harmful to the aquatic environment, indirect cooling systems or special preventive measures are considered.

For prevention of the development of *Legionellae pneumophila* (*Lp*) an adequate water treatment programme is advised. No upper concentration limits for *Lp*, measured in colony forming units [CFU per liter], could be established below which no risk is to be expected. This risk has to be particularly addressed during maintenance operations.

- **Residues from cooling systems operation**

Little has been reported on residues or wastes. Sludges from cooling water pretreatment or from the basin of cooling towers have to be regarded as waste. They are treated and disposed of in different ways depending on the mechanical properties and chemical composition. Concentration levels vary with the cooling water treatment programme.

Environmental emissions are further reduced by applying less harmful conservation methods for equipment and by selecting material that can be recycled after decommissioning or replacement of cooling systems' equipment.

4. Key BAT conclusions

BAT or the primary BAT approach for new and existing systems are presented in Chapter 4. The findings can be summarised as follows.

It is acknowledged that the final BAT solution will be a site-specific solution, but for some issues techniques could be identified as general BAT. In all situations the available and applicable options for reuse of heat must have been examined and used to reduce the amount and level of non-recoverable heat, before the dissipation of heat from an industrial process into the environment is considered.

For all installations BAT is a technology, method or procedure and the result of an integrated approach to reduce the environmental impact of industrial cooling systems, maintaining the balance between both the direct and indirect impacts. Reduction measures should be considered maintaining at minimum the efficiency of the cooling system or with a loss of efficiency, which is negligible, compared with the positive effects on the environmental impact.

For a number of environmental aspects, techniques have been identified that can be considered BAT within the BAT approach. No clear BAT could be identified on the reduction of waste or on techniques to handle waste while avoiding environmental problems such as contamination of soil and water or, with incineration, of air.

- **Process and site requirements**

Selection between wet, dry and wet/dry cooling to meet process and site requirements should aim at the highest overall energy efficiency. To achieve a high overall energy efficiency when handling large amounts of low level heat (10-25ºC) it is BAT to cool by open once-through systems. In a greenfield situation this may justify selection of a (coastal) site with reliable large amounts of cooling water available and with surface water with sufficient capacity to receive large amounts of discharged cooling water.

Where hazardous substances are cooled that (emitted via the cooling system) involve a high risk to the environment, it is BAT to apply indirect cooling systems using a secondary cooling circuit.

In principle, the use of groundwater for cooling has to be minimized, for instance where depletion of groundwater resources cannot be ruled out.

- **Reduction of direct energy consumption**

Low direct energy consumption by the cooling system is achieved by reducing resistance to water and/or air in the cooling system, by applying low energy equipment. Where the process to be cooled demands variable operation, modulation of air and water flow has been successfully applied and can be considered BAT.

- **Reduction of water consumption and reduction of heat emissions to water**

The reduction of water consumption and the reduction of heat emissions to water are closely linked and the same technological options apply.
The amount of water needed for cooling is linked to the amount of heat to be dissipated. The higher the level of reuse of cooling water, the lower the amounts of cooling water needed.

Recirculation of cooling water, using an open or closed recirculating wet system, is BAT where the availability of water is low or unreliable.
In recirculating systems an increase of the number of cycles can be BAT, but demands on cooling water treatment may be a limiting factor.
It is BAT to apply drift eliminators to reduce drift to less than 0.01% of the total recirculating flow.

- **Reduction of entrainment**

Many different techniques have been developed to prevent entrainment or to reduce the damage in case of entrainment. Success has been variable and site-specific. No clear BAT have been identified, but emphasis is put on an analysis of the biotope, as success and failure much depend on behavioural aspects of the species, and on proper design and positioning of the intake.

- **Reduction of emissions of chemical substances to water**

In line with the BAT approach, the application of the potential techniques to reduce emissions to the aquatic environment should be considered in the following order:

1. selection of cooling configuration with lower emission level to surface water,
2. use of more corrosion resistant material for cooling equipment,
3. prevention and reduction of leakage of process substances into the cooling circuit,
4. application of alternative (non-chemical) cooling water treatment,
5. selection of cooling water additives with the aim of reducing impact on the environment, and
6. optimized application (monitoring and dosage) of cooling water additives.

BAT is reducing the need for cooling water conditioning by reducing the occurrence of fouling and corrosion through proper design. In once-through systems, proper design is to avoid stagnant zones and turbulence and to maintain a minimum water velocity (0.8 [m/s] for heat exchangers, 1.5 [m/s] for condensers).

It is BAT to select material for once-through systems in a highly corrosive environment involving Ti or high quality stainless steel or other materials with similar performance, where a reducing environment would limit the use of Ti.

In recirculating systems, in addition to design measures, it is BAT to identify the applied cycles of concentration and the corrosiveness of the process substance to enable selection of material with adequate corrosion resistance.
It is BAT for cooling towers to apply suitable fill types under consideration of water quality (content of solids), expected fouling, temperatures and erosion resistance, and to select construction material which does not need chemical conservation.

The VCI concept applied by chemical industry aims at minimizing the risks for the aquatic environment in case of leakage of process substances. The concept links the level of environmental impact of a process substance with the required cooling configuration and monitoring requirements. With higher potential risks for the environment in case of leakage the concept leads to improved anti-corrosiveness, indirect cooling design and an increasing level of monitoring of the cooling water.

- **Reduction of emissions by optimized cooling water treatment**

Optimization of the application of oxidizing biocides in once-through systems is based on timing and frequency of biocide dosing. It is considered BAT to reduce the input of biocides by targeted dosing in combination with monitoring of the behavior of macrofouling species (e.g. valve movement of mussels) and using the residence time of the cooling water in the system. For systems where different cooling streams are mixed in the outlet, pulse-alternating chlorination is BAT and can reduce even further free oxidant concentrations in the discharge. In general, discontinuous treatment of once-through systems is sufficient to prevent fouling. Depending on species and water temperature (above 10-12°C) continuous treatment at low levels may be necessary.

For seawater, BAT-levels of free residual oxidant (FRO) in the discharge, associated with these practices, vary with applied dosage regime (continuous and discontinuous) and dosage concentration level and with the cooling system configuration. They range from ≤ 0.1 [mg/l] to 0.5 [mg/l], with a value of 0.2 [mg/l] as 24h-average.

An important element in introducing a BAT-based approach to water treatment, in particular for recirculating systems using non-oxidizing biocides, is the making of informed decisions about what water treatment regime is applied, and how it should be controlled and monitored. Selection of an appropriate treatment regime is a complex exercise, which must take into account a number of local and site-specific factors, and relate these to the characteristics of the treatment additives themselves, and the quantities and combinations in which they are used.

In order to assist the process of BAT decision making on cooling water additives at a local level, the BREF seeks to provide the local authorities responsible for issuing an IPPC permit with an outline for an assessment.

The Biocidal Products Directive 98/8/EC regulates the placing of biocidal products on the European market and considers as a specific category the biocides used in cooling systems. The information exchange shows that in some Member States specific assessment regimes are in place for the application of cooling water additives.
The discussion as part of the information exchange on industrial cooling systems resulted in two proposed concepts for cooling water additives, which can be used as a complementary tool by the permitting authorities:

1. A screening assessment tool based on the existing concepts, which allows a simple relative comparison of cooling water additives in terms of their potential aquatic impact (the Benchmarking Assessment, Annex VIII.1).
2. A site specific assessment of the expected impact of biocides discharged in the receiving water, following the outcome of the Biocidal Products Directive and using the methodology to establish Environmental Quality Standards (EQSs) of the future Water Framework Directive as key elements (the Local Assessment for Biocides, Annex VIII.2).

The Benchmarking Assessment can be seen as a method to compare the environmental impact of several alternative cooling water additives while the Local Assessment for Biocides provides a yard stick for the determination of a BAT compatible approach for biocides in particular (PEC/PNEC <1). The use of local assessment methodologies as a tool in controlling industrial emissions is already common practice.

- **Reduction of emissions to air**

The reduction of the impact of emissions to air from cooling tower operation is linked to the optimization of cooling water conditioning to reduce concentrations in the droplets. Where drift is the main transporting mechanism, the application of drift eliminators, resulting in less than 0.01% of the recirculating flow being lost as drift, is considered BAT.

- **Reduction of noise**

Primary measures are applications of low noise equipment. The associated reduction levels are up to 5 [dB(A)].
Secondary measures at inlet and outlet of mechanical cooling towers have associated reduction levels of a minimum of 15 [dB(A)] or more. It must be noted that noise reduction, in particular by secondary measures, can lead to pressure drop, which needs extra energy input to compensate.

- **Reduction of leakage and microbiological risk**

BAT are: preventing leakage by design; by operating within the design limits and by regular inspection of the cooling system.
For the chemical industry in particular, it is considered BAT to apply the safety concept of VCI as has been mentioned before for reduction of emissions to water.

The occurrence in a cooling system of *Legionella pneumophila* cannot be fully prevented. It is considered BAT to apply the following measures:
- avoid stagnant zones and keep sufficient water velocity,
- optimize cooling water treatment to reduce fouling, algae and amoeba growth and proliferation,
- apply periodic cleaning of the cooling tower basin and
- reduce respiratory vulnerability of operators by supplying noise and mouth protection when entering an operating unit or when high-pressure cleaning the tower.

5. Distinction between new and existing systems

All key BAT conclusions can be applied to new systems. Where it involves technological changes, the application may be limited for existing cooling systems. For small cooling towers produced in series, a change in technology is considered to be technically and economically feasible. Technological changes for large systems are generally cost intensive requiring a complex technical and economic assessment involving a large number of factors. Relatively small adaptations to these large systems, changing part of the equipment, may be feasible in some cases. For more extensive changes of technology a detailed consideration and assessment of the environmental effect and the costs may be necessary.

In general, BAT for new and existing systems are similar, where the focus is on reducing environmental impact by improvement of the systems' operation. This refers to:
- optimization of cooling water treatment by controlled dosage and selection of cooling water additives aiming at reduction of the impact on the environment,
- regular maintenance of the equipment, and
- monitoring of operating parameters, such as the corrosion rate of the heat exchanger surface, chemistry of the cooling water and degree of fouling and leakage.

Examples of techniques considered BAT for existing cooling systems are:

- application of suitable fill to counteract fouling,
- replacement of rotating equipment by low noise devices,
- prevention of leakage by monitoring heat exchanger tubes,
- side stream biofiltration,
- improvement of the quality of the make up water, and
- targeted dosage in once-through systems.

6. Conclusions and recommendations for future work

This BREF has met a high level of support from the Technical Working Group (TWG). To assess and identify BAT for the process of industrial cooling is generally considered as complex and very site- and process-specific, involving many technical and cost aspects. Still, there is clear support for the concept of general BAT for cooling systems based on the general BREF-Preface and the introduction on BAT in Chapter 4.

The process of information exchange revealed a number of issues where further work is needed when this BREF is reviewed. The local assessment of cooling water treatment will require further investigation on how to take into account all relevant factors and chemical characteristics related to the site, but at the same time clear guidance and a workable procedure are necessary. Other fields of interest where additional efforts would be needed concern alternative cooling water treatment techniques, the minimization of microbiological risk and the relevance of emissions to air.