NEOM – INTERIM ENVIRONMENTAL STANDARD

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Marine Discharge Quality

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Name		Signature (required)
Martina Konrad, Environmental Quality Manager, NEOM	Author	
Alf Ziegler, Director Environmental Quality, NEOM	Reviewer	
Dr. Ameer Eweida, Director Marine, NEOM	Reviewer	
Paul Marshall, Chief Environment Officer, NEOM	Approver	

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INTERIM ENVIRONMENTAL STANDARD – MARINE DISCHARGE QUALITY

TABLE OF CONTENT

PART 1 EXECUTIVE SUMMARY

This document sets a NEOM-wide Interim Environmental Quality standard for Marine Discharge and is intended to reduce the environmental impacts of direct discharges of industrial once-through sea-water cooling systems to the marine environment.

The document includes definitions for NEOM's Zero Liquid Discharge (ZLD) approach (Section 3), provides an overview about once-through Seawater direct cooling Systems (Section 4) and related Best Available Technology (BAT – Section 5), and NEOM's Marine Discharge Quality Standard for once-through seawater direct cooling system in Section 6 of this document.

The NEOM zone present Standard for Marine Discharge Quality sets the allowable increase in temperature of the receiving water at not more than 2.0 °C over the ambient average maximum water temperature at the discharge point and at not more than 1.0 °C at the edge of a mixing zone defined to be at 100 m from the discharge point.

PART 2 PREAMBLE

This NEOM Interim Marine Discharge Quality Standard has been developed with the objective of obtaining and enhancing the highest standards of marine water quality achievable in the geographic context of NEOM. It is primarily meant to regulate and control direct discharges of industrial once-through sea-water cooling systems to the marine environment. This Standard is based on an assessment of international and regional standards, including those of the International Financial Corporation (based on EU and US EPA), World Bank regulations, the Kingdom of Saudi Arabia (KSA), Jordan (ASEZA), Oman (Ministry of Regional Municipalities – Muscat), Qatar and the UAE (Customs Free Zone Corporation, Dubai), Great Barrier Reef Marina Park Authority (GBRMPA), Australia and New Zealand Guidelines for Fresh and Marine Water Quality. This Interim Standard is integrated with the NEOM Sustainability Code, Nature Conservation Standard, NEOM Integrated Water Management Principles and international best practice guidance. In case of absence or inconsistency of specific acceptable best practice pollutant values, IFC and EU standards must be followed at a minimum with the most stringent prevailing. The most comprehensive guiding documents regarding cooling water discharge requirements are the Integrated Pollution Prevention and Control (IPPC) BREF documents of the European Commission (Reference Document on the application of Best Available Techniques to Industrial Cooling Systems, Dec. 2001). It is well established that the cooling BREF is "horizontal" in nature, and that it is not possible to identify a "BAT cooling system" as such because a lot is dependent on the specific process that is being cooled, and the location of its application (especially climate, water supply etc.). Therefore, the approach to be taken must be one of providing "tools" to help the Project Proponents (PP) rationalize what options are available, and select an optimal cooling solution (both in terms of equipment, and "operating conditions") which will represent BAT for IPPC permitting purposes.

This NEOM Interim Marine Discharge Quality Standard will, in an actualized version, become final once the NEOM Founding Law, to which these Standards are aligned, has been enacted.

PART 3 ZERO LIQUID DISCHARGE (ZLD)

3.1 APPLICABILITY AND IMPLEMENTATION

Any Energy and /or Industrial project intending to draw sea water from its source, use it as a coolant and then return it to its original source, shall be subject to a comprehensive ESIA (Environmental and Social Impact Assessment) and respective permitting process. This process will set the conditions to be abided by the Project Proponent (PP).

This Interim Marine Discharge Quality Standard shall specify the conditions for any marine discharge of cooling water (not Process water). This Interim Standard only covers the marine discharge for once through direct cooling system components described below; it does not cover other forms of discharges into other medium (e.g. to the air) or other liquid discharges other than untreated seawater; this means that it excludes blow-down and make-up water etc. Should the PP however opt for a combined cooling solution then a staged cooling system would have to be used to eliminate any liquid discharge from eventual blowdown flows; additionally respective Environmental Quality Standards (EQS) for any emissions to the ambient air would have to be followed (not included in this document).

Individual ESIA processes and separate permitting for construction and operation prevail. The conditions for these permitting processes aren't object of this Interim Standard and shall be dealt with separately.

Accompanying all applications, approvals and licensing of proposed and existing industrial activities, NEOM requires estimates of total volumes and quality of intended liquid marine discharges.

NEOM requires the online real-time monitoring of discharge sea-outlets and live telemetric transfer of respective emissions data to NEOM. Additionally, supporting sampling and analysis events at a minimum every three months, or more frequently in specific cases will be required as deemed necessary.

3.2 ONCE-THROUGH SEAWATER DIRECT COOLING SYSTEMS

Seven types of cooling systems are discerned using the definitions as provided in the Industrial Cooling System BREF. The cooling system type addressed in this NEOM standard is a sub-type of the open, once-through direct system without cooling tower. In this system the coolant (i.e. water) is pumped from a source (in NEOM just the sea) and passed through a heat exchanger (where heat is transferred from the industrial process to the coolant in contactless manner through a partition wall), and finally, it is discharged back to the receiving water body.

In a once-through cooling system virtually all water taken in, is returned to the source water body, albeit at a slightly higher temperature.

This NEOM Standard does not speak about other wet cooling systems using recirculation of water, typically with a cooling tower, which would discharge heat for a large part into the atmosphere. With this Standard the main energy and industrial key sectors of power generation, iron and steel manufacturing, refineries and the chemical sector shall be covered in order to inform and allow for respective project design - yet just in case for respective low-level heat generation. In case of a plant thermal efficiency leading to high level non-recoverable heat no Marine Discharge shall be permitted. Waste heat should as far as possible be put to productive use in industrial processes in order to minimize the cooling needs.

This NEOM Standard shall be suitable for assessment of aggregated projects in the frame of respective ESIAs.

The design of potential industrial plants or facilities and their cooling systems will typically aim for an economically efficient optimum, considering local cooling water availability and environmental regulations. The resulting cooling water intake and discharge may vary widely from plant to plant and therefore any such project development would need an individual ESIA considering compounded impacts and respective water body IDs linking to potential measures for reducing cooling water, non-recoverable heat and implying best heat integration.

3.2.1 Requested Basic Data from the Project Proponent (PP):

- Basic information about the facility:
  - Water IDs and basic parameters based on local register
  - Geographic location
  - Plant/ facility type and capacity
- Information about the cooling system (here seawater once-through system) and related water use:
  - Type of cooling system
  - Volumes of cooling water withdrawal consumption and discharge (gross volume annual sums, low and high estimates, mean, respective monthly assumptions)
- Specific cooling water use factors:
  - Specific cooling water intake (in m3/ MWh for power plant; m3/ton of product throughput for other plants)
  - Specific cooling water discharge
  - Specific cooling water consumption (for the concerned seawater once through system this should be approximately zero)
  - Temperature of cooling water withdrawal and discharges
  - Quality of cooling water discharge (as per this Standard).

Environmental impacts of cooling water discharge are typically associated with the following:

Temperature increase of the water body that may have an impact on aquatic life when exceeding certain limits. Details on temperature in combination with cooling water volumes would give detailed insights in heat being discharged and process efficiency.

Release of small quantities of chemicals that are added to the cooling water to assure a proper operation of the cooling process. These additives are used to prevent amongst others algae growth, corrosion or scaling.

3.2.2 Water body information

- Water body ID if any,
- Water body type (fresh, sea etc.); in the present document just seawater is considered, and
- Location of intended withdrawal and discharge points.

3.2.3 Environmental aspects

For once-through systems the major environmental aspects mentioned are:

- The use of large amounts of water,
- Heat emission,
- The risk of fish intake,
- Sensitivity to biofouling, scaling or corrosion,
- The use of additives and the resulting emissions to water,
- Energy consumption, mainly for pumps,
- The risk of leakage from the process stream, and
- The silting-up of sieves at water intake.

Kindly refer to the following table for Environmental aspects of industrial cooling systems.

	Energy Consumption (direct)	Water requirement	Fish[2] entrainment	Emissions to surface water		Air emissions (direct)	Plume formation	Noise	Risk		Residues
Cooling system	(§ 3.2)	(§ 3.3)[1]	(§ 3.3)	Heat (§ 3.3)	Additives (§ 3.4)	(§ 3.5)	(§ 3.5)	(§ 3.6)	Leakage (§ 3.7)	Micro biol. risk (health) (§ 3.7)	(§ 3.8)
Once-through cooling (direct circuit)	Low	++	+	++	+ (biocides)	--	--	--	++	--/low	+[6]
Once-through cooling (indirect circuit)	Low	++	+	++	+ (biocides)	--	--	--	Low	--/low	+[6]
Open wet cooling tower (direct circuit)	+	+	--	Low	+[3]	Low (in plume)	+	+	+	+	--/low
Open wet cooling tower (indirect circuit)	+	+	--	Low	+[3]	Low (in plume)	+	+	Low	+	+
Open wet/dry cooling tower	+	Low	--	Low	Low[3]	--	--[5]	+	Low	?	+
Closed circuit wet cooling tower	+	+	--	--	Low	Low[4] (in plume)	--	+	Low	Low	--/low
Closed circuit dry cooling	++	--	--	--	--	--/Low	--	++	Low	--	--
Closed circuit wet/ dry cooling	+	Low	--	--	Low[3]	Low	--	Low	Low	Low	--/low

Notes:

--	none/not relevant	1: paragraph in text
Low	relevance below average	2: other species can also be entrained
+	relevant	3: biocides, antiscaling, anticorrosion
++	highly relevant	4: potentially in case of leakage
		5: if properly operated no issue
		6: waste refers to sludge from water intake and from decarbonization

Table 1: Environmental aspects of industrial cooling systems[1]

3.2.4 Cross-media issues

The issue of restricting the use of water relates to the following environmental aspects:

- Heat emission to the surface water;
- Application of cooling water additives;
- Energy consumption of both cooling system and production process;
- Noise and vibration; and
- Indirect emissions.

[1] Table from the IPPC BREF Industrial cooling systems, p.66; tm001 Bloemkolk, 1997

3.3 DEFINITIONS OF COOLING WATER INTAKE, DISCHARGE AND CONSUMPTION

Cooling of industrial processes can be considered as heat management and is part of the total energy management within a plant. The amount and level of heat to be dissipated requires a certain level of cooling systems performance. This performance level will in turn affect the system configuration, design and operation and consequently the cooling systems' environmental performance (direct impact). Reversibly, the cooling performance will also affect the overall efficiency of the industrial process (indirect impact). Both impacts, direct and indirect, need to be balanced, considering all variables. Every change in the cooling system must be considered against the consequences it may have for this balance.

3.3.1 Cooling water intake

Total gross amount of deliberately abstracted, or withdrawn, water from a water body or system for the use of cooling. Note: no Make-up water for a (recirculating) cooling system is included here.

3.3.2 Cooling water discharge

Total gross amount of deliberately released liquid water used for cooling that is being discharged back into the aquatic environment. Water that leaves the plant in gaseous/vapor form or bound into waste and (secondary) products is not considered as part of this.

3.3.3 Cooling water consumption

Consumptive use of cooling water is calculated as the total amount of cooling water intake minus the total amount of cooling water discharge. Since we are considering here a once-through direct and contactless cooling system the intake-volumes should be approximately equal to the discharges.

The amount and temperature of the intake water and its temperature are likely to vary from year to year or over the course of the seasons. Other seasonal effects are the temperature and humidity which affects the cooling capacity of the cooling system. The cooling system design needs to accommodate these annual and seasonal variations in order not to reduce its capacity to operate within the limits of the respective operational permit and also to ensure plant efficiency is not compromised unduly.

Figure 1 shows the exemplary specific cooling requirements for the most dominant production processes in the chemical sector, expressed in GJ heat discharge per ton product.

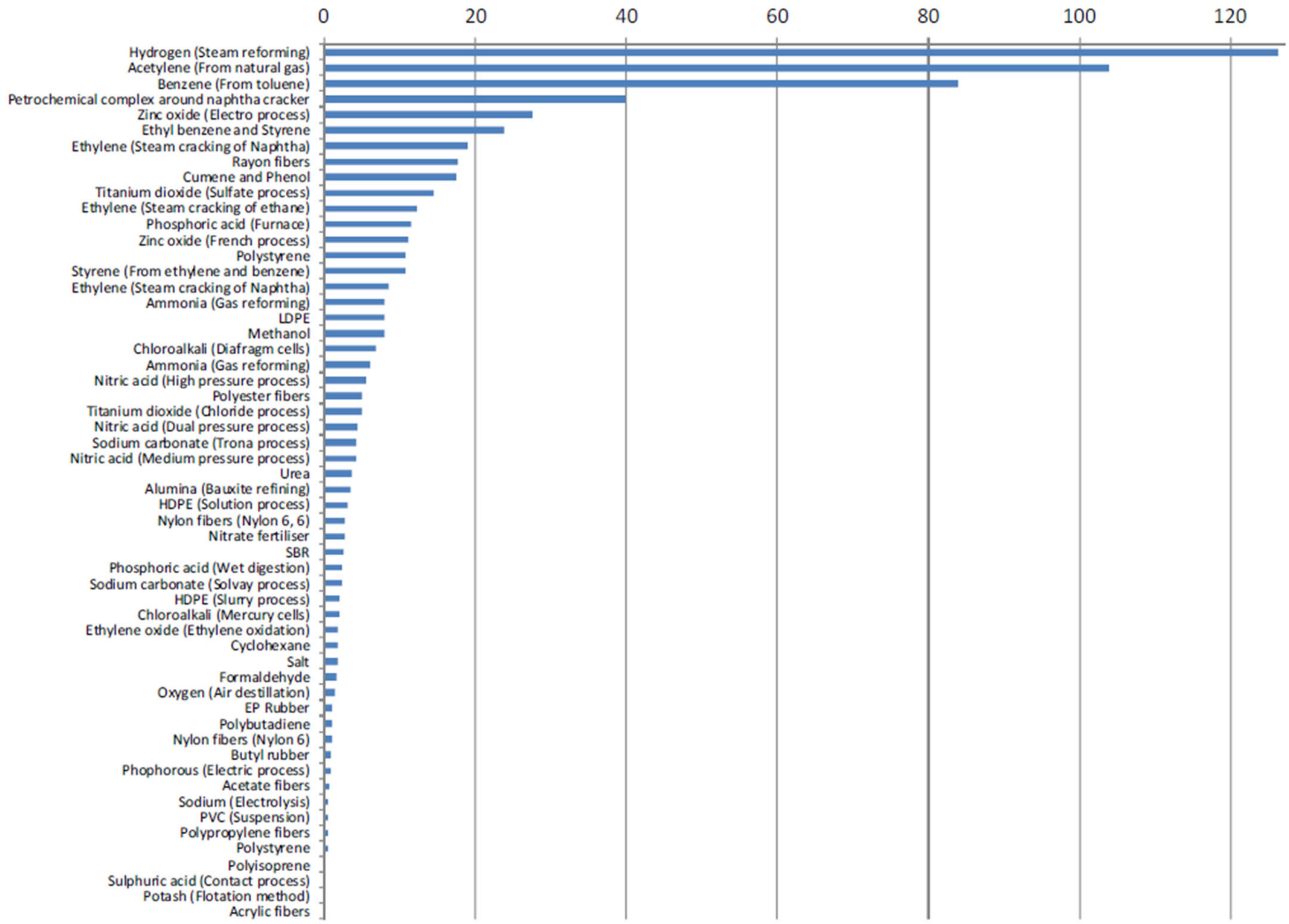

Figure 1: Cooling heat load in 9GJ/t)[2]

The total set of facilities was derived from different sources:

- Ammonia: from the IPPC BREF 2003
- Ethylene: from the Petro Chemicals Europe website: http://www.petrochemistry.eu/aboutpetrochemistry/facts-and-figures.html
- Hydrogen: taken from “Hydrogen plants in the EU” (roads2hycom 2007).

Table 2 includes estimates for specific cooling water use for the production of Ammonia, Ethylene and Hydrogen (source: (roads2hycom 2007) – just indicative here the present Interim Standard being for Once Trough Seawater cooling systems only.

[2] Ecofys, Geo-localised inventory of water use in cooling processes, assessment of vulnerability and of water use management measures, 2014

Product	Cooling water requirement	cooling water recirculation ratio	specific cooling water intake	specific cooling water consumption	specific cooling water consumption	specific cooling water discharge
	m^3/t	#	m^3/t	% of circulating flow	m^3/t	m^3/t
Ammonia						
Low	200	7	29	2%	4	25
High	200	3	67	2%	4	63
Ethylene						
Low	200	7	29	2%	4	25
High	200	3	67	2%	4	63
Hydrogen						
Low	2000	7	286	2%	40	246
High	2000	3	667	2%	40	627

Table 2: Cooling requirements for the most dominant production processes[3]

3.4 CONCEPTUAL ASPECTS FOR COOLING NEEDS OPTIMIZATION AND MITIGATION MEASURES

In the following just a brief summary of some main conceptual aspects pertaining to cooling system design and mitigation measures is given – this isn't meant to be comprehensive and would be element of a much more detailed ESIA process.

Conceptual measures to reduce cooling water use and waste heat discharge into the environment are one potential way to reduce vulnerability. However, this would require careful evaluation of the respective trade-offs and may not be desirable. Furthermore, gross and net use of cooling water need to be clearly distinguished in this process.

Conceptually, measures may consist of:

- Increase efficiency: with increasing process efficiency less thermal energy needs to be removed from the process. This reduces the cooling need and with it the need for cooling water use in the case of cooling with water.
- Reduction of the level of heat discharge by optimization of internal/external heat integration /re-use: next to optimizing the primary process, the export and consumption of excess heat can be a means to reduce the cooling need and water use.
- Reduce water use and heat discharge. The last step can be broken down into:
    - Reduction of water requirement; and
    - Reduction of heat emissions.

[3] Ecofys, Geo-localised inventory of water use in cooling processes, assessment of vulnerability and of water use management measures, 2014

Economics of reducing the cooling water use and excess heat discharge tend to be very site-specific. The BREF therefore provides only rules of thumb.

These, however, cannot be applied to any specific plant. Local circumstances including cost of water, cost of energy, taxes, technical characteristics have a strong influence and should be considered when drafting a detailed set of mitigation measures for the use of cooling water.

Main considerations are:

- Increase efficiency
  Costs of reducing the vulnerability to availability of cooling water greatly depend on the starting point, considering the primary process that is cooled and energy costs. The net costs may be negative if savings outweigh costs but could also come at substantial cost.
- Reduction of heat discharge by optimization of internal/external heat reuse
  Internal use or selling excess heat to consumers, e.g. industrial process heat or district heating, may be an economically viable solution depending on the local circumstances related to proximity of heat demand, technical configuration, geographical specifics and the regulatory framework. All such factors have a strong influence in the cost and benefits of this mitigation measure. Typically, this is a measure which is part of the station planning stage. Once a power / production plant is built it may be difficult and costly to retrofit such a system or exploit a new potential heat load arising.
- Reduce water use and heat discharge
  The estimate of what is feasible in the mitigation of water use and heat discharge should be assessed on a case by case basis and depends on the requirements by (local) authorities and the site-specific limitation and possibilities. Furthermore, there are substantial trade-offs to consider, for example in terms of efficiency of the primary process and other environmental impacts.

Key aspects to consider when evaluating a site specific best available technology (BAT) solution for industrial cooling are shown in the graphic below.

Figure 2: Site-specific BAT evaluation[4]

PART 4 OVERVIEW ABOUT ONCE-THROUGH SEAWATER DIRECT COOLING SYSTEM

4.1 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.

Design and positioning of the intake and various devices (screens, barriers, light, sound) are to be applied to reduce the entrainment and impingement of aquatic organisms. The effect of the devices depends on the species. 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.

4.2 EMISSIONS OF HEAT INTO THE SURFACE WATER

As mentioned before the emissions of heat into surface water can have environmental impacts on the receiving surface water. Factors of influence are e.g. the available cooling

[4] Ecofys, Geo-localised inventory of water use in cooling processes, assessment of vulnerability and of water use management measures, 2014

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.

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.

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 must be considered.

4.3 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 (here not applicable);
- 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.

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.

The following table lists chemical components of cooling water treatments used in open and recirculating wet cooling systems (the latter not applicable here).

Examples of chemical treatment*	Water quality problems					
	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						

Table 3: Chemical components of cooling water treatments[5]

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.

4.4 USE OF BIOCIDES

The water withdrawn for cooling purposes may sometimes be the cause of chemical releases into the receiving environment. The following may be concerned in particular:

- Reagents used to avoid the scaling of cooling systems;
- Reagents used to fight against biological developments, reaction products of some of them;
- Iron sulphate anti-corrosion treatments to protect, in some cases, copper alloy condensers;
- Corrosion products of heat exchangers and piping.

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 MWth 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

[5] Table from the IPPC BREF Industrial cooling systems, p.82; derived from tm35 Nalco, 1988

will lead to environmental loads primarily by producing halogenated by-products.

As concerns the marine environment, the purpose of the biocide treatment is to maintain the systems sufficiently clean to ensure their proper operation. For the sea intakes, the main problem is to avoid the development of molluscs (mussels, oysters, etc.) inside the cooling system. The current practice is the injection of chlorine. It is generally produced on-site by seawater electrolysis. This process avoids the risk involving the transport of NaOCl by truck. The chlorination can be made on continuous or discontinuous (seasonal) basis depending on many factors such as meteoclimatic characteristics of the site, water quality, cooling circuit design and biofouling typology (settlement periods and growth rates).

Mainly the injection takes place in low doses so that the concentration in free chlorine in the discharge is generally between 0.1 and 0.5 mg/l normally (sporadically 0.7 mg/l). The value of this limit concentration is set by local regulations. However, when it reacts with some organic matter, chlorine may lead to the formation of organo-halogenated substances (mainly bromoform in seawater). Some studies nevertheless show that bromoform concentrations in the plumes of warm water discharges from coastal-sited industrial plants remain extremely low (about 15 µg/l).

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.

Common anti-fouling treatments surveys (biocides) enable to draw the following conclusions: Mechanical cleaning of the systems and water filtration are the most commonly used processes. They involve the continuous cleaning of the tubes of condensers by foam balls or brushes, manual cleaning, use of trash rakes, filters with meshes of different widths.

Three other physical methods are also regularly used for the anti-fouling treatment of industrial systems. They concern the following:

- Maintaining of velocities high enough to avoid the fixation of organic organisms (v > 2m/s), this recommendation is applied to a large extent today;
- Temperature increase which consists in raising the temperature of the cooling water beyond 40 ºC for some dozens of minutes; this technique eliminates the fixed organisms (mussels), but nevertheless requires an appropriate design of the cooling systems;
- Non-toxic coatings and paints, which reduce the fixation of the organisms, reinforce the velocity effect and facilitate cleaning; these coatings are nevertheless expensive and must be renewed every 4 to 5 years.

Other techniques are sometimes used, the following in particular:

- Dryout;
- Installation of specific filters (mussel filters).

The physical methods can be applied both in seawater and soft water.

A non-chemical treatment applied in some cases is UV, however so far more widely applied in other industrial processes.

Chemical treatment can be applied in cases where physical methods are not appropriate or show insufficient results. There are oxidizing products, chlorine, monochloramine, ClO_2 and ozone, which can be used as antifouling treatments. Some degradable organic compounds applicable intermittently and non-toxic in the receiving environment, might be an alternative to chlorination. Among these, some amine film inducing polymers appear to be promising as anticorrosion chemicals, but so far intermittent treatment of ferro-sulphate is more efficient.

4.5 EMISSIONS TO AIR:

Not applicable for the once -through system without cooling towers.

4.6 NOISE

The emission of noise is a local issue for all mechanical cooling systems. Unattenuated sound power levels vary between 70 for natural draught and about 120 [dB(A)] for mechanical towers (here not applicable). Variation is due to differences in equipment and to place of measurement as it differs e.g. between air inlet and air outlet. Fans, pumps and falling water are the major noises sources. Noise also travels further and faster in the sea, so this may have an impact on sound producing species. Kindly also refer to NEOM Noise pollution controls and related standards.

4.7 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 program 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 must be particularly addressed during maintenance operations.

4.8 RESIDUES FROM COOLING SYSTEMS OPERATION

Little has been reported on residues or wastes. Sludges from cooling water pretreatment (as far as applicable) must be regarded as waste. They are treated and disposed of in different ways depending on the mechanical properties and chemical composition. Recycling and reuse options should be investigated in order to meet NEOM's circular economy vision.

Concentration levels vary with the cooling water treatment program. 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.

PART 5 BEST AVAILABLE TECHNOLOGY (BAT)

5.1 REDUCTION OF WATER AND ENERGY 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.

Energy consumption will increase if heat exchangers are fouled. The sediment can be classified into microfouling and macrofouling. Blockages caused by shellfish and other solid sediment preventing the flow of water through the pipes may be regarded as macrofouling. Microbial slime, scaling, deposits, that each in turn result in the formation of corrosion products on or in the warm cooling pipe, are all classified as microfouling. A characteristic common to all the various forms of fouling mechanisms is the concomitant increase in the internal energy consumption.

The choice of material used for the cooling system plays an important role. Especially the selection of materials for the coolers (heat exchangers), in many cases is a complex matter. It is the result being a balance between the requirements due to the chemistry of the water and the operational requirements (restricted additive use, number of cycles of concentration). To meet these requirements a large range of materials is offered. There are various options for materials to be used in case of brackish water for open once-through systems. A qualitative selection of applications is given in the respective BREF. In the individual case, the final selection will need to involve cost values to make a fair comparison considering also the consequences of a selection for the operational costs.

5.2 CHOICE OF MATERIALS FOR HEAT EXCHANGERS

There are many factors that come together to determine the ultimate choice of materials for heat exchangers, such as:

- Composition and corrosiveness of the cooling water;
- Manner of operation, e.g. through-flow or re-circulating cooling;
- Corrosiveness and nature of the medium to be cooled;
- Type of cooler;
- Lifespan; and
- Costs.

These are some of the most important criteria that are taken into consideration in the design of a new cooler, based on which ultimately a certain choice of materials is made. In many cases, this ultimate choice is the best possible compromise adhering to the principle that the cooler must have an economically acceptable 'life-pan'. Within this lifespan however many coolers will start leaking. An important cause of this is that, in practice, the cooler is not used in accordance with its design principles, whereas a change of process conditions for a variety of different reasons is quite common. Important causes that can lead to leakage are:

- Too high or too low speeds in the tube bank and poor circulation in the shell (see table below);
- Poor water treatment, i.e. applied method and control; and
- Too high metal temperatures on the cooling water side.

Regarding temperatures a metal temperature of 60 ºC is taken as an upper borderline as above this temperature most corrosion inhibitors are less or not effective. Also, in once through systems formation of calcium salts occurs.

5.3 COOLING WATER VELOCITY AND TYPE OF MATERIAL

Material	Velocity (m/s)
Aluminium brass	1.0 - 2.1
Copper nickel (90-10)	1.0 - 2.5
Copper nickel (70-30)	1.0 - 3.0
Carbon steel	1.0 - 1.8
Austenitic stainless steel (316)	2.0 - 4.5
Titanium	2.0 – 5.0

Table 4: Cooling water velocity and type of material[6]

5.4 CHOICE OF MATERIAL FOR PUMPS

The choice of material for a pump is less critical because in many cases this equipment is doubled (has a back-up). This means that if a pump breaks clown, the process is often not disturbed. Another factor is that the available walls are often much thicker than is strictly necessary (corrosion allowance).

5.5 CHOICE OF MATERIALS FOR COOLING WATER TUBES

In most cases carbon steel with a sufficiently high corrosion allowance is chosen for the cooling water tubes. If a corrosion allowance of more than 3 mm is insufficient for an acceptable life span, alternative materials are chosen, such as plastics, carbon steel with an organic coating, concrete or, in exceptional cases, alloys of higher quality, such as stainless steel, monel and other nickel alloys, etc. Tubes have an advantage over machines in that they are much easier and cheaper to replace, which is why the choice of materials is less critical.

5.6 REDUCTION OF ENTRAINMENT AND SUITABLE INTAKE POSITIONING

With a large water intake, such as for once-through cooling water systems, the impingement and entrainment of fish is an issue. Entrained fish - mainly fish larvae passing through the sieves at the cooling water intake, the pumps and the condensers - are not generally sampled. Entrainment is a local matter and the quantity of entrained fish is based on a complex of technical and hydrobiological factors that lead to a site-specific solution. Water is drawn into inlet channels in large quantities and at considerable speed. The inlet channels are generally equipped with debris filters to protect the heat exchangers against clogging and mechanical damage. Impingement occurs when fish are pressed against the sieves placed at the condensers or heat exchangers. A lot of smaller creatures is taken in with the cooling water and is killed by mechanical damage, which is called 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 behavioral aspects of the species, and on proper design and positioning of the intake.

With varying results, several techniques have been developed and applied by the industry

[6] Table from the IPPC BREF Industrial cooling systems, p.185; derived from tm001, Bloemkolk, 1997

to prevent the intake of fish due to large cooling water intake. The optimum solutions and results and the ability to meet BAT requirements are influenced by a wide variety of biological, environmental and engineering factors that must be evaluated on a site-specific basis. A comparison of the different techniques is therefore impossible.

5.7 COOLING TECHNOLOGY

Technology changes made to avoid fish entrainment have not been reported. It is obvious that fish entrainment will not be an issue when changing to open or closed recirculating cooling systems, which is a costly operation. It may be considered in a greenfield situation. Devices to prevent intake of fish can be found in e.g. power industry and refineries. Solutions for prevention are:

- Sound devices, positive to divert (a shoal of) scale fish but not for eel;
- Light systems with underwater lamps, positive to divert eel;
- Position, depth and design of the inlet;
- Limits to speed of the water inflow (although the data from studies carried out in England indicate that the entrained fish allow themselves to be carried by the flow (i.e. deliberately drifting or dispersing) even when they are physically capable of escaping the flow by swimming); and
- Mesh size of the cooling water sieves (against damage to the cooling system).

Observations have shown that, in the same power plant, a mesh size of 5 x 5 mm on average doubles the number of surviving entrained fish at the cooling water outlet compared with a mesh size of 2 x 2 mm, because impingement mortality of fish larvae is higher than entrainment mortality [KEMA, 1972] and [Hadderigh, 1978].

Mortality of impinged fish can be decreased by a good system to wash the fish from the cooling water sieves and to sluice them back to the surface water.

5.8 OPERATING PRACTICE AND END-OF-PIPE TECHNIQUES

Lowering the inflow velocity to below 0.1-0.3 m/s clearly showed a positive effect and reduced the amount of fish drawn in. However, lowering the velocity may mean that larger inlet channels are required, which may have technical and financial consequences. In general, changes in operating practice or the application end-of-pipe techniques do not apply to fish entrainment, but there is also a view –not shared by all- that entrainment could be reduced by taking account of the diurnal and seasonal patterns of entrainment.

Category	Protection technique	Effects	Remarks
Fish collection systems	Optimizing (increasing) the mesh-size of the travelling water screens	Improve survival of entrained fish larvae and very young fish stadia	Entrainment mortality of these fish stadia is lower than the impingement mortality of these stadia.
	Low pressure water jets to wash off the fish from the travelling screens and to return them to the surface water	Transport of fish back to the surface water	Requires a second high pressure jet system to clean the travelling screens
	Fish buckets on the screens	Improve survival of impinged fish	The fish remain in water permanently during transport back to the surface water
	Continuous rotation of the travelling screens	Improve survival of impinged fish	Reduction of impingement time
	Fish pumps	Transport of fish back to the surface water	Complicated to keep right conditions in pipes
Fish diversion systems	Angled screens or louvres with a fish by-pass	- Survival harder species (50-100%) > fragile species - Not for fish eggs, larvae and small invertebrates	- Requires uniform, constant low-velocity flow - Debris must be removed

Behavioural barriers	Lights
	- strobe lights
	- continuous lights
	  - mercury lights
	  - other lights
		Effects of different light systems depend on local situation, fish species and developmental stadia of the fish.	In many situations a by-pass for diverted fish is necessary

	Sound	Effects depend on local situation, fish species and developmental stadia of the fish.	In many situations a by-pass for diverted fish is necessary

Table 5: Available fish protection technologies for cooling water intake devices[7]

5.9 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 (design and material) 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

[7] BREF, p 76; derived from [TM152, TAFT, 1999]

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.

5.10 REDUCTION OF LEAKAGE AND MICROBIOLOGICAL RISK

Leakage can occur both in water- and air-cooling systems, but generally leakage is a concern of water-cooled systems. In particular in once-through systems contamination will enter the aquatic environment immediately via the cooling water. In open and closed circuit wet and wet/dry systems this will not happen immediately, but leakage will contaminate the coolant and the chemistry of the coolant will be disturbed with consequences for the heat exchanging process.

This effect of leakage on the working of oxidizing and non-oxidizing biocides has been clearly illustrated [tm090, Grab et al, 1994].

BATs are:

- Preventing leakage by design;
- 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 for reduction of emissions to water.

The occurrence in a cooling system of Legionella pneumophila (for fresh water and cooling tower) cannot be fully prevented. In marine waters some halophilic vibrios species, pathogenic for fish or man, can develop in once-through cooling systems. The species mentioned occur in the natural environment in generally low and harmless concentrations. Due to the raised temperature a favorable climate can occur in cooling systems enhancing the development of those bacteria, which can create a potential risk for human health.

It is considered BAT to apply the following measures:

- Avoid stagnant zones and keep enough 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 performing high-pressure cleaning.

5.11 REDUCTION OF EMISSIONS BY OPTIMIZED COOLING WATER TREATMENT

5.11.1 Corrosion inhibitors

Corrosion can be defined as the destruction of a metal by chemical or electrochemical reaction with its environment. The result is a metal oxide or other salt having little structural ability, which causes damage to the material. In cooling systems, corrosion causes two basic problems:

- The first and most obvious is the failure of equipment with the resultant cost of replacement and plant downtime.

- The second is decreased plant efficiency due to loss of heat transfer, which is the result of heat exchanger fouling caused by the accumulation of corrosion products. Corrosion is caused or favored by the presence of oxygen, the salt content, formation of deposits, or an excessive low pH level. Corrosion can also result from fouling by the growth of organism, so called microbiologically influenced corrosion (MIC): acid producing bacteria cause corrosion and vibrating mussels cause erosion.

5.11.2 Applied corrosion inhibitors

Corrosion inhibitors can be identified by their function. They remove corrosive material, passivate, precipitate or adsorb it. Passivating (anodic) inhibitors form a protective oxide film on the metal surface. Precipitating (cathodic) inhibitors are simply chemicals, which form insoluble precipitates that can coat and protect the surface. Adsorption inhibitors have polar properties, which cause them to be adsorbed on the surface of the metal. The use of corrosion inhibitors varies from system to system. In once-through systems polyphosphates and zinc are applied and there is limited use of silicates and molybdates. In some countries hardly any corrosion inhibitors are dosed in once-through systems except for yellow metal inhibitors (e.g. ferrosulphate) dosed in copper alloy heat exchangers or condensers.

Theoretically, closed water systems should not require corrosion inhibitors. Any oxygen introduced with the initial make-up water should soon be depleted by oxidation of metals, after which corrosion should no longer occur. However, closed systems usually lose enough water and leak enough air to require corrosion protection. Another theory is that the high residence time of the water, up to several months, is responsible for the heavy treatment with corrosion inhibitors. For closed systems the three most reliable corrosion inhibitors are chromate, molybdate, and nitrite materials. Generally, the chromate or molybdate have proven to be superior treatments. The toxicity of chromate restricts the use, particularly when a system must be drained. In many cases a non-chromate alternative is available, but in some states their use is still permitted. Molybdate treatments provide effective corrosion protection and are seen as more environmental acceptable as chromate treatments. Finally, it depends on the systems conditions (materials used and pH) what kind of corrosion inhibitors are best applicable. For instance, the most effective corrosion inhibitors for copper are the aromatic azoles. Concentrations in evaporative recirculating cooling systems typically range from 2 to 20 mg/l as active compound. For some anodic inhibitors (such as chromates, molybdates and nitrites) concentrations used in the past are reported to be 500 to 1000 mg/l in closed systems.

5.11.3 Scaling and scaling inhibitors

If concentration of salt in the water film within the heat exchanger exceeds its solubility, precipitation occurs, which is referred to as scaling. The main forms of scale are calcium carbonate and calcium phosphate, but also calcium sulphate, silicates, Zn and Mg deposition can occur depending on the minerals contained in the water. Scaling reduces the performance of the heat exchanger, since the thermal conductivity of calcium carbonate is about 25 times lower than that of steel. Scaling depends on three major factors: mineralization (alkalinity), higher temperature and pH of the circulating water and of secondary factors: presence of complex inorganic matters and chemical composition of the heat exchanger surfaces. Also, certain shape of the heat exchanger body favor scaling. Corrugations, oblique channels and an insufficient ratio of water flow per film surface area favor scaling. In recirculating systems high cycles of concentration can lead to scaling as well.

The most important scale control agents are polyphosphates, phosphonates, polyacrylates, copolymers and ter-polymers. Typical concentrations of scale control agents range from 2 to 20mg/l, as active compound. Hardness stabilizers prevent the formation of crystals and are used in recirculating systems, but rarely or never in once-through systems.

5.11.4 Fouling and fouling inhibitors

Fouling occurs when insoluble organic particulates suspended in water of both once-through and open recirculating cooling systems form deposits on the systems' surface. Particulate matter, particle sizes and low water velocities are factors that enhance fouling. Foulants can be sand, silt, iron oxides and other corrosion products and they can react with some water treatment chemicals as well. They can either be airborne, can enter the cooling system with the water (silt,

clay) or are introduced by process leaks and can be very finely dispersed with sizes as small as 1-100 nm.

Dispersants are polymers used to prevent fouling by removing particulate (organic) matter (e.g. microfouling and slime layer) from the heat exchanger surface by increasing the electric charge resulting from absorption. The particles repel each other and as a result remain suspended. To facilitate penetration of biocides into microfouling and slime layers surfactants often referred to as biodispersants can be used. Dispersants help to keep the surface of heat exchangers clean, thereby reducing the risk of corrosion. It is common practice to dose biocides in combination with dispersants at levels of 1-10 mg/l as active ingredients.

5.11.5 Applied biocidal treatment

Non-oxidizing biocides are mainly applied in open evaporative recirculating cooling systems and therefore are not further mentioned here.

The application of oxidizing biocides in once-through systems needs to be optimized 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. In order to assist the process of BAT decision making on cooling water additives at a local level, this interim Standard aligned to the BREF seeks to provide to the Environment Department responsible for issuing an operational permit in line with IPPC (Integrated Pollution Prevention and Control) and an outline for an assessment. Integrated pollution prevention means that selection of best available cooling technology and application of techniques, of treatments or ways of operating should consider not only the direct environmental impacts of the different cooling systems, but also the indirect environmental impacts due to varying efficiencies of the different processes. It must be decided at local level whether this should be pursued by focusing on the cooling system rather than on the production process. The increase of the indirect impacts can be considerably higher than the decrease of direct impacts of the selected cooling system.

5.12 HEAT EMISSION TO SURFACE WATER

All heat that is discharged will finally end up in the air. If water is used as the intermediate cooling medium, all heat will be transferred to the air, either from the water droplets in a cooling tower or from the surface of the receiving water. Before the heat has left the surface water it may affect the aquatic ecosystem, and this should be avoided.

Heat emission is also an issue closely related to the amount of cooling water used and discharged. Once-through systems, both direct and indirect, by definition form the largest source of heat discharged to the surface water, as the heat is entirely discharged via the cooling water.

There is little information on the effects on the aquatic ecosystem of heat emissions, but there are experiences with high summer temperatures and small receiving waterways. Temperature rise may lead to increased rates of respiration and of biological production (eutrophication). The discharge of cooling water into the surface water influences the total aquatic environment, especially fish and coral reefs. The temperature has a direct effect on all life forms and their physiology and an indirect effect by affecting the oxygen balance. Warming reduces the saturation value of oxygen; with high oxygen concentration, that leads to a reduced oxygen level. Warming also accelerates the microbial degradation of organic substances, causing increased oxygen consumption. Also, where circulation of the cooling water occurs or where several industries use the same limited source of surface water, heat emissions need careful consideration to prevent interference with the operation of industrial processes downstream.

From the specific heat of water amounting to approximately 4.2 kJ/kg/K the temperature rise of water can be calculated. For example, when cooling water is warmed up by an average of 10K,1 MWth of heat requires a cooling water flow of about 86 m^3/hour. Broadly speaking each kWth needs 0.1 m^3/hour of cooling water. With recirculating cooling water, heat is transferred to the air through evaporation via cooling water in a cooling tower with the evaporation heat of water being 2,500 kJ/kg (at 20ºC).

In the power industry in particular, the factors playing a role in the discharge of large quantities of heat into the surface water have been researched. Several physical phenomena must be taken into account when heat emissions are being assessed, such as:

- Seasonal variation in the temperature of the receiving water;
- Seasonal variation in the water level of rivers and the variation in the velocity of the stream;
- The extent of mixing of the discharged cooling water with the receiving water (near field and far field);
- At coastal sites, tidal movements or strong currents; and
- Convection in the water and to the air.

The behaviour of the hot water plume in the surface water will not only be valuable in protecting the receiving environment, but also for choosing the right place for the inlet and outlet. It will always be important to prevent circulation of the plume affecting the temperature of the water taken in and consequently the efficiency of the cooling system. As an example, the extent of a thermal plume, defined as the area within the 1K heating isotherm, without mixing with strong currents (e.g. in a lake), is about 1 ha per MWe for a conventional power plant, or about 45 km2 for a 5,000 MWe power plant.

In most cases, a fairly large part of the discharge of a thermal power plant takes place in the aquatic-environment. Various physical phenomena come into play here:

- Turbulent diffusion;
- Convection in water;
- Flow of fluids of variable density; and
- Evaporation, radiation, convection in the air.

Depending on the extent of the discharge and according to the receiving environment, such a phenomenon is preponderant and affects the way the heat is distributed in the receiving environment.

The near field of the cooling water discharge should be distinguished from the far field. The near field is defined in a river as the area in which the mixing of the warm water plume with river water is incomplete. The water temperature in the near field depends upon the mixing of water released by the power plant with the water of the receiving environment. Heating can be reduced in this area by rapidly mixing the effluent with the water of the receiving environment by means of specific devices.

The far field is the warm water geometry that is fully mixed with depth within the water column and is thus a background heat field. The excess temperature in the far field is gradually reduced due to the dilution with ambient waters and heat exchange with the atmosphere. As concerns discharges in a tidal sea or sea with strong currents, the warm water plume formed by the discharge of the power plant is mainly governed by the existence of major velocities in the receiving environment. They bring about a rapid mixture of the water preventing any stratification caused by the difference in density between the warm water and cold water. The temperature drop in the warm water plume principally comes from the mixing and not from heat losses at the surface of the water area. The extent of the warm water plume in a tidal sea, defined as the area within the 1 K heating isotherm, covers an area from 2 to 10 km2 for a discharge corresponding to that of a 5 000 MWe power plant. The behavior of the warm water plume in a tideless sea is first of all that of a stratified flow.

The temperature drops very quickly through dilution due to friction and turbulence. In a tideless sea (or lake) the spreading or transport of cooling waters is strongly influenced by wind-induced currents and thermocline conditions and is estimated as roughly 1 ha/MWe. Normally for coastal power plants the cooling water is discharged to the sea surface through an open discharge channel.

In all cases, recirculation in the water body must be avoided or the recirculation rates for discharges into the sea reduced to a minimum to ensure efficiency and safe operation of industrial plants. The position and design of water intake and outlet structures are determined to eliminate the risk of recirculation. Preliminary studies make it possible to design water intake and outlet structures and devices best adapted to avoid recirculation and favor the initial mixing of heated water discharges. They rely on physical models (hydraulic models) and numerical models. Where possible the numerical modelling etc. should be based on site-specific hydrographic survey data. The use of these tools as part of the impact study of projected facilities serves to give assurance that regulatory thermal limitations will be respected, whether they concern maximum heating in the mixing area or the temperature level after the mixing.

5.13 MONITORING

Given the flowrates of industrial plant cooling systems, one cannot conceivably operate them without an advanced monitoring and control system. This reasoning is applicable both for problems concerning scale and biological development. As concerns the follow-up of biological developments, many types of sensors exist and are implemented. Among these should be mentioned biomonitors, and electrochemical sensors. A control of the quality of drainage water is desirable in order to monitor parameters like temperature, oxygen concentration, pH, conductivity etc.

In once-through systems, macrofouling is sometimes controlled by the application of heat treatment, without any biocide use. Sodium hypochlorite is the most important biocide that is applied. Dosing is shock-wise or continuous. The dosing strategy on macrofouling control should be preventive, since curative dosing, when a lot of macrofouling has abundantly developed, requires very high doses over extended periods. It is recommended that consideration be given to the option of targeted dosage at locations with a high fouling risk, such as heat exchanger inlet and outlet boxes. Chemical monitoring is essential to establish the minimum required biocide dose. Since the applied oxidizing biocide concentration will decrease in the Cooling Water System (CWS), chemical monitors are needed to register the effective residual level of biocide at the critical points in the CWS. On-line meters should be hand-calibrated with the colorimetric DPD (N-N-diethyl-p-phenylenediamine) test on a regular basis. Toxicity-based measurement of biocide concentrations in the cooling water is also useful for optimization schemes. Macrofouling monitoring devices give information on the settlement and growth of macrofouling organisms and on the performance of the biofouling control program. This information is essential for biocide optimization programs in once-through systems that have macrofouling problems.

The monitoring of biofouling is based on the monitoring of microbiological activity in the cooling system as well as the actual microbiocide treatment levels. The key to measuring the effectiveness of any biocide program is the ability to measure quickly and accurately the microbiological activity in the cooling system.

To obtain a good dosage regime the following strategy for once-through systems has been suggested:

- Make a problem analysis on the organism(s) to target;
- Characterize seasonal differences in occurrence (e.g. breeding period of mussels);
- Take into account water temperature and water quality (fresh/salt);
- Select a dosage program (e.g. locally per section: continuously or intermittently);
- Decide on the dosage units that will reduce consumption especially if linked to a monitoring system; and
- Decide on the monitoring program (mussel detection tank (breeding period determination) or mussel/oyster monitor (concentration detection).

5.14 BENCHMARK ASSESSMENT CONCEPT FOR COOLING WATER CHEMICALS

As already set out in the Preamble to this document the cooling water discharged back to the sea is supposed to be untreated and therefore of unchanged quality. However, since industries of the kind to be operating in NEOM are hardly to be expected to not do the slightest treatment to their cooling media and systems, it is necessary to give some benchmark assessment concept. It is reiterated that should the water discharge quality fall under the threshold (see below) this water would have to be declared as Industrial Wastewater and fall under the ZLD requirement.

The presented benchmarking should help the Industries compare different chemicals one with another on the basis of potential environmental impact. Without such a tool, the complexity of making decisions could be a serious obstacle in determining what is BAT for cooling systems in a rational way at the local level. As is described below, most of the main elements for establishing such a risk-based benchmarking tool can already be found in EU-Community legislation and its official supporting documentation. The present approach seeks to draw together elements from: the IPPC Directive,

the Water Framework Directive, and Risk Assessment legislation and the supporting “Technical Guidance Document” in a coherent manner, to provide a tool to help evaluate cooling chemicals.

Any assessment of cooling water chemicals should involve both intrinsic properties and local situation characteristics (risk-based approach).

The ensuing Benchmarking Assessment Concept arises as a result of consideration of existing assessment schemes and methodologies and seeks to provide a starting point for proper consideration of both intrinsic properties and the local level situation in the assessment of different possible treatment regimes.

The assessment concept does not enter into a discussion of the Intrinsic Hazard Approach but concentrates on the task of explaining and clarifying the Benchmarking (relative ranking) Procedure.

It essentially focuses on individual substances, giving brief indications of how the method could be extended to multi-substance complete chemical treatments.

Also, only the most complex case (and most frequent) of open recirculating systems (cooling systems with an evaporative cooling tower) is dealt with, with the possibility of later extension to once-through, closed systems, etc.

5.15 RELEVANT LEGISLATIVE BACKGROUND

There is no need, here, to evoke in any detail the legislative requirements which have led to the development of BAT reference documents. It is enough to mention Article 16.2 of the IPPC Directive on exchange of information, and the initiative of the EU-Commission to develop, through the institution of the Information Exchange Forum, a tool which should assist and guide PPs to set Emission Limit Values (ELV) for IPPC Listed Plants.

It is of importance, though, to underline one of the key aspects of the Directive: the control of emissions and their impact on the environment through a “combined” method of BAT set emission limit values to be checked against environmental quality standards. Also, very relevant in this context is the shortly to be adopted Water Framework Directive (WFD).

Although it might be the case that a correct evaluation of the effects of chemical treatments used in cooling systems should be subject to a multimedia assessment, it is also correct to state that the major concerns associated to the use of these chemicals regard the main potential receiver of polluting substances: the aquatic-environment.

A few words are therefore necessary to briefly review the relevant parts of the WFD.

5.16 THE WATER FRAMEWORK DIRECTIVE (WFD)

While the WFD goes much further than providing elements to prevent and control emissions from Industrial IPPC Plants, it does in fact supply one key link with the IPPC Directive. It fixes methods and procedures for the EU-Commission to prioritize dangerous substances and to propose, for these, emission controls and EQSs (Environmental Quality Standards; or "Quality Standards"), to be adopted.

It introduces in an annex (Annex V Section 1.2.6) a simple procedure to be used by PPs to calculate EQSs for chemical substances in water.

In other words, it provides one of the conditions required by the IPPC Directive to implement a combined approach:

- Methods and procedures to calculate Quality Standards.
- According to the WFD text (Annex V Section 1.2.6), EQSs are to be determined in the following way:

Test Method	Safety Factor
At least one acute $L(E)C_{50}$ from each of three trophic levels of the base-set	1000
One chronic NOEC (either fish or daphnia or a representative organism from saline waters)	100
Two chronic NOECs from species representing two trophic levels (fish and/or daphnia or a representative organism from saline waters and/or algae)	50
Chronic NOECs from at least three species (normally fish, daphnia or a representative organism for saline waters & algae) representing three trophic levels	10
Other cases, including field data or model ecosystems, which allow more precise safety factors to be calculated and applied.	Case by case assessment

Table 6: Environmental Quality Standards according to WFD[8]

While a more detailed analysis of the significance and implications of this table will be made later, there are a few notes that need to be made at this point:

- The Quality Standards set on this basis only take into account the protection of the aquatic system, without considering the indirect-human effects;
- The numbers resulting from the above table are Predicted No Effect Concentrations (PNEC) (See Technical Guidance Document for Regulation 793/93/EEC);
- The Commission has developed a Prioritization Procedure, which is based on a systemin where an aquatic effect score is combined with a bio-accumulation

[7] BREF, p 219; derived from WFD Annex V Section 1.2.6

score and a human effect score. The procedure has been used to provide the basis for the Commission's proposed "priority list" of substances to be controlled at EU level by means of emissions controls and EQSs to be adopted under the Water Framework Directive.

The following benchmarking assessment concept is also based on the above method of Calculating Quality Standards. This is for the following reasons:

- In the context of the BREF, the method must be clear, simple straight forward, transparent and easy to use;
- It is most probable, even if a lot of work is needed to prove this, that the aquatic environment is the weakest link of the chain;
- Benchmarking methods will be used in combination with EU chemicals legislation (Intrinsic Hazards), which implicitly includes evaluation of potential indirect adverse effects (both on the aquatic-environment and on humans) through the inclusion of bioaccumulation, the CMT properties (carcinogenic, mutagenic, teratogenic) as well as chronic effects in the classification of hazardous chemicals.

5.17 BENCHMARKING - INTRODUCTION OF THE CONCEPT

The Benchmarking Assessment Concept is founded on carrying out substance by substance comparisons using a standardized theoretical measure of the Predicted Environmental Concentration (herewith referred to as PEC standardized). This PEC standardized is compared with the corresponding Predicted No Effect Concentration (PNEC) or EQS of the substance, determined in accordance with the method contained in Annex V of the Water Framework Directive. In this way a ration can be calculated for each substance which permits a preliminary ranking of substances based on potential impact.

While the terms PNEC and PEC have now entered in the legislative language in the context of emissions law, and their significance will become common knowledge, it is worth at this point clarifying the concepts as they apply to the Benchmarking Procedure.

5.18 THE PNEC

The Benchmarking Procedure does not attempt to rank the chemicals mentioned in the BREF itself.

The real-life situation is complicated by the fact that only rarely do chemical treatments for cooling systems consist of a single substance. The attempt to rank treatments in a BREF would imply the application of an "additive" procedure of some sort to an enormous list of possible substances combinations in the treatments. Assuming these combinations can be made available, this would require a large quantity of work and time and would almost certainly fail to be either exhaustive or up to date. Therefore, this standard follows the BREF Assessment Concept that aims to offer a standard methodology, rather than a numerical assessment of substances or treatments.

At any rate, aquatic toxicity data must be available and be made available by chemical suppliers to permit evaluations of PNECs. This is a fundamental aspect of any ranking procedure.

5.19 FURTHER CLARIFICATION

A few words of clarification seem appropriate here. The fewer data there are available the higher the assessment factor to be applied to convert toxicity data to PNECs.

The availability of chronic data reduces the factor. Progressing through a set of intermediate situations, having chronic data on three trophic levels allows the use of a factor of 10, compared to a factor of a 1000 when only acute toxicity data are available. The costs associated with performing chronic tests are much higher than the costs for acute testing. Thus, it is likely that more acute than chronic toxicity data will be available.

When the Benchmarking Procedure is applied locally, the available data will have to be used together with the corresponding assessment factor.

It will be left, in this case, to the supplier of chemicals to decide whether or not to invest additional resources in obtaining chronic data, as and when this might prove necessary. For example, for a given plant it could be the case that using only acute data (which implies obtaining an EQS by dividing the LC50 by a “safety factor” of 1000 to take account of uncertainty) there may be difficulty in complying with the stringent resultant EQS. In this case the supplier might opt to obtain the more “certain”, but equally more time-consuming and more costly, chronic data. Chronic data implies dividing test result concentrations by a safety factor of only 10, which will lead to a more “certain” EQS, which may also be more achievable.

PART 6 MARINE DISCHARGE QUALITY STANDARD FOR ONCE-THROUGH SEAWATER DIRECT COOLING SYSTEM

6.1 WATER QUALITY PARAMETERS FOR DISCHARGE TO COASTAL BODIES

The water quality discharge should meet, as a minimum the requirements of the National Ambient Water Quality Standard for KSA and the water quality parameters identified in the table below under “Minimum Requirements” for all NEOM developments. These parameters have been developed considering international best practice guidance in order to preserve the existing water bodies.

Note: for temperature the delta given in the below table prevails for other than seawater cooling discharges (e.g. for storm water); for the special case of seawater used as coolant for industrial processes refer also to the section “Temperature Dispersion”.

		Saudi Arabia Ambient Water Quality Guidelines		Minimum Requirement
Parameter	Unit	Red Sea		Coastal Waters
		Marine (C1)	High- value (C2)	
Temperature	°C	Δ3	Δ2	Δ1
pH	-	Δ0.2	Δ0.1	Δ0.1
TSS	mg/l	5	2	2
Turbidity	NTU	2	1.5	1
Dissolved oxygen (DO)	mg/l	>5	>5	>5
BOD_5	mg/l	10	10	1.5
COD	mg/l	25	20	20
Phosphorus (total)	mg/l	0.5	0.25	0.0001
FRP (filtrable reactive phosphate)	mg/l	n/a	n/a	0.006
Ammonia (free, as NH_3)	mg/l	0.1	0.05	0.05
Chlorophyll a	mg/l	n/a	n/a	0.002
Calcium (Ca)	mg/l	1,200	1,200	160
Ammonia Nitrogen (NH_4-N)	mg/l	n/a	n/a	0.015
Total Nitrogen	mg/l	n/a	n/a	0.14-0.2
Inorganic nitrogen (as Nitrite and Nitrate)	mg/l	1.5	1.2	0.014
Aluminium	mg/l	0.2	0.2	0.2
Arsenic	mg/l	0.05	0.05	0.05
Barium	mg/l	0.5	0.5	0.5
Cadmium	mg/l	0.005	0.002	0.0007
Chromium (Cr III)	mg/l	n/a	n/a	0.0077
Chromium (Cr VI)	mg/l	n/a	n/a	0.05
Cobalt	mg/l	0.05	0.05	0.000005
Copper	mg/l	0.05	0.05	0.0029
Iron	mg/l	0.5	0.1	0.1
Lead	mg/l	0.05	0.005	0.0022
Manganese	mg/l	0.01	0.01	0.01
Mercury	mg/l	0.0004	0.0004	0.000025
Nickel	mg/l	0.05	0.05	0.0083
Silver	mg/l	0.1	0.07	0.0008
Selenium	mg/l	n/a	n/a	0.071
Zinc	mg/l	0.8	0.2	0.007

Table 7: Water quality parameters for discharges to coastal bodies [8]

[8] NEOM Stormwater and Pollutant Runoff Management Guideline

6.2 TEMPERATURE DISPERSION

The following appreciation of Temperature Dispersion of Cooling water Discharges is based on international best practice benchmarking and is considering the environmental conditions requested for an effective long-term protection of the marine biome of the Red-Sea Coastline.

In order to study temperature dispersion of cooling water discharged into seawater, temperature values need to be recorded daily for different transects over at least a year. A model would have to be developed to estimate the dispersion of temperature after discharge from the cooling system into the oligotrophic seawater of the Red Sea. Temperatures recorded along transects would then exhibit an expectable gradual decrease from the discharge point with distance.

In a study run in 2015 on the northern coast of the Gulf of Aqaba (“Temperature dispersion of cooling Water Discharge into oligotrophic seawater“ 2015) the maximum difference between either the intake or ambient seawater and a station 100m from the discharge was 1.2 °C.

The Cooling Water System is one of the most efficient methods to remove heat from components and industrial equipment. Cooling water effluent of industrial plants around the world is discharged into seawater with temperatures 1-3 °C above ambient seawater at the low-end and up to temperatures as high as 6-15 °C above ambient. The permitted temperature of the discharge may change due to the differences in local climates, plant efficiencies, volumes of water required for cooling and last but not least the assessed impact outcome of respective ESIAs run by the Project Proponents under the custody of the authorities in charge. The warm effluent water may cause thermal pollution in the receiving water body. Temperature is a key factor in marine life and any change in temperature may cause severe stress or even death to aquatic organisms. Change in temperature may impact productivity, growth, development, as well as metabolic and physiological processes.

Tropical and subtropical latitudes, like those of the Red Sea, generally have little temperature fluctuation, due to the large ocean surfaces and absence of a pronounced cold season. For example, the Red Sea surface temperature fluctuates only 4 to 6 °C seasonally, and 1 °C diurnally. Accordingly, temperature variation of only a few degrees may be considered a proportionally large change for organisms that are adapted to this relatively stable thermal environment. Therefore, small changes in temperature could have a disproportionately greater impact on the larval development of tropical organisms than on the larvae of temperate systems which naturally experience large temperature variations.

Coral reef species live within a relatively narrow temperature margin, and anomalously low and high sea temperatures can induce coral bleaching which has previously affected Red Sea reefs in 1998 and 2002/2003. Photosynthetic and calcification activities of corals of the Red Sea were impacted by higher temperatures.

Elevation of the seawater temperature may also decrease gas solubility in seawater which may decrease the Oxygen level while increasing respiration rates (possibly increasing CO_2 levels). This could impact marine organisms, community composition, and biogeochemical cycling of key elements such as carbon, nitrogen, and phosphorus.

According to the World Bank guidelines, the increase in temperature of the receiving water should not be more than 3 °C at the edge of a mixing zone or 100 m from the discharge point. Such guide, however, wouldn’t speak to the special conditions relevant most organisms of a coral reef environment. For such seawater, the quality and temperature are playing a most vital role. Tropical and subtropical organisms are highly sensitive to small variations in water temperature. Previous studies reported a negative impact of temperature rise on such organisms due to changing gas solubility, changes in photosynthesis and respiration rates, etc. The tolerance of Coral Reefs around the world lies around 1°C temperature delta.

6.3 SEAWATER TEMPERATURE IN A MIXING ZONE

A mixing zone is defined as the area where an effluent discharge undergoes initial dilution and is extended to cover the secondary mixing in the ambient water body. Such initial mixing zone should not exceed 100m.

The allowable difference in temperature between the intake and discharged waters is herewith restricted to be not more than 1 °C at 100 m distance of the discharge point.

The NEOM zone present Standard for Marine Discharge Quality sets the allowable increase in temperature of the receiving water at not more than 2.0 °C over the ambient average maximum water temperature at the discharge point and at not more than 1.0 °C at the edge of a mixing zone defined to be at 100 m from the discharge point.

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