EDF Energy Nuclear Generation Ltd

Company Technical Standard

for

The Control of Marine Fouling

Chemistry

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Approved By:	A Rudge Chief Chemist	Date:	December 2015
Approved By:	D Armstrong Chief Engineer	Date:	December 2015

REVISION	AMENDMENT	IMPACT LEVEL	DATE
003	Three-yearly review incorporating details of alternative biocidal methods, a new monitoring method, the deletion of Action Level 2, other minor changes and updating to new CTS document format.	Minor	Dec 15

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VERIFICATION CERTIFICATE

Document Title:	The Control of Marine Fouling
Station:	***All AGR and PWR Stations***
Document Reference: Revision: Task File Number: QA Grade of document:	BEG/SPEC/ENG/BEOM/006 003 TSK/GEN/5680 2 (Appendices – QA Grade 3)
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Verification Statement:	Verification includes: (i) check that practice remains appropriate following change to CTS format; (ii) format is correct; (iii) information in appendices is accurate and relevant (QA grade 3); (iv) references are appropriate and quoted correctly; (v) check of format, spelling, grammar and readability
Approved by:	A Rudge Chief Chemist, Design Authority

CONTENTS

1 PURPOSE

The purpose of BEOM 006 is to specify the mandatory requirements for the control of marine fouling due to sessile organisms (such as mussels) and biofilms, present guidance on best operational practices and to summarise the underlying technical principles. It supersedes the advice given in EDF Energy Nuclear Generation's BEG/SPEC/ENG/BEOM/006 Rev 002 (Ref. 1).

1.1 Mandatory Requirements Justification

Mandatory requirements within the Technical Governance (TG) process must be necessary to achieve legal compliance or mitigate significant safety, environmental, commercial or lifetime risks, where there is a strong business case for this.

2 SCOPE

The requirements, guidance and information presented in this document are applicable to all EDF Energy power stations. This BEOM only considers the control of actual biological settlement on surfaces; no consideration is given to the effects of impingement (e.g. shell, jellyfish, fish or weed impingement on screens). It covers both normal operation and shutdown conditions.

As a BEOM, this is not an operational document but is instead designed to present requirements and guidance for incorporation into station specific operational procedures, for example Technical or Environmental Specifications and Operating Instructions. This BEOM does not specify the monitoring requirements required by the individual sites to demonstrate compliance with their specific Consent to Discharge.

All mandatory requirements presented in this BEOM are highlighted in bold. For ease of understanding, monitoring requirements that are mandatory are referred to in this BEOM as 'control parameters'. Monitoring requirements that are recommended as best practice and are suitable for the diagnosis of faults, but are not mandatory are referred to as 'diagnostic parameters'.

This BEOM does not constitute a safety case. Care has been taken in the production of this document to ensure that any safety case commitments have been appropriately addressed. If a safety case commitment is found to be more onerous than this BEOM, then the safety case shall take precedence.

2.1 System / Component Description Summary

The goal of this BEOM is to define the best practice for the chemical control of marine fouling on these sites for the main cooling water systems and the station specific systems detailed in Table 1.

2.2 EPRI Codes

This BEOM has a direct or indirect affect on the following systems

F11 Main CW Systems (Inc. Electrochlorination)

F12 Conventional Plant CW (Sea Water)

F13 Reactor Plant CW (Sea Water)

2.3 Document Hierarchy

This document forms part of the Technical Governance (TG) document suite for Chemistry which sets out a fleet wide approach to standardisation of mandatory requirements for plant operation, maintenance and modification (Ref.2)

2.4 Ageing Management and Plant Lifetime Extension (PLEX)

This BEOM sets out the current strategy for the control of marine fouling to provide safe and reliable plant operation. The mandatory requirements have been determined to ensure that the plant reaches the declared accounting lifetime with a view to safe, reliable operation over an extended lifetime.

2.5 Requirements Derivation

Mandatory requirements are generally derived from any of the following

a. Previous documentation.

b. Past experience of EDF Energy’s power stations.

c. Best practice from other operators and organisations, e.g. EPRI, WANO, INPO.

d. Consideration of commercial implications.

2.6 Requirements Compliance

Mandatory requirements in this BEOM are numerically identified and written in bold text.

Reference 3 outlines how all TG documents (inc. BEOMs) must be complied with across the fleet.

3 RESPONSIBILITIES

The responsibilities specific to this document are listed below.

3.1 Head of Design Authority (DA)

The Head of DA has responsibility for approving all new TG Company Technical Standard documents, and revisions that have an impact level of Moderate or Major. This is to ensure that the document does not contradict, conflict with, or undermine any existing nuclear Safety Cases or generation substantiation points. (Ref. 4)

3.2 The Chief Engineer

The Chief Engineer as Technical Governance Process Owner is responsible for ownership of the TG Specifications, templates and associated process management documentation that enables achievement of the overall TG objectives.

3.3 The Chief Chemist

The Chief Chemist is the Document Owner for this BEOM. The Document Owner is responsible for monitoring the adequacy of the BEOM and, when necessary, initiating a review. The maximum period between reviews shall be 3 years in accordance with Document Control (Ref. 5). It is also the document owner's responsibility to regularly review compliance with the requirements and guidance of the BEOM, and to provide additional support to the stations where appropriate.

3.4 Fleet Leads (or equivalent)

Not applicable as the Chief Chemist also acts as Fleet Lead.

3.5 Station Director

The Station Director (SD) has responsibility for ensuring compliance with this document at Station level and for recording compliance with, and dispensation from, the requirements of the documentation.

The SD is also responsible for the distribution of new TG documents on station (normally amongst the Station Engineers) and the delegation of management of any mandatory requirements that documents impose.

3.6 Station Engineering Manager (or delegate)

The Station Engineering Manager is responsible for ensuring awareness, dissemination and familiarisation of applicable station staff with this document.

In general the Station Engineering Manager is also responsible for station implementation of TG documents on behalf of the Station Director, as well as maintaining appropriate records of compliance (or dispensation) for the document. However, in practice with most of the Chemistry TG documents this is delegated to the Station Chemist/Chemistry Group Head.

Station Engineering Managers are responsible for appointing a Station Point of Contact (SPOC) to oversee station engagement with the TG process.

4 PRACTICE

All mandatory requirements are numerically labelled in bold text.

4.1 Basic Principles

The overall strategy adopted by EDF Energy Nuclear Generation Ltd. is screen, clean and dose. Effective screening and cleaning are critical activities as these are the first lines of defence. Consequently appropriate plant and practices should be maintained by each individual station. Screening and filtration help prevent systems becoming fouled but eventually the systems will need to be cleaned. Chemical dosing is a means of limiting biological fouling and deferring the need to clean but will be altogether ineffective if cleaning is not adequately maintained. The detailed dosing regime adopted will depend on the propensity for fouling at each site. The current choice of biocide is sodium hypochlorite solution - either brought in as a bulk reagent or generated in-situ by the electrochlorination of seawater. Other biocides are available, but these are not currently approved within EDF Energy.

The Main Cooling Water system (MCW) provides a continuous supply of sea water to the main condensers the purpose of which is to condense low pressure (LP) feed steam and in so doing maintain a vacuum and optimum condensate temperatures. This system also provides water to the dump condenser (where fitted), and other cooling water systems either directly or indirectly. These ‘other’ systems are termed differently at different stations and a glossary of terms and the plant which they support is included in Table 1.

Sea water provides an effective heat removal system for both essential and non-essential plant during both operational and shutdown conditions. The safety case claims on the CW system are discussed in Appendix A.

4.1.1 Normal operation

The biocide dosing regime is related to the fouling risk for each Station. Due to the potential for changes to water quality, bio-species composition and biomass that can occur over time (Ref. 6) the fouling risk for each station needs to be assessed on a regular basis. The frequency of the risk assessment needs to be compatible with the potential impact of any unexpected fouling and the operational effort and cost involved with an assessment

Mandatory Requirement 1

A strategic risk assessment of the prevalent biofouling risk at each specific site shall be undertaken every 3 years.

The strategic risk assessment should be carried out as described in reference 6 and the latest assessment was carried out in early 2015. The assessed level of fouling risk (High, Moderate or Low) for each station is given in Table 2 (Ref. 7). The required dosing regime associated with the level of risk is given in Table 3.

Mandatory Requirement 2

Stations shall adopt and comply with, all mandatory requirements of the dosing strategy commensurate with the level of risk identified in Tables 2 and 3.

Mandatory Requirement 3

Station shall monitor and comply with all control parameter requirements presented in Table 4 in accordance with their dosing regime, Control parameters are identified in bold.

Mandatory Requirement 4

Any proposed operational changes to Tables 2-4 shall be endorsed using the chemistry dispensation process.

The chemistry dispensation process is specified in E/PROC/ENG/BI/464 (Ref. 8). The chemistry dispensation form is the formal record of the dispensation approval process (Ref. 9).

Mandatory Requirement 5

The Station Chemist (or nominated deputy) shall be informed when any chemistry excursion leads to entry into an Action Level, and a Condition Report raised, when any chemistry excursion leads to entry into an Action Level for three days or more.

4.1.2 Off-load Operation

This section covers both planned outages (for maintenance or refuelling) and unplanned outages. The requirement for biocide dosing is dependent on the length of time the cooling system is shut down irrespective of the main plant's status. The advice given below constitutes best practice but, under some circumstances, stations may wish to vary this:

Where a cooling water flow is maintained during a shutdown the normally applied chlorination programme should be maintained.

When cooling water flow is stopped for a planned period of <14 days the system can be left flooded and boxed.

Where the cooling water flow is stopped for a planned period of >14 days the systems should be isolated and drained down.

Best practice is given in Table 5.

4.1.3 Start-up

Should any system that normally receives a flow be allowed to remain static, flooded or drained down for a time, it should be assumed that it will contain quantities of dead and decaying organisms or loosened silt associated with a foul. On return to service this may result in quantities of loose debris being flushed downstream potentially causing total or partial blockage of plant.

Fouling to this extent should have been apparent before the outage, as increased drawdown or as substantial volumes of debris in waterboxes. Planned inspection programmes would also highlight the problem. The main risk on return to service is not to the environment as a consequence of the release of particulate material but to the commercial operation of the station due to the possibility of blocking filters, strainers and plant. The outage plan, therefore, should allot additional time to checking strainers and coolers on auxiliary circuits and be prepared for some flushing of systems to reduce blockage potential.

4.1.4 Microfouling

Where operational CW systems exhibit a sustained reduction in observed efficiency of main or other cooling water system over a period of 5 days, this should be investigated. If the cause is marine microfouling, Action Level 1 is entered and the dosing regime shall be reviewed and modified to halt this trend.

Mandatory Requirement 6

Where separate chemical control of microfouling is necessary, a dosing regime shall be implemented to control it.

A number of strategies have been used effectively, these include:

(i) Dosing to achieve a continuous TRO concentration of 200 µg.kg^{-1}, or

(ii) dosing to achieve a TRO concentration of 200 µg.kg^{-1} for 12 to 24 hours, one day a week, or

(iii) dosing to achieve a TRO concentration of 500 µg.kg^{-1} at the outlet to each condenser pass (or the discharge point from an ECW/ACW leg) for 10 minutes per day.

Other variants of the intermittent dosing strategies described in (ii) and (iii) may also be effective. It is suggested that stations consider taking technical advice if they wish to adopt a strategy not described in (i) to (iii) above.

Care must be taken to ensure that limit values established by the station's Consents to Discharge are not transgressed. These vary from site to site but will typically require the TRO concentration to be less than ~300 µg.kg^{-1} at the outlet. In such circumstances, option (iii), therefore, could only normally be used at stations where the condenser design permits sequential dosing of passes or sections of the condenser.

4.1.5 Planned Maintenance

Continuous dosing regimes are sub-acute toxic systems, i.e. they are not primarily aimed at killing the fouling organisms but at limiting their growth. Nevertheless, continuous dosing at 200 µg.kg^{-1} TRO will eventually kill adult mussels but it may take of the order of 6 months. The mussels have the capacity to close up in the face of biocide dosing; they will not feed and change over to an anaerobic metabolism. They will continue to do this during periods of continuous chlorination but if the dosing is stopped they will quickly revert to an aerobic metabolism. This means that after two days without chlorination, the mussels will have recuperated and the 6 months of dosing required to kill them starts again. This has important implications for the reliability and maintenance regimes for electrochlorination plant.

Best practice for maintenance of electrochlorination plant is to carry out maintenance that prevents dosing either (i) during plant shutdowns when dosing is not required, or (ii) when the sea water temperature is below 10 °C. If this is not possible then outages should be kept as short as is practicable, preferably less than 24 hours.

In recent years, both Dungeness B and Sizewell B have requested dispensations to allow outages for planned maintenance during the winter months to improve reliability in the summer. These have been supported with the caveats that the length of outage is minimised and reliability monitoring is used to demonstrate the benefit of these outages.

In consultation with CTO SQEP, between January 1st and March 31st each year, planned maintenance work on the Hypochlorination/Electrocholrination plant is permitted in a single outage of not more than 28 consecutive days. The outage period should be kept to the minimum practicable period and subsequent reliability of these systems should be monitored to demonstrate the effectiveness of such maintenance compared with plant performance.

4.1.6 Measurement Methods

The colorimetric method using DPD (N, N-diethyl-p-phenylene-diamine) is the default method to be used for all reference measurements. This method is the most widely accepted analytical procedure for the application and is convenient for rapid analysis of unstable samples, using portable equipment.

Details of the DPD method are given in Appendix I.

Where continuous monitoring is available using a Pi TRO Monitor, this method may be used in place of the DPD method for reference measurement for BEOM compliance only.

Details of the Pi TRO Monitor method are given in Appendix I.

4.1.7 Units of Measure

The density of seawater at the surface is typically in the region of 1.025 grams per litre. For compliance with this BEOM the units of measure of mg kg^{-1} and mg l^{-1} can be used interchangeably.

4.1.8 EA/SEPA Discharge Consents

Monitoring of the cooling water system is required in order to demonstrate compliance with the requirements of the site's effluent discharge Consents, abstraction licenses, and associated legislation. The responsibilities for these are set out in Ref.10.

The frequency of monitoring to confirm compliance with a Consent limit may be stipulated in a site specific Authorisation. This may have a requirement for a higher frequency of monitoring of discharged waters than that given as the minimum default requirement for operational control within this BEOM. However, it is recommended that the frequency of monitoring to demonstrate compliance with a discharge limit should not be any less than the minimum default operational frequency.

4.1.9 Technical Principles

The technical principles underpinning the guidance presented in this BEOM are presented in a series of Appendices that provide more detailed background information on CW system design (Appendix A), the nature of biofouling (Appendix B), managing the risks of biofouling (Appendix C), practical considerations for the application of a biofouling control strategy and current practices for individual stations (Appendices D – K) and the regulatory considerations (Appendix L).

4.1.10 Contingency Plans

Stations which, as a result of risk assessment, are exposed to high or moderate risk of bio-fouling should be able to maintain the applied dosing programme at all times and have contingency plans to restore the applied dosing programme within a defined time period if there was a major failure of the installed dosing system. An Engineering Advice Note, Reference 11 provides a first attempt at capturing the relevant information to allow contingency plans to be produced. Contingency plans should be reviewed periodically as required.

Mandatory Requirement 7

Contingency plans, detailing necessary actions and time scales, shall be available at all stations in the event of the loss of ability to dose or a significant change in the biofouling potential.

4.2 Procedure / Instructions

Not required

4.3 Compliance / Non-compliance

Control parameters specified in this BEOM shall be routinely monitored for compliance as per Mandatory Requirements 2 and 3.

5 DEFINITIONS

Action Level 1 (AL1)	Parameters in AL1 present a ‘chronic’ risk to the plant, i.e. prolonged operation in the action level is expected to result in component life reduction. A parameter enters AL1 when its value is outside the normal operating range. When a parameter is in AL1 appropriate corrective action shall be identified and implemented to restore the parameter to the normal operating range as soon as possible and within 3 days of entry to the action level. If, after a further two days the TRO concentration has not been returned to the normal operating range, the continued operation of the cooling system shall be the subject of a formal review using the Operational Decision Making (ODM) process (Ref. 12) or similar. The start of entry to the action level is defined as the time the sample was taken except when the cause is identified as marine microfouling where operational CW systems exhibit a sustained reduction in observed efficiency of main or other cooling water system over a period of 5 days. In this case the start of entry to the action level is defined as the point at which the reduction in efficiency was first observed.
Chlorination	The application of chlorine or a chlorine based oxidant to a water supply in order to control organic growth.

Chlorine/hypochlorite	The words "chlorine" and "hypochlorite" are used interchangeably in this document to describe the current practise of oxidant introduced to the cooling water by means of electrochlorination or dosing of sodium hypochlorite solution.
Consent	The permit granted by the regulator to an operator that allows the discharge of identified substances into controlled waters subject to defined conditions and limits. Unless given consent to do so, "a person shall be guilty of an offence if he causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste matter to enter controlled waters," such as coastal, ground or surface waters.
Control parameter	A parameter that has a demonstrated relationship to the ability of the turbine oil to lubricate, cool or protect plant and to material degradation, deterioration in plant performance or life reduction. Control parameters are therefore mandatory and have associated action levels
Controlled waters	These bodies of water specified for particular regulatory control under statutory environmental regulations: these include all surface waters (watercourses, lakes and reservoirs), all ground waters and all coastal/estuarine waters.
Daily	Weekdays only, excluding weekends and Bank Holidays
Decay	The degree to which a residual excess of a dosed oxidant is depleted by its passage through the CW system after the demand of the sea or estuarine water has been met measured in $mg.kg^{-1}$.
Demand	The degree to which sea or estuarine water will chemically absorb a dose of oxidant before a residual (excess) level of oxidant becomes measurable - normally measured in $mg.kg^{-1}$.
Effective toxicity	The toxic influence of the biocide on the target organisms involved in biofouling. In practice this depends upon a number of factors: the species concerned, the level of residual oxidant, the speed of flow of the cooling water over the fouled surface, the thickness of that fouled surface, and any upstream influence (such as another foul) which might have exerted further chemical demand.
Free Chlorine	Chlorine existing in water as hypochlorous acid or as the hypochlorite ion is termed free available chlorine
Low-level chlorination	Application of a residual at a level where the effective toxicity is deliberately set below a threshold that would cause an acute reaction in the target organisms. Instead of causing death in the short term this strategy reduces settlement, rates of growth and survival amongst the fouling organisms. Without the application of more sophisticated risk assessment strategies or instrumentation, it is considered a simple and cost-effective means of controlling fouling at direct cooled coastal power stations.
Macrofouling	The untoward development of visibly discrete organisms such as mussels, barnacles, anemones or 'whiteweed' in inlet tunnels, culverts, water boxes and heat exchangers.
Microfouling	The untoward development of a film of microbial organisms, clay minerals and other ionic substances on condenser tubes, heat exchangers and other exposed surfaces: the establishment of a microbial film on a surface is generally a necessary precursor to macrofouling.
Normal Operating Range (NOR)	The normal operating range is the range of values expected to be permissible for the operational life of the reactor. Station systems should be designed to keep the parameter within the normal operating range and as close to the target value as possible. The target value is within the normal operating range, but not necessarily in the middle of it.

Residual	The excess level of oxidant in any volume of sea or estuary water after its demand has been exerted on the dose applied - normally measured in $\mu g.kg^{-1}$. This is usually described as total residual oxidant.
Risk Level	Level of risk of fouling based on an objective, site-specific review. The level of risk is used to determine the most appropriate dosing regime.
Spat	The larvae of potentially fouling organisms such as barnacles and mussels. A significant settlement event, where many larvae are suddenly found to have settled over surfaces over a short period, is called a spatfall.
Target Value	The recommended or optimum single value at which the parameter should be maintained.
Total Residual Oxidant (TRO)	Following the dosing of oxidant, the total free and combined oxidant remaining in a specific water after an arbitrary time period as a result of the oxidant demand of the water.

6 REFERENCES

1.	BEG/SPEC/ENG/BEOM/006 Rev 002	The Control of Marine Fouling
2.	BEG/ICP/ENG/SH/001	Integrated Company Practice for Technical Governance
3.	BEG/SPEC/DAO/SH/002	Company Specification for Technical Governance Documentation Implementation and Compliance
4.	BEG/SPEC/DAO/SH/001	Company Specification for Technical Governance Document Production and Approval
5.	BEG/ICP/DM/003	Integrated Company Practice for Document Control
6.	E/EAN/BPKB/0113/GEN/09	BEOM006 Propensity for Fouling Risk Assessments
7.	E/EAN/BPKB/0218/GEN/14	The control of marine fouling - a three-yearly review of risk levels for AGR and PWR stations.
8.	E/PROC/ENG/BI/464	Central Engineering Support Function Branch Instruction - Implementing Chemistry BEOM/CTS Dispensations
9.	BEG/FORM/OPS/079	Dispensation Form for Chemistry BEOMs/CTS,
10.	BEG/SPEC/SHE/ENVI/006	Management of Abstractions from and Discharges to Controlled Waters and the Water Environment
11.	E/EAN/BPKB/0111/GEN/09	BEOM 6 Hypochlorite Dosing Strategy Contingency Plans
12.	BEG/SPEC/OPSV/CAP/007	Decision making process
13.	BEG/ICP/QUA/006	Integrated Company Practice for Records Management
14.	BEG/FORM/ENG/SH/002	Technical Governance Compliance Tracker
15.	BEG/SPEC/QUA/020	Company Specification for Management System Auditing

7 RECORDS

Cooling water data shall be retained as a station lifetime record in accordance with the requirements of Reference 13. Data will normally be recorded within the station chemistry database system, for example the Laboratory Information Management System (LIMS) that is in use at all stations for future reference and for trending purposes.

7.1 Compliance and Dispensation Records

Fully traceable records for compliances and dispensations must be kept to demonstrate that the requirements of this BEOM have been met. This is done using the Technical Governance Compliance Tracker (Ref. 14) or the Chemistry Dispensation form (Ref. 8).

The application of all mandatory requirements shall be audited in accordance with the specification for management system auditing (Ref. 15).

Cooling Water records associated with this document shall be controlled, stored and archived in accordance with the requirements of Reference 13.

Record title	Form No. / Identifier	Retention period	Record originator	Where records are retained

Table 1 **Glossary of Cooling Water Systems**

Station	Supporting System	Function, provides cooling to:
Dungeness B	Auxiliary CW System (ACW)	• Start-up boiler feed pump lub oil coolers • Turbine generator lub oil coolers • Condensate coolers • Generator transformer water coolers
	Essential Cooling Water (Seawater) (ECWS)	• Main and emergency boiler feed pumps • Essential diesel generators • Towns water cooling system • Membrane cooling system (Active Vessel Cooling system and Vessel Cooling system) • Boiler valve gland cooling system • Gas circulator lub oil and seal oil cooling • Cooling pond water coolers • Heating and ventilating chiller units • Vessel cooling deaerator vacuum pump coolers • Condenser vacuum maintaining plant cooler • Dump condenser • Man access cooler
Hartlepool	Auxiliary Cooling Water (ACW)	• Lub, Seal oil & Distilled Water coolers. • Air Extraction equipment • Sub-atmospheric Gland Steam Condenser units (SAGSC).
	Essential CW System (ECW)	• Reactor Ancillary Cooling Water (RACW) • Turbine House Ancillary Cooling Water (THACW) • Pressure Vessel Cooling Water System (PVCW) • Buffer Store CW system • Generator Transformers (was Main CW) • Decay Heat loop (DHL)
	Auxiliary Sea Water System	• Provides constant supply of CW to Gen transformer oil coolers • Also available to boost CW to THACW CW/226 and CW/225, THACW heat Exchangers. • Provides cooling to the Decay Heat System Heat Exchangers
Heysham 1	Essential CW System (ECW)	• Reactor Ancillary Cooling Water (RACW) • Turbine House Ancillary Cooling Water (THACW) • Pressure Vessel Cooling Water System (PVCW) • Additional Fuel Storage Facility (AFSF) • ECW can also supply the Generator Transformer Oil Coolers • Generator transformer oil coolers (no Tech. Spec. or nuclear safety significance)

Heysham 2	Auxiliary Cooling Water (ACW)	• General Services Water (GSW) coolers, • Turbine Lub. Oil Coolers, • Generator Seal Oil Coolers, • Generator Coolant Coolers, • Main Boiler Feed Pump Lubricating Oil Coolers.
	Reactor Sea Water (RSW)	• Reactor Auxiliary Cooling System (RACS) – Pressure Vessel Cooling System (PVCS) – Diagrid Support Skirt Cooling System (DSSCS) – Circulator Auxiliary Cooling System (CACS) – By-pass Gas Plant Cooling System (BPGPCS) • Pond Water Pre-Cooler
Hinkley Point B	Auxiliary CW System (ACW)	• Aux CW Seal oil coolers. • Generator transformer CW pumps • Distilled Water Coolers • Lub Oil Coolers • Sub Atmospheric Gland Steam Condenser • Reactor Man Access and Shutdown Heat Exchangers, • GSW Coolers and Strainers • Dump Condenser • VMU Intercondenser • Liquid Ring Pump Seal Water Coolers • Generator Transformer oil Coolers,
Hunterston B	Reactor Cooling Water (RCW)	• Reactor Ancillaries CW System (RACW) • Pressure Vessel CW System (PVCW) • Pond Secondary Cooling Heat Exchangers
	Auxiliary CW System (ACW)	• Generator Transformer oil Coolers, • GSW coolers (via. GSW strainers) • Decay Heat Dump Condenser, • DW/Man-Access Coolers • Unit Auxiliary cooling services
Torness	Auxiliary Cooling Water (ACW)	• Distilled water coolers • Lubricating oil coolers • Seal oil coolers (air side) • Seal oil coolers (gas side) • Booster air extraction pump cooler • Main air extraction pump cooler • General service water coolers • Starting/standby Boiler Feed Pump lubricating oil coolers • Starting/standby Boiler Feed Pump fluid coupling oil coolers • Indirectly cools all turbine equipment (H_2 coolers, stator water, FRF etc.)

Torness	Reactor Seawater System (RSW)	• Pressure Vessel Cooling System (PVCS) • Reactor Auxiliaries Cooling System (RACS) - DSSCS, BPGP • Circulator Auxiliaries Cooling System (CACS) • Pond water Cooling System • Generator Transformer Cooling System • Turbine house drains sump cooling
Sizewell B	Essential Services Water (ESW)	• Removes heat from the Component Cooling Water by taking water from and returning it to the sea via the Circulating Water System.

Table 2 Risk levels for individual stations

Station	Risk	Comments
Dungeness B	**High**	Risk exists all year round. The station has been subject to several fouling episodes (mussels) associated with an inconsistent chlorination regime.
Hartlepool	**High**	Sessile bivalves, particularly mussels, are increasingly being found in the Tees Estuary as water quality steadily recovers. The station has been susceptible to several fouling episodes (mussels) as a consequence of historical unreliability in the chlorination regime. Also potential for barnacle fouling.
Heysham 1	**High**	There are significant beds of sessile bivalves, particularly mussels, found in the vicinity. Over the last decade the reef building worm *Sabellaria* has become endemic locally - this species presents significant risk.
Heysham 2	**High**	There are significant beds of sessile bivalves, particularly mussels, found in the vicinity. Over the last decade the reef building worm *Sabellaria* has become endemic locally - this species presents significant risk.
Hinkley Point B	**Low**	There have been few incidences of macro-fouling or micro-fouling in more than a decade. During this period, there has not been any chlorine dosing to the CW system. The macrotidal conditions of the Severn Estuary are unfavourable to many potential fouling species as levels of turbidity are high, and suspended solid levels are relatively low in organic content and high in mineral content, effectively scouring surfaces subject to high flow rates. Annual ecological surveys of the Hinkley Point foreshore have provided evidence to support this understanding. Although *Sabellaria*, the reef-building worm, is endemic to this area operational experience has, unlike at Heysham, demonstrated that it does not constitute a significant fouling risk locally. The reason for this difference between sites is unknown - it may be a different species or water quality conditions may be the cause.
Hunterston B	**Moderate**	Epifaunal species which might cause biological fouling problems, such as barnacles, hydroids and *serpulid* worms are common locally and their larvae enter the CW system routinely. Sessile bivalves also present.
Sizewell B	**High**	Beds of sessile organisms have been found in the locality (evidence of mussels on the structures offshore). During the last outage a survey of the intake structure revealed a number of breaches in tboth the north and south dosing lines such that dosing had been limited for some significant period. Reefs of mussels in the poorly dosed intake culvert were clearly evident supporting the assessment of high risk.
Torness	**High**	Epifaunal species which might cause biological fouling problems, such as barnacles, hydroids and *serpulid* worms are common locally and their larvae enter the CW system routinely. Control of fouling has been maintained sufficiently to avoid significant fouling or secondary siltation. Sessile bivalves also present.

Table 3 Dosing Regimes

Risk level	Dosing Regime	Definition	Return to default dosing regime
High	Default	To maintain a continuous, year-round dose of 200 $\mu g kg^{-1}$ Total Residual Oxidant (TRO) at the condenser inlet or outlet and at the discharge from an auxiliary circuit(s)	
Moderate	Seasonal	To maintain the default regime from when the CW intake temperature rises for the first time above 10°C until it falls continuously below 10°C. Station shall maintain both the surveillance and the means to apply the default regime at all times	Fouling observed on settlement monitors or at inspection and/or consistent downward trend in coolant water system efficiency over a period of five days
Low	No chlorination	No chlorination programme required, but Station shall maintain continuous surveillance to detect uncontrolled fouling	Successful spatfall observed on settlement monitors or at inspection and/or consistent downward trend in coolant water system efficiency over a period of five days

Table 4 Chemical Control of the Main, Emergency and Auxiliary Cooling Water Systems

Parameter	Units	Monitoring Frequency	Target	Normal Operating Range [1] [2]	AL1	Comments
TRO	**$\mu g.kg^{-1}$**	**Daily**	**200**	**150-300**	**<150**	**Contingency plans, detailing necessary actions and time scales, shall be available at all stations in the event of the loss of ability to dose or a significant change in the biofouling potential**

Note

1 The recommended Normal Operating Range's (NOR) maximum concentration needs to be consistent with individual sites' Authorised environmental discharge limits for TRO. For some sites the recommended NOR may need to be constrained to 150-250 $\mu g.kg^{-1}$

2 Regular operation above the recommended target value has a commercial penalty due to increased power or reagent consumption

3 It is noted that the discharge authorisations for Hunterston B and Torness are based on Total Residual Chlorine and these values are also used for compliance with this BEOM.

Table 5 Strategies for shutdowns

The advice below constitutes best practice.

Conditions		**Response**
Shutdown Period	**CW Flow Condition**	
Any period	Flow maintained	Continue chlorination specified by the normal operational dosing regime.
Planned < 14 days	Flow stopped	No dosing possible. Leave system flooded and boxed
Planned > 14 days	Flow stopped	No dosing possible. Isolate and drain down all sections

APPENDIX A: THE PRINCIPLE OF CW SYSTEM DESIGN AND SAFETY CASE IMPLICATIONS

A1 Main Cooling Water (MCW) system design

The Main Cooling Water system (MCW) (Circulating Water system at Sizewell B) provides a continuous supply of sea water to the main condensers the purpose of which is to condense low pressure (LP) feed steam and in so doing maintain a vacuum and optimum condensate temperatures. This system also provides water to the dump condenser for those stations with them, and other cooling water systems either directly or indirectly. These ‘other’ systems are termed differently at different stations and a glossary of terms and the plant which they support is included in Table A1.

Sea water is taken from source via an inlet culvert (Figure A1) and forebay (Figure A2) incorporating coarse screens (see Figure A1 insert) and drum screen chambers with drum screens (Figure A3) which are used to remove large marine debris including fish etc. The main CW pumps maintain the flow and CW supplies to the main turbine condensers and turbine auxiliaries. Water is discharged into a surge chamber before returning to sea.

Figure A1 (Right) A view of the Heysham 2 inlet culvert

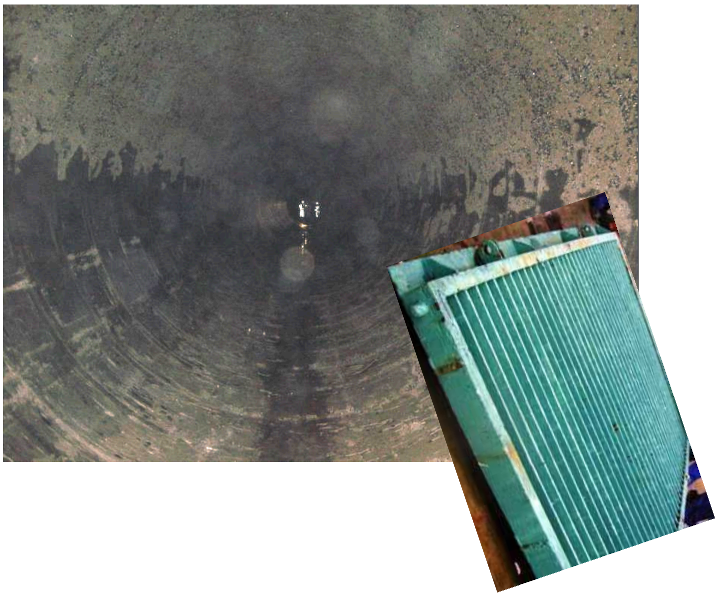


Figure A2 A view of the forebay and a course screen (inset)

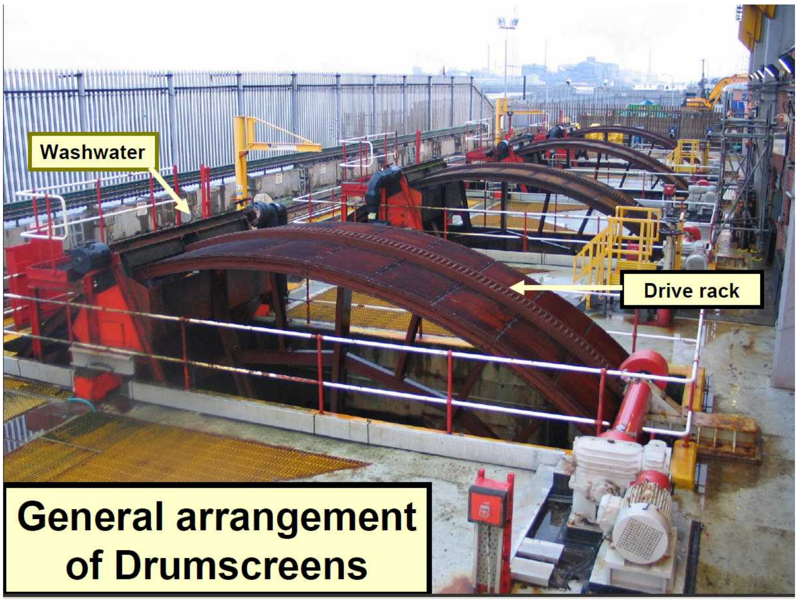


Figure A3 A view of the uppermost part of the drum screens

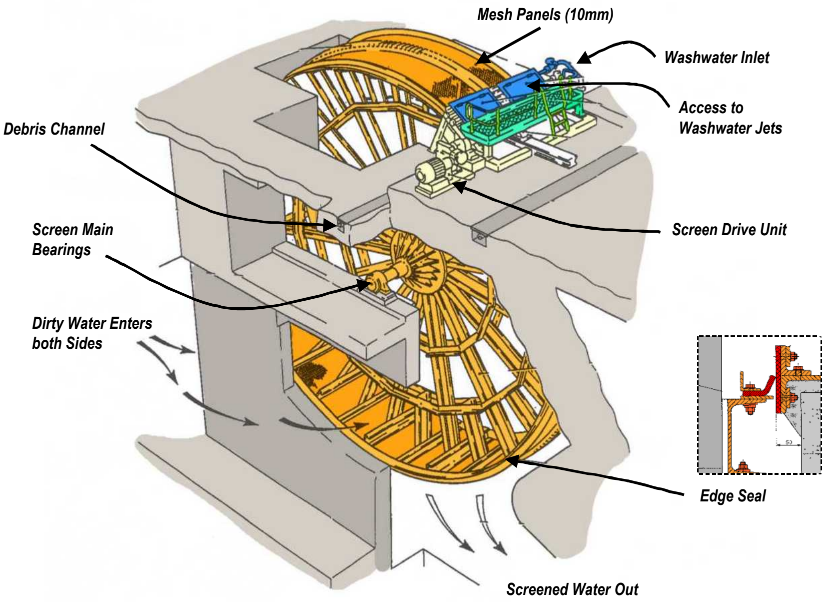


Figure A4 Diagram showing the water flow and functional elements of a drum screen (Sizewell B)

The drum screens (Figures A3 and A4) are cleaned of debris such as seaweed by wash water. As the drum rotates debris is caught on the inside of the mesh and carried upwards on the trash catchers. Wash water jets spray water through the mesh from outside to inside. The debris either falls off or is washed off by the sprays which are positioned across the width of the screen. The debris is collected in trash hoppers and washed down gulleys into trash baskets or returned to sea.

All CW water returns via a surge chamber and exits to the sea. The surge chambers have two functions: to maintain water in the discharge pipework at low tide and, if a MCW pump trips, prevents damage to outlet water boxes.

At some stations dump condensers are employed the purpose of which is to remove fission product decay heat from the reactor in the event of a reactor trip with a simultaneous loss of the main condenser. It is also part of the suction integrity route. The dump condenser can also be used during reactor start up before steam is admitted to the turbine, and could facilitate rapid cooling of the reactor for man entry purposes.

A3 Safety Case requirements

The specific safety case requirements for each station are summarised in Table A1.

A3.1 AGR Safety Case requirements

The main CW system and turbine auxiliary cooling systems typically have no direct nuclear safety significance. The design basis for these systems is for reliable economic operation whilst maintaining safety to personnel and plant, for the lifetime of the station. For this purpose therefore a degree of diversity, redundancy and segregation criteria is employed. However, on some stations CW pump availability requirements are specified in Tech Specs for off-load refuelling in order to provide a cooling water supply to the dump condensers.

The reactor plant auxiliary cooling systems interface directly with plant used for post-trip cooling and pressure vessel cooling. Tech Specs give availability requirements for these systems and any back-up systems fitted.

A loss of CW, caused by blockage of the main drum screens for example, is a classic common mode failure causing severe problems and a potential Site Incident if reactor auxiliary cooling flow is not restored (Ref. A4.1).

A3.1 PWR Safety Case requirements

Although the screens are not considered as safety classified equipment, they do support safety classified equipment, the Essential Service Water (ESW) pumps. During loss of on site power they are designed to continue to screen the seawater whilst in a stationary mode. However, if the CW drum screens become completely blocked or the ESW temperature drops below the normal design operating temperature (below 3°C) then the Reserve Ultimate Heat Sink (RUHS) system can be placed in service. This would allow the ESW pumps to be taken out of service, thus all of the screening plant could be shut down. (Note all other pumps would be shut down and the station would not be generating).

The flow of water through the condensers is important to ensure a reliable means of condensing the steam into water is maintained so that there is a feed supply to the Steam Generators to act as a means of cooling the reactor before RHR is put in service.

Threats to loss of ESW are:

- Extreme tides - High = Flood, Low = loss of flow
- Degradation by Silt
- Seaweed blockages on course/drum screens
- Large shoals of fish/jellyfish

Apart from Tech Spec 3.7.8 for Essential Service Water System which is loosely related to the Circulating Water System, there are no Tech Specs applicable to this system (Ref. A4.2).

Table A1 **Station by station cooling water systems relationship to Safety Cases**

Station(s)	System	Function	Safety Case role	Source
Dungeness B	Main Cooling Water (MCW)	Cools turbine generator main condensers	MCW is a commercial system with **no** nuclear safety duty	Living Safety Case Document 3.16.4
	Auxiliary Cooling Water (ACW)	Cools turbine generator auxiliaries and other items of non-essential plant	Only nuclear safety duty of ACW is to provide cooling for the start-up boiler feed pump lube oil coolers	Living Safety Case Document 3.16.4
	Essential Cooling Water (ECW)	Provides cooling to essential items of plant and maintains supply post-trip. Also provides ultimate heat sink for fuel route cooling. Cools main and emergency boiler feed pumps; essential diesel generators; towns water cooling system; membrane cooling system; boiler valve gland cooling system; gas circulator lube and seal oil cooling; dump condenser; main access condenser	ECW must provide cooling to all the essential systems its serves at power and post-trip	Living Safety Case Document 3.16.1
Hinkley Point B Hunterston B	Main Circulating Water (MCW)	Cools main condensers	Design intent is to operate continuously during normal power operation and following a trip to provide cooling for main condensers, dump condensers and other turbine auxiliaries	Hinkley Point B: Living Safety Case Document; System Based View 3.16.05 Hunterston B: Visible Safety Case Document; System Based View 3.16.06
	Auxiliary Circulating Water (ACW)	Supplies sea water cooling to generator transformer oil coolers; seal oil coolers; condenser air extraction vacuum maintaining units; dump condenser; distilled water coolers; sub-atmospheric gland steam condenser; turbine lube oil coolers; general service water coolers; reactor shutdown and man access coolers	Design intent is to operate continuously during normal power operation and following a trip to provide cooling for dump condensers and other turbine auxiliaries	Hinkley Point B: Living Safety Case Document; System Based View 3.16.05 Hunterston B: Visible Safety Case Document; System Based View 3.16.06
	Reactor Circulating Water (RCW)	Provides sea water heat sink to the Pressure Vessel Cooling Water (cools PCPV) and Reactor Auxiliaries Cooling Water (cools gas circulators) systems at power and post-trip	Design intent is to provide sufficient flow to adequately cool the RACW, PVCW and pond cooling secondary circuit systems at power and post-trip.	Hinkley Point B: Living Safety Case Document; System Based View 3.16.01 Hunterston B: Visible Safety Case Document; System Based View 3.16.01, 3.16.03

Station(s)	System	Function	Safety Case role	Source
Hartlepool Heysham 1	MCW	Cools turbine generator main condensers	No defined Safety Function	HRA/SCRM/4.16, HYA/LSD/3.16.06
	ASW	Cools turbine hall plant	No defined Safety Function	HYA/LSD/3.16.07
	ECW	Cools RACW, THACW, PVCW and AFSF	Provides cooling water to Safety Related Systems (RACW, THACW & PVCW) – maintains supply post trip to ensure nuclear safety.	HRA/SCRM/4.16, HYA/LSD/3.16.01
Heysham 2 Torness	MCW	Cools turbine generator main condensers	Limited safety significance – viable source of water and discharge route for RSW system	Heysham 2 – C33SDD/108 A2.3 Torness – C34/SDD/108 PSR2 topic review HYB/PSR2/MR/R3.16
	ACW	Cools turbine auxiliaries via coolers. (General Services Water (GSW) coolers, Turbine Lub. Oil Coolers, Generator Seal Oil Coolers, Generator Coolant Coolers, Main Boiler Feed Pump Lubricating Oil Coolers).	No specific duty identified in SSR	Heysham 2 – C33SDD/108 A2.3
	RSW	Cooling the PVCS, CACS, reactor auxiliaries cooling system (DSSCS and BGPCS).	Cooling the PVCS, CACS, reactor auxiliaries cooling system (DSSCS and BGPCS). Post-trip heat sink for CACS	Heysham 2 – C33SDD/108 B2.6 Torness – C34/SDD/108
Sizewell B	Circulating Water System (CWS, DA)	Provides cooling water to main condensers, the ESWS and the ACWS	No claims made on the continued operation of CWS following faults in the safety case. No primary safety role but ability to provide sea water to ESWS is important to its functioning	Safety Case Users Guide (SXB-IP-786041)
	Auxiliary Circulating Water System (ACWS, EA)	Provides cooling water to process auxiliaries in the turbine hall and mechanical annexe (via General Services Water System (EB))	Does not have a safety role but ability to provide cooling to components associated with the condensate system and main feedwater pumps post-trip is desirable but not essential.	Safety Case Users Guide (SXB-IP-786044)
	Essential Circulating Water System (ESWS, EF)	Provides normal route for heat rejection for the Component Cooling Water System heat loads during normal plant operation and following some faults	Provides route for heat rejection for the Component Cooling Water System heat loads following some faults	Safety Case Users Guide (SXB-IP-786048)

A4 References

A4.1 BEG/TRNG/SN/101/0030/08, Barnwood Ops Generic Fundamentals Training - Plant Systems Overview - CW Systems - Student notes.

A4.2 SZB/TRNG/SWB/100/1001V, Plant Systems Training - Main Circulating Water System

APPENDIX B: THE NATURE OF BIOLOGICAL FOULING

This Appendix provides further information on the technical background to micro- and macro-marine fouling.

B1 Introduction

EDF Energy Generation nuclear generating stations in the UK are sited on open coastal or estuarine coasts and rely on sea or estuary water for the primary cooling of plant components. Seawater contains numerous living organisms which, upon being entrained in the cooling circuits, may settle in hospitable areas and grow. This infestation is known as biological fouling or biofouling.

B2 Fouling organisms

There is a range of fouling organisms that affect EDF Energy Generation's coastal stations. This range is getting larger due to improving water quality, increasing average sea temperatures and the arrival of “exotics” through shipping. An excellent source of further information on fouling organisms is the Marine Life Information Network for Britain and Ireland website, www.marlin.ac.uk.

B2.1 Mussels

Mussels are the most common fouling species experienced by EDF Energy Generation sites. Mussel fouls tend to be in the form of large mats of mussels joined together by fibrous material and containing large quantities of silt. Unfortunately, mussel excrement is sticky which tends to bind the silt together.

Figure B1 - A view of a mussel population in their natural habitat

B2.1.1 Species

There are three main species seen: the blue (*Mytilus edulis*), the horse (*Modiolus modiolus*) and the Mediterranean (*Mytilus galloprovincialis*). Of these, the blue mussel is the most common.

B2.1.2 Feeding, growth and reproduction

Mussels grow by depositing calcareous material onto the free edge of the shell from the mantle. The mantle is the thin layer of tissue that lines the inside of the shells and they can grow very rapidly given the right conditions; up 2 or 3 cm over a summer if the food supply is good and the sea temperature is warm, certainly growing large enough to block small bore tubing.

Mussels feed by filtering water, picking out the organic nutrients. To do this, they need to have their shells partially open. As a result they are susceptible to toxins present in the water.

Reproduction is very temperature dependent, taking place by fertilisation of eggs suspended in the water, generally from April to June with sometimes a second period in September. If the water temperature is below 10 °C, the growth rate is very low but you can get mussels at any time of the year.

B2.1.3 Lifecycle

After fertilisation, the eggs develop into free-swimming larvae called veligers. Depending on water temperature and food, in 2 to 4 weeks the larvae develop into the final larval stage, the pediveliger. These sink to the bottom and start crawling, looking for a substrate to settle on. The walls of a CW system are an ideal such substrate. At this settlement stage, they are called spat. Spatfall is where very small mussels arrive in the CW system, attach themselves to substrates and start to grow. Once attached, they stay there for the remainder of their lifespan.

B2.1.4 Mussels and CW systems

A power station CW system is an ideal home for mussels. There is a good substrate for them to attach to. It is nice and warm and there is plenty of food. Given the flow rates in CW systems, there is an abundance of food passing them by. In addition, the main predators can't get at the mussels. Overall, a CW system is as close as it gets to heaven for mussels.

However, flow is a factor and mussels won't settle if the velocity of the water is greater than about 3 m s^{-1}. That is why there tends to be more fouling in lower flow areas of the system.

There is a common misconception that if there are mussel beds directly outside of the CW intake at a power station, this will pose a threat to the CW system. This is not the case. It takes several weeks from fertilisation to settlement so the mussels that affect a system will have come from perhaps 50 or 100 km away.

B2.2 Barnacles

Barnacles are related, distantly, to crabs and lobster. The most common species found in CW circuits is *Balanus crenatus*. Barnacles grow to 10-25 mm across and 25-30 mm high. They are fixed head down onto firm substrates, like the walls of a CW system. They feed by means of their legs, which extend outside of the shell to rhythmically beat creating a current of water flowing through them allowing planktonic particles to be filtered out as food.

Barnacles are hermaphrodite, having both male and female sex organs. Fertilisation is internal, producing eggs that give rise to free swimming shrimp-like larvae, the nauplius. These develop into bivalved cypris larvae, and it is these that settle and develop into the adult barnacle. Larvae can be released at any time of the year with the maximum between March and May.

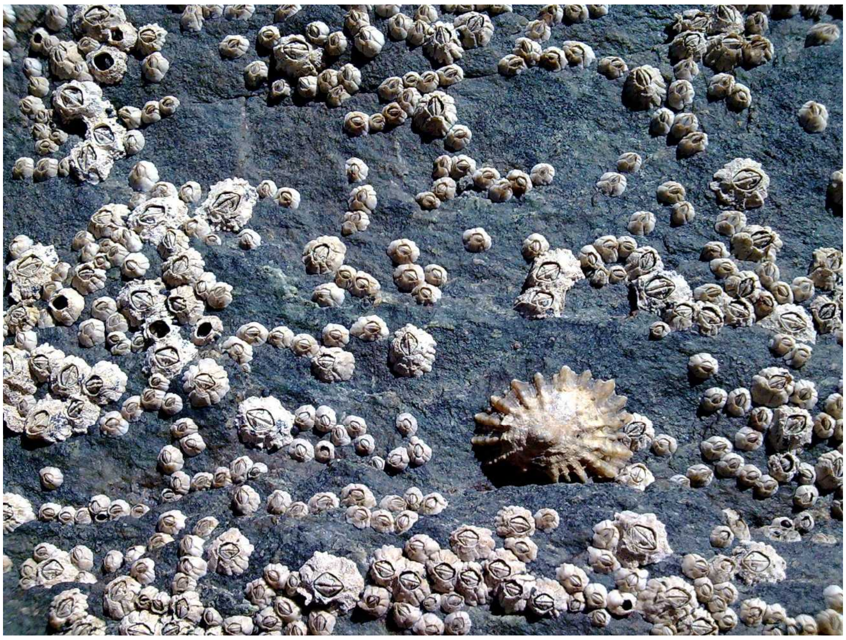


Figure B2 - A view of a Barnacle population in their natural habitat

B2.3 Worms

Reef worms are also known as *Sabellaria*. They form large aggregations which are like concrete. They are particularly prevalent in Morecambe Bay where they form large reefs. Species include the Ross worm (*Sabellaria spinulosa*) and the honeycomb worm (*Sabellaria alveolata*).

Tube worms, such as *Serpula vermicularis* are also found in CW systems, forming calcerous tubes 5 to 7 cm long.

Figure B3 - A view of a *Sabellaria* population in their natural habitat

B2.4 Hydroids

These are also known as ‘white weed’. They belong to the same part of the animal kingdom as coral, jellyfish and sea anemones.

Figure B4 - A view of hydroids also known as 'whte weed'

B2.5 Sea Squirts

Sea squirts are sessile macro fouling organisms from a class known as ascidians that can either be solitary or live in colonial assemblages (depending on the location/species). Like mussels they are filter feeders. There are a number of species found around the UK. Little is known regarding their reproductive life cycle (also varying with the species). What is known is that they are hermaphrodites with a suspended larval stage that can travel up to 10km away (the precise seasonal timing is not well documented). It is possible that they could grow in power station CW systems (on the same basis as mussels), however unlike mussels and other biofouling organisms there is a lack of evidence that they present a significant risk.

Specifically, in respect of the vicinity of Sizewell B, the sub-tidal & inter-tidal habitat is such that marine surveys (New Nuclear Build (NNB)) have not identified any local ascidian populations that could potentially 'seed' Sizewell B's CW system locally. Whilst it is possible that there may be some found in harbour/port areas and on the hulls of ships (and possibly on the intake/outfall structures), the likelihood of large colonies suddenly growing in Sizewell B's CW system is considered to be relatively limited.

In terms of fouling control there is a suggestion that toxic paints/coatings may have had some success. It is also likely that, as with mussels, chlorine dosing is effective at controlling the settlement and growth of these creatures. However, there is very little in the way of scientific research and operational experience (OpEx) in support of this hypothesis. This may be because sea squirts are not known to cause major issues historically for UK power stations and therefore extensive research on their bio-fouling control has not been warranted.

B3 Forms of biological fouling

Fouling of power station plant may take two different forms, a largely arbitrary classification depending upon the types of organism involved.

Macrofouling - growth of visibly discrete organisms such as mussels or barnacles, typically in inlet tunnels and culverts, and:

Microfouling - growth of films of bacteria or fungi and their waste products on condenser tubes, heat exchangers and other exposed surfaces: the establishment of such a 'microbial film' on a surface is known to be a necessary precursor to macrofouling.

These have different properties but the only real difference between the two categories is that macrofouling organisms are larger, and may as a consequence provide secondary problems of physical blockage if they are detached from their initial points of settlement. In general, microfouling organisms are film forming and microbial, either bacteria or fungi. They are described in more detail in the following sections of this appendix and in References B1, B2, B3 and B4.

B3.1 Macrofouling

Macrofouling organisms often colonise man-made surfaces, such as those of cooling water systems, piers and ships' hulls. Details of the most common fouling organisms are given in Section B2. As highlighted, one of the most troublesome of these organisms in United Kingdom waters is the common blue or edible mussel, *Mytilus edulis*. Although mussels are a notorious example of a fouling species, there are many others, such as a variety of barnacle species, tube-building worms, and hydroids ('white-weed'). Each has its own characteristics in terms of settlement behaviour and the effects and the occurrence of each species varies with site, season and from year to year. Such organisms may readily settle within power station cooling water intake tunnels and culverts, the screen forebays and rotary screens, condenser tube plates and, occasionally, the discharge tunnels.

B3.1.1 Settlement

Organisms such as mussels settle on available surfaces as planktonic larvae (Ref. B2). Larvae have the ability to survive for a considerable length of time in the plankton before settling, which renders the timing of such settlement within cooling water systems largely unpredictable. Early larvae settle on the first suitable surfaces with which they come into contact, preferring roughened or fractal surfaces, such as filamentous algae, hydroids and other already-settled animals and plants. In contrast, progressively older and larger larvae, the result of failure to find suitable sites, will be less discriminating in their choice of substrates: the same may apply to secondary settlement after disturbance. Once one larva has settled successfully, it tends to improve the immediately adjacent hydrodynamic conditions for others to follow.

Ingress and settlement of late stage planktonic larvae may occur at any time of the year (Ref. B4). It is impractical to stop these entering culverts from offshore intakes since they are generally much less than 3 mm long and cannot be retained even by well-maintained fine-mesh screens. Once settled, exposure to chemical toxins in the water will not cause them to migrate. There is evidence to suggest that these toxins will reduce settlement success. Recently settled larvae may also be very much more sensitive to toxic stresses than older organisms. One of the reasons why mussels are so successful in colonising cooling water systems is that older organisms may protect themselves from exposure by, for instance, closing their shells. Equally, an established foul will entrain silt and the build up of organic matter may itself exert a demand on chlorine residuals locally, protecting organisms living within that foul.

B3.1.2 Growth

The majority of macrofouling organisms which may become established within power station cooling water systems are filter-feeding animals, depending for their nutrition on suspended particulate organic matter. These cooling water systems thus provide ideal circumstances for growth, compounded by the fact that it is very much more difficult for predators to become established. As both their food supply and their metabolic rates are temperature dependent and food is in relatively short supply when United Kingdom coastal waters are below 10 °C, the greater rate of growth occurs in the late spring, summer and autumn. In general, the likelihood of year-round growth increases towards the south where this arbitrary 10 °C threshold has less meaning.

In the warmer season, when food supply is not limiting, mussels are capable of very high growth rates. The highest rates have been recorded for mussels living under mariculture conditions, and in power station culverts. Following spring settlement, mussels can easily grow sufficiently large during the first year of life to be capable of lodging in a 22 mm diameter condenser tube. Mussel growth monitoring work reported by Jenner, Whitehouse, Taylor and Khalanski (Ref B3) quotes examples of rapid shell growth of 10mm in 30 days. Exposure to chemical toxins in the water causes stress, reducing growth.

The strategy adopted by EDF Energy Nuclear Generation Ltd. for the control of macrofouling is intended both to discourage initial settlement and to retard growth.

B3.2 Microfouling

The process of biofilm formation involves several steps (Ref. B1). Surfaces placed in the sea are immediately coated with a film consisting of proteins, polypeptides, polysaccharides and lipids derived from the degradation products of marine organisms. Bacteria common to coastal waters settle on the film and within six hours will have consolidated their presence, as polymeric fibrils are exuded from them within the film.

Within seven days at temperatures of 10 to 20 °C, a layer of bacteria some 50-100 μm thick or more develops on the surface. Waste products from these micro-organisms contribute to the film itself. After fourteen days the slime film will reach its maximum thickness, which rarely exceeds a few hundred μm even in nutrient-rich waters. The biofilm so formed can act as an anchor for any silt or mud in the water and such deposits further impair heat transfer. The existence of a biofilm is often a necessary precursor for the settlement of other organisms. A microfouling control strategy will thus partially assist in macrofouling control.

Whereas the settlement within cooling water circuits of mussel larvae is more common during the spring and summer, microfouling of untreated warm condenser tube surfaces will occur all year round. Titanium condenser tubes are much more prone to acquire slime films than those made from copper-based alloys, the ready dissolution of the metals involved being toxic to the micro-organisms involved.

B4 References

B1 Jenner H A, Whitehouse J W, Taylor C L, Khalanski M, 1998, Cooling water management in European power stations: biology and control of fouling. A manual, Hyrdoecologie Appliquee, Tome 10, Volume 1-2.

B2 Whitehouse J W, Khalanski M, Saroglia M G and Jenner H A, 1985. The control of biofouling in marine and estuarine power stations. Collaborative (CEGB, EDF, ENEL, NV KEMA) Research Working Group Report published by CEGB North West Region. NW/R 191 9 85.

B3 Jenner H A, Review of marine fouling control at the coastal stations of British Energy and Magnox Generation, Report for BE 50351849-KPS/MEC 04-7016, 2003.

B4 Lewis B G, 1985. Confidential addendum to 'Mussel control and chlorination'. Comments with reference to GOM 82. CEGB CERL Report TPRD/L/BY/065/M85.

APPENDIX C: OPERATING EXPERIENCE AND THE CONSEQUENCES OF MARINE FOULING

This Appendix describes consequences of marine fouling and illustrates these with some real plant examples. It is not intended to be a comprehensive review of the issue but rather to provide some real examples from plant to illustrate issues raised elsewhere within this document.

C1 The consequences of marine fouling

There is a risk associated with marine fouling but it is often difficult to quantify this due to the uncertainties associated with fouling. This means that there may be periods where a station operates at risk due to a lack of effective dosing where there are no obvious consequences. This does not mean that it is acceptable to not comply with the requirements of this CTS.

The consequences of fouling can be categorised as:

- Reactor trip.
- Compromise of safety case.
- Loss of efficiency/generation.
- Increased cleaning burden.
- Corrosion.

C1.1 Reactor trip

C1.1.1 Hunterston B R3 1996

In July 1996, Hunterston B R3 tripped on chloride ingress protection (Ref. C1). This was caused in part by fouling problems in the CW system. Following a period without any dosing, hypochlorite from road tankers was introduced into the system. While, this helped to control further mussel growth, significant amounts of mussel debris were released. Blockages were occurring in the RCW and auxiliary strainers and these were opened up and cleaned 7 times in the 24 hours before the trip. The RCW system was also being back-flushed with sea water on a regular basis. The dirty drain pumping system was unable to cope with such large quantities of sea water and consequently sea water entered the clean drain tank via the overflow pipe. This was then pumped into the main condensate system causing the chloride ingress protection to trip the reactor.

C1.1.2 Heysham 2 R8 2009

On the 15th January 2009, at 10:45hrs, Heysham 2 Unit 8 was tripped manually due to rising Main Turbine Lub Oil temperatures attributed to inadequate cooling on 8A and 8C Main Lub Oil Coolers (Ref. C2). This was due to severe blockage of the ACW System causing a higher than normal differential pressure across the baffle plate. Preliminary investigations revealed that the Main Boiler Feed Pump Strainers were choked on the Auxiliary Cooling Water side. Following a clean of 8A top water-box a more detailed inspection revealed that both joints had been blown out and slight deflection had occurred in the division plate. Only superficial damage (cracking in the gel coat) resulted, and the division plate had sprung back to near its original position, but the volume of marine waste (mussels and silt) found on the inlet side was worse than ever seen before. 8C was also inspected and the findings very similar to 8A. This explained the higher than normal flows and bypassing that Efficiency had measured in the days running up to the trip. The reactor was shut down for 9 days for cleaning. Figure C1 shows blockages to the oil cooler and other pipework, illustrating the extent of cleaning required.

Wash-water pipe-work mussels infestation 75% flow path lost. Discharge pipe leg from pumps to strainer pit to be cleaned.

Only three out of circa 400 cooling tubes visible due to marine fouling.

Figure C1 – Photographs showing the infestation of pipework and a cooler tubeplate

C1.2 Compromise of the safety case

Ultimately, the degradation of plant systems by marine fouling organisms either by heat transfer impairment or by erosion/corrosion mechanisms could lead to nuclear safety cases being compromised for those plant areas which carry a nuclear safety related function. Appendix A, Table A1 provides an overview of such plant areas. It is essential, therefore that station remain in control of their marine fouling potential through the careful management of their dosing requirements and actively monitoring plant systems for early signs of emerging problems.

C1.3 Loss of condenser efficiency/ reduced generation

The fouling of the waterside of condenser tubes with biofilms can result in impairment of heat transfer with associated loss of condenser vacuum of between 1 and 4 mbar. Each mbar loss represents a significant increase in annual generating costs. Siemens Kraftwerk Union (KWU) calculated that the formation of a 26 µm thick biofilm in a heat exchanger of a 740 MWe plant results in a loss of 2 MWe. For a 1300 MWe plant, this loss amounts to 5 MWe (Ref. C3). In addition, it may be necessary to reduce load to back-flush condensers.

There has been a number of events over the years, below are some examples:

- HAR 2004: 40% load reduction on TG2 to clean the inlet endplates of the main condenser (Ref. C4). The debris removed consisted of a combination of mussels and Taprogge balls.
- DNB 2004: backwashing condenser passes due to mussel deposition on the inlet face of the cooling tube nests (Ref. C5).
- DNB R21 2005: backwashing CW passes due to debris /silt blocking the condenser tubes; drain line constantly blocking up with mussels meaning that backwashing of a pass became a three man job (Ref. C6).
- HYA 2007: reduced load on three occasions due to fouling of the condensers (Ref. C7).
- 2007 HYB R7: 100 MWe load drop twice a day to backflush fouled condenser (Ref. C8).
- HYB R8 2008: 60 MWe load drop for 4 hours to backflush fouled condenser (Ref. C9).
- HYB R8 2008: 60 MWe load drop for 2 hours to backflush fouled condenser (Ref. C10).

- HYA R1 2010: condenser fouling eroding temperature pick-up margin leading to the need to reduce boiler feed flow from 102.5% to 98.5% on three occasions to increase margin (Ref. C11)
- HYA 2013: having to reduced boiler feed flow to manage temperature pick--ip margins due to condenser fouling (Ref. C12).

C1.4 Increased cleaning burden

The overall philosophy for managing marine fouling is screen, clean and dose. Cleaning to remove marine fouling is an inevitable consequence of operating in a sea water environment. However, the consequences of poor control are an increase in both the frequency and the extent of cleaning. This is illustrated in the following sub-sections.

C1.4.1 Colonisation of pipework and culverts

In cooling water piping, the settlement of macro-organisms leads to a substantial decrease in pipe diameter, resulting in higher pumping costs and eventually forced plant outages to enable removal.

In the early 2000s, Dungeness B lost dosing to their intake culvert and a foul became established. This caused problems with CW flows. Once dosing was restored and the foul began to die off, the station experienced an extended period (1 to 2 years) where large agglomerations of silt/mussels (football size) impinged on the drum screens and there were large amounts of silt/mussel shell debris in waterboxes etc. There were also issues associated with silt production which are discussed in section 1.4.3 below.

In 2005, extensive blockages were found in some sections of the Heysham 2 R7 ACW culverts within the turbine hall (Ref. C13). The section between the GSW inlet and the main boiler feed pump was blocked to approximately 90% with hard packed silt and sand (up to 30m in length). Another section was partially blocked to approximately 50% with mussel growth. Very slow progress was made with cleaning of the silt and sand blockages.

In 2007, Heysham 2 experienced fouling of the ECW system by sabellaria (Ref. C14). The diameter of the 24 inch pipe was reduced on average by 2 inches with some regions up to 4 inches.

C1.4.2 Blockage of other coolers

The colonisation of coolers by macroscopic organisms can restrict cooling water flows resulting in reduced plant thermal efficiency and an increased cleaning burden. Some examples are given below:

- HYA 2006: THACW heat exchangers flows were reduced significantly due to marine fouling (Ref. C15). When heat exchangers were backflushed, large quantities of mussels were removed.
- HYA 2006: Generator transformer oil coolers blocked by mussels (Ref. C16), caused by mussels in the ECW system fouling tubeplates.
- HYA 2006: Fouling of heat exchangers in the RACW and PVCW systems (Ref. C17). In this case the fouling was a mixture of small and large mussels and large quantities of silt; cleaning was required when flow rates fell below target.
- HNB TG7 2008: Large amounts of marine debris were found in the generator transformer oil coolers (Ref. C18).The debris on the bottom water box cover was so thick that the drain valve had to be removed and a rod used to create a path to drain the coolers.The marine debris consisted mostly of silt and mussel shells; the size of the shells indicated that mussels had been growing in the coolers. There were also barnacles growing inside the water boxes.
- HYB TG7 2008: additional burden of repeated cleaning (two or three times a week) of TG7 main air pump seal water coolers (Ref.C19).
- HYA 2012: repeated cleaning of generator transformer oil coolers due to marine fouling (Ref. C20).

C1.4.3 Silt accumulation

Mussel excrement is sticky. The appearance of more silt may be a consequence of accumulations of mussels. The Dungeness B intake foul (see Section 1.4.1) led to:

- Greatly increased silt burdens in the fore bay region entailing major digging out exercises (e.g. 225 m^3 of silt/mussels removed from fore bay in 2002).
- Blocking of some of the diffusers at the end of the intake culvert.
- Greatly increased silt burdens in the drum screen chambers with football-sized lumps of mud and mussel shells being found at the drum screens.

During work to replace the 3/CW/51 valve at Heysham 1 in 2004, in preparation for ECW suction pipework replacement, it was noted that there was a high volume of silt/sludge within the 30" pipework. This effectively reduced the nominal bore of the pipe by over 75% (Ref. C21).

At Heysham 2 in 2009, turbine lube and seal oil cooler ACW supply header repeatedly blocked up with a significant amount of marine debris which was cleaned each outage (Ref. C22), Figure C2.

Figure C2 - A view of silt/sludge accumulation within pipework

C1.5 Corrosion

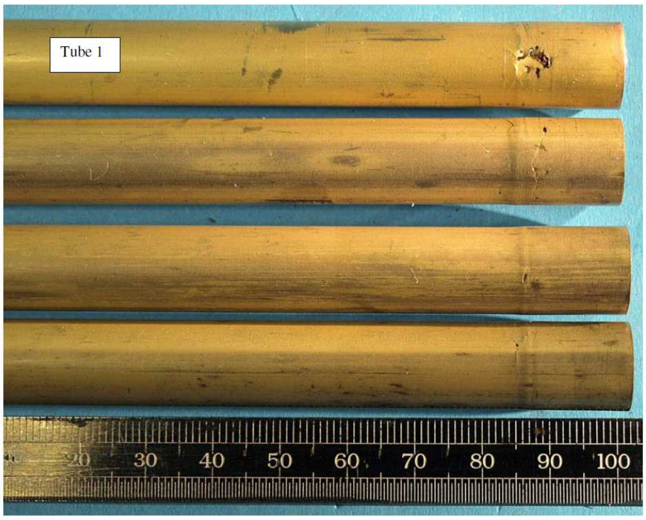
C1.5.1 Microbially induced corrosion

The deposition of micro-organisms on metallic surfaces can also lead to localised microbial influenced corrosion (MIC) of metal surfaces beneath the slime, which can result in pitting or perforation of condenser tubes, or damage to cooling system equipment. Condenser tube leaks and subsequent cooling water ingress into high purity steam/water cycles can present a serious risk (Refs. C23, C24, C25).

The wholesale detachment of established mussels, barnacles, hydroids and other fouling organisms can blanket screening plant and condenser tube plates. If the condenser tubes are not made from titanium, turbulence set up by organisms or dead shells which become lodged in them may cause impingement attack leading to tube failure, salt contamination of the feedwater and consequent risk to main plant availability. Ancillary cooling circuits are particularly vulnerable. Mussel and hydroid blanketing of coolers has, in the past, placed at risk the reliable operation of essential safety-related equipment such as auxiliary diesels.

C1.5.2 Oil cooler failure/release of oil to sea

A number of incidents of failures of turbine lubricating oil coolers have been reported (Refs. C26 to C34 inclusive). These failures are caused by erosion and/or corrosion, sometimes associated with debris from fouling within the system. The pictures below relate to Reference C14. One consequence of these tube leaks was the release of lubricating oil to the sea, between 2,000 and 10,000 l in some cases. Such discharges are environmentally unacceptable and carry the potential for prosecution.



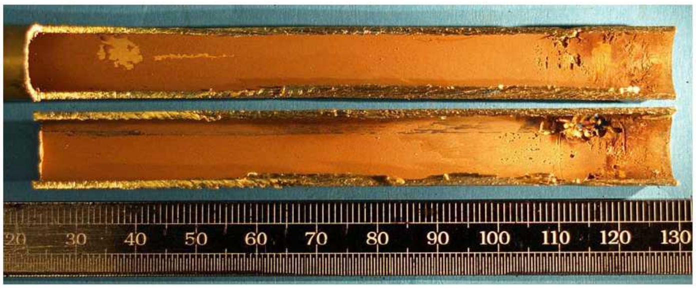
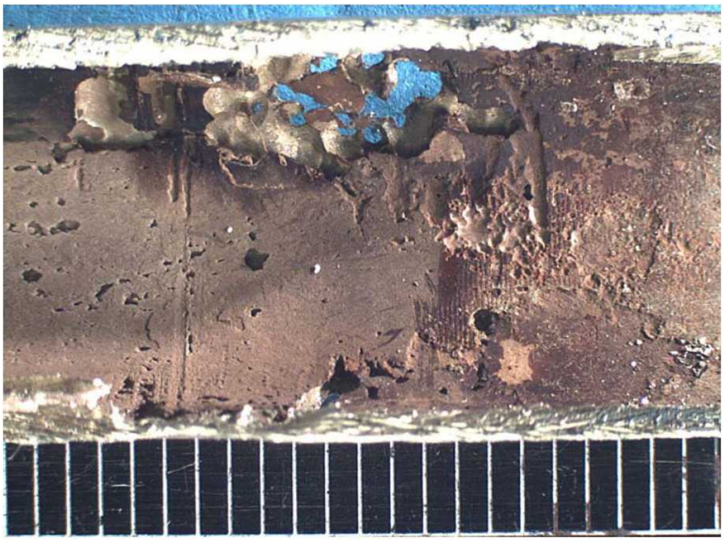


Figure C3 - Four leaking tubes from inside Hunterston B 8A seal oil cooler (left) and the inside of tube 1 (above) together with a close up (below)



C2 Other relevant operating experience

C2.1 WANO SOER 2007-2 Intake Cooling Water Blockage

This SOER (Ref. C35) reviewed a number of events were cooling water systems were compromised by intake blockages. The majority of these events were related to debris impingement and thus are outside the scope of this BEOM. The key conclusions of the review were:

- Blockage of intake cooling water reduced safety margins and increased the potential for a common mode loss of the ultimate heat sink for many safety-related loads. In addition, some managers have not fully considered the impact of such events on the availability of cooling water for safety- related systems.

- Changes in environmental conditions were often not compared to the plant design bases to ensure the design supports current plant and environmental conditions. Changing environmental conditions caused unexpected or sudden increases of algae, seaweed, marine life, debris intrusion or formation of frazil ice and some design features were inadequate to mitigate these conditions. In addition to changes in the natural environmental conditions, some intake blockages have resulted from manmade effects, such as oil spills.
- Monitoring techniques and prediction methods did not provide sufficient early warning to manage intake cooling water blockage scenarios.
- Design reviews did not identify vulnerabilities in the original design of intake structures, equipment and associated systems or in modifications intended to improve the robustness of screens, screen wash systems, strainers and heat exchangers.
- At many stations, key intake cooling water structures, equipment and associated systems were not maintained to an appropriately high standard and preventive maintenance was either not performed or not performed on a schedule to support preparations for seasonal challenges, such as to prepare for the high grass season. As a result, these systems and components, once thought to be reliable are proving to be less effective than originally designed.
- Station personnel were often ill-prepared to minimise the likelihood and consequences of an event. In many cases, procedures did not provide adequate guidance to operators responding to intake cooling water problems. Similarly, operations and maintenance personnel were not provided sufficient training to mitigate and respond to intake cooling water blockage events.
- Lessons learned from intake blockage scenarios from station and industry operating experience were not sufficiently identified or implemented at some stations to ensure that the plant design was sufficiently robust to handle intake blockage scenarios to prevent repeat events.

EDF Energy carried out a MEVL in response to this in 2011 (663930) identifying strengths and areas for improvement.

C2.2 Toxic sludge

There have been a number of events where sludge containing biological debris has produced toxic atmospheres (primarily due to H_2S) affecting people working in the vicinity. A number of events at Magnox sites are summarised in Ref. C36. In addition, there have been a number of events on EDF Energy sites:

- HYB R7 2005: stagnant water and sludge in the Reactor Seawater Cooling System released H_2S into the work area leading to an evacuation (Ref. C37).
- HYA 2008: cracking a CW pump discharge valve produced H_2S levels of 36 ppm against a work area limit of 5 ppm (Ref. C38).
- TOR R2 2009: decaying mussels in CW intake 2A1 produced H_2S (Ref. C39).
- HYA 2010: high levels of ammonia and hydrogen sulphide after mussels not cleared from forebay (Ref. C40).

C3 References

C1 Reactor 3 trip on chloride ingress protection following ingress of water from dirty drain system, NUPER report HUB00139, 1996

C2 U8 Unplanned Tripped following elevated Turbine Lube Oil Temperatures, ACIN CR 510586

C3 Bruijs, M., Venhuis, L., Jenner, H., Licina, G. and Daniels, D., (2001), “Biocide Optimisation Using an On-Line Biofilm Monitor”, PowerPlant Chemistry, 3 (7), 400-405

C4 TG2 condenser performance, CR 166335

C5 Condenser CW backwashing, CR 185041

C6 Backwashing of T21 A condenser pass, CR 306261

C7 Fouling of condensers necessitating 3 deloads for cleaning, CR 382604

C8 U7 condenser fouling, CR 414676

C9 Unit load reduction to facilitate 8B1 condenser backflush, CR 490504

C10 TG8 load drop to backflush 8C2 condenser pass, CR 508800

C11 De-load of Reactor One due to condenser fouling, CR 596021

C12 Unplanned load reduction due to condenser fouling, CR 803946

C13 ACW turbine hall culverts, CR 297141

C14 Significant marine fouling in ECW B main pipework, CR 426422

C15 Fouling of THACW heat exchangers hot weather, CR 340564

C16 R1 Gen TX oil coolers being blocked by mussels, CR 349449

C17 Marine fouling of ECW system, CR 350039

C18 High amount of marine debris found in No. 1 Gen Trans cooler, CR 339294

C19 TG7 cooler marine fouling - workload burden, CR 471875

C20 Marine fouling of generator transformer oil coolers, CR 767129

C21 Excessive silt/marine debris in ECW system pipework, CR 163107

C22 Turb lub & seal oil ACW supply header - marine debris, CR 522723

C23 Pope D H, A study of microbiologically influenced corrosion in nuclear power plants and a practical guide to countermeasures, EPRI report NP-4582, May 1986

C24 Licina G J, Sourcebook for microbiologically influenced corrosion in nuclear power plants, EPRI report NP-5580, 1988

C25 Licina G J, Detection and control of microbiologically influenced corrosion, EPRI report NP-6815, 1990

C26 Loss of lubricating oil from TA/1 coolers to sea via Cooling Water system, NUPER report HYA00329, 1997

C27 Discharge of oil from leaking lubricating oil cooler, NUPER report HPB00500, 1997

C28 Loss of lubricating oil to sea from degraded turbine lubricating oil cooler tube, NUPER report HUB00195, 1998

C29 Loss of oil to sea due to Turbine/Generator lubricating oil cooler tube leak, NUPER report HUB00226, 2000

C30 Heysham 1- Loss of turbine lub oil to sea via CW surge chamber due to oil cooler leak, EVNT 207583

C31 Hinkley Point B - CW pump 8 oil cooler leak, EVNT 143160

C32 Hinkley Point B - CW pump 9 shut down with suspect oil cooler leak, EVNT 157090

C33 Hunterston B - 8A seal oil cooler leak (HNB-SACI), OPEX 587559

C34 Hinkley Point B - CW pump 9 - suspect oil cooler leak, CR 695976

C35 Intake Cooling Water Blockage, WANO SOER 2007-2

C36 Sludge, Berkeley Site No. 108, 2012

C37 H_2S gas in CD strainer pits - 9'S, CR 298888

C38 Dangerous concentration of toxic gas within CW system, CR 463973

C39 2A1 CW intake still contains sea debris, CR 530323

C40 High levels of ammonia and hydrogen sulphide in forebays, CR 615359.

APPENDIX D: FOULING RISK CATEGORIES AND ASSESSING THE PROPENSITY FOR FOULING

There are three levels of fouling risk: high, moderate and low. These are defined below. The strategies appropriate to each risk level are outlined in the main text.

D1 High risk

High risk is defined as occurring where significant beds of sessile organisms, such as mussels, *Sabellaria*, (the reef building worm), barnacles or "whiteweed" (*bryozoans* and hydroids), are found in the locality. In most instances this case will apply to muddy estuarine conditions with a low to moderate tidal range, but will also apply increasingly to open coastal areas as one moves south through the UK as conditions for year-round growth and reproduction improve. These organisms should be assumed to breed intermittently throughout the year. Settled organisms can be displaced from one point of attachment to another, compounding their unpredictability.

This case poses the highest operational risk. The most extreme caution is justified and the default regime must be adopted, i.e. continuous low level chlorination must be sustained throughout the year.

D2 Moderate risk

Moderate risk is defined as occurring in low to moderate tidal ranges, in the absence of significant beds of sessile organisms. This case may apply equally to lower estuarine and more northerly rocky coast situations and is the most generally applicable. Where the predominant habitat locally is rocky shores or seabed the diversity of likely species involved can give rise to very much more complex fouls. In general, this category of risk necessitates careful assessment and continuous surveillance.

A relaxed variant of the default regime may be appropriate, where sustained low-level chlorination is only instigated when the cooling water intake temperature rises above 10 ^{o}C in the spring or when the settlement monitors indicate, whichever is sooner. Dosing then ceases when temperatures fall below 10 ^{o}C in autumn, but if the monitors detect significant settlement or growth thereafter the instigation and prolonged maintenance of dosing should be considered. This is known as seasonal dosing.

This is the most difficult strategy to sustain, requiring expert advice from a suitably qualified and experienced marine biologist on the significance of out of season settlement events. However, it offers a demonstrable optimisation of application, allowing a limitation of environmental harm and a reduction in costs.

D3 Low risk

Low risk is defined as occurring where growth is limited by water quality conditions. For EDF Energy Generation's current nuclear power stations, this applies to the middle and upper Bristol Channel and Severn Estuary only, i.e. Hinkley Point B. In this area there is a high tidal range with sustained high turbidity, the suspended solids having a relatively low organic content but high mineral content. These particular conditions are food-limiting, and thus stressful to many potential fouling species; scouring within the cooling water system adds to this to reduce both the likelihood of fouling and subsequent growth.

In this case no dosing may be necessary at all, but if this course is to be adopted then the rate of growth and degree of survival of local populations shall be ascertained first. Settlement monitors must be maintained even if no fouling has been discerned over many years. Particularly careful attention must be paid to relatively slack water areas where concreting reef-building organisms such as *Sabellaria,* or *ascidians* and sponges may prosper. There have been dramatic records of fouls by these groups at Oldbury in the past which appear to contradict the general perception of limited growth in the Severn Estuary.

Where dosing plant has been installed it must be maintained and kept ready for use even if dosing is not normally carried out. Where it has not been installed, or it is demonstrably not cost-effective to maintain it serviceable, a contingency plan for the acquisition and delivery of hypochlorite to the circuits must be prepared and the option maintained. If a need to dose arises in this circumstance, fouling of the intake culverts may be considered tolerable in the light of the probable difficulty in maintaining injectors at the intake headworks. A pragmatic short-term solution would be to inject the oxidant at the intake surge shaft/drum screen area rather than at the intake, ensuring the biocide is well mixed throughout.

D4 Risk assessing the propensity for fouling

EDF Generation's default dosing strategy is the adoption of a year-round (24 hour/365 day) continuous dosing programme to maintain a TRO residual of $200\mu g.kg^{-1}$ at the outlet of vulnerable plant systems. This programme should be applied to sites evaluated as being at High Risk of biofouling.

However this BEOM allows individual sites to move away from the default regime on the basis of the findings of a three yearly, objective, site specific assessment of the risks. The risk of fouling will vary both between sites (zoogeography) and between years at individual sites. This variation will have a direct bearing on the control strategy to be used. A justified move away from the default condition has obvious commercial, operational and environmental benefits from the reduced use, or generation, of biocide.

It is required that each site shall undertake a strategic assessment of biofouling risk every 3 years. This Risk Assessment would establish the biofouling threat to the specific site and indicate the optimized biocide dosing programme needed to mitigate the threat. It is expected that this assessment would be undertaken by a specialist contractor organisation and could be managed on behalf of the stations by CTO staff. The individual stations would be responsible for ensuring that the assessment is done.

The primary elements of a site specific risk assessment should address:

- Ecological data on the abundance and distribution of the relevant organisms, their movement and settlement patterns, water quality and the availability of food.
- Historic information on known settlement patterns determined using in-circuit settlement monitors, off-site settlement plates or both.
- Historical records detailing the past incidence and severity of fouling.
- Use of settlement monitors (providing indication of macrofouling).
- Shoreline surveys in the vicinity of the station (either carried out by the operator or reported in the scientific literature). Surveys can give an indication of settlement and growth over a number of years and hence provide an estimate of the degree of risk to the local plant. Guidance from specialist marine ecologists will be required in specifying and conducting surveys. Site investigations to review the risk attaching to a particular site should include such information as the temporal variation in chlorine demand of the influent seawater, the rate of decay of TRO in the water after dosing, water quality, local habitat types, and especially the proximity of mussel and other commercial shellfish beds and the distribution and abundance of other local, potentially fouling, organisms such as *Sabellaria*.
- System specific design considerations i.e. number of circuits, continuity of flow
- The adequacy of on-line instrumentation to confirm plant condition e.g. pressure and/or temperature differential indications over key plant components
- The ability to condition monitor all parts of the system without process restrictions
- The ability to comply with TRO discharge limits if enhanced dosing may be required for a finite time to recover plant health
- The inclusion of additional countermeasures such as condenser tube mechanical cleaning, condenser back-flushing

Further guidance can be found in Reference D1.

The results and recommendations of the strategic risk assessments should be forwarded to CTO for their review and endorsement. Records of the strategic risk assessments should be retained by the respective station and CTO.

D5 References

D1. E/EAN/BPKB/0113/GEN/09, BEOM006 Propensity for Fouling Risk Assessments.

APPENDIX E: THE DETECTION OF FOULING

The appropriate fouling control strategy is determined primarily by the periodic risk assessment as described in Appendix D. The assessment is supported by the results of surveillance, surveys and the use of other available information. A contributor is the application of an on-going plant condition monitoring programme to confirm that plant health is maintained.

This Appendix describes the various ways that early stages of fouling and its effects can be detected by an on-going plant condition monitoring programme. The best strategy is likely to involve a combination of the monitoring methods detailed below.

A key aspect of any monitoring regime is to record findings as accurately as possible both in terms of the nature of the foul and its magnitude. Previously CRs raised to record fouling events have often referred to ‘fouling’, ‘debris’ etc rather than ‘mussels’, ‘silt’, etc. In essence the nature of the foul should be recorded in terms of whether the dosing of a biocide could or would have prevented or inhibited the problem. If larger organisms such as fish or seaweed or other sizeable materials are observed this could be indicative of a breach at the drumscreen. Photographs taken periodically of the same plant areas can significantly assist the assessment of fouling trends and help to ensure that problems are efficiently diagnosed and resolved.

E1 Routine surveys of shoreline and visible cooling water intake structures

Shoreline surveys assess the local marine ecology in a systematic way. They can provide an early warning of changes and will be a key input into the 3-yearly risk assessment process.

Currently, Hinkley Point B is the only station that carries out regular systematic surveys (Ref. E1). Details of the methodology are:

- The foreshore in front of the power station is walked on visually searching for live mussels and shell remains. The path of the survey started at the western end of the site boundary wall, and followed a course down and across the foreshore, from west to east. At the eastern end of the shore, the survey followed the shore of the CW discharge channel.
- A hand-held GPS unit is used to record the track of the survey; waypoints are added to record the positions of live mussel colonies.
- The survey team members work approximately 3 metres apart, to maximise the area of habitat covered.
- There are additional surveys at Blue Anchor, Minehead and Gore Point. At Blue Anchor and Minehead, the surveys are restricted to the areas of rock likely to provide a habitat for mussels. At Gore Point, the survey is concentrated on the area of freshwater run-off midway down the rocky shore, as this is where mussels had previously been recorded.
- Mussels from each colony observed are collected and preserved on ice until they can be analysed in the laboratory. The length and width of each shell is noted, and for the larger specimens, the flesh is removed from the shell, placed in a weighed glass dish and dried in an oven at 40°C for 24 hours. The dish is then reweighed, to calculate the dry flesh weight. The relationship between this figure and the shell length is a simple indicator of the condition of the mussel, as a healthy shellfish with an abundant food supply will have a greater flesh weight for a given shell length.

Typical conclusions would cover:

- Observations of mussels and their numbers.
- Changes since the previous survey.
- Link between observations and the risk of fouling.

E2 Degradation of plant performance

Increases in pressure differentials across items of cooled plant or changes in temperature profiles across heat exchangers may indicate the onset of fouling. In general, it is suggested that any steady decrease in the performance of a cooler should be presumed to be related to fouling and equally any sudden decreases which may be brought about by flushing with water from a fouled section of plant.

Performance levels of coolers are often set by safety case considerations. A typical maintenance regime is to monitor the flows through such coolers at fortnightly intervals. If the flow is below the appropriate level then the cooler is backflushed. If backflushing does not bring the cooler performance back into the specified range it is then taken out of use and disassembled for cleaning. Keeping a record of the foul (photographs) and the frequency of cleaning can provide a valuable insight into any deteriorating (or improving) trend.

E3 Visual inspection of plant

Fouling may also be detected by routine inspection, i.e. inspecting plant that is out of service and drained down. The application of an on-going plant condition monitoring programme to confirm absence of biofouling is a primary consideration. Every practicable opportunity should be sought to inspect internal surfaces of cooling water circuits for fouling – this may be opportunistic but may need to be planned if plant availability is restricted.

The two primary symptoms of biological fouling are visible biological growth on surfaces and an accumulation of silt or debris - the one may apparently exist without the other. Biological growth is most likely to begin where there is any local variance in flow conditions, such as on a construction seam, within a re-entrant. Examples include an inspection hatch entry or take-off point, behind bends, or where the cross-sectional area of a culvert or pipework increases, such as the box before or after a condenser or cooler. Records should be kept of the degree of fouling and siltation discovered in each instance; with photographs being taken at standard locations, of features of interest identified by the CW System Engineer and Station Chemist, and of anomalous findings of silt or growth. If the nature of the biological growth is unknown a sample should be taken and preserved either in alcohol or through freezing for subsequent examination. Such a record will prove invaluable in seeking advice from the marine ecologist.

E4 Monitoring

E4.1 Microfilm Monitoring

It is well understood that microfilm formation on a surface exposed to seawater is an essential precursor to the growth of larger organisms such as barnacles and mussels. A microfilm is typically made up of a surface coating of clay minerals, ionic particulates and a variety of micro-organisms. The microfilm itself, as it develops, will lead to a decrease in heat-exchange efficiency but monitoring temperature differentials alone across condensers will not detect its early development. A more sophisticated approach employs Redox detectors to measure microfilm development more closely. Such detectors also have the advantage of simultaneously measuring the amount of oxidant (biocide) in the immediate vicinity. Thus for the first time it is possible to link biocide dosing very precisely with microfilm development and exercise precise control remotely. This has the obvious advantages of maximising the effectiveness of dosing whilst minimising the resources used and it is considered to be the basic tool for setting up 'pulse' or 'intermittent' dosing regimes.

E4.2 Fouling Monitors

A variety of monitors are used by cooling water users world-wide to monitor the development of macrofouling, these range from simple plates or ropes hung within the cooling water flow and removed at intervals for inspection to more sophisticated arrangements which are plumbed in to the cooling water system itself. Amongst the latter are the 'Fawley Biobox' and the 'KEMA settlement monitor'. All provide a surrogate for the physical inspection of plant that is difficult or impossible to access on a frequent routine basis.

For the purposes of this BEOM, the use of some surrogate for physical inspection of plant between outages is advocated as potentially advantageous in that it can provide early warning of a developing fouling problem that needs to be brought under control. However, unless properly installed and used according to manufacturer's instructions proprietary monitors can provide misleading information. The use of such monitors, maintained and operated in proper order, is recommended where either an intermittent regime or an absence of dosing is routine over the warmer months of the year. Surveillance using settlement monitors should be complemented by regular inspections of the plant. The use of monitors must not be taken as a reason to reduce actual physical inspections and will not necessarily lead to an agreement that a less stringent dosing regime is appropriate.

E5 References

E1 Beach survey for mussel populations at Hinkley Point and adjoining shores, September 2014, R.M.H Seaby, J.R. Somes & M. Cox, Pisces Conservation Ltd

APPENDIX F: PREFERRED REAGENT FOR BIOFOULING CONTROL AND THE TECHNICAL BASIS FOR THE DEFAULT CONTROL STRATEGY

F1 The EDF Energy Nuclear Generation Ltd. strategy

The basic strategy for the control of marine fouling, determined by the design of existing EDF Energy Nuclear Generation Ltd. stations, is screen, clean and dose. The dosing of a biocide retards the growth of the fouling organisms and hence defers the need to clean. The default methodology of biocidal control is continuous dosing through low-level chlorination. It should be noted that dosing does not remove the need to clean altogether, it only delays it.

The use of direct surface treatments (such as non-stick paints) which need regular renewal is limited by the inaccessibility of the majority of the systems of a coastal power plant prone to fouling. Similarly, the design of cooling water systems and environmental regulations do not permit heat treatment.

Film forming agents to coat surfaces are marketed which claim to provide not only protection against fouling by micro and macro-organisms but also a measure of protection against corrosion. Such agents rely heavily on an initial application and subsequent frequent ‘topping up’ by adding the agent to the intake water. This is problematic as it assumes that flows through both main and ancillary systems will be uniform and that the diminishing concentration will be adequate to coat all of a diverse range of materials that make up these systems. For AGRs particularly, an additional problem arises if the condensate polishing plant (CPP) performance is compromised as a result of fouling by a film forming on the resin surface in the event of a condenser leak at a time when the installed resins would be expected to remove the resulting impurity ingress. These considerations are supported by operating experience from Le Harve suggest that these film forming agents are unsuitable for use in complex power plant cooling water systems.

From the range of possible biocides, those that are chlorine and hypochlorite based are the only realistic choices on the grounds of efficacy, cost and current environmental acceptability. Since the transportation of bulk chlorine is regarded as unacceptably hazardous (Ref. F1), the choice is further restricted to the use of chlorine in solution. This may either be delivered in bulk or generated on-site by electrolysis or other means.

The screen, clean and dose strategy has been evolved over the past 35 years and is considered to be both conservative and secure. The use of biocides to control fouling has been evaluated by a broad grouping of collaborating organisations in Europe (Refs. F2, F3 and F4). Continuous low level chlorination linked to filtration and physical cleaning is the current "Best Practicable Environmental Option" and "Best Available Technique (BAT)" for the control of invertebrate fouling in the once-through cooling water circuits of coastal and estuarine based power plant.

F1.1 Use of sodium hypochlorite

Chlorination is currently the standard practice for the control of biofouling (both macrofouling and microfouling) in the direct cooling water circuits of power plants due to its proven effectiveness, limited environmental impact and acceptable capital and operating costs. Historically, chlorine was applied as a gas, but is now generally applied as sodium hypochlorite solution.

Chlorine is effective at preventing macrofouling through the inhibition of the ability of molluscs to feed and respire. The reagent is readily detectable by molluscs’ chemoreceptor system at effective concentrations. The molluscs respond by withdrawing their siphon tubes and closing their shells and so are unable to feed or respire freely until the oxidiser has passed. Therefore, the maintenance of a sufficient residual oxidant concentration eventually kills the organism, or prevents settlement.

Low level chlorination can be undertaken either on a continuous or semi-continuous basis at seawater or estuarine water cooled plant. Discontinuous (shock) dosing is rarely undertaken on direct cooled systems due to low effectiveness. In most waters, prevention of settlement with continuous low level chlorination based on hypochlorite requires the maintenance of a total residual oxidant (TRO) concentration of 200µg.kg^{-1}. To protect vulnerable plant components this residual value is maintained at the outlet of the plant component provided that final residual concentration discharged to the environment is compliant with site specific authorised limits.

The term TRO is used because chlorination of seawater results in the displacement of bromine from naturally occurring bromide (approximately 65 mg.kg^{-1}) so that most of the total residual oxidant and biocidal activity is bromine based. However, it is noted that the discharge authorisations for some stations require free chlorine to be measured rather than TRO.

The main disadvantage of chlorination is that reaction with organic matter leads to the formation of organohalogenated substances, including chloroform and bromoform. Concerns over the persistence, toxicity and bioaccumulation of certain halogen-based compounds, particularly chloroform, has resulted in the introduction of a broad range of legislation that is contributing to a more general pressure to reduce the overall use of chlorine.

Consequently sites employing chlorination should, as a minimum, be able to demonstrate optimisation of the dosing programme. As a general principle the biocide dosing regime should be developed and optimised for individual sites taking account of plant design, the nature of the cooling water and the potential for biofouling.

In recent times two alternative or variant chlorine based biocides have been considered to have some potential benefits over sodium hypochlorite alone. These alternatives are discussed in section F2. Any change to the existing hypochlorite based biocidal regime either on a trial or a permanent basis would be subject to the engineering change process and would require a formal dispensation against the requirements of this BEOM in the first instance.

F1.2 Biocide dosing points

The primary biocide dose should be to the point of initial CW intake to provide maximum protection to the complete system. Best available techniques should be incorporated in the design of the dosing system to maximize the mixing of the applied dose in the seawater. For example, this may be achieved by installing a ‘grid dosing’ system.

When flow rates are low, the applied dose should be increased to ensure protection downstream of the injection point. The decay and demand model (Refs. F5, F6) may be used to estimate the demand and decay rates involved in any particular situation. It should be noted that demand can vary considerably throughout the year at any particular site and that the appropriate residual must be maintained beyond that demand.

If the chlorine demand of the water is such that the residual biocide level is depleted below the default dose level before the dosed water’s exit from vulnerable systems then additional, supplementary dose points may be required.

Consequently, the potential dose point locations could be:

(i) Intake headworks for off-shore CW intake channels

(ii) CW pumps’ suction dock down stream of the fine filters (drum screens) where no extensive intake channels are included.

(iii) Intakes to auxiliary cooling water systems where the default dosing level cannot be maintained by the main cooling water dose programme and where the site-specific risk of fouling is high or moderate.

(iv) Intakes to auxiliary cooling water circuits that are not part of the main cooling water flow but which may be vulnerable to fouling with consequent safety or operational implications

Though the most desirable strategy is to have the capability to dose the auxiliary circuits independently, it is recognised that this may not be possible on all stations. Consequently it may be necessary to increase the dose of the main system to ensure the recommended residual TRO concentration is maintained at the outlet of vulnerable auxiliary systems. This action can only be done if it does not pose a threat to the site's Consent to Discharge's limit on TRO released to the environment (Ref. F7).

In recent times dosing of the auxiliary circuits has been reliably achieved by administering a very dilute solution of hypochlorite using softened water.

F1.3 Frequency and magnitude of dosing

Many years of experience at many sites around North West Europe have led to the conclusion that organisms such as mussels are best dealt with by seeking to retard growth rather than killing them outright. The latter strategy would require that very much higher levels of toxin were sustained over long periods. The ability of such organisms to close down abruptly on detection of high levels of biocides has also led to the realisation that intermittent dosing strategies are generally of limited value for macrofouling control although they will remain ideal for the control of microfouling.

At Heysham 1 the fixed dosing system was incapable of dosing both wings of the intake to the drum screens. Consequently, fouling arose in the undosed wing whilst the dosed wing remained clean. A modification to the plant which enables the dosing to switch alternately to either wing of the intake to the drumscreen has proved to be beneficial in effectively controlling the mussel populations in both wings. Even so, an effective intermittent dosing regime, which could reduce the usage of biocide with a potential cost saving and ease the burden from a COMAH perspective, would need to be the subject of further work and trials before an effective intermittent dosing regime could be more generally applied. Ongoing research in collaboration with RWE into the potential for chlorine dioxide as a biocide suggests that an intermittent dosing regime may have potential for controlling macrofouling particularly if the frequency regularly changes however; any proposal for such a dosing regime is some way off.

F1.4 Optimum biocide concentration

Previous experimental trials concluded that there was a significant difference between the rate of growth of mussels in running water containing 50 and 100 $\mu g.kg^{-1}$ TRO but no significant difference in growth between 100 and 200 $\mu g.kg^{-1}$ TRO content. This suggested that dosing to 100 $\mu g.kg^{-1}$ TRO should be adequate to control mussel growth in seawater systems. However, seawater has a natural oxidant demand. This varies: site-specifically, seasonally, tidally, when there is a phytoplankton bloom, and according to local weather conditions (e.g. when strong winds cause mixing). Typically this demand is around 1000 $\mu g.kg^{-1}$ oxidant equivalent. In order to maintain 100 $\mu g.kg^{-1}$ TRO a station would therefore need to dose at 1100 $\mu g.kg^{-1}$. Tracking variations in demand to leave an adequate residual level with as small a margin for error as this has in the past been extremely difficult. Furthermore, the variation of the results from the DPD methods of analysis typically used for TRO determination is around ± 100 $\mu g.kg^{-1}$ at this level. The instability of the sample will add further inaccuracies. At best, when a reading of 100 $\mu g.kg^{-1}$ TRO is found, the actual level will be somewhere between 200 $\mu g.kg^{-1}$ and zero. In this case, there can be no confidence that a residual actually exists. Consequently, it is safer to choose a target level of 200 $\mu g.kg^{-1}$ TRO so that a measured level between 100 and 300 $\mu g.kg^{-1}$ TRO can be assured. Methods other than those based on DPD are available but have not previously been regarded as reliable, however, Heysham 2 have recently trialled a continuous monitoring instrument (see F1.6 below) successfully which could allow for more a more efficient, effective dosing regime.

F1.5 Control of microfouling

Whereas the settlement within cooling water circuits of mussel larvae is more common during the spring and summer, microfouling of untreated warm condenser tube surfaces will occur all year round. For this reason chlorination may be required at coastal stations to control microfouling even when the perceived macrofouling risk is low.

Various alternate dosing strategies ('pulse', 'shock', 'intermittent') are possible which offer environmental benefits and cost-effective alternatives to continuous dosing – see Section 4.1.4. However, if such alternatives are considered so too should the use of recent developments in dosing and control technology, such as in-situ (in-pipe) electrochlorination packages and redox biofilm/oxidant monitors. This is especially applicable to operational and safety-critical plant such as coolers.

F1.6 Auxiliary circuits

Dosing of the auxiliary cooling circuits may still be required, whether or not the main cooling water system is dosed. Cooling water circuits which are not part of the main cooling water flow should be dosed independently as flow rates tend to be low allowing for very much higher levels of oxidant decay to occur, and surface area to volume ratios mean a disproportionate surface demand on the oxidant.

The TRO residual should be maintained at the discharge from an auxiliary circuit. This is a conservative approach to take into account the longer dwell times of cooling water in auxiliary circuits and the different internal surface area to volume ratio involved.

At Heysham 1, the installed ECW dosing skid was found to be unreliable and there had been problems with crystallisation of the diluted sodium hypochlorite. To resolve this problem they installed an ECW dosing system including a buffer storage tank, water softener and metering/dilution skid. The dilution of the bulk sodium hypochlorite to ~1% using softened water has proved highly successful (Refs. F8, F9).

F2 Trials of alternative control strategies

The potential reward from large system trials of alternate control strategies may seem great but it is judged that the risks are always likely to be greater. It is further judged that the risk of such experiments is increasing with time as the available expertise in applied industrial ecology within the UK (and indeed the rest of Europe) declines.

The reasons for experimentation often seem very plausible. For example, the use of bromine-based biocides in seawater and the suggestion that deep culverts did not need to be protected due to the combination of hydrostatic pressure and flow rate seemed superficially to be very attractive when suggested by sales reps and external consultants, but both turned out to be flawed.

Similarly, a number of suppliers have sought to sell alternative biocides or molluscicides to control fouling of cooling water systems (either themselves or through 'independents'). Many substances sold in this way tend to have been used primarily as treatments for potable water and the suppliers have attempted to establish an alternative market. However, one common factor with the majority of these substances is that they are unproven as cooling water biocides for coastal power plant. Information regarding their use is largely provided by the suppliers themselves, or comes from trials of little relevance to their application in power station cooling systems. It is judged that the trials that have been carried out tend to have been poorly designed and lacking proper experimental control. Another common factor is the lack of any relevant information on marine toxicity and biodegradability: information that is needed in seeking Consents to Discharge from the regulators. EU regulations are changing and the new "Biocides" Directive will require the supplier to provide very much more information. As a result the number of such products being proffered by chemical company reps is likely to become far fewer.

In spite of the above problems, there may be some potential merit in exploring the efficacy and practicality of alternative compounds. Many purport to act by coating surfaces (such as mussel gills), clogging them; some are claimed to weaken the organic matrix fixing animals to substrates; others are simply toxic. Some of the more interesting ones seek to exhaust the animals by giving them something akin to slimming foods (either bulking agents or metabolically useless sugars) or by narcotising them or otherwise causing respiratory stress (CO_2 injection). Some of these may have been investigated as small scale comparative trials with several biocides on once-through sea water systems by utilities; for example, the biocide cum filming agent known as 'Mexel' was tested on an inland power station by KEMA and EdF, with equivocal results (Refs. F10, F11).

Many of these alternative antifouling substances are dosed to kill, not simply to restrict growth as this BEOM intends. Thus, an operator either starts with a pristine system, or anticipates loosening whatever is fouling the surfaces within the cooling system. In the latter case, the fouling matter will very quickly loosen from surfaces and be carried downstream to the immediate hazard of plant which may rapidly, maybe some time later, block. In some circumstances the loosening may be useful, but the same thing can also be accomplished by heating, purging with fresh water, drying down or rendering a system static for a sufficient length of time. The efficacy of each of the approaches depends very much on opportunity, the system fouled and the fouling species concerned.

In conclusion, generally, the use of alternative biocides to chlorine should not be considered because:

- Their effectiveness in power station sea water cooling systems has not been proven.
- There are regulatory constraints and concerns about the release of poorly understood biocides into coastal waters.
- The current best practice of continuous, low-level chlorination is of proven utility and low cost (as reflected in this BEOM)

In terms of chlorine based biocides, technological improvements now mean that in-situ (actual within-pipe) electrochlorination and redox monitoring (for microfilm development and immediate oxidant levels) suggest that potentially cost-effective opportunities now exist for spot, intermittent and shock dosing and the particular care of operational and safety-critical plant.

In recent times two alternative biocides have afforded some attention, though much work would need to be done before these alternatives could be deployed. These are described in sections F1.2.1 and F1.2.2 below.

F2.1 Mixed Oxidant (MOS)

MIOX is the name of a company based in the USA specialising in electrolysis. They consider themselves to be an electrochemical cell development company. They market the equipment that produces a mixed oxidant (known as 'MOS') of sodium hypochlorite and hydrogen peroxide. Sodium Hypochlorite is generated electrolytically from brine with the hydrogen peroxide being generated from the hydrogen gas produced by the hypochlorite generating unit. As an example, to produce an effective dose, typically the footprint of MIOX cells are smaller than conventional seawater electrochlorination systems but to set this in context the MIOX company judge that for both units at Heysham 2, six of their largest 'Rio Grande' units would be required to produce sufficient MOS to treat the whole CW system.

Each Rio Grande generator costs approx. $200,000 - $300,000 (excluding installation) this system produces 700kg per day (hypochlorite cell version) whilst the Hydrogen Peroxide cell produces less product and requires more power. Each unit at Heysham 2 would require two Hypochlorite and one peroxide Rio Grande units, i.e. three per unit.

The MIOX generators use food grade Sodium Chloride diluted down with water (softened or preferably demineralised water) from site. It should be recognised that the quality of the source water is important since impurities; particularly divalent magnesium or calcium salts can lead to the cell scaling and increased requirement for chemical cleaning (acid). Therefore reliability, life time and maintenance of the MIOX systems are critically dependent on water quality and salt purity even though the company claim that their technology and cell design are superior to those generally available. Currently MIOX are developing cell self-cleaning system (based on reversing the cell polarity) and they expect to have this available in the next couple of years.

In terms of resources, 1 kg of free available chlorine (FAC) requires 3 kg of salt, 4.4 kw/hr and 18 m^3/hr demineralised/softened water. Recent research by MIOX has shown that the only products of the mixed oxidant cells (MOS) is hypochlorous acid and hydrogen peroxide with the concentration of hydrogen peroxide at approximately 100 to 200 ppm. FAC concentration is 4500 ± 1000 ppm

In terms of efficacy, MIOX claim that the MOS system is more effective than hypochlorite alone due to the effect of hydrogen peroxide which acts in a similar way as chlorine dioxide and penetrates biofilms (attacks the polysaccharides). However, there appears to be no available data on the toxicity of MOS to mussels and if there is any synergistic effect of having the hydrogen peroxide present

MIOX don't appear to have done any decay rate measurements for the combined MOS system i.e. they cannot measure the individual components in the (hypochlorite and peroxide) at the same time and only have the combined decay rate. Therefore the impact of the hydrogen peroxide on the initial chlorine demand is unknown. As with hypochlorite, MOS will produce chlorinated by product analysis but MIOX have not determined if there are additional CBPs arising from the combined or peroxide component.

A key disadvantage of the system at the current time is that there is a potential for automatic system shutdown which would require intervention by the manufacturer/agent. It isn't clear how long the response time might be but this could be a significant factor during high demand periods. At the current time there are no Rio Grande units operating in the UK. This may present an issue should spares be urgently required and also impact of service/maintenance charges.

MIOX cells have an expected life of at least 5 years (there warranty period) before requiring replacement or maintenance. No on-site maintenance can be done and they either work or they don't. The hypochlorite/peroxide production rate is fixed cannot be varied to match demand therefore a buffer tank is required to accommodate variations in demand.

MIOX claim that the cells are easy to lay up if needed as all that is required is to flush the cells with demineralised water before they are stored. MIOX, using Heysham 2 as an example, claim that tanker movements would be expected to reduce by 80% (difference in the salt vs hypochlorite lorries).

F2.2 Chlorine Dioxide

Chlorine Dioxide (ClO_2) has long been recognized as an effective microbiological biocide, combining the highly desirable qualities of high microbiological efficiency with excellent biofilm penetration capabilities together with a lower tendency to produce hazardous disinfection by-products, comparatively low dose rates and low oxidation potential. As such over the past 20 years ClO_2 production and delivery systems have been developed and adapted for use in small to medium sized water consumers such as the food, beverage and potable water industry. However, its development for use among high volume water users with water consumptions over 4000m^3 per hour (96 Million litres per Day (MLD)) has been restricted, mainly due to the comparatively high operational cost of generating the biocide on site from chlorite based precursors (See also Appendix H).

The recent introduction to the market of new generation chemistry, adapted from that which has been used in the pulp and paper industry for over 30 years has recently led to dramatic falls in the overall cost per kilo of the ClO_2 biocide, leading to an increasing examination of its potential for use in high volume, once through and recirculating water cooling systems. Patented technology has been developed for the on-site generation of chlorine dioxide using a single precursor blend of Sodium Chlorate and Hydrogen Peroxide. This unique precursor offers large water treatment users with ClO_2 requirements greater than 1 kilo per hour to access the lower operational costs offered by use of chlorate based precursors. As a result of this innovation, ClO_2 use has, for the first time become cost-competitive with 'on-site' electrochlorination, Hypochlorite and Bromine based treatments, and allows high water volume industrial cooling systems to benefit from the superior biocidal efficiency of ClO_2 (Ref.F12).

In practise, ClO_2 can be produced by the reduction of sodium chlorate by hydrogen peroxide under acidic conditions. For example, the SVP-Pure™ ClO_2 generator uses a proprietary product 'Purate' and sulphuric acid to produce ClO_2 on-site that is easily piped to the point of application. Importantly, no chlorine gas is used or produced in this process. The pre-blended product, Purate solution, is formulated with 40 wt% of $NaClO_3$ and up to 8 wt% hydrogen peroxide and shipped to site in IBC totes, ISO containers and bulk trailers.

Research carried out by RWE suggest that the effective dose is significantly lower than that of Socium Hypochlorite and during the Summer of 2015 further research is being undertaken jointly with EDF Energy. Results of the research are awaited but are expected to show that the effective dose is lower than previously envisaged. The research also includes assessing a potential for intermittent dosing. As a consequence ClO_2 may provide a cost effective alternative to sodium hypochlorite with environmental benefits and an advantageous impact on COMAH considerations.

F3 References

F1. CEGB, 1980. Interim report of the Steering Group on the phasing out of bulk liquid chlorine. Operations Department Report No SGBLC/80/2.

F2 Whitehouse J W, Khalanski M, Saroglia M G and Jenner H A, 1985. The control of biofouling in marine and estuarine power stations. Collaborative (CEGB, EDF, ENEL, NV KEMA) Research Working Group Report published by CEGB North West Region. NW/R 191 9 85.

F3 Jenner H A, Whitehouse J W, Taylor C L, Khalanski M, 1998, Cooling water management in European power stations: biology and control of fouling. A manual, Hyrdoecologie Appliquee, Tome 10, Volume 1-2.

F4 The environmental consequences of cooling water system antifouling; the state of the art. Common Statement of the Joint Technical Meeting of European Power Utilities and Chemical Industries. Barnwood, December 1993.

F5 The FARL chlorine dissipation model - a working manual, FCR 010/92

F6 Chlorine residuals: What am I measuring?, FCR 002/91

F7 Management of Abstractions from and Discharges to Controlled Waters and the Water Environment, BEG/SPEC/SHE/ENVI/006

F8 Heysham 1 : New Hypochlorite Plant , PowerPoint slides, HYA/TRNG/PPT/106/816

F9 Heysham 1 - Hypochlorite Storage & Dosing. Project Definition Document, HYA/DSGN/A238/PDD/001

F10 File Référence (French) T:\TSK-5680\Mexel 432\MEXEL point en 2012 actualisation de certaines données mars 2014.zip

F11 File Reference: (Translation of Reference F8) T:\TSK-5680\Mexel 432/ MEXEL Le Harve

F12 Cameron, A., Callachan, G.D., ClO_2 Treatment of Seawater Handling Systems
Known Effects of Oxidising Biocides vs. The Unknown Risks of Microbially Induced Corrosion

APPENDIX G: STRATEGY FOR THE CONTROL OF BIO-FOULING

This Appendix provides a general overview of control strategies used in the power industry and introduces the EDF Energy Generation strategy of screen/clean/dose.

G1 Options for the treatment of fouling

There is a range of possible anti-fouling techniques for power plants (Refs. G1 and G2), see Table G1. These can be split into four categories:

- Filtration, e.g. coarse grids, rotating screens, drum filters.
- Mechanical cleaning, e.g. digging out, high-pressure water cleaning, sponge balls.
- Other physical methods, e.g. high-velocity water flows in-circuit, thermal control.
- Chemical treatment, e.g. non-toxic release paints/coatings, filming agents, chemical dosing including ozone, CO_2 gas injection, biocides.

These are described in more detail in the following sections and summarised in Table G1. The choice of the technique depends on a number of factors including accessibility of plant, controllability and environmental compliance.

G1.1 Filtration

Coarse grids (10 cm spacing) situated at the water intake are often the first line of protection preventing the entrainment of large items of flotsam and jetsam and large mobile animals such as seals and whale. Such screens may be fitted with trash racks for removing debris but currently none are fitted on EDF Energy Generation nuclear power stations.

The travelling screens are the second line of protection. They consist of drum or band screens with a mesh between 8 and 10 mm. They remove debris such as seaweed, aquatic plants, mussel mats and shells. These are cleaned using pressurised water backflushing the impinged material into waste gullies and thence to trash baskets or a return system (Sizewell B only) or a maceration and return system (Dungeness B only).

Debris filters, typically with 1 mm mesh size, can be installed just before heat exchangers to protect them. Debris is removed by back-washing or periodic manual replacement.

Some manufacturers (e.g. Taprogge) provide filtration systems that will clean the water to greater degree. This would normally only be worthwhile on the most critical and sensitive systems. There are no applications of this practice within EDF Energy Nuclear Generation Ltd..

G1.2 Physical Cleaning

Condensers can be cleaned on-line by recirculation of foam rubber balls, often coated with abrasive carborundum (Taprogge system). Unless very carefully maintained such a system can release large numbers of balls to the liquid effluent waste stream in direct contravention of Consent compliance requirements.

Heat exchangers are cleaned off-line by high-pressure water jets. Manual cleaning to remove macro-biofouling can also be carried out off-line in areas of the cooling water system that are accessible.

G1.3 Heat Treatment

Thermal treatment is a highly efficient way of eliminating all macro-biofouling in a cooling water circuit. The cooling water is recirculated and thus heated to around 40 °C and the circuit held at this temperature for a short period (30 minutes to 2 hours). Any macrofouling organisms are killed by the heat shock. It is not, however, efficient against bacterial slime. While this approach has the advantage of not involving chemicals, there are a number of difficulties associated with it:

- It requires a specially designed cooling water system with feedback loops.

- Thermal cycling of concrete walls of tunnels and conduits may result in damage.
- Loss of turbine efficiency and generation.
- Discharge of hot (~40 °C) water to the sea.
- Potential for blockages of plant components due to the possible release of large amounts of bio material.

G1.4 Paints and Coatings

There are two kinds of coatings, those containing one or more toxic substance, and those which work through their physical, surface properties - the so-called non-toxic release antifouling paints such as 'Intersleek'. These products were developed, for the most part, for use of ships' hulls. In order to apply them to cooling water systems, it is necessary to consider the effects of any toxic compounds released, the lifetime of the coating and, particularly with the non-stick paints, its ease of applicability to the materials used in cooling water systems.

G1.4.1 Toxic Paints and Coatings

Selected toxic substances are progressively released from the coating by a process of leaching and surface erosion. Coatings containing tri-butyl tin oxide (TBTO) are known to be very effective against all types of marine organisms. Copper and zinc compounds are also effective. The toxicity of organic tin is now well documented but coatings containing Cu_2O do not have such adverse ecological effects. The use of such paints within cooling water systems needs to be considered very carefully and only implemented through a phased approach agreed with the environmental regulator. Toxins released by such paint will need to be covered by the appropriate discharge Consent.

G1.4.2 Non-Toxic Paints and Coatings

These coatings work by weakening the bond between the organism and the coating. Silicone-based coatings tend to accumulate less fouling and are easier to clean. They may reduce the total level of fouling and may also make cleaning from the surface of fouling very much easier.

G1.5 Chemical Treatment

This approach is based, for the most part, on the use of oxidising substances.

G1.5.1 Chlorine

Chlorine has been used since the early 1900s for the disinfecting of drinking water. An ideal biocide would be highly toxic to specific organisms with no side effects on non-target organisms, would not be consumed by reactions with materials in the water yet would break down into non-toxic forms as soon as it enters the environment. Chlorine is a long way from this ideal in that it is non-specific and reacts with virtually all constituents of natural water forming a range of products with varying degrees of persistence and toxicity.

Historically, chlorination can be done in three ways:

- Dissolution of chlorine gas. There are transport and storage issues associated with liquid chlorine so this is not normally practiced in the power industry presently and is not employed by EDF Energy.
- Sodium hypochlorite solution, stored in tanks, with an active chlorine content of 10 to 15%.
- In situ by electrolysis of seawater, electrochlorination.

EDF EnergyGeneration nuclear power stations employ either bulk sodium hypochlorite or the in-situ generation of hypochlorite by electrolysis at its operational sites. Expanded information on the use of hypochlorite is given in Appendix F.

G1.5.2 Chloramine

Periodic dosing of chloramine has been used at a number of power stations in Belgium to control bryozoans.

G1.5.3 Chlorine dioxide

Chlorine dioxide is a potential alternative to chlorine because it produces fewer organohalogen by-products. On the other hand it produces chlorite and chlorate. It is mainly used in the pulp and paper industry but it has been tested on large marine cooling water systems in Spain and Italy. Although once regarded as a very much more expensive option than chlorination, developments in the technology involved (it is now a popular means of disinfecting drinking water) mean that it is a potentially viable alternative to electrochlorination plant.

Some doubts do however remain over the efficacy of chlorine dioxide as an antifouling agent rather than as a disinfectant. The oxidant involved is powerful and reacts aggressively on first contact with raw natural seawater. A suspicion exists that an insufficient residual persists far enough downstream of injection points to have any influence on organisms already fouling surfaces.

It cannot be condensed and liquified because of the risk of explosion. It is produced on-site from sodium chlorite, $NaClO_2$, either by oxidation with chlorine gas or acidification with hydrochloric acid. In both instances there is an element of hazard.

G1.5.4 Ozone

Ozone, which is produced on site, is a stronger oxidising agent than chlorine. However, although there is evidence that it is effective in fresh water, it is not applicable to marine cooling systems.

G1.5.5 Other oxidising substances

Bromine has been used in some freshwater cooling water systems and has certain advantage in higher pH ranges, but the natural bromine concentrations in seawater render it no more effective than established chlorination procedures, which themselves generate a bromine chemistry. As bromination is significantly more expensive than chlorination this is not a cost-effective alternative.

G1.5.6 Non-oxidising substances

There are three major groups of organic compounds used to control fouling in cooling water systems:

- Products containing isothiazolones as the toxic agent.
- Products containing quarternary amines as the toxic agent.
- Filming agents.

These tend to be used in recirculating systems and, for reasons of cost, efficacy and environmental impact, are not appropriate for direct cooled plant.

G2 References

G1 Whitehouse J W, Khalanski M, Saroglia M G and Jenner H A, 1985. The control of biofouling in marine and estuarine power stations. Collaborative (CEGB, EDF, ENEL, NV KEMA) Research Working Group Report published by CEGB North West Region. NW/R 191 9 85.

G2. Jenner H A, Whitehouse J W, Taylor C L, Khalanski M, 1998, Cooling water management in European power stations: biology and control of fouling. A manual, Hyrdoecologie Appliquee, Tome 10, Volume 1-2.

Table G1 Summary of anti-fouling methods

Process/ Treatment	Methods		Biofouling target
Water filtration	Gross filtration (>1 to 10 cm)	Grids at water intakes generally equipped with trash racks	To remove natural or artificial drifting debris at water intakes
	Fine mesh filtration (1 to 10 mm)	Rotating screens, band or drum filters at water intakes. Debris filters to protect heat exchangers. Removable grids with screens.	To remove natural or artificial drifting debris at water intakes. Stops biological debris arising from the fouled walls of the intake culverts (shells)
Mechanical cleaning	Manual cleaning	Dry or underwater cleaning of pipes and basins. High-pressure water cleaning of removable screens and heat exchanger.	To remove settled macro-biofouling. To eliminate bacterial slime on condensers or plate-type heat exchangers
	Automated cleaning systems	High-pressure water cleaning of rotating screens	To remove drifting debris from the screen
		Continuous cleaning of condenser tubes by sponge balls	To remove bacterial slime (and some scale)
		Self-cleaning debris filters	To remove biological debris produced by macro-biofouling
		Cleaning plate-type heat exchangers by vacuum suction processes.	To remove biological debris and mineral deposits
Other physical methods	High-velocity water	Increasing the water velocity above critical values dependent on the species to be eliminated	To avoid settlement of macro-biofouling
	Heat	Increasing the water temperature by recirculation for a few hours several times a year	To avoid settlement of macro-biofouling on parts of the circuit with lower water velocities
Chemical treatments	Low-toxicity paints and coatings	Applied on parts of the circuit with lower water velocities	To avoid settlement of macro-biofouling
	Chlorination with sodium hypochlorite or chloramine	Continuous treatment at a low dosage. Possibility of semi-continuous injection	To control marine macro-biofouling and bacterial slime. To eliminate *Bryozoans* in cooling tower basins
		Shock chlorination of cooling water tower basins	To eliminate green and blue-green algae

APPENDIX H: CHLORINE CHEMISTRY IN WATER

This Appendix provides background information on chlorination and estimating chlorine demand.

H1 Chemistry

Chlorination is used widely for the control of both microfouling and macrofouling in power plant cooling water circuits due to proven effectiveness, acceptable capital and operating costs, versatility of chemicals and easy adaptation for existing facilities.

Traditionally the two most common chlorination chemicals used in power plant applications have been chlorine gas and sodium hypochlorite. Because of the potential risk associated with the storage and handling of the liquid chlorine from which the gas is obtained, it is now believed not to be used in any UK utility power plant.

The addition of chlorine (or sodium hypochlorite) to fresh water results in an equilibrium mixture of hypochlorous acid (HOCl) and hypochlorite ions (OCl^-):

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$$

$$NaOCl + H_2O \leftrightarrow HOCl + Na^+ + OH^-$$

The hypochlorous acid formed is a weak acid and undergoes partial dissociation to give hypochlorite ions:

$$HOCl \leftrightarrow H^+ + OCl^-$$

The equilibrium concentrations of hypochlorous acid and hypochlorite ion are a function of the pH and temperature of the chlorinated water. Lower pH and temperatures effect higher ratios of hypochlorous acid to hypochlorite ion. At pH 7.4, the concentrations of hypochlorous acid and hypochlorite ion are approximately equal, whereas at pH 9.5, all of the available chlorine is in the hypochlorite form. For disinfection purposes, the desired form of chlorine in water is as hypochlorous acid, which is significantly more effective as a biocide than the hypochlorite ion.

The presence of ammonia in water reduces the effective dose of chlorine applied through the reaction of hypochlorous acid with ammonia to form chloramines:

$$NH_3 + HOCl \leftrightarrow NH_2Cl \text{ (monochloramine)} + H_2O$$

$$NH_2Cl + HOCl \leftrightarrow NHCl_2 \text{ (dichloramine)} + H_2O$$

$$NHCl_2 + HOCl \leftrightarrow NCl_3 \text{ (trichloramine)} + H_2O$$

The chloramines produced are weak oxidants, but can still act as disinfectants. Note that chlorine can also react with nitrogen-containing organic compounds to form organic chloramines. In this respect, free available (or free residual) chlorine is defined as that existing in water as hypochlorous acid and hypochlorite ion only. Combined available chlorine is the residual chlorine existing in water in chemical combination with ammonia or organic nitrogen compounds. Total residual chlorine is the sum of free available chlorine and combined available chlorine. The chlorine demand is defined as the difference between the amount of chlorine added to water and the amount of available chlorine remaining at the end of a specified contact period.

In seawater, chlorination results in the displacement of bromine from naturally occurring bromide, so that most of the total residual oxidant and biocidal activity is bromine based. In seawater, bromide is present in concentrations of approximately 70 mg/l Br. When bromide containing waters are chlorinated, the bromide ions are rapidly oxidised by hypochlorous acid to form hypobromous acid:

$$HOCl + Br^- \leftrightarrow HOBr + Cl^-$$

Hypobromous acid is an effective biocide, but will partially dissociate to give the hypobromite ion. The dissociation constants are such that, for a given pH value, the proportion of hypobromous acid relative to hypobromite is significantly greater than the corresponding values for the hypochlorous acid - hypochlorite system. This substantially improves the effectiveness of biofouling control. When ammonia is also present, the competing reactions of chlorine with bromide and ammonia are likely to result in the rapid formation of both monochloramine and hypobromous acid.

The main by-product of chlorination is the chloride ion, which has no environmental impact at the resulting concentration increases. Similarly, the major product from sea water chlorination will be bromide ions, i.e. the bromide is mainly returned to its original state.

H2 Chlorination by-products

The chlorination of power plant cooling systems results in the formation of undesirable halogenated organic compounds from natural organic matter present in the cooling water, such as trihalomethanes (THMs) and adsorbable organohalogens (AOXs). In sea water, hypobromous acid or hypobromite formed during chlorination will react with organic matter in the water to form bromoform and other brominated compounds.

A key understanding is that the effective toxicity of the biocide within the cooling water system is exerted primarily by the oxidants involved, but that the wider environmental regulatory interest is in the by-products - the chlorinated and brominated organic substances. Unlike the oxidants these by-products do not dissipate very quickly upon discharge to sea - some are known to be both persistent in the environment and toxic.

A consequence of this is that although TRO is a useful measure of the likely effectiveness of an antifouling regime being applied within a plant, it is of little value as a correlate of environmental harm beyond the point of discharge. Nevertheless the UK regulators consistently use this measure. Elsewhere in Europe limits are also set for key by-products, such as bromoform.

EDF Energy Nuclear Generation Ltd. has assessed the degree of by-product formation at each site and found the levels involved to be low. Comprehensive ecotoxicological assessments of this by-product loading have been completed. Further information on this can be obtained from ERO.

H3 Chlorine demand

Sea or estuarine water will exert a demand on any oxidant added to it. Thus the level of residual oxidant present in a cooling water stream will be determined by the initial dose minus that 'instantaneous' demand. Decay reactions will subsequently reduce that residual level through the cooling water system and, upon discharge, a sudden demand will again be encountered as admixture with fresh so-far unaffected water occurs. The concepts of both 'demand' and 'decay' down the variety of rapid and low flow systems involved at any one site are thus of critical importance when considering that site's dosing regime.

More detailed information on the parameters used, and the model that has been developed for EDF Energy Nuclear Generation Ltd. to describe residual oxidant demand and decay, can be found in References H1 and H2.

The cooling water requirement for a nuclear power station is around 45 m^3s^{-1} for every 1000 MWe of installed plant. Much of the chlorine dosed at the beginning of a cooling water intake is used up satisfying the chlorine demand of the organic material in the water within the few minutes that it takes to reach the condensers (Ref. 1). With seawater chlorine demands of 1 mg

kg^{-1} or more, dosing rates will be of the order of 3-5 tonne of hypochlorite solution equivalent per day for stations of this generating capacity.

At every site it will be a routine requirement to understand the background demand against which a residual level of oxidant will need to be maintained. Demand will vary with water temperature and so will change seasonally. Peaks in demand can be expected to be both tidal and related to storm events or nearby dredging activities. Excess demand will be experienced within-circuit if a significant foul, such as by mussels (which can involve heavy silt burdens), occurs. The methodology for measuring demand is described in Ref. H2.

Decay will also need to be understood, especially as the dwell time of some circuits is very much longer than that of the MCW. Again, the methodology is described in Ref. H2.

H4 References

H1 M H Davis, J Coughlan, the FARL chlorine dissipation model - a working manual, Fawley Aquatic Research Labs. paper FCR 010/92, July 1992

H2 J Coughlan, Chlorine residuals: what am I measuring? Fawley Aquatic Research Labs. paper FCR 002/91, November 1991

APPENDIX I: ANALYTICAL MONITORING METHODS

This Appendix describes the method for measuring Total Residual Oxidant (TRO), the reasons for the choice of the DPD method and a description of how it is done.

The control levels for chlorine/hypochlorite in seawater are quoted in terms of TRO (Ref. I1). An arbitrary method of measuring the residual has to be used because of the complex nature of the interaction between hypochlorite solution and seawater. TRO also has the merit of having been found to correlate directly with effective toxicity (effective toxicity being what is required of the fouling control procedure) and to have precisely the same meaning where an ECP product rather than sodium hypochlorite solution is utilised. The chosen reference method for determination of TRO uses DPD reagent and is detailed below. Any other methods used for the determination should be demonstrated to give comparable results to this reference method under the relevant circumstances.

There are two reasons for measuring and recording TRO levels routinely at operational power station sites. The first is the operational requirement, in order to prove that the necessary level of TRO is being applied to effect toxicity control over any real or potential biological fouling. The second and entirely separate reason is due to the fact that the UK environmental regulators currently prefer to use TRO as a control parameter within Consents to Discharge. These consents may not explicitly require such routine monitoring but, in order for these consents to be a valid defence from prosecution under the law, we are required under the law itself to ensure compliance. Arguably TRO may be relevant to effective toxicity within-circuit but not beyond the point of discharge: this is why elsewhere worldwide more appropriate measures of environmental impact are regulated instead, such as bromoform production or adsorbable organohalogens (AOX).

A number of commercial instruments exist on the market for the continuous monitoring of TRO. Generally, no instrument has given reliable experience in continuous measurement of low levels of TRO in a seawater matrix with varying levels of suspended solids. However, trials at Heysham 2 of an instrument which is not DPD based has proved successful and it compares favourably with the colorimetric method. More experience/evaluation is needed, consequently, the absolute reliance on continuous on-line instrumental monitoring for operational control and the demonstration of regulatory compliance is not recommended.

I1 Methods of measuring residual oxidant in seawater

In addition to sodium and magnesium chlorides, sea water contains approximately 70 mgkg^{-1} of bromide ions, 40 μgkg^{-1} of iodide, chemically reactive organic matter, and quantities of oxygen, ammonia, sulphide etc. which vary with the source of the water.

Chlorine and hypochlorite react with seawater in a complex manner. Within seconds of mixing, most of the hypochlorite has oxidised bromide ions to produce the equivalent amount of hypobromite. The hypobromite will subsequently oxidise organics and, according to the degree that ammonia is present, chloramines and bromamines will be formed. These latter reactions are relatively slow and the concentrations of the products, which change with time, depend on the initial concentration of hypochlorite and the pH of the water. With the added complexity of the flowing power station cooling water system, it is clear that a proper understanding of the dispersion of the oxidant through the plant is a necessary precursor to the selection of a suitable point for sampling for routine surveillance.

The hypochlorous acid plus hypochlorous ions (and the corresponding bromine analogues) which have not reacted further are referred to as 'residual chlorine'. Many of the further reaction products, such as the mono- or dichloramines and organic chloramines, also respond like residual chlorine to analytical procedures and are referred to as combined residual oxidants. Like hypochlorous acid they are also biotoxic to differing (and generally unquantified) extents. It is customary, therefore, to adopt an analytical procedure that merely indicates the sum of the free and combined residual oxidants or, more correctly, the total residual oxidant (TRO). There are a number of analytical methods for the determination of TRO: e.g. potentiometric, amperometric, colorimetric (DPD).

For the purposes of dosing, it is also necessary to be aware that sea or estuarine water will exert a demand on any oxidant added to it. Thus the level of residual oxidant present in a cooling water stream will be determined by the initial dose minus that 'instantaneous' demand. Decay reactions will subsequently reduce that residual level through the cooling water system. At discharge, a sudden demand will again be encountered as mixing with unaffected water occurs. The concepts of both 'demand' and 'decay' down the variety of rapid and low flow systems involved at any one site are thus of critical importance when considering the dosing regime (Ref. I2).

I2 Choice of appropriate method

The colorimetric method using DPD (N, N-diethyl-p-phenylene-diamine) shall be used for all reference measurements. This method is the most widely accepted analytical procedure for the application and is convenient for rapid analysis of unstable samples, using portable equipment. In the absence of iodide ion, free residual chlorine reacts instantaneously with DPD to produce a red colour. Subsequent addition of small amount of iodide ions acts catalytically to cause monochloramine to produce colour and addition of excess iodide evokes a further response from dichloramine. Iodide is already present in seawater, so that TRO rather than free residual chlorine is determined by this method. Any other method to be used for routine control measurements shall be proven against the DPD method as giving comparable results.

I3 DPD method of total residual oxidant analysis

I3.1 Introduction

Chlorine reacts with seawater in a complex manner giving a series of products, many of which act like chlorine to certain analytical procedures. In the case of the DPD method, the presence of iodide ions in seawater will ensure that it responds to a wide range of these materials to give an estimate of the total residual oxidant (TRO) content of the sample.

Excess potassium iodide is added with the reagent to ensure that the reaction is complete. DPD reacts similarly to free chlorine, free bromine and free iodine. The method has the advantage that it is amenable to operation using a simple portable comparator. This means that problems with the instability of the sample may be overcome by making the measurement at the point of sampling. Furthermore, the simplicity of the apparatus allows it to be used by other competent staff when chemistry staff is unavailable. The simple comparator method is given below; it is also possible to make the measurement on a laboratory colorimeter at a wavelength of 515 nm.

I3.2 Method

I3.2.1 Reagent

Reagent powders are available from a number of suppliers in pre-weighed sachets. These sachets of powder are stable for a year or more, depending upon conditions of storage. They should be discarded if the normally white powder shows brown or greasy mottling.

There are a range of reagent powders available which enable TRO or, as is the case at Hunterston B and Torness, free chlorine.

I3.2.2 Apparatus

Lovibond Comparator (e.g. Lovibond 2000), Comparator discs 3/40A (0.1 to 1 mg kg^{-1}) and 3/40B (0.2 to 4 mg kg^{-1}), Dulling screen (if used with 3/40B disc of older pattern), 13.5 mm cells, or similar.

Alternatively, the determination of Total Residual Oxidant (TRO) can be achieved using a HACH Pocket Colorimeter. This instrument is in use at a number of stations and the procedure detailed under section I2.2.2 is an extract from Reference I3.

I3.2.3 Procedure

Lovibond Comparator method:

1. Fit the appropriate disc (with dulling screen, if necessary) into the comparator.

2. Place a cell containing sample water only into the left-hand compartment behind the colour standards of the disc.
3. Rinse a similar cell with the sample. Add the reagent powder(s) to the prepared cell.
4. Allow the powder(s) to dissolve, swirling gently.
5. Make up to the 10 cm^3 calibration mark with sample.
6. Mix and place the cell in the right hand compartment of the comparator.
7. Match the red colour developed immediately, holding the comparator against a standard source of white light (e.g. a Lovibond White Light Cabinet) or north daylight.
8. Record the result as mgl^{-1} TRO.

HACH Pocket Colorimeter method:

1. A packet of DPD Total Chlorine or TRO reagent is added to the sample requiring analysis.
2. Fill a 50 cm^3 syringe with the sample and attach a 0.45μm syringe filter, clean both samples cells with the filtered water before filling one with 10ml of the seawater sample (this sample cell will be referred to as the 'blank'), cap the cell and make sure its dry. Samples must be analysed immediately and cannot be preserved for later analysis.
3. Remove the cover from the top of the colorimeter by sliding it off the instrument.
4. Place the blank in the cell holder, making sure the diamond mark on the cell faces the front of the instrument. Cover the cell with the instrument cap (flat side should face the back of the instrument). Be sure it fits tightly against the instrument.
5. Press the 'zero' button on the colorimeter. The instrument will power up and the display will show -- followed by 0.00. If 0.00 is not displayed immediately repeat the step.
6. Press 'Read' button on the colorimeter. The instrument should still display 0.00. If not repeat step 6.
7. Remove the blank from the cell holder. Fill the second sample cell with 10ml of the sample requiring analysis as in step 2. Alternatively carry out step 8 on the blank sample cell.
8. Add the contents of one DPD Total Chlorine Powder Pillow to this sample cell. Cap the cell and gently shake for 20 seconds.
9. Wait for three minutes*, and then within three minutes* after this time period, place the sample cell into the colorimeter again making sure that the diamond on the sample cell faces the keypad.
10. Cover the cell with the instrument cap. Press 'READ'. The instrument will show --- and after a few seconds the results in mg/litre total chlorine or TRO will be calculated.
11. Repeat this step until a stable measurement has been achieved.
12. After all analysis has been completed ensure that the cells are thoroughly clean and dry.

* Note the developing time and the analytical time frame will vary dependent on the reagent used to measure TRO or total chlorine

I3.2.4 Precautions

Samples to be analysed for TRO cannot be stored. Measurement should take place immediately after sampling. However, with DPD, the sample can be "fixed" with the reagent and there is little change in colour over a 15 to 20 minute period.

The DPD method was originally developed for the measurement of chlorine in fresh and waste waters. Experience over many years indicates that it may also be satisfactorily applied to seawaters. However, owing to the possible changes in composition in seawater found at any power station site with time, it is advisable to carry out recovery tests occasionally to confirm the effectiveness of the technique. These would comprise analysis of known amounts of chlorine added to seawater after the chlorine demand of the water has been satisfied.

The quantity of reagent used in the DPD tablets has been chosen to suit the respective range of chlorine concentrations covered by each Lovibond comparator disc. Samples containing higher concentrations must be diluted by chlorine free water. Concentrations of chlorine above 8 mg kg^{-1} may bleach the colour entirely and indicate an apparent zero concentration. At this concentration the smell of chlorine would be apparent. If there is any doubt about the need for dilution, the use of two tablets rather than one would remove ambiguity. A very decided increase in colour would indicate the need for diluting the sample. A measured amount of demineralised water should be placed in the cell first, before adding the reagent tablet and the requisite amount of sample, and finally topping up to the calibration mark with further demineralised water.

The HACH pocket colorimeter is factory calibrated to save the analyst time and expense in constructing their own calibration curve. Control standards should be analysed on a three monthly basis (scheduled by LIMS) to check the accuracy of this calibration curve. Control standards used are *HACH DPD - Chlorine – LR Spec Check Secondary Standards*

To perform standard check:

1. Remove the cover from the top of the colorimeter by sliding it off the instrument.
2. Wipe the control standards with a tissue and place the control standard labelled as ‘Blank’ into the colorimeter again making sure that the diamond mark on the cell is properly aligned, replace the cap and press the ‘zero’ button.
3. The instrument will power up and the display will show --- followed by 0.00. If 0.00 is not displayed immediately repeat the step.
4. Press ‘Read’ button on the colorimeter. The instrument should still display 0.00.
5. Now place the control standard labelled as ‘STD1’ into the colorimeter making sure that it is correctly aligned, replace the cap and press the ‘Read button’ until a stable measurement is achieved.
6 Repeat the above step with the other two control standards ‘STD2’ & ‘STD3’.
7. Record the instrument reading for each control standard into the LIMS system. The value of each control standard should be within the stated tolerances given on the standard box. The information held on LIMS should reflect these tolerances. When a new set of control standards are used for the first time, the LIMS administrator should be made aware of the new standard valves and tolerances. This will allow LIMS to be updated accordingly.

I4 Alternative instrumental methods - Amperometric Membrane Sensor method of total residual oxidant analysis

I4.1 The Process Instruments (Pi) HaloSense Chlorine Analyser

Heysham 2 have previously used Siemens TRO analysers in order to analyse CW chlorine concentrations. However, the small bore piping and metallic components of the instrument quickly failed due to blockages and corroded components. In order to prevent these issues, a TRO analyser was required capable of coping with sea water, microbiological films and large particulate matter. The following requirements were outlined:

- Large bore piping
- Few metallic components
- Resistance to microbiological growth
- A simple maintenance regime

- Few or no chemical reagents
- Stable, reliable and continuous analysis
- Data logging capabilities
- Data output capabilities

The Process Instruments HaloSense analyser shown below (Figure I1) has an amperometric membrane sensor which is insensitive to a change in pH, uses no reagents, is extremely stable and has reduced maintenance and reduced whole life costs. Use of amperometric sensors is accepted under US EPA method 334.0. More information can be found in the manufacturer's brochure.

The instrument was trialled at Heysham 2 to determine if the Pi instrument provided an efficient means of continuous TRO monitoring, with a view to reducing time spent below the dosing target, reducing overdosing and the associated cost of sodium hypochlorite.

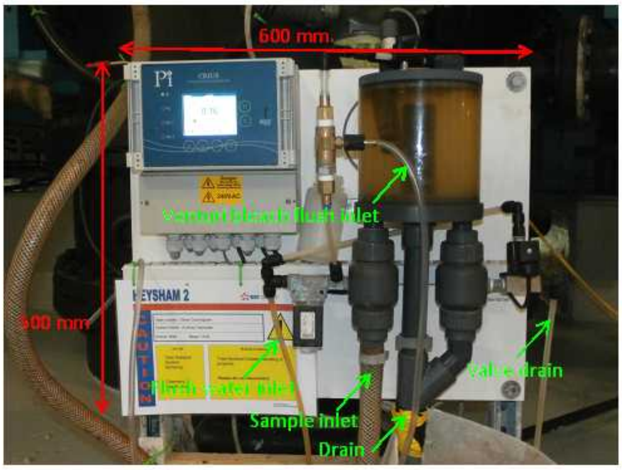


Figure I1 - The Process Instruments HaloSense Analyser

Over the course of 15 weeks, the instrument was run continuously, sampling directly from the condenser water box sampling point. During this time, weekly cross checks and/or calibrations were performed to assess the accuracy and precision of the analyser. In particular:

- CW Dosing Pump Isolation - The response time of the Pi analyser was assessed via monitoring of a decreasing sodium hypochlorite concentration, achieved by isolation of CW dosing. Data from the Pi instrument was cross checked with two HACH colorimeters. A gradual decline in TRO value was observed over 30 minutes with a range from 0.21 ppm to 0.01 ppm. Due to the nature of the bulk dosing onto the surface water in the forebay, the analyser responded as expected. The analyser reading returned to 0.21 ppm upon returning the dosing pumps to service.
- Daily Cross-checks - The Pi analyser was calibrated, and TRO results from the Pi analyser and the DPD/HACH colorimeter were compared daily for 4 weeks. Any loss of calibration over a long-term period would become evident. TRO results from the Pi analyser and the DPD/HACH colorimeter were comparable over a period of 4 weeks and were within manufacturer claimed offsets.
- Weekly Cross-checks With Calibration - TRO results from the Pi analyser and the DPD/HACH colorimeter were compared weekly for 11 weeks. The Pi analyser was re-calibrated using the reading from each cross-check. This might present an alternative mode of operation for in-service TRO monitoring. TRO results from the Pi analyser and the DPD/HACH colorimeter were comparable over a period of 11 weeks, although seemed to suggest a greater variance in data against DPD/HACH colorimeter readings when compared to the previous method.

The trial of continuous TRO monitoring at Heysham 2 with a Pi analyser highlighted an issue with single data-point checking, as carried out using the currently employed DPD/HACH colorimeter method. Data produced between May and August 2015 showed that the TRO value is dependent upon the time of sampling, or more specifically, the stage of the tide cycle. Consequently, DPD/HACH colorimeter TRO readings, individually, produce data of limited value for optimising dosing efficiency. TRO values were found to be dependent not only upon the daily tide height, but also the tidal range. 'Troughs' in TRO values were typically observed at the mid-point of an incoming tide, corresponding to a maximum rate of water flow past the forebay entrances into which the hypochlorite was dosed. Similar results had been observed from continuous Pi TRO monitoring at Heysham 1. It is possible that hypochlorite may be being drawn out of the forebays at these extremes of tidal flow.

Data obtained via the DPD method up to the summer of 2015 suggested that the amount of sediment brought in through the condenser passes, which varied according to the rate of tidal flow and dredging activities, influenced the TRO values. The effect of turbidity (particulate matter) upon TRO values would be the subject of further study. The Pi TRO instrument is unaffected by sediment and, therefore, more suited to the study of fouled waters.

Particulate is also known to cause problems with the DPD/HACH colorimeter sampling. The sample often requires filtering to remove sediment which increased the value produced by the colorimeter. Oxidant in the water sample reacts with the debris collected in the syringe filter producing artificially low values. Conversely, if the sample was not filtered (the method currently employed) high levels of particulate produce artificially high readings, resulting, in effect, a moderation or tempering of results.

As a result of the trial it was concluded that:

- The Pi TRO instrument had the required sensitivity for analysis of residual oxidant within the range of interest (0.01 – 0.21 ppm), as confirmed by a CW dosing isolation pump test.
- The Pi analyser did not lose calibration against DPD/HACH colorimeter readings over a period of 4 weeks.
- A method for continuous Pi analyser TRO monitoring with calibration against DPD/HACH colorimeter readings had been established.
- Single data point readings from the DPD/HACH colorimeter had been shown to have limited value for optimising dosing efficiency; the reading produced is dependent upon the time of sampling, or more directly, the tidal height and tidal range, translating to the rate of flow of sea water past the forebays.
- Suspended organic particulate i.e. turbidity, might account for differences between readings obtained from the Pi TRO instrument (not affected by turbidity) and the DPD/HACH colorimeter (affected by turbidity). Data is currently being collected to confirm this, and a turbidity limit may be applied when calibrating the Pi unit (Ref. I4).

I4.2 Maintenance and Calibration

At Heysham 2 the following controls have been applied as a maintenance and calibration regime:

- Seawater flow must be maintained > 500 ml/min. – daily check.

  Maintaining a clear sample inlet line free of debris is critical to the accuracy of the TRO analyser. Inlet valves must be closed/opened on a regular basis, to prevent sediment build up behind the valves and maintain inlet seawater flow into the analyser chamber containing the probe. If seawater flow out the Pi analyser drain is measured below 500 ml/min., the valves must be rodded at the condenser water box sample outlet.

- Pi instrument calibration – weekly check.

  The unit must be cross checked on a weekly basis against a TRO value produced by the DPD/HACH colorimeter method.1 If calibration is required, this is carried out as follows: The Pi analyser should be reading a stable value. This value is recorded at the time of DPD sampling. Once a value is obtained from the HACH colorimeter (after 3 mins.), if a difference is observed from the Pi analyser value noted initially, the current reading from the Pi unit must be adjusted by the difference e.g. if the value from the HACH colorimeter reads 0.22, and the Pi analyser produced a value of 0.20 at the time of DPD sampling, then 0.02 should be added to the current value from the Pi unit.

  Whilst the Pi analyser probe is ideally calibrated at higher TRO values as per the manufacturers recommendations, it has been deemed acceptable that as long as accuracy is maintained at the lower TRO threshold of 0.15 ppm, accuracy at higher values is considered less important. Higher TRO levels can be achieved temporarily by increasing the hypochlorite dosing pump stroke during which time the Pi instrument can be calibrated; there is, however, an obvious associated wastage of chemical.

If Pi analyser values are markedly and consistently different to values produced by the HACH meter even after calibration, or are unstable, the Pi probe electrolyte solution or the probe itself may need replacing.

A measurement of turbidity may in future be included into the Pi analyser calibration regime, with a set turbidity limit.

- The probe chamber must be free of organic detritus – weekly check.

  The current flush cycle program comprises of a 2 min. towns water flush every two hours, with a 5 min. post-flush data hold. If organic build-up (algae or biological film etc.) is observed within the probe chamber, a dilute bleach stream may be introduced into the flush cycle by connecting the venturi tube (Figure 1) to a 10 l drum containing 1% wt./wt. hypochlorite. The venturi flow is adjusted to draw approx. 50 ml hypochlorite solution during the 2 min. flush cycle; this can be calibrated using a measuring cylinder containing water. The bleach stream is removed once the probe chamber becomes clear of detritus. The post-flush hold may have to be lengthened to avoid recorded data spikes after the flush.

I4.3 Continuous TRO Data Analysis - Daily Reporting

A TRO data point is obtained every 5 mins. by the Pi analyser. Two methods have been defined for analysis of this data:

- Averaged daily values: the CW hypochlorite dosing pump stroke is adjusted to achieve an average of 0.175 ppm (mid point between 0.15 and 0.20 ppm). This method has been employed due to the simplicity of data processing.
- Time below the 0.15 ppm threshold: this method should perhaps be evaluated as time below the threshold translates to time at risk (mussels and barnacles etc are able to reproduce). Data processing is, however, less trivial (Ref. I4)

I5 References

I1 J Coughlan, Chlorine residuals: what am I measuring? Fawley Aquatic Research Labs. paper FCR 002/91, November 1991

I2 M H Davis, J Coughlan, the Farl chlorine dissipation model - a working manual, Fawley Aquatic Research Labs. paper FCR 010/92, July 1992

I3 HB/OTI/SWI/011/CSM/NRW/002, Issue 05, The Determination of Total Residual Oxidant (TRO) Using HACH Pocket Colorimeter, 30 March 2010

I4 Total Residual Oxidant (TRO) Analyser - A justification for use of the Process Instruments (Pi) HaloSense Chlorine Analyser, 25th August 2015

APPENDIX J: DOSING, STORAGE AND GENERATION SYSTEMS

J1 Injection systems

Hypochlorite dosing systems for both off-shore and on-shore cooling water intakes should be designed to guarantee adequate distribution and good mixing so that all the incoming water has chlorine in it by the time it reaches any part of the waterway surface. Injection points should be designed to be resistant to fouling and corrosion and to be as easily accessible as possible for examination. This may be problematic with an off-shore intake but in such circumstances routine examination of the injection point, and explicit confirmation that the intended dose is reaching that point, will be required.

The ideal layout of plant would be for serial injection points downstream from the intake point through the MCW plus parallel dosing points on all ECW/ACW/RSW limbs.

Dosing should always take place at the cooling water intake, to protect the full length of the culverts, so that break-away of settled material causing blockages may be avoided. At stations with long off-shore intake tunnels, the TRO concentrations may decay to such a low level during transit of the water that supplementary hypochlorite injection at forebays to the rotating screens may be necessary. The objective should be to maintain a TRO value of at least 200 µg kg^{-1} in all parts of the waterways without dosing an impracticably high concentration at the intake.

J2 Bulk hypochlorite storage facilities

The bulk chemical storage facilities provide strategic storage of the reagent.

Figure J1 – Photograph of a sodium hypochlorite bulk storage tank at Heysham 2

Due to the corrosive effect of sodium hypochlorite on common metals, stock tanks are normally fabricated of PVC externally reinforced with GRP, high density polyethylene or rubber lined carbon steel.

All bulk storage tanks (above) should be located in bunded areas and the tank filling points should be positioned within the bunded areas. Different chemicals should not be stored in the same bunded area. The bunds should be sized to accommodate 110% of the contents of the single largest tank within the bunded area. Facilities should be included for the controlled emptying of the bunded areas.

The chemical discharge line(s) from the tanks and mechanical forwarding pumps to the point(s) of application would ideally be double walled to contain any leakage and would be located above ground. The outer containment should be transparent so that any leakage is visible.

Figure J2 – Photograph showing the sodium hypochlorite dosing equipment - Hypochlorite is fed via double contained piping and valves to each of four dosing cubes incorporating the pump unit

All chemical discharge line(s) from the suction line of mechanical forwarding pump to the point(s) of application should be provided with suitable facilities to flush and drain chemicals from the system in a safe manner.

Adequate vehicular access should be provided to the bulk storage tanks to allow the safe access of delivery road tankers. It should be possible, with a tanker in the delivery position, to isolate the chemical delivery area from the surrounding area using barriers.

The floor drainage of the delivery area should be designed to accommodate an accidental release of chemicals during discharge to the storage tanks. The drains system should be designed to contain, or divert to a suitable receiving facility, any spillage.

Each tank should include a contents gauge. The contents gauge should be visible from the tank filling area and should include a high level alarm which, when activated, would initiate alarms locally and in the Central Control Room (CCR).

A flushing water supply should be provided at the tank filling location(s).

Adequate safety equipment (showers, eye baths) should be provided at all locations where an occupational hazard exists from chemical handling.

Activation of any safety shower should initiate an alarm in the CCR.

Care should be taken in diluting hypochlorite solutions to avoid scaling which can cause blocking of pipework and delivery nozzles.

J3 Electrochlorination plant

J3.1 Design

The upper concentration of the chlorine-equivalent generated by a seawater electrolysis unit is approximately 2 g l^{-1}. Although higher concentrations are possible with gaseous chlorine, this type of plant, which involves the storage of liquid chlorine, is no longer permitted in EDF Energy Nuclear Generation Ltd. power stations. Hence pipe layouts, pressure drops, pump ratings and buffer tank capacities must be designed to overcome this output limitation. Care is especially necessary if it is planned to dose hypochlorite selectively to a number of cooling water circuits. This may occur, for example, when changing over from dosing at cooling water intake to continuous or sequential dosing at condenser inlets for microfouling control during the winter.

Electrochemical cells operate more efficiently the higher the temperature of the influent water. Cells designed with warm-water anodes should have alternative sources of seawater supply at 15 °C or greater or they may be unable to operate when the condenser circuit which provides this water is out of commission. At stations where a warm seawater supply is not available, special low-temperature cells will need to be installed to avoid restrictions on the supply of product during the winter and early summer. Special care should be taken to ensure that the seawater supply lines to the electrochlorination plant are not themselves subject to fouling.

Figure J3 – Photograph of an electrochlorination plant

The main seawater strainer, filters and control valves of electrolysis units should be capable of by-pass operation or should be doubled up to provide ease of maintenance without loss of product supply. Cells and pipework should be of modular, flanged design so that minor faults, to which this type of plant is prone, do not result in shutdown of the whole system for maintenance.

J3.2 Maintenance

Continuous dosing regimes are sub-acute toxic systems, i.e. they are not primarily aimed at killing the fouling organisms but at limiting their growth. Nevertheless, continuous dosing at 200 μg.kg^{-1} TRO will eventually kill adult mussels but it may take of the order of 6 months. The mussels have the capacity to close up in the face of biocide dosing; they will not feed and change over to an anaerobic metabolism. They will continue to do this during periods of continuous chlorination but if the dosing is stopped they will quickly revert to an aerobic metabolism. This means that after two days without chlorination, the mussels will have recuperated and the 6 months of dosing required to kill them starts again. This has important implications for the reliability and maintenance regimes for electrochlorination plant.

Best practice for maintenance of electrochlorination plant is to carry out maintenance that prevents dosing either (i) during plant shutdowns when dosing is not required, or (ii) when the sea water temperature is below 10 °C. If this is not possible then outages should be kept as short as is practicable, preferably less than 24 hours.

In recent years, both Dungeness B and Sizewell B have requested dispensations to allow outages for planned maintenance during the winter months to improve reliability in the summer. These have been supported with the caveats that the length of outage is minimised and reliability monitoring is used to demonstrate the benefit of these outages

In consultation with CTO SQEP, between January 1st and March 31st each year, planned maintenance work on the Hypochlorination/Electrocholrination plant is permitted in a single outage of not more than 28 consecutive days. The outage period should be kept to the minimum practicable period and subsequent reliability of these systems should be monitored to demonstrate the effectiveness of such maintenance compared with plant performance.

J3.3 Optimisation of performance

There are a number of factors that should be considered in seeking to get the best performance from electrochlorination plant. These include:

- Not mixing new electrodes with old on the same bank.

- Ensuring that electrodes are connected up properly and that the polarities are not reversed.
- Considering the use of hydrocyclones on feed supply to keep sediment levels down.
- Taking advantage of local reconditioning facilities for used electrodes.
- Considering new in-pipe electrolysis units for point dosing rather than adding lots of long runs of small bore piping to the system.

J3.4 Operating Experience

J3.4.1 Sodium Hypochlorite inventory vs dosing requirements

Hartlepool dose hypochlorite from bulk storage tanks supplied by tanker. Several CRs have been raised since 2011 regarding the stations ability to maintain an adequate stock of sodium hypochlorite to continuously dose the CW system since the introduction of the COMAH regulations which limit the storage of a maximum of 50te of hypochlorite on site. Hartlepool is a lower tier COMAH site (CR 653237, 659334, 666852, 695248, 696831,722023, 724178, 729471, 732271, 750632, 751538, 764282, 765580, 772104, 834245, 835391, 842082, 843300, 880017, 935891). The consequence of all these events is an increased risk of CW system marine fouling, loss of condenser and cooler performance etc.

J3.4.2 Electrochlorination plant problems

Heysham 1 and 2 and Hartlepool discontinued the use of their electrochlorination plant in favour of bulk tankered supplies due to reliability surmounting costs of maintenance and lack of spares. Other stations with electrochlorination plants experience similar difficulties with stations categorised as high risk being particularly vulnerable.

Sizewell B have experienced a wide range of difficulties and CRs raised since the beginning of 2013 illustrate this. Key problems include defective cells, transformer cables and disentrainment tank level indication. The following CRs refer: (CR 940499, 930874, 930338, 929670, 925311, 921616, 919680, 914771, 911865, 899210, 891310, 882618, 882432, 881101, 879592, 879406, 877393, 868074, 846128, 842539, 841251, 832529, 818214, 801411, 790035, 789143).

Dungeness B have also experienced a wide range of difficulties and CRs raised since the beginning of 2013 illustrate this. Key problems include transformer rectifiers, low pressure to pumps, defective cells and strainer blockages (CR 944686, 930271, 892303, 885511, 877818, 877706, 876023, 875597, 874116, 872969, 869003, 867929, 843944, 867446, 792465).

J3.4.3 Auxiliary system dosing

Both Heysham 2 and Hunterston B have experienced difficulties in maintaining adequate dosing to their RSW and RCW systems respectively but in recent times both stations have adopted the use of softened water to dilute the Sodium Hypochlorite prior to injecting it into the system. This reduced the potential for crystalline materials to form and block the injection point and has proved highly successful.

Hunterston B

CR 950031 (6 August 2015) For the majority of a week free chlorine residual in the main CW system was in the range of 0.10 - 0.15ppm and <0.10 in the RCW system (outwith target limits of 0.15 - 0.3ppm).

CR 841062 (10 October 2013) For the majority of a week there was a number of occasions when hypo residual in main and RCW systems was outwith target values. The, system was re-primed on a number of occasions to help with dosing pump performance due to air ingress and dosing pumps/hypo flow optimised so to achieve free chlorine residual targets. System now performing as expected.

CR 682052 (17 June 2011) RCW residual chlorine levels were lower than the turbine condenser outlet levels, and sometimes below required dosing level (<0.150 mg kg^{-1} TRO).

Heysham 2

CR 804352 (26 March 2013) Prior to 26 March 2013 there were multiple occurrences of non-compliance with BEOM 006 requirements for RSW hypochlorite dosing. This increased the potential for fouling of RSW system and associated heat transfer impairment of coolers. Whilst the mechanism of poor compliance is not understood, performance monitoring data over recent years strongly suggests that dosing arrangements are adequate for macrofoulling control.

CR 578152 (8 December 2009) The TRO level on Unit 7 and U8 RSW system was last in BEOM recommended levels in August 2008. The temporary dosing on Heysham 2 does not provide any significant dose to the RSW system.

J3.4.4 Dosing rates not being adjusted when plant affecting cooling water flow is altered.

There have been a number of events which have resulted in excessive dosing with a potential to breach Discharge Consents. These events relate to changes in seawater pump status with no consequential change in dosing pump status. The following CRs illustrate this.:

Heysam 1 – CR 945990 (11 July 2015) Elevated hypo level on the ECW 'B' main in the turbine hall. It was discovered that the MCW hypochlorite dosing system was running without an associated MCW pump in service.

Sizewell B – CR 686783 (12 July 2011) Investigation showed that dosing pump 3 was in-service at 100% pump stroke with the corresponding CW pump (2A) being out of service. The dosing pump was immediately taken out of service. Higher levels than normal of chlorine were found in the 2A drumscreen forebay.

Hunterston B – CR 661851 (26 February 2011) During the once weekly winter dosing of CW with sodium hypochlorite it was noted that the residual chlorine was at an elevated level of 0.46 mg kg^{-1}. The expected target for residual in the system is 0.15-0.25 mg kg^{-1}. It was discovered that TG7 CW had been taken out of service thus lowering flow and in turn raising dosing quantity.

Dungeness B - CR 586745 (28 January 2010) Aat the syphon recovery, residual chlorine was found to be 0.6 mg kg^{-1} against an action level being 0.5 mg kg^{-1}. Nominal levels are 0.15 to 0.25 mg kg^{-1}. The significant rise in this level was attributed to isolation and shut down of one MCW pump, leaving only one MCW pump in service. The reduction in flow requires less input from the electrochloriation plant.

Heysham 1 – CR 553857 (18 March 2009) When hypo dosing pump 1 was taken out of service, pump 2 was set to deliver sufficient dose to compensate for its unavailability. When pump 1 was returned to service, no readjustment of pump 2 was made. Consequently, when chemistry personnel checked TRO it was found to be 0.44 mg kg^{-1}. The Discharge Consent set by the EA is 0.5 mg kg^{-1}.

J5 Alternative dosing systems

J5.1 Mixed Oxidant (MOS)

MIOX is the name of a company based in the USA specialising in electrolysis. They consider themselves to be an electrochemical cell development company and market the equipment that produces a mixed oxidant (known as 'MOS') of sodium hypochlorite and hydrogen peroxide. This is said to be more effective as a biocide than Sodium Hypochlorite alone with less undesirable chlorinated by-products. The Mixed Oxidant (MOS) is generated electrolytically from brine by way of the following reaction.

$$NaCl + H_2O \rightarrow NaOCl + H_2 \text{ and } O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$$

Peroxide is generated from the hydrogen gas produced by the hypochlorite generating unit. A significant cost is the sodium chloride which needs to be high purity and ideally demineralised water should be used to preserve electrolytic cell life and reliability. MIOX claim that the only products of the MOS cells is hypochlorous acid and hydrogen peroxide (95:5) with the concentration hydrogen peroxide at approximately 100 to 200 ppm. The normal level of hypochlorous acid is approximately 1%, which is below the COMAH limit. The MOS cell produces hypochlorite at approx. 0.5%

J5.2 Chlorine Dioxide

Chlorine Dioxide is generally produced by the reaction of a metal chlorite or chlorate based salt with an acid or acid containing ion exchange resin:

Sodium Chlorite Electrolysis or Catalysed Ion Exchange

$$NaClO_2^- + H^+ \rightarrow H + ClO_2^- + Na^+$$

Sodium Chlorite / Hydrochloric Acid

$$5\ NaClO_2 + 4\ HCl \rightarrow 4\ ClO_2 + 5\ NaCl + 2\ H_2O$$

Sodium Chlorate / Sulphuric Acid

$$2\ NaClO_3 + H_2O_2 + H_2SO_4 \rightarrow 2ClO_2 + Na_2SO_4 + O_2 + 2\ H_2O$$

The predominant technology in use within the water treatment market is the acidification of Sodium Chlorite based precursors based on the first two reaction schemes above. Patented technology has been developed for the on-site generation of chlorine dioxide using a single precursor blend of Sodium Chlorate and Hydrogen Peroxide. This offers large water treatment users with ClO_2 requirements greater than 1 kilo per hour to access the lower operational costs offered by use of chlorate based precursors.

As a result of this innovation, ClO_2 it is claimed that this technology is cost-competitive with electrochlorination, Hypochlorite and Bromine based treatments (Ref.J1). See also Appendix F.

J6 References

J1 Cameron, A., Callachan, G.D., ClO_2 Treatment of Seawater Handling Systems Known Effects of Oxidising Biocides vs. The Unknown Risks of Microbially Induced Corrosion

APPENDIX K: SUMMARY OF CURRENT PRACTICE FOR INDIVIDUAL STATIONS

K1 Normal operation

The current regimes adopted by each station (as of 2011) are given In Table K1. The dosing regime is based on the fouling risk level described in more detail in Table K1. Table K1 also contains information on:

- Surveillance.
- Means of dosing (sodium hypochlorite solution or electrochlorination plant).
- Points of action for the dosing.
- Analysis requirements.

Station	Risk Category	Regime	Dosing	Points of dosing	Analysis	Surveillance
Dungeness B	High	Continuous.	Hypochlorite solution generated by ECP.	Seaward end of the CW intake.	TRO measured daily (5 days a week) at forebay and seawater return	Accessible parts of the CW system are inspected when out of service/stat outage. Sludge/mussel banks removed from forebays. Condenser waterboxes are inspected and cleaned as required based on performance. ECW seawater system can be back-flushed. Trash baskets and drum screens inspected
Hartlepool	High	200 μg.kg^{-1} TRO all year round. Biocide dosing stopped for approximately three hours per day to allow ferrous sulphate dosing to take place.	Hypochlorite solution supplied by bulk tanker ~14% solution from corporate supplier	Both sides of MCW screen chambers and ECW pump suction. New dosing system has 2 pumps per drumscreen	TRO measured at condensers and in ECW system on a daily basis (5 days/week)	Accessible parts of the CW system are inspected when available.
Heysham 1	High	Continuous level of 200 μg.kg^{-1} TRO in front of the condensers all year round	Hypochlorite solution supplied by bulk tanker	Both sides of MCW screen chambers and ECW pump suction.	Aim for daily TRO measurement at the condenser inlet and appropriate ECW heat exchanger	Accessible parts of the CW system are inspected when available.
Heysham 2	High	Continuous.	Hypochlorite solution supplied by bulk tanker at 14% FAC.	Into forebays. Into RSW suction legs.	TRO measured 5 days a week at the condenser inlet and RSW strainer inlet. Also monitored 3 times a week at ACW inlet. EA surveillance once a week at the CW/RSW outfall.	Accessible parts of the CW system are inspected at statutory outages. Heat exchangers are inspected in between stat outages to assess risk and the condenser performance is used as an indicator. Spat monitors are located at the CW intake but are not used.

Table K1: Current practice for normal operation

Station	Risk Category	Regime	Dosing	Points of dosing	Analysis	Surveillance
Hinkley Point B	Low	Chlorination is not carried out	Not Applicable	Historical dose point was at seaward end of the CW intake.	Not Applicable	Annual ecological survey of the foreshore adjacent to Hinkley Point to detect any marked changes in the composition and fouling potential of organisms in the vicinity. Performance monitoring of condensers and other coolers undertaken
Hunterston B	Moderate	Seasonal dosing. Continuous dosing whenever entrained cooling water temperature > 10 °C. Dosing stops when the sea temperature drops below 10 °C in the winter. During winter, CW systems are dosed one day in seven to prevent micro-fouling.	Sodium hypochlorite solution (14.5% available chlorine in water)	CW stream immediately on entrainment within the intake culvert (facility located adjacent to the intake jetty).	Free Chlorine is measured at the main condenser outlet and the RA or PVCW h/ex 5 days per week during the summer dosing regime and once per week during the winter dosing regime.	Accessible parts of the CW system are inspected at statutory outages

Table K1 (continued): Current practice for normal operation

Station	Risk Category	Regime	Dosing	Points of dosing	Analysis	Surveillance
Sizewell B	High	Continuous dosing. Dosing to maintain a continuous level of 200 μgkg^{-1} TRO at condenser inlet	Hypochlorite solution from ECP	At the seaward end of the CW intake (inlet tunnel). Also the facility for point injection into the ACW and ESW systems, and main CW pumps (drum screens)	TRO measured weekly at Forebays and drum screen , 7 days/week at condenser inlets, ESW, ACW and CW discharge	All accessible parts of the CW system inspected when out of service. Accessible parts of the CW system are inspected during statutory outages
Torness	High	Continuous level of 200 μgkg^{-1} TRO at the condenser inlet all year round	Sodium hypochlorite solution (ca. 15% in water])	Sodium hypochlorite is dosed to the MCW stream immediately up- stream of the fine band screens. Dosing is linked to the main CW. If main CW pump is tripped, dosing pumps associated with that screen chamber are also tripped to prevent over-dosing. Targeted dosing was discontinued as it proved to be too unreliable	Free Chlorine is measured at the condenser inlet and the RSW outlet chambers 5 days a week	Accessible parts of the CW system are inspected during statutory outages. Condenser performance is monitored. Any evidence of fouling during routine maintenance of cooling water systems is reported

Table K1 (continued): Current practice for normal operation

APPENDIX L: LEGISLATION AND REGULATION

This Appendix provides information on the environmental/regulatory framework that EDF Energy Nuclear Generation Ltd. operates in. It is recommended that power station representatives contact Generation Environment Management (GEM) in Barnwood for advice on current and future regulation.

A complete list of all environmental legislation that is relevant to EDF Energy Nuclear Generation Ltd. can be found in the Register of Legislation (BEG/SPEC/SHE/ENVI/002) (Ref. L1). This specifies the requirements under ISO 14001:2004, as well as those specific to separate environmental legislation. It is a legal requirement to remain compliant with the conditions found in each site specific discharge consent/permit. Any failure to do so may result in criminal prosecution.

For further guidance and information on the management of non-radiological liquid discharges to controlled waters please refer to BEG/SPEC/SHE/ENVI/006 (Ref. L2).

L1 Regulatory issues

L1.1 BAT

Continuous low level chlorination of the cooling water has been chosen as the ‘Best Practicable Environmental Option’ and ‘Best Available Technique’ (BAT) within EDF Energy Nuclear Generation Ltd for the control of biological fouling. The chosen fleet approach is explained further in this BEOM. Robust arguments can be presented to the regulators in support of the use of low-level chlorination, its behaviour in sea water is well characterised and it is of proven efficacy against macro- and micro-fouling. BAT is discussed in Environment Agency sector Guidance Notes and/or IPPC BREF (Ref. L3) documents. Further advice and information on this can be sought from the Marine Specialist (GEM) or the relevant SQEP personnel in Chemistry and CO_2 Oxidation Group, Barnwood.

L 1.2 Management of change

Should a station suspect the need to alter its regime under this BEOM, or see opportunity for further limiting/increasing the use of biocide, the technical detail of this should be discussed and agreed with both GEM and the relevant SQEP personnel in Chemistry and CO_2 Oxidation Group, Barnwood, before any change is made (as this has implications on BAT and compliance with the BEOM).

With respect to potential alterations to discharge effluents, BEG/SPEC/SHE/ENVI/006 (Ref. L2) contains more details on how to manage a change in chemical use and associated regulatory requirements. Likewise, should there be a significant change in legislation GEM will advise stations accordingly.

L 1.3 Permissions

Stations should ensure that, no matter what dosing regime is currently employed; permission to discharge up to the levels defined in the default methodology is specified and maintained in Consents to Discharge granted by the Environment Agency (EA) in England and Scottish Environmental Protection Agency (SEPA) in Scotland. These consents are regulated under the Environmental Permitting Regulations 2010 (EPR) in England and The Water Environment (Controlled Activities) (Scotland) Regulations 2011 in Scotland (Refs. L4 and L5).

Also, stations (or their agent, Supply Chain) should ensure that the vendors of biocidal products have ensured compliance with existing UK legislation (under the EC 'Biocidal Products Directive', Reach Regulation (EC) No 1907/2006 (as amended)) (See Section L3 for more details).

L1.4 Environmental Management System

Stations should, under the ISO 14001:2004 (Environmental Management System) standard, consider the storage, use and subsequent discharge of all biocides under the Aspect Identification and Scoring Process (BEG/SPEC/SHE/ENVI/011) (Ref. L6).

The wastes (including solids) that result from physical cleaning of cooling water systems should be considered in a similar manner and disposed of in an appropriate way (as specified by BEG/SPEC/SHE/ENVI/005) (Ref. L7).

L2 UK regulations subsidiary to EC law

Three fundamental principles have become established in recent years.

(i) *Sustainability*. A working definition is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' The sustainable development approach is contributing to pressure to move away from the use of chemicals that are persistent or give rise to persistent by-products.

(ii) The precautionary principle. A subset of sustainability that argues for conservative decision making where a risk of harm may, in the absence of information to the contrary, be presumed.

(iii) The principle of *Polluter pays* seeks to make polluters such as industry responsible for its emissions and liabilities.

Member states of the EU implement Directives through national legislation and regulation. A major piece of EC Directive that seeks to cover pollution prevention and the control of chemical discharges is the Water Framework Directive (see section L3.3 below for more details). Again, details of relevant legislation to EDF Energy Nuclear Generation Ltd. sites can be found in BEG/SPEC/SHE/ENVI/002.

Such legislation seeks to control water pollution at a number of levels:

- by controlling specific products in the market;
- by controlling specific practices within industrial sectors;
- by controlling the release of specific hazardous substances to the environment by discharge;
- by defining environmental quality objectives and associated standards.

These regulatory controls have a direct effect on the use of biocides in cooling water and are further explained in section L3. Advice on these can be sought from SQEP personnel in Chemistry and CO_2 Oxidation Group, Barnwood, and GEM.

L3 Other controls

L3.1 Market controls

L3.1.1 Biocidal Products (Amendment) Regulations 2010

These regulations amend the Biocidal Products Regulations 2001 (SI 2001 No.880) to further implement Directive 98/8/EC (the Biocides Directive) concerning the placing of biocidal products on the market. The Amendment Regulations extend by a further four years the transitional period when active substances used in biocidal products can be reviewed and considered for inclusion in Annex 1 of the Biocides Directive.

The European Commission has published a proposal to revise the Biocidal Products Directive (98/8/EC). This Directive, which came into force on 14 May 1998, aims to harmonise the European market for biocidal products/ active substances and to provide a high level of protection for humans, animals and the environment. HSE is the UK Competent Authority for Biocides. Regulation of the revision applied in Member States from 1 September 2013.

In relation to the control of biofouling as specified under BEOM006, the following summary is of interest;

- We are only able to use a biocide if it is provided to us, and registered as such, as a biocide under the regulations.
- The bulk of the compliance requirement rests with the supplier, who has to first register the products involved and provide comprehensive portfolios of the environmental consequence of its use, in every intended scenario. In practice this means that some chemicals previously used as biocides will become unavailable.
- An oddity of the regulations is that they apply to the precursors of a biocide if that biocide is created in situ. The most obvious example is chlorine dioxide, where it is not chlorine dioxide itself that will be registered but its precursors - sodium chlorate and sulphuric acid.
- The HSE understanding of in-situ biocide generation does not include the electrochlorination of seawater, so use of ECP is not currently covered by the Directive or the UK regulations.

L3.1.2 REACH

REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) came into force on 1 June 2007. It brings together in a single framework a number of EU Directives & Regulations. It provides controls on marketing on a wide range of chemicals including biocides and contains provision for certain substances covered by the Biocidal Products Regulations (Any active substance on Annex I or IA of the Biocidal Products Directive, or any active substance that is in the review programme are regarded as being registered under REACH). The registration process is phased over several years.

As with the Biocidal Products Regulations, the onus is on the manufacturer to ensure registration but equally we should not procure unregistered products.

L3.2 Storage and Control of Major Accidents - COMAH

Control of Major Accident Hazards Regulations 1999 came into force on 1 April 1999 and was amended by the Control of Major Accident Hazards (Amendment) Regulations 2005 (Ref. L8). COMAH applies mainly to the chemical industry, but also to some storage activities, explosives and nuclear sites, and other industries where threshold quantities of dangerous substances identified in the Regulations are kept or used.

The company specification BEG/SPEC/SHE/COP/037 Control of Major Accident Hazards (COMAH) (Ref. L9) covers EDF Energy specific arrangements and management.

The purpose of this Code of Practice (COP) is to ensure that policy and processes are in place to:

a) prevent/control a chemical major accident,

b) pursue continuous improvement, and,

c) comply with the Control of Major Accident Hazard (COMAH) regulations.

For further advice or guidance please refer to this document or to SQEP personnel in Chemistry and CO_2 Oxidation Group and GEM, Barnwood.

L3.3 Water Frameworks Directive

The Water Framework Directive (2000/60/EC) (WFD) sets out requirements for the European Commission to propose further laws to protect against water pollution. Two 'daughter' directives, one aimed at protecting groundwater, the second aimed at reducing pollution of surface water (rivers, lakes, estuaries and coastal waters) by pollutants on a list of priority substances, have been adopted at European level.

The WFD took over from the Dangerous Substances Directive (76/464/EEC) when it was repealed in 2013. Dangerous Substances have been split between those identified as Specific Pollutants or Priority Substances (see below).

The WFD is designed to improve and integrate the way water bodies are managed. It came into force on 22 December 2000, and was put into UK law (transposed) in 2003. Member States must aim to reach 'good chemical and ecological status' in inland and coastal waters by 2015 subject to certain limited exceptions. It is designed to:

- enhance the status and prevent further deterioration of aquatic ecosystems and associated wetlands which depend on the aquatic ecosystems
- promote the sustainable use of water
- reduce pollution of water, especially by 'priority' and 'priority hazardous' substances
- ensure progressive reduction of groundwater pollution

The WFD provides wide ranging protection to designated 'water bodies' which includes all waters of interest to EDF Energy Nuclear Generation Ltd. Specifically;

- This includes 'good chemical status', which will require that the Environmental Quality Standards (EQS) proposed for 'chlorine' is achieved at the edge of a mixing zone
- And 'good ecological status', which will require that the ecology is not adversely affected by the discharge (as a result of all impacts) and that compliance with WFD objectives is maintained.

UK Technical Advisory Group (UKTAG) on the Water Framework Directive provides expert guidance on the above (Ref. L15).

Requirement to achieve the quality required for Protected Areas. These include areas afforded protection for both ecological and commercial reasons:

- Areas designated for the protection of economically significant species (e.g. shellfish)
- Designated Recreational Areas including Bathing Waters
- Areas designated for protection of habitats or species, including Natura 2000 sites (under the Habitats Directive, Ref L11).

It is likely that EA and SEPA would seek to achieve any change relating to chlorination or its products required for WFD purposes through the existing regulatory mechanisms (i.e. variations of discharge consents). Many of EDF Energy Nuclear Generation Ltd.'s plant discharge cooling water into or near Natura 2000 sites (such as Special Protection Areas (SPAs), Special Areas of Conservation (SACs) or Ramsar sites). An assessment of the potential for the discharge to adversely affect such a site may arise, deemed by the Competent Authority to trigger 'Appropriate Assessment'. A wide variety of issues may be assessed including the potential for bio-accumulation of chlorination by-products and the potential for associated ecological impacts which in principle could lead to restrictions on chlorination. Under these circumstances EA H1 Guidance should be followed (Ref. L14). The technical detail of any such cases arising should be discussed with the Marine Specialist (GEM).

L3.3.1 Priority Substances (and Priority Hazardous Substances)

The Directive on Environmental Quality Standards (Ref. L12) (EQSD), also known as the Priority Substances Directive, sets EQS for the substances in surface waters (river, lake, transitional and coastal) and confirms their designation as priority or priority hazardous substances.

Concentrations of Priority and Priority Hazardous Substances in water must meet the WFD environmental standards by 2015 in order to achieve 'good chemical status'. In addition Priority Hazardous Substances emissions must be phased out by 2025. To protect human health and the environment the concentration of Priority Substances must be limited. Priority Substances are harmful substances. Priority Hazardous Substances are a subset of these and are considered extremely harmful.

A daughter directive on Priority Substances is being developed and will introduce the environmental standards for Priority and Priority Hazardous Substances. The list of Priority Substances will be reviewed regularly by the European Commission. Priority Substances and their environmental standards are likely to be reviewed using ecological monitoring data at the end of the first River Basin Planning cycle in 2015. The proposed Daughter Directive on environmental standards is available on the European Commission website (Ref. L13).

Should regulatory inquiries into by-product generation and EQS occur locally, stations are advised to contact GEM.

L4 Eels (England and Wales) Regulations 2009

Reference L16 sets down NGL's planned response to the Eels (England and Wales Regulations 2009 (SI 2009/3344), and satisfies, in part, Improvement Conditions attached to EPR RSR permits for the six EDF Energy nuclear power stations in England. The precise wording, of these ICs, which this report satisfies, is as follows:

The Operator shall provide the Environment Agency a report detailing progress to date and a programme of work (to meet the 30 September 2014 deadline) by 30 September 2013.

NGL believe that the programme of work detailed in this report, and the progress made against it, constitute 'best endeavours' within the context of the short timescales for delivery, the current and historic uncertainties in delivery of the Eels Regulations, and NGL's riskbased investment process.

L5 References

L1 BEG/SPEC/SHE/ENVI/002 - Register of Environmental Legislative, Regulatory and Other Policy Requirements

L2 BEG/SPEC/SHE/ENVI/006 - Management of Abstractions from and Discharges to Controlled Waters and the Water Environment

L3 EIPPCB, 2001, 'Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems', European Integrated Pollution Prevention & Control Bureau, Seville, Dec 2001

L4 SI 2010/675 The Environmental Permitting (England and Wales) Regulations 2010. Amended by SI 2010/676 and SI 2010/2172

L5 SSI 2011/ 209 The Water Environment (Controlled Activities)(Scotland) Regulations 2011

L6 BEG/SPEC/SHE/ENVI/011 - Environmental Aspect Identification and Scoring Process

L7 BEG/SPEC/SHE/ENVI/005 - Management and Disposal of Non-Radioactive Waste

L8 SI 1999/743 Control of Major Accident Hazard Regulations 1999 (COMAH) (as amended by SI2005/1088 and SI2008/1087).

L9 BEG/SPEC/SHE/COP/037 Control of Major Accident Hazards (COMAH)

L10 The Water Framework Directive (2000/60/EC)

L11 Conservation of Natural Habitats and of Wild Fauna and Flora (the Habitats Directive) (92/43/EEC)

L12 Directive on Environmental Quality Standards (Directive 2008/105/EC)

L13 http://ec.europa.eu/environment/water/water-dangersub/pri_substances.htm

L14 EA Horizontal (H1) Guidance - http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

L15 UK Technical Advisory Group website - http://www.wfduk.org/tag_guidance/GuidancePapers/view

L16 ERO/REP/0082/GEN - Progress Against the Requirements of the Eels (England and Wales) Regulations 2009 (SI 2009/3344)

APPENDIX M: DOCUMENT WORKING GROUP MEMBERS

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Fiona Davidson	Chemistry Group Head/Station Chemist	HNB (HU01116)
Douglas McMillan	Chemistry Group Head/Station Chemist	TOR (TO00043)
Simon Patterson	Chemistry Group Head/Station Chemist	HPB (KKEAAD6)
Jim Roberts	Chemistry Group Head/Station Chemist	HYA (DDABE4F)
Andrew Wilson	Chemistry Group Head/Station Chemist	HRA (DDSTU75)
Georgina Billson	Chemistry Group Head/Station Chemist	DNB (DNB0942)
Reb Salar	Acting Chemistry Group Head/Station Chemist	SZB (HYB0123)

APPENDIX N: TECHNICAL GOVERNANCE IMPLEMENTATION PLAN

Document Information

Implementation Plan Overall Owner:	Station Chemists (or delegate)
Document title:	The Control of Marine Fouling
Document reference number:	BEG/SPEC/ENG/BEOM/006
Fleet Lead / Discipline Chief:	Andy Rudge
Document author:	Carl Atkinson/Chris Eley
Doc. Production Working Group:	Chemistry Peer Group
Superseded document:	BEG/SPEC/ENG/BEOM/006 Rev 002
Stations affected by document:	All AGR and PWR Stations
Priority within TG Programme:	***Medium***

Business Impact on Station

The station Engineering Manager is responsible for overall ownership of this implementation plan.

It is anticipated that this document will have a Minor impact.
It is a revision of an existing document.

The boxes below state the responsible person and anticipated resource requirements for the implementation of the required activities, as agreed by the document working group.

Required activities	**Owner**	**Impact estimate**	
		Internal/ Man-days	**External/ £k**
Gap Analysis	Station Chemist	1 mdays	
Implement compliance activities (e.g. update procedures, carry plant mods)	Station Chemist	2 mdays	
Fleet self assessment	N/A	N/A	N/A

Improvements from Document	**Description**
Estimated Equipment Improvement / Risk Reduction	Three-yearly review incorporating details of alternative biocidal methods, a new monitoring method, other minor changes and updating to new CTS document format.

Staff Awareness

Which of the following method of notification will be used to make staff aware of the documents release?

E-mail	Yes	Team brief	Yes
Meeting (Station PHC)	No	Document brief	Yes
Workshop	No	Intranet announcement (SSH)	No

Record Updates

The following records relating to BEG/SPEC/ENG/BEOM/006 will need to be checked and updated as necessary.

Associated document references	Uncontrolled copies stored at station
Internet/Intranet Links	Uncontrolled copies stored by users

Suggested Implementation Actions and Timescales

No	Mandatory Requirement Details	Proposed Actions	Proposed Action Owner	Guideline Timescales	Business Impact	Requirement Justification
		Become aware of the following: The BEOM is now in CTS format which includes the concept of numbered requirements. Requirements in bold are mandatory. There has been significant structural change. The supplements to the tables are now individual to each station/station pair and are located immediately after the table for that station.	Station Chemist	End 2015	1 manday	None
1	A strategic risk assessment of the prevalent biofouling risk at each specific site shall be undertaken every 3 years	There are no changes to the level of risk for any station (E/EAN/BPKB/0218/GEN/14 refers). ***All STNs*** *Station chemist to confirm, but no change to current practice is required.*	Station Chemist	End 2015	1 manday	Commercial/Nuclear Safety
2	Stations shall adopt and comply with, all mandatory requirements of the dosing strategy commensurate with the level of risk identified in Tables 2 and 3.	There are no changes to the level of risk for any station (E/EAN/BPKB/0218/GEN/14 refers). ***All STNs*** *Station chemist to confirm, but no change to current practice is required.*	Station Chemist	End 2015	1 manday	Commercial/Nuclear Safety
3	In according with their dosing regime, Station shall monitor and comply with all control parameter requirements presented in Table 4. Control parameters are identified in bold.	Undertake gap analysis against current status, taking note of the following changes: ***All STNs*** There are changes to the detail of Action Level 1, and Action Level 2 has been deleted.	Station Chemist	End 2015	1 manday	Commercial/Nuclear Safety

No	Mandatory Requirement Details	Proposed Actions	Proposed Action Owner	Guideline Timescales	Business Impact	Requirement Justification
4	Any proposed operational changes to Tables 2-4 shall be endorsed using the chemistry dispensation process	Undertake gap analysis against current status, taking note of the following changes: ***All STNs*** There are changes to the detail of Action Level 1, and Action Level 2 has been deleted.	Station Chemist	End 2015	1 manday	Commercial/Nuclear Safety
5	The Station Chemist (or nominated deputy) shall be informed when any chemistry excursion leads to entry into an Action Level, and a Condition Report raised, when any chemistry excursion leads to entry into an Action Level for three days or more	(i) Undertake gap analysis against current status. Station chemist to confirm, but no change to current practice is expected, If this is not the case then; (ii) Address identified shortfalls to enable compliance to be declared (or complete dispensation form).	Station Chemist	End 2015	None	Commercial/Nuclear Safety
6	Where separate chemical control of microfouling is necessary, a dosing regime shall be implemented to control it.	(i) Undertake gap analysis against current status. Station chemist to confirm, but no change to current practice is expected, If this is not the case then; (ii) Address identified shortfalls to enable compliance to be declared (or complete dispensation form).	Station Chemist	End 2015	None	Commercial/Nuclear Safety
7	Contingency plans, detailing necessary actions and time scales, shall be available at all stations in the event of the loss of ability to dose or a significant change in the biofouling potential	(i) Undertake gap analysis against current status. Station chemist to confirm, but no change to current practice is expected, If this is not the case then; (ii) Address identified shortfalls to enable compliance to be declared (or complete dispensation form).	Station Chemist	End 2015	None	Commercial/Nuclear Safety

APPENDIX O: COMPANY TECHNICAL STANDARD DOCUMENT SPECIFICATION

Document Specification for Company Technical Standards	
Document title:	The Control of Marine Fouling
Document reference:	BEG/SPEC/ENG/BEOM/006
Document type:	Company Technical Standard (CTS)
Mandatory Requirements Justification:	All mandatory requirements should be suitably justified in accordance with the requirements set down in section 1.1 of the CTS template. Mandatory requirements may be derived from: a. Previous documentation. b. Past experience of EDF Energy's Power c. Best practice from other operators, e.g. EPRI, WANO, INPO d. Consideration of commercial implications e. Legislation f. External codes of practice or standards
Parent/Child BERL Risk:	N/A
Technical Policy:	Conduct of Chemistry at Nuclear Power Stations, BEG/SPEC/OPS/067
New/Revision Document:	Revision
Document Impact:	Minor
Responsible Group:	Chemistry Peer Group
Task File:	E/TSK/GEN/5680
Task Engineer:	Carl Atkinson
Key Responsibilities:	• Complete this Document Specification • Update Doc Spec to include Working Group comments • Produce the TG document • Draft Generic implementation plan • Address Verification/Fleet Lead/Working Group comments
Chief Chemist:	Andy Rudge, Chief Chemist
Key Responsibilities:	• Ensure adequate SQEP resources to author and verify the document • Ensure this Document Spec is accurate and in line with the document requirements • Distribute Specification to the Working Group • Distribute TG document and draft Generic Implementation plan to the Working Group • Co-ordinate and chair the Working Group • Mediate conflicting comments on the document content and escalate to the Chief Discipline Engineer, as appropriate • Approve the document in Passport on behalf of the Working Group
Working Group Member: (Review of Spec / Implementation Plan)	**HPB:** Simon Patterson **HNB:** Fiona Davidson **DNB:** Georgina Billson **HRA:** Andrew Wilson **HYA:** Jim Roberts **HYB:** Oliver Cunningham **TOR:** Douglas McMillan **CTO:** Chris Eley **Chief Engineer:** Andy Rudge
Planned Issue Date:	September 2015
Background:	The purpose of BEOM 006 is to specify the mandatory requirements for the control of marine fouling due to sessile organisms (such as mussels) and biofilms, present guidance on best operational practices and to summarise the underlying technical principles. It supersedes the advice given in EDF Energy Nuclear Generation's BEG/SPEC/ENG/BEOM/006 Rev 001 (Ref. 1).

Scope of document / proposed content:	This BEOM applies to all EDF Energy Nuclear Generation Ltd. stations. It defines the best practice for the chemical control of marine fouling on these sites. This BEOM only considers the control of actual biological settlement on surfaces; no consideration is given to the effects of impingement (e.g. shell, jellyfish, fish or weed impingement on screens). It covers both normal operation and shutdown conditions. This BEOM does not constitute a safety case. Care has been taken in the production of this document to ensure that any safety case commitments have been appropriately addressed. If a safety case commitment is found to be more onerous than this BEOM, then the safety case shall take precedence. Any inconsistency between a safety case and this BEOM should be raised via a Condition Report directed in the first instance to the custodian of this document. This BEOM does not specify the monitoring requirements required by the individual sites to demonstrate compliance with their specific Consent to Discharge. Mandatory aspects of the document are identified in bold text. A series of appendices provide more detailed background information on CW system deign (Appendix A), the nature of biofouling (Appendix B), the consequences of it and EDF Energy Nuclear Generation Ltd.'s approach to managing the risks of biofouling (Appendix C), practical considerations for the application of a biofouling control strategy and current practices for individual stations (Appendices D – K) and the regulatory considerations (Appendix L).
Expected / Proposed Mandatory Requirements:	As per Revision of BEG/SPEC/ENG/BEOM/006
Exclusions:	None
Document Specific References:	Technical references will be identified as required during production.
Relevant Good Document Examples:	N/A
Prerequisites:	For producing and revising documents the Task Engineer shall have read and become familiar with BEG/ICP/ENG/SH/001 (Technical Governance) and BEG/SPEC/DAO/SH/001 (Technical Governance Documentation Production and Approval) and BEG/ICP/DM/003 (Document Control).
Process:	Documents shall be produced and revised following the procedures set down in BEG/ICP/ENG/SH/001, BEG/SPEC/DAO/SH/001 and BEG/ICP/DM/003. All documents shall be produced using the approved Technical Governance document templates, referenced within the process specification.
Implementation Plan:	A Generic Implementation Plan will be produced in parallel with the CTS. The Generic Implementation Plan will be produced by the author for approval by the appointed Working Group.
Additional information:	N/A
Agreed with Working Group:	Yes
Agreed with Discipline Chief Engineer:	Yes
Records of agreement should be stored in the document task file.	

DISTRIBUTION LIST

Role	**Name**	**User ID / Alert Group**
Technical Governance Project Team		CDO-TGV-040
Technical Governance Chief Engineer	Dave Armstrong	LLPAS1O
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TG Station Point of Contact – Heysham 1	Stephen Blackshaw	DDABE2J
TG Station Point of Contact – Heysham 2	Ian Crabtree	OOE2I05
TG Station Point of Contact – Torness	Stuart Cunningham	TO02600
TG Station Point of Contact – Sizewell B	Frances Hitchcock	BBEAR09
Station Chemist – Hunterston B	Fiona Davidson	HU01116
Station Chemist – Hinkley Point B	Simon Patterson	KKEAAD6
Station Chemist – Dungeness B	Georgina Billson	DNB0942
Station Chemist – Hartlepool	Andrew Wilson	DDSTU75
Station Chemist – Heysham 1	Jim Roberts	DDABE4F
Station Chemist – Heysham 2	Oliver Cunningham	HEY0542
Station Chemist – Torness	Douglas McMillan	TO00043
Station Chemist – Sizewell B	Rebwar Salar	HYB0123
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Engineering Manager – Dungeness B	David Brown	TO01055
Engineering Manager – Hartlepool	Richard Howarth	LLPAS1I
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Operations Manager (Hartlepool)	Darren Bentham	LLPAS78
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Operations Manager (Torness)	Alastair Brockie	PK01052
Operations Manager (Sizewell B)	Gavin Lancaster	BBBAC38