Environment Agency

Evidence

Nuclear power station cooling waters: evidence on 3 aspects

SC170021/R1

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Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

http://www.gov.uk/government/organisations/environment-agency

ISBN: 978-1-84911-426-4

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Dissemination status:
Publicly available

Keywords:
Cooling water; permitting; impingement; entrainment; behavioural deterrents; USEPA; assessment models

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SC170021

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

New nuclear power stations planned at coastal or estuarine sites in the UK will have a large demand for waste heat removal. Abstraction of high volumes of cooling waters from the sea or estuaries for this purpose has an impact on fish and other aquatic organisms through entrapment and entrainment in the process.

Cooling water discharges are controlled in accordance with permits that are issued by the Environment Agency. As specified in the National Policy Statement for Nuclear Power Generation (EN-6) (DECC 2011), applicants for those permits are expected to demonstrate the use of Best Available Techniques to minimise the impacts of cooling water discharges.

In 2010 the Environment Agency published a review 'Cooling Water Options for the New Generation of Nuclear Power Stations in the UK' in preparation for the government's production of the National Policy Statement for Nuclear Power Generation (DECC 2011). The progression of proposals for new nuclear power stations since then has continued and it is prudent to update the 2010 report. Following a scoping study outlining areas of interest, a thorough review of the more recent literature on the following 3 subjects was conducted:

- fish behavioural deterrent systems
- decisions on cooling waters taken by other environmental regulators
- fisheries and other aquatic biota impact assessment

This report presents the findings and conclusions from this review.

Methodology

Each piece of literature identified for review, and the evidence within it, was critically evaluated in line with the Government Chief Scientific Adviser's 'Guidelines on the Use of Scientific and Engineering Advice in Policy Making'. A qualitative scoring method to assess the confidence for each piece of evidence identified was developed based on:

- **Quality of information sources** – such as whether the evidence is based on peer-reviewed papers, grey literature or expert judgement and whether the evidence is presenting primary, secondary or synthesised data
- **Applicability of evidence** – such as whether the evidence is based on similar activities, scales of abstraction, environments, fish species or regulatory paradigms
- **Strength of conclusion** – considering whether the evidence draws clear conclusions on the direction and magnitude of impact, efficacy and international opinion/practice and so on

Each aspect was scored using High, Medium or Low confidence criteria. The wider evidence base for the 3 subjects was assessed using the same confidence criteria to give an overall assessment of the confidence for each subject. High confidence is where a permitting decision could be advised with a high level of confidence that the available evidence is sufficient to inform the assessment, or that decisions made by other international organisations are applicable and transferrable to the UK regulatory situation. Medium or Low confidence requires varying levels of uncertainty management and/or additional mitigation to make a permitting decision, and the decisions made by other international organisations are not directly transferrable or require additional evidence and consideration to be transferrable.

The evidence review also collected input via a project-specific questionnaire from a number of international experts including representatives from the USA, the Netherlands and Germany as well as UK experts with international experience.

Key findings: Fish behavioural deterrent systems

Regulators can have **Medium** confidence in the evidence:

- on the ability to site and install available and suitable systems in onshore and offshore environments
- on the effective operation, safe maintenance and reliability of a system in onshore and offshore environments and at the scale required for a new nuclear power station in the UK and over the lifetime of the station
- that systems are effective for fish protection in onshore and offshore environments under different environmental conditions

Key findings: Decisions on cooling waters by other environmental regulators

- Regulators can have **High** confidence that cooling water developments in other countries are sufficiently comparable with the UK's new nuclear industry for their regulatory decisions to be considered a relevant evidence base
- Regulators can have **Medium** confidence that the rationales for decisions made in other countries for the purpose of reducing entrainment and impingement of aquatic biota are comparable with the UK permitting framework
- Regulators can have **Low** confidence in the evidence on the potential implications of the decisions made by other environmental regulators

Key findings: Fisheries and other aquatic biota impact assessment

- Regulators can have **Medium** confidence that models are available to satisfactorily assess impacts from cooling water on fish stocks including considering new intake and screen technologies, and long-term stock/ecosystem level implications
- Regulators can have **Medium** confidence that model input data and their associated uncertainties are available sufficient for use
- Regulators can have **Low** confidence that the available models are validated with empirical monitoring data

Recommendations

These seek to develop and expand the evidence base available for the 3 topics and to improve confidence. They can be summarised as follows:

- early provision of evidence on proposed behavioural deterrent systems
- sharing of currently unavailable evidence on behavioural deterrent systems
- further analysis of the effect of entrainment and impingement on populations (both alone and cumulatively for a number of projects)
- collation of a database of appropriate robust data and guidance on assessment methods and models to ensure consistency in assessments and the provision of sufficient detail

- steps to validate impact assessment methods to improve predictions of effects.

Acknowledgements

The authors would like to thank the representatives of various organisations who attended the workshop on 28 April 2018 to discuss the current state of knowledge in the subjects covered by this report. Their expertise, information and questions have helped to shape the approach adopted by this report and to highlight areas of particular interest.

The authors would also like to thank the international experts who contributed to the study through the completion of questionnaires:

- Steve Amaral, Alden Research Laboratory Inc.
- Maarten Bruijs, Independent Consultant
- Paul Geoghegan, Normandeau Associates Inc.
- Marq Redeker, CDM Smith Consult GmbH
- Richard Seaby, Pisces Conservation Ltd

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1 Introduction

New nuclear power stations planned at coastal or estuarine sites in the UK will have a large demand for waste heat removal via cooling waters. Abstraction of high volumes of cooling waters from the sea or estuaries for this purpose has an impact on fish and other aquatic organisms through entrapment and entrainment in the process. Habitats and species found adjacent to the planned sites normally have high levels of designation and require protection.

Under the Environmental Permitting Regulations (England and Wales) 2010, specified industrial processes with the potential to cause pollution or environmental harm are required to operate under permits that are designed to protect the environment and reduce any pollution they may cause. Cooling water discharges for new nuclear power stations are controlled in accordance with permits that are issued by the Environment Agency. As specified in the National Policy Statement for Nuclear Power Generation EN-6 (DECC 2011), applicants for those permits are expected to demonstrate the use of Best Available Techniques (BAT) to minimise the impacts of cooling water designs. For the Environment Agency to be effective in this permitting role, it is necessary for it to:

- continually review and evaluate the latest scientific evidence
- consider how advances in technology and the decisions of other international environmental regulators may help inform the thinking in permitting decisions

The European Commission's review of Best Available Techniques (BAT) for industrial cooling systems culminated in the 'Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems' (European Commission 2001). This BAT reference document (BREF) includes a discussion on the environmental aspects of industrial cooling systems and applied prevention and reduction techniques. The document also examines the risk of fish entrapment (entrainment and impingement) and sets out the BAT approach to the reduction of the entrapment of organisms.

In preparation for the government's production of a 'National Policy Statement for Nuclear Power Generation' (EN-6) (DECC 2011), the Environment Agency published the review, 'Cooling Water Options for the New Generation of Nuclear Power Stations in the UK' (Environment Agency 2010). This report considered current knowledge on the engineering, siting and environmental issues likely to be of importance for a new generation of nuclear power stations with a large requirement for cooling. A specific aim of the review was to assess the validity of the BREF's statement that direct cooling was BAT following challenges in the UK with regard to the Pembroke combined cycle gas turbine (CCGT) power station, and in the USA by Riverkeeper, Inc. under the Clean Water Act s.316(b). The review concluded that 'direct cooling may be the best environmental option for large power stations sited on the coast or estuaries, subject to current best planning, design and operational practice and mitigation methods being put in place' (Environment Agency 2010, p. v.).

The development in technologies since the 2010 review meant there was a need to revisit some aspects of that report, particularly considering:

- biota protection methodologies
- emerging technologies
- experience in the installation, operation and maintenance of these technologies

Given their size, the majority of intakes for nuclear power stations in the UK are likely to be required to be sited in deeper water offshore locations. In 2017, the Environment Agency initiated a project to conduct a review of:

- the available biota protection methodologies for large-scale cooling waters in use or development in the UK and around the world
- any changes since the 2010 Environment Agency cooling water options report

As some information is held commercially and some new information may be unpublished, a scoping study was conducted to identify available information. The scoping report provided a comprehensive list of literature available in the public domain on mitigation measures for biota entrainment at large cooling water intakes (Environment Agency 2018).

The scoping report considered 14 different topic areas and briefly discussed the publically available information, current issues and applicability to the UK new build nuclear power stations. The topic areas were:

- optimising cooling water intake siting for minimising impacts on aquatic biota
- intake head designs: engineering practice
- approach/escape velocity
- fish behavioural deterrents
- cooling water system tunnels: pressure change effects
- forebay and screenwell design, including hydraulic conditions
- onshore screening, including fish recovery facilities
- fish return launders and discharge head design
- fish lift pumps: ensuring fish friendliness for appropriate fish recovery and return dependent species
- biofouling control, implications for fish return and recovery and fish risk assessment protocols
- cooling water systems downstream of fine screens
- monitoring and assessment protocols for fish recovery and return facilities
- monitoring and assessment protocols for fish deterrent effectiveness
- updated methods for fisheries impact assessment:
    - equivalent adult value (EAV)
    - equivalent area of lost production (EALP)

Two aspects from this scoping review were considered to be of high current interest, but the quality of evidence available on which to inform permitting decisions was unclear. In addition, the recent approach of the United States Environmental Protection Agency (USEPA) to restrict once-through cooling options in favour of recirculating/closed cooling systems required examination to understand the evidence on which this approach was based and whether it had any relevance to the UK regulatory situation. Consequently, 3 subjects are reviewed within this document:

- fish behavioural deterrent systems (Section 3.1)
- decisions on cooling waters taken by other environmental regulators (Section 3.2)
- fisheries and other aquatic biota impact assessment (Section 3.3)

This report aims to build on the findings of the cooling water options report (Environment Agency 2010) using the literature collated in the scoping report (Environment Agency 2018) to provide an update in available evidence since 2010 pertinent to the new nuclear power station permitting process for these 3 aspects.

A full review of the remaining 12 topics of the 14 considered in the scoping report is planned, which will incorporate the findings of the 3 subjects covered in this report. It is expected that this future full review will be published to provide one document bringing together all the updated information on biota protection in large-scale cooling water systems applicable to nuclear power stations in the UK.

2 Methodology

When reviewing current information on any subject, it is important to summarise and present the pertinent evidence within the available research that will help to identify issues, solve problems and promote evidence-based decision-making. This approach ensures that:

- the science and evidence are appropriately weighted in the decision-making process and for informing policy
- the science used by government is robust, relevant and of high quality

An evidence review needs to be open and transparent, and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.

This project sought to:

- conduct an independent review of existing data and research sources on the following 3 key topics relating to cooling water applications for new nuclear power stations:
  - fish behavioural deterrent systems
  - decisions on cooling waters taken by other environmental regulators and fisheries
  - other aquatic biota impact assessment
- assess the confidence that can be placed in the existing evidence

2.1 Literature selection

A list of literature to be considered for the review was produced as part of the 2018 scoping study. This list was supplemented as appropriate by members of the Environment Agency and contractor's project team, as well as through discussions with industry partners.

It was only possible to consider papers and documents within this review that were available in the public domain. Other documents relating to specific developments or case studies were unfortunately not available for this review for one of several reasons.

- They were still in draft form and subject to change.
- They might contain sensitive information on the development.
- The study was incomplete.

Further information pertinent to this review may therefore become available over time.

It is hoped that the methods by which the literature is examined in this report can be used as an approach to critique future literature and that this body of evidence can remain present for future applications.

2.2 International expert consultation

One recommendation from the Government Chief Scientific Adviser's 'Guidelines on the Use of Scientific and Engineering Advice in Policy Making' (Government Office for Science 2010) is that consideration should be given to consulting experts from outside the UK. This is

particularly true where UK policy may affect other countries or where other countries may have valuable experience in the policy being considered.

The experience of other countries is of particular value to this project, as demonstrated by one of the important areas of its project scope being to review 'decisions on cooling waters taken by another environmental regulator'. Although this primarily relates to the US decision-making process, information from other countries may also be relevant to the UK.

A number of international experts were consulted during the course of this study. Experts included representatives from the USA, the Netherlands and Germany as well as UK experts with international experience. Their input was collected through the use of a project-specific questionnaire. The template questionnaire and the completed forms from each expert are provided in Appendix A. Brief overviews of the received information for each topic are provided in the individual topic discussions in Section 3.

2.3 Individual evidence scoring

Each key document identified for review was critically evaluated in line with the Government Chief Scientific Adviser's guidelines (Government Office for Science 2010). The approach taken was as follows:

- A general summary of the document is presented.
- Key pieces of evidence within the document were identified and described.
- A confidence assessment was made for each document as a whole using the criteria set out below.
- Where appropriate, if the document covered a number of differing key pieces of evidence, confidence was assessed for each piece of evidence.
- The potential implications of uncertainty (or a wide range of expert opinion) within the evidence base for policy decisions was indicated.
- Emerging findings on the 3 topics since the Environment Agency (2010) review were identified.
- Any mechanisms for managing the uncertainty within the evidence base were recommended as appropriate and where possible.

This assessment allowed the identification of high quality and robust evidence to inform decision-making from a wide range of expert advice sources.

A number of methods are available to conduct an assessment of confidence in an existing evidence base to inform decision-making. The confidence assessment method developed for this study follows a matrix-based approach similar to other studies within the marine environment such as Pérez-Domínguez et al. (2016) and Tillin and Tyler-Walters (2014). This approach was reviewed by the Environment Agency project team and was consulted on with a wide range of experts from the Environment Agency, Natural England, Natural Resources Wales, the Marine Management Organisation and the Inshore Fisheries and Conservation Authorities at a workshop held in April 2018. The minutes of this workshop are provided in Appendix B.

The matrix-based approach used for this study applies a qualitative scoring method based on 3 aspects of confidence in evidence as listed below:

- **Quality of information sources** such as whether the evidence is based on peer-reviewed papers, grey literature or expert judgement, and whether the evidence is presenting primary, secondary or synthesised data.
- **Applicability of evidence** such as whether the evidence is based on similar activities, scales of abstraction, environments, fish species or regulatory paradigms.
- **Strength of conclusion** – considering whether the evidence draws clear conclusions on the direction and magnitude of; impact, efficacy, international opinion/practice and so on.

These 3 aspects of confidence and the criteria against which the evidence was assessed were developed with regard to Government Chief Scientific Adviser's Guidelines on the Use of Scientific and Engineering Advice in Policy Making (Government Office for Science 2010). The confidence rules and scoring criteria proposed for this study are set out in Table 2.1. A score of Low (1), Medium (3) or High (5) was given to each piece of evidence in relation to each of the 3 aspects of confidence.

Table 2.1 Criteria for the assessment and scoring of confidence in individual pieces of evidence

Confidence level	Quality of information source	Applicability of evidence	Strength of conclusion
High score = 5	Evidence is: • peer-reviewed or by an unbiased established expert organisation on the subject, or • based on mature, primary and up-to-date evidence which is unbiased • targeted towards answering the question and supported by robust statistical analysis	All or primary aspects of the evidence are based on: • similar activities • similar scales of abstraction • similar environments • similar fish species • validated UK conditions, or • regulatory paradigms	Evidence draws clear conclusions on: • the direction and magnitude of impact, efficacy or opinion/practice Confidence and uncertainty transparently discussed.
Medium score = 3	Evidence is based on: • potentially biased grey literature or well-documented expert judgement, or • emergent primary or mature secondary up-to-date evidence which may have some bias that can be identified and managed • studies not targeted towards the question or not statistically robust but which add to the evidence base	Some aspects of the evidence are based on: • similar activities • similar scales of abstraction • similar environments • similar fish species • validated UK conditions, or • regulatory paradigms	Evidence draws clear conclusions on: • the direction but not magnitude of impact, efficacy or opinion/practice Confidence and uncertainty partially discussed or alluded to.
Low score = 1	Evidence is based on: • expert judgement or grey literature which is not well-documented, or • historic, secondary or synthesised data and may not represent the status of current technology or policy/opinion Study is not targeted towards the question or is not statistically robust, and so does not meaningfully add to the evidence base. Study contains bias that cannot be effectively managed.	Few or no aspects of the evidence are based on: • similar activities • similar scales of abstraction • similar environments • similar fish species • validated UK conditions, or • regulatory paradigms	Evidence does not draw clear conclusions (or possibly any conclusions) on: • the direction or magnitude of impact • efficacy or opinion/practice Confidence and uncertainty not discussed.

2.4 Subject area scoring

For each of the 3 topic areas considered, a matrix was produced which scored the confidence in the evidence base to inform a permitting decision (Tables 2.2 to 2.4).

The scoring system is based collectively on all the evidence reviewed for that subject. A score of Low (1), Medium (3) or High (5) was given to each technical category and aspect of confidence. A traffic light system was applied to this scoring for easy visual interpretation: Low (red), Medium (amber) and High (green). Finally the individual scores were totalled to provide an overall confidence for each technical category: Low (<6), Medium (6–12) and High (>12). A brief commentary provided alongside the overall scores provides a justification of the scores selected.

The subject scoring matrices include a new confidence category. The **degree of concordance** is the level to which the evidence base agrees on the direction and magnitude of the conclusions. If there is no concordance between all of the data sources, however, exclusion of those with low or medium confidence from the evidence base may be recommended (as appropriate) provided the sources with high classifications for other confidence aspects are all consistent.

The potential implications of the different total scores are as follows.

For the 2 technical topics under review (fish behavioural deterrent systems and fisheries and other aquatic biota impact assessment):

- **High**. A permitting decision could be taken with a high level of confidence that the available evidence is sufficient on which to base an assessment to inform a permitting decision.
- **Medium**. Some precaution, clear presentation and management of uncertainty and inclusion of additional mitigation may be required to have sufficient confidence in the assessment to make a permitting decision. May require additional evidence.
- **Low**. Considerable precaution, management of uncertainty and mitigation are likely to be required based on the current state of the available evidence base for an assessment to inform a permitting decision.

For the review of decisions made by other international organisations:

- **High**. There is a high level of confidence that decisions made by other international organisations are applicable and transferrable to the UK regulatory situation, and can be considered within permitting decisions.
- **Medium**. There are aspects of the evidence that are not applicable or transferrable to the UK situation (for example, the evidence is site or species specific or the regulatory mechanism does not accommodate the approaches promoted in the UK). So although the evidence provides useful context for permitting decisions in the UK, caution is required in relying on its conclusions.
- **Low**. There are significant aspects of the evidence that are not applicable or transferrable to the UK situation (for example, the evidence is site or species specific, or the regulatory mechanism does not accommodate the approaches promoted in the UK).

Table 2.2 Confidence criteria: fish behavioural deterrent systems

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance
Evidence on the ability to site and install available and suitable systems in onshore and offshore environments with consideration of nuclear safety requirements	Evidence will be scored on: • its sources and potential for bias • whether it is hypothetical design information or is from existing installation experience and existing manufactured equipment • whether it is up-to-date information • whether it is primary, secondary or synthesised evidence	Evidence will be scored on: • whether it is representative of the nuclear cooling water industry in the UK • if sufficient information is available for onshore and offshore installations under different environmental conditions • whether it provides enough evidence to satisfy the nuclear safety requirements	Evidence will be scored on whether: • it agrees on the direction and magnitude of the availability, suitability, complexities and feasibility of installing fish behavioural deterrent systems in onshore and offshore environments • these systems can comply with nuclear safety requirements
Evidence on effective operation, safe maintenance and reliability of a system in onshore and offshore environments and at the scale required for a new nuclear power station in the UK and over the lifetime of the station	Evidence will be scored on: • its sources and potential for bias • whether it is hypothetical operation information or is from existing operation experience • whether it is up-to-date information • whether it is primary, secondary or synthesised evidence	Evidence will be scored on: • whether it is representative of the nuclear cooling water industry in the UK in particular the scale of abstraction required • if sufficient information is available for onshore and offshore operation and safe maintenance under different environmental conditions • whether it provides enough evidence to satisfy the nuclear safety requirements	Evidence will be scored on whether: • it agrees on the direction and magnitude of the complexities and feasibility of operating and maintaining fish behavioural deterrent systems in onshore and offshore environments at the scale required for new nuclear power stations in the UK and over the lifetime of a station

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance
Evidence that systems are effective for fish protection in onshore and offshore environments under different environmental conditions	Evidence will be scored on: • its source and potential for bias • whether it is modelled efficiency estimates or is experience from existing operating systems • whether it is coincidental evidence or from a targeted question • whether it is up-to-date information • whether it is primary, secondary or synthesised evidence The length of the monitoring data series will also be considered to determine the efficacy of systems over the long term.	Evidence will be scored on: • whether it is representative of the nuclear cooling water industry in the UK • in particular the scale of abstraction required and the different types of intake configurations and screens under consideration • if sufficient information is available for onshore and offshore operation under different environmental conditions	Evidence will be scored on whether: • it agrees on the direction and magnitude of the efficacy of fish behavioural deterrent systems for protecting fish at new nuclear cooling water intakes in onshore and offshore environments under different environmental conditions

Table 2.3 Confidence criteria: decisions on cooling waters taken by other environmental regulators

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance
Are cooling water developments in other countries sufficiently comparable with the UK new nuclear industry for their regulatory decisions to be considered a relevant evidence base?	Evidence will be scored on: • whether there is sufficient information to determine the comparability of the industries on which the international decisions were based and the UK new nuclear industry The sources of the evidence and any potential bias will be considered.	Evidence will be scored on whether: • the industries on which international decisions have been made are representative of the new nuclear cooling water industry in the UK	Evidence will be scored on whether: • it agrees on the extent and direction of how comparable the industries on which international decisions have been made are to the new nuclear industry in the UK
What are the rationales for decisions made in other countries (for example, compliance with environmental regulation, protection of specific fish species, non-fish related drivers) and are they comparable with the UK permitting framework?	Evidence will be scored on: • whether there is sufficient information to determine the comparability of the rationales on which the international decisions were based and the UK permitting framework for the new nuclear industry. The sources of the evidence and any potential bias will be considered.	Evidence will be scored on whether: • the international decision-making rationales are representative of the UK permitting framework for the new nuclear cooling water industry	Evidence will be scored on whether: • it agrees on the extent and direction of how comparable the rationales on which international decisions have been made are to the permitting framework for the new nuclear industry in the UK
Is there any evidence available on the implications of decisions made by other environmental regulators (for example, a reduction in new development applications, or objections from developers)?	Evidence will be scored on: • whether there is sufficient information to determine if there have been any implications of international decisions The sources of the evidence and any potential bias will be considered.	Evidence will be scored on whether: • any identified implications are relevant to the UK new nuclear cooling water industry	Evidence will be scored on whether: • it agrees on the extent and direction of how relevant any identified implications from international decisions may be to the UK new nuclear industry

Table 2.4 Confidence criteria: fisheries and other aquatic biota impact assessment

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance
Are models available to satisfactorily assess impacts from cooling water on fish stocks including considering new intake and screen technologies, and long-term stock/ ecosystem level implications?	Evidence will be scored on whether: • there is sufficient information on potential available models for cooling water impact assessment • the models have been developed specifically for this purpose or if they have been adapted from other applications The level of impacts that could be detected by the models and their suitability for new nuclear cooling water fisheries and other aquatic biota impact assessments will also be considered.	The application of the models and evidence base to UK new nuclear cooling water impact assessment will be assessed in terms of comparable: • industries • environmental conditions • intake/screen designs • fish species • fish stock sizes and so on	Evidence will be scored on whether: • it agrees that models are available and suitable for the assessment of impacts from new nuclear cooling water in the UK at a species or ecosystem level
Are sufficient model input data and their associated uncertainties available for use?	Evidence will be scored on whether: • the input data required for the models is available and suitable for this application, and, • uncertainty can be considered and quantified. This will include consideration of fish stock/life history parameters and impingement/ entrainment fish survival data in particular.	Is the evidence base applicable to UK new nuclear cooling water impact assessments in terms of comparable: • fish species • fish stock sizes • cooling water conditions (for example, mechanical, temperature, pressure and chemical stressors) • potential new nuclear cooling water models • environmental conditions • intake/screen designs	Evidence will be scored on whether: • it agrees on the types, volumes and accuracy of data required for the models • uncertainty is considered within existing model outputs • there is agreement on the direction and magnitude of uncertainty • there is agreement on the reporting and management of uncertainty

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance
Are the available models validated with empirical monitoring data?	Evidence will be scored on whether: • models have been validated with empirical monitoring and the nature of the monitoring Where validation has been undertaken and reported, the strength of the monitoring design and any statistical analysis will be considered.	The applicability of the validation examples to UK new nuclear cooling water impact assessments will consider: • industry • environmental conditions • onshore/offshore location • scale of abstraction • intake/screen designs and so on	Evidence will be scored on whether: • model outputs agree with empirical monitoring data where available in terms of the direction and magnitude of impact

3 Evidence review

3.1 Fish behavioural deterrent systems

3.1.1 Introduction

The BREF for industry cooling systems identified direct cooling as BAT for large power plant cooling systems (European Commission 2001). However, a key specification for once-through cooling to be BAT in rivers and/or estuaries was that 'cooling water intake is designed aiming at reduced fish entrainment' (European Commission 2001, p. 125). Entrainment in this instance is considered to be the combined effect of impingement and entrainment, now termed 'entrapment'. The guidance goes on to state that:

> 'from the applied or tested fish protection or repulsive technologies, no particular techniques can yet be identified as BAT' (European Commission 2001, p. 128).

However, the fish behavioural deterrent systems and studies of their operation and efficacy on which this judgement were based are now outdated, with the most recent reference being from 1997.

Positive physical exclusion screening (that is, physical screening of an intake prior to the point of water entry to the intake) was considered to be BAT for fish protection in the 2010 cooling water options document (Environment Agency 2010). However, it was acknowledged that it was unlikely to be considered to be viable for nuclear cooling water systems. This is especially the case in hostile offshore environments, where the viability of physical screens has not been tested; there is blockage risk and access for maintenance is difficult. Best practice for coastal sites was therefore determined to consist of a combination of fish recovery and return (FRR) and acoustic fish deterrent (AFD) systems. The combination of 'mitigation measures' was specified to provide sufficient protection of behaviourally insensitive but robust species through the FRR system and hearing-sensitive and delicate species with the AFD system. The 2010 report pointed out that, at the time the BREF was produced, behavioural deterrents were largely restricted to the use of bubble curtains (Environment Agency 2010).

The Environment Agency 2010 report provided an update on the 'biota exclusion and deflection techniques' that were available and had been reported on at that time.

- **Air bubble curtains**. A curtain of bubbles is used to deflect fish from coming into close proximity of the intake. The only operational installation reported on was the system at the Heysham A and B plants described in Turnpenny (1993).
- **Velocity control**. A 'velocity cap' is installed over the intake to eliminate vertical velocity components that pose a risk to fish; Sizewell B was reported on as an example from Turnpenny and Taylor (2000). However, the low velocity side entry was presented as a conceptual design and no installations were available to report on.
- **Acoustic fish deterrents and strobe lights**. AFD and strobe light systems are operated at a number of cooling water sites around the UK to deflect fish away from intakes. A number of AFD case studies were reported on including Doel nuclear station in Belgium, Fawley oil-fired power station, Shoreham CCGT, Great Yarmouth CCGT, Marchwood CCGT, Staythorpe CCGT and the Lambton plant in Canada. No existing strobe light

installations were presented, though the proposed Pembroke CCGT which is now in operation was mentioned.

The recent scoping study (Environment Agency 2018) provides overviews of a number of more recent fish deterrent installation studies including:

- a literature review of behavioural deterrents by Noatch and Suski (2012)
- a review of primary and grey literature on the effectiveness of light stimulus to deflect downstream migrating eels (EPRI 2017)

The Doel nuclear power station study (Maes et al. 2004) was, however, reported as the primary study on biota deflection efficiency trials for cooling water systems. Studies on the application of similar deterrent systems for other purposes were also considered (Bowen et al. 2009, Ruebush et al. 2012, California Department of Water Resources 2014).

An update on the available literature on fish deterrent systems, syntheses of the information available and assessment of the level of confidence in the evidence base is given below.

3.1.2 Documents reviewed

Fish protection at cooling water intake structures – 2012 update (EPRI 2013)

This technical reference manual from the Electric Power Research Institute (EPRI) in the USA is a review of fish protection technologies and their biological performance for use at power plant cooling water intake structures. Different categories of fish protection technologies were investigated including:

- physical barriers
- collection systems
- diversion systems
- behavioural guidance technologies (impingement only)
- flow reduction technologies

A number of case studies from both laboratory and field scenarios were investigated for each technology, with several case studies focused on applications to nuclear power stations.

Only the information on behavioural guidance technologies was considered as part of this review; a summary of the relevant studies is presented below for both light and sound systems.

Other technologies discussed in the report included air bubble curtains. The report stated that:

- the most extensive investigations of air bubble curtains had been conducted at steam electric stations to block the passage of fish into cooling water intake systems
- the device appeared to have potential for reducing fish passage under various conditions of turbidity if used in combination with strobe lights

However, the report deemed the effectiveness of air bubble curtains to be highly species-specific with some freshwater species – carp (*Cyprinus carpio*), silver chub (*Hybopsis storeriana*) and white bass (*Morone chrysops*) – being attracted to the device.

Light systems

According to EPRI (2013), the majority of light tests have used strobe or mercury lights. There is a large body of research conducted on the biological effectiveness of lights, but there are relatively few permanent installations to date. Where possible, the relevance of each study was assessed in this project based on:

- the habitat or environment the study was carried out in (including the turbidity of the water, considering the highly turbid nature of some UK estuarine and coastal environments)
- the species considered
- whether the example was from a nuclear power station
- whether flows were large (nominally assigned as >20m^3 per second, as intake flows for new nuclear power stations are unlikely to be below this; for example, the proposed Hinkley Point C nuclear power station has an intake volume of 125m^3 per second)

If the project was for a nuclear power station, or 2 or more other measures were applicable (Table 3.1), the case study was reviewed in full.

Table 3.1 Relevance of studies within EPRI (2013) for light systems as fish protection technologies

Study	Marine or estuarine environment?	Relevant species?	Nuclear power station?	Flow (>20m^3 per second)?	Included as case study?
Milliken Steam Electric Station	x	x	x	x	x
Roseton Generating Station	x	✓	x	✓	✓
Hiram M. Chittenden Locks	x	x	x	x	x
White Rapids Hydroelectric Project	x	x	x	✓	x
Burbank 3 Intake Channel	x	x	x	x	x
Pickering Nuclear Generating Station	x	x	✓	x	✓
McNary Dam	x	x	x	x	x
Mattaceunk Hydroelectric Project	x	✓	x	x	x
Rolfe Canal Hydroelectric Project	x	✓	x	x	x
Four Mile Hydroelectric Project	x	x	x	x	x
Fort Halifax Hydroelectric Station	x	✓	x	✓	✓
York Haven	x	x	x	✓	x
Hadley Falls Hydroelectric Project	x	x	x	x	x
Puntledge Generating Station	x	x	x	✓	x
Rocky Reach Dam	x	x	x	x	x
Seton Creek	x	x	x	x	x
Dworshak Dam	x	x	x	x	x
Kingsford Hydroelectric Project	x	x	x	x	x
Roza Diversion Dam	x	x	x	x	x

Study	Marine or estuarine environment?	Relevant species?	Nuclear power station?	Flow (>20m^3 per second)?	Included as case study?
Ludington Pumped Storage	x	x	x	x	x
R. H. Saunders Generating Station	x	✓	x	x	x
Lake Oahe	x	x	x	x	x
Laboratory study – Saimaa Fisheries Research and Aquaculture Station, Finland	x	x	x	x	x
Laboratory study – Pacific Northwest National Laboratory	x	x	x	x	x
Laboratory study – San Onofre Nuclear Generating Station	x	✓	✓	x	✓
Laboratory study – Lee County Hyacinth Control District	x	x	x	x	x
Laboratory study – Marine Biology Unit at Fawley, UK	x	✓	x	x	x
Laboratory study – EPRI/University of Washington	x	x	x	x	x
Laboratory study – EPRI/University of Iowa	x	x	x	x	x
Laboratory study – McIninch and Hocutt	x	x	x	x	x
Laboratory study – Ontario Hydro	x	x	x	x	x
Laboratory study – Simon Fraser University	x	x	x	x	x
Weldon Dam, Mattaceunk Project	x	x	x	x	x
Various Dutch stations and water bodies	x	✓	x	x	x
Poutès Dam, France	x	x	x	x	x
Wanapum Dam	x	x	x	x	x
Wapatox Canal Fish Screening Facility	x	x	x	x	x
Annapolis Tidal Generating Station	✓	✓	x	✓	✓
Bellows Falls Hydroelectric Project	x	✓	x	x	x
Priest Rapids Dam	x	x	x	x	x
Cabot Station	x	✓	x	x	x
Kingsford Hydroelectric Station	x	x	x	x	x
Laboratory study – EPRI/University of Washington	x	x	x	x	x
Laboratory Study – Ontario Hydro	x	x	x	x	x
Richard B. Russell Pumped Storage Project	x	x	x	x	x
Halsou Hydroelectric Plant	x	x	x	x	x
Rosa Diversion Dam	x	x	x	x	x
Laboratory study – University of Maryland	x	x	x	x	x
Laboratory study – South Dakota State University	x	x	x	x	x

Notes: Shaded rows are those included as case studies.
Relevant species are defined as those species which spend part or all of their life cycle in the marine or estuarine environment, or are closely related to individuals in UK waters which do.

- **Pickering Nuclear Generating Station.** (Patrick et al. 1988). Strobe lights at Pickering Nuclear Generating Station were tested as one of 3 behavioural devices at the nuclear station. Alewife (*Alosa pseudoharengus*)

were the focus of this study. The effectiveness of the system was determined as 56% for inshore moving fish and 21.2% for offshore moving fish. See below for a discussion of the sound technologies applied at this site.

- **San Onofre Nuclear Generating Station** (Jahn and Herbinson 2000). In 1995, laboratory tests of strobe lights and overhead incandescent flood lights were carried out to investigate their application at the San Onofre Nuclear Generating Station). Three species were tested: Northern anchovy (*Engraulis mordax*), white croaker (*Genyonemus lineatus*) and Pacific sardine (*Sardinops sagax*). Based on the laboratory test results, a bank of lights was installed in the power station screen well to provide a stimulus to direct fish into the bypass system.

- **Roseton Generating Station on the Hudson River** (Matousek et al. 1988a, Matousek et al. 1988b, LMS 1989). This power station is applicable due to the flow volume of 41.4m^3 per second entering the cooling water intake system. The effectiveness of strobe lights, and a poppers and an air bubble curtain were evaluated in different combinations at the site during 1986 and 1987. Dominant species recorded in the study included white perch (*Morone Americana*), bay anchovy (*Anchoa mitchilli*), blueback herring (*Alosa aestivalis*), alewives and American shad (*Alosa sapidissima*). A robust effectiveness index was acquired from the number of fish in treatment and control periods. Statistical analyses were conducted to determine significant differences in impingement rates. The overall effectiveness index for strobe light was 22.6% in 1986 and 3.3% in 1987. Largely, the effectiveness of strobe lights combined with other devices was low and variable for individual species and for all fish combined. The authors deemed that the observed results were not statistically significant.

- **Fort Halifax Hydroelectric Station** (Environmental Consulting Services et al. 1994). This study is applicable due to the flow volume of 24.1m^3 per second passing through the station (Environmental Consulting Services and Lakeside Engineering, 1994). Mark recapture techniques were used to assess the ability of the strobe light to repel or guide juvenile alewife away from the turbine intakes and towards the bypass entrance. The paper concluded that the strobe light did not appear to affect alewife behaviour; limited water visibility (that is, high turbidity) was named as a possible reason for a lack of response to the strobe light.

- **Annapolis Tidal Generating Station** (McKinley and Kowalyk 1989). This study evaluated mercury lights for their ability to attract alewife, blueback herring and American shad. The tests were carried out in tidal waters. The results indicated that adult fish of these species were slightly attracted to the mercury lights, while hydroacoustic data indicated that fish activity increased slightly in the area in front of the fish bypass when the mercury lights were turned on. Tests conducted with juvenile fish had similar results to the tests with adult fish, showing a slight attraction to the mercury lights.

Sound systems

Although low frequency systems (100–20kHZ) have been shown to cause behavioural responses from a wide range of fish species during cage tests and some pilot-scale field evaluations, there has been limited success in field trials at water intakes (EPRI 2013). High frequency systems (or ultrasound) (>100kHz) have, however, been effective in prompting avoidance responses from several clupeid species during both cage tests and field trials.

As for the studies on deterrents using light, the relevance of each study within EPRI (2013) was assessed based on:

- the habitat or environment the study was carried out in
- the species considered
- whether the example was from a nuclear power station
- whether flows were large (nominally assigned as >20m^3 per second)

If the project was for a nuclear power station, or 2 or more other measures were applicable (Table 3.2), the case study was reviewed in full.

Table 3.2 Relevance of studies within EPRI (2013) for sound systems as fish protection technologies

Study	Marine or estuarine environment?	Relevant species?	Nuclear power station?	Flow (>20m^3 per second)?	Included as case study?
Doel Nuclear Power Plant, Scheldt Estuary, Belgium	□	□	□	□	□
James A. Fitzpatrick Power Plant	x	□	□	x	□
Salem Generating Station	□	□	□	□	□
Arthur Kill Generating Station	□	□	x	x	□
Cresent and Visher Ferry Hydroelectric Project	x	□	x	x	x
White Rapids Hydroelectric Project	x	x	x	□	x
Hiram M. Chittenden Locks	x	x	x	x	x
Richard B. Russell Pumped Storage Project	x	□	x	□	□
Pejepscot Hydroelectric Project	x	□	x	□	□
Berrien Springs Hydroelectric Project and Buchanan Hydro Project	X	x	x	x	x
Racine Hydroelectric Plant	x	x	x	x	x
Georgiana Slough	x	x	x	x	x
Wilkins Slough Pumping Station	x	x	x	□	x
Institute of Freshwater Ecology's River Laboratories, Frome River, Dorset, UK and Blantyre Hydroelectric Station	x	□	x	x	x
Bonneville Dam	x	x	x	x	x
York Haven Hydroelectric Project	x	□	x	□	□
Vernon Hydroelectric Project	x	□	x	□	□
Hadley Falls Hydroelectric Project	x	□	x	x	x
Lennox Generating Station	x	□	x	x	x

Study	Marine or estuarine environment ?	Relevant species?	Nuclear power station?	Flow (>20m^3 per second)?	Included as case study?
Seton Hydroelectric Station	□	x	x	x	x
Allegheny Reservoir	x	x	x	□	x
Arthur Kill Generating Station	x	□	x	x	x
Cage tests – NYPA and ESEERCO	x	□	x	x	x
Pickering Nuclear Generating Station	x	□	□	x	□
Manimota Bay, Japan	□	x	x	x	x
Laboratory study – Kinectrics	x	□	x	x	x
Lake Borrevann, Norway, and Tihange Nuclear Power Plant, River Muese, Belgium	x	□	□	x	□
Annapolis Tidal Generation Station	□	□	x	□	□
Kingsford Hydroelectric Project	x	x	x	x	x
McNary Dam	x	□	x	x	x
Roza Dam	x	x	x	x	x
Rolfe Canal Hydroelectric Project	x	□	x	□	□
Small Hydroelectric Intake, Sandvikselven, Norway	x	□	x	x	x
Laboratory and field study, River Imsa, Norway	x	□	x	x	x
Hiram M. Chittenden Locks	x	□	x	x	X
Sommaroyhamn, Norway	x	□	x	x	x
Laboratory study – Pacific Northwest National Laboratory	x	□	x	x	x
Laboratory study, Oregon State University	x	□	x	x	x
Laboratory study, Norway	x	□	x	x	x

Notes: Shaded rows are those included as case studies.
Relevant species are defined as those species which spend part or all of their life cycle in the marine or estuarine environment, or are closely related to individuals in UK waters which do.

- **Lake Borrevann, Norway and Tihange Nuclear Power Plant, River Muese, Belgium** (Sonny et al. 2006). The avoidance response of several European fish species to intense infrasound was studied at the Tihange Nuclear Power Plant in Belgium and Lake Borrevann in Norway. The infrasound source generator was monitored using an echo sounder. The number of fish entering the intake during sound 'on' periods was significantly lower than during sound 'off' periods; reductions of 44–86%

were observed. Based on the results from the 2 studies, it was concluded that infrasound is an effective deterrent for cyprinids.

- **Pickering Nuclear Generating Station** (Patrick et al. 1988). The biological effectiveness of hammer devices in an open lake test were carried out at this nuclear power plant located on the north shore of Lake Ontario. The target species (alewife) showed a regular negative response of adult fish to the hammer (85% of adults exhibited a significant reduction in inshore movement).

- **Salem Generating Station** (Taft et al. 1996, Taft and Brown, 1997). A sound deterrent study involving both cage and intake testing was carried out at the Salem Generating Station located on Delaware Bay. Caged behaviour was observed using an underwater video system and species-specific responses were produced over the frequency range evaluated. The cage tests were then used to develop hybrid signals for use in the intake. Bay anchovy impingement reduced by approximately 30–35% during the summer and autumn survey periods, but only the autumn period was statistically significant. For Atlantic silverside (*Menidia menidia*), a statistically significant reduction in the impingement was observed during the autumn period, and was 20% lower during sound 'on' periods than during sound 'off' periods. For blue crab (*Callinectes sapidus*), however, a negative result was recorded with impingement rates approximately 20–25% higher than during sound 'off' periods. Hearing specialist Clupeid species results were unclear, with alewife and blueback herring demonstrating positive repulsion – though the alewife results were non-significant and the herring exhibited significant responses in only one of 3 tests.

- **Arthur Kill Generating Station** (Consolidated Edison Company of New York 1994). High and low frequency sound was evaluated during cage tests on bay anchovy and alewife as part of a wider study that measured the ability of a sound system to reduce impingement at the station. During 66 tests, the high frequency signals did not elicit any discernible responses from bay anchovy. During 38 of these tests, alewife demonstrated consistent avoidance responses to signals with frequencies >120kHz. In 10 tests, the initial pulses of low frequency signals produced startle responses from hearing specialist bay anchovy, but these reactions reduced with time and were not directional.

- **James A. Fitzpatrick Power Plant on Lake Ontario** (Dunning et al. 1992, Ross et al. 1993, Ross et al. 1996, Dunning 1997). This study investigated the use of sound projection to deter fish from a submerged cooling water intake. The study involved cage tests, field evaluations and full-scale system tests. The cage test results showed that alewife consistently avoided several high frequency sounds at higher sound pressure levels. Following these tests, a full-scale acoustic system was installed and a short 10-day demonstration test carried out. Alewife impingement was reduced by about 85% during periods of full power and full cooling water flow and by approximately 88% when the plant was in a non-operating mode with only 2 intake pumps operating.

- **Doel Nuclear Power Plant in Belgium** (Maes et al. 2004). This nuclear power plant is located within the Scheldt Estuary, an important fish nursery area. The cooling water intake abstraction rate is 25.1m^3 per second and has screens with a 4mm mesh. An AFD system was installed in 1997. Target species included herring (*Clupeidae*), sprat (*Sprattus sprattus*), white bream (*Abramis bjoerkna*), smelt (Osmeridae), common sole (*Solea*

solea), European flounder (*Platichthys flesus*) and gobies (*Pomatoschistus* sp.). It was found that the AFD was particularly successful in reducing the number of herring impinged, with a total average reduction of 94.7%; the system less effective for other species. Species-specific differences were attributed in part to differences in hearing capabilities. Species with swim bladders showed clear avoidance of the system. Fish size and associated swimming performance were also thought to be a factor, suggesting that larger fish are more successful at showing avoidance than smaller ones.

- **Annapolis Tidal Generation Station** (Gibson and Myers 2002). This study evaluated a high frequency fishpulser (hammer) system alongside other behavioural deterrents. The tidal generation station has a discharge of 408m^3 per second and 2 fishways for fish passage. The study aimed to monitor fish deterrence and diversion from the turbine intake. Transducers were mounted across the turbine intake. A total of 53,000 fish across 27 taxa were recorded. The results demonstrated that the sound barrier was partially effective at deterring shad species from the tailrace, but was ineffective for all other species, with 90% of the sample consisting of Atlantic silverside (*Menidia menidia*).

- **Richard B. Russell Pumped Storage Project** (Nestler et al. 1992, Pickens 1992, Nestler et al. 1995, Ploskey et al. 1995, Nestler et al. 1998), **Pejepscot Hydroelectric Project** (Northrup D & T et al. 1997), **York Haven Hydroelectric Project** (SWETS 1994), **Vernon Hydroelectric Project** (RMC Environmental Services and Sonalysts 1993), **Rolfe Canal Hydroelectric Project** (Lakeside Engineering 1996). These hydroelectric stations are of relevance due to their high flow volumes >20m^3 per second and because the studies investigated relevant species such as shads, herrings and salmonids. High frequency sound projectors were tested at these sites for their effectiveness at deterring migrating species. Ranges of effectiveness of the systems at deterring fish species were found by the studies, with a reduction in blueback herring for example of 56%.

- **Plant Barry** (Baker 2008). This report describes a study completed at Plant Barry on the Mobile River, southern USA, which assessed the effectiveness of: (1) a 'hybrid' strobe and sonic/ultrasonic sound deterrent; and (2) a sonic sound-only system (the treatments). The deterrents were installed to reduce entrainment of fish species into the cooling water intake relative to an adjacent intake structure without deterrent devices (the control). Additional evidence on the behavioural response of fish in relation to the deterrent devices was gathered using hydroacoustic (DIDSON and Biosonic) devices installed at each intake. The report drew clear conclusions from the data, stating that there was no evidence to suggest that either of the deterrent devices evaluated were capable of reducing the entrainment rates of any of the fish species monitored during the study, which included the threadfin shad and bay anchovy. Ultimately, the report concluded that on the basis of the results the 2 devices assessed would not be a viable technology option for complying with the US Clean Water Act at this site.

Evaluation of strobe lights for reducing fish impingement at cooling *water intakes* (EPRI 2008)

The report describes a study conducted at 2 power plants (Widows Creek Power Station and Cumberland Fossil Plant) in the south-east USA to determine the effectiveness of strobe light deterrent devices for reducing the number of fish entrained

into the cooling water abstraction. A limited response to the strobe light units were observed during the trial for the 3 target fish species [threadfin shad (*Dorosoma petenense*), gizzard shad (*Dorosoma cepedianum*) and freshwater drum (*Aplodinotus grunniens*)], with a maximum 20% reduction in impingement at one lighted screen during the study period. The report also describes an additional study that assessed the reaction of gizzard shad to overhead strobe light devices in a laboratory setting with inconclusive results. The results were considered to confirm the entrainment study field observations in that shad did occasionally display aversion, although this was not consistent and appeared to be influenced by additional (unknown) environment factors.

Trials of an AFD system at Hartlepool Nuclear Power Station (Turnpenny et al. 1995)

The report described a study at Hartlepool Nuclear Power Station on the Tees Estuary in 1995 to assess the efficacy of AFD systems in reducing the impingement rates of fish species. Under an initial configuration, the performance of the system was deemed to be poor, with only herring displaying significant reductions in impingement. Following modification of the system to include additional mid-channel projectors, however, significant reductions in impingement were recorded for all of the main fish species of interest (including sprat, herring and whiting), with a mean impingement reduction of 55.9% across all species.

Investigation into minimising fish entrainment and mortality at Environment Agency Pumping Stations (Phase 1: Bolland et al. 2012, Styles et al. 2012; Phase 2: Styles et al. 2015)

These reports presented a summary of a study of spatial and temporal variations in fish populations at 11 Environment Agency pumping stations in its Anglian Region in eastern England. The study used DIDSON to examine fish movements and behaviour at pumping stations. The results indicated that fish occupation in pumping station sump chambers was highest during the day in winter, possibly due to thermal refuge and shelter from predators. The study also assessed the effectiveness of deterrent (strobes) and scarer devices (acoustic with strobes, and air blast) installed at the Environment Agency's Anglian Region pumping stations. Both the acoustic with strobes and the air blast scaring devices failed to encourage fish to leave the pumping stations studied, suggesting that these installations may not reduce the likelihood of entrainment effectively during pumping station start-up and operation.

Lambton diverts fish and saves millions (OPG Power News 2005)

This piece of evidence comes from a news article about a combination of flashing strobe lights and sound systems to target gizzard shad at Lambton Generating Station on the St Clair River in Ontario, Canada. Kinectrics Inc. assessed the type of fish (gizzard shad), entering the water intake from the St Clair River and installed a diversion system at the intake. The article states that the fish diversion system has proved to be '90% effective'.

In situ testing of sound-bubble-strobe light barrier technologies in preventing range expansions of Asian carp (Ruebush et al. 2012)

This study investigated in situ tests of the effectiveness of sound-bubble-strobe light barrier technologies at repelling carp species within Quiver Creek in Illinois in the hope that they would slow the range expansions of Asian carp (*Hypophthalmichthys nobilis*

and *H. molitrix*). The study suggested that these technologies could be used as a deterrent system to repel Asian carp, but should not be used as an absolute barrier to prevent range expansions. The study supported previous research that sound-bubble-strobe light barrier and sound-bubble barrier technologies do deter fish. The addition of strobe lights, however, did not appear to make an appreciable difference in deterring the fish assemblage.

Evasive responses of American shad to ultrasonic stimuli (Plachta and Popper 2003)

This paper investigated the responses of American shad (*Alosa sapidissima*) to ultrasonic stimuli. The results seemed to demonstrate from 2 hydrophone experiments that American shad can determine the direction of the signal at least on the horizontal plane, displaying fast evasive behaviour away. It was found that:

- when shad detect ultrasound signals in frequencies at the edge of echolocation beams, they turn slowly from the source
- if they detect continuous frequencies between 70kHz and 110kHz they form groups to decrease discrimination of individual fish
- when the range becomes close enough to be threatened they show a random fast panic response

Allis shad exhibit an intensity-graded behavioural response on exposure to ultrasound (Wilson et al. 2008)

This study tested the response of adult allis shad (*Alosa alosa*) to sinusoidal ultrasonic pulses at 70kHz and 120kHz. It was found that:

- allis shad responded to the ultrasonic frequencies
- increased sound intensity leads to stronger behavioural responses

The latter finding demonstrated that allis shad have an intensity-graded response to the output of its ultrasound detector.

Downriver passage of juvenile blueback herring near an ultrasonic field in the Mohawk River (Dunning and Gurshin 2012)

This study investigated whether ultrasound could be used to divert juvenile blueback herring away from a turbine intake during downriver migration. The results suggested that, if it was valid to assume that water flow directly influences entrainment and impingement, then the significantly higher than expected number of blueback herring that migrated downriver in the main channel could be an indication that ultrasound was partially effective in diverting fish.

2011 Georgiana Slough non-physical barrier performance evaluation project report (California Department of Water Resources 2012)

The purpose of this study was to test the effectiveness of a bioacoustic fish fence (BAFF) in preventing out-migrating juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from entering Georgiana Slough in Sacramento County, California. The barrier consisted of perforated bubble pipe (bubble curtain), sound projectors and modulated intense lights. The study found that there were significant increases in

deterrence, protection and overall efficiency for juvenile salmon when the BAFF was on; fewer of the tagged salmon migrated into Georgiana Slough when the BAFF was on than when it was off (7.1% versus 22.4%). Predation rates were comparatively low and there was no evidence that the BAFF was attracting predators to the area or increasing predation on juvenile salmon.

3.1.3 Review synthesis

A number of studies have investigated the installation of behavioural fish deterrents at water intakes with evidence from over 20 relevant stations being included in this review.

A large proportion of the sites reported on have cooling water intakes of a size applicable to new nuclear cooling water systems in the UK. Sites include nuclear power stations as well as other power station technologies including hydroelectric plants. The environments in which the investigations have been made include lake, river, estuarine and coastal examples. Relevant investigations have generally been undertaken onsite at the water intake facility, though there are also a number of laboratory-based studies.

The results indicate that the efficacy of different technologies is very site- and species-specific. The application of efficacy results from laboratory-based trials is therefore likely to be restricted to the specific case it was designed to investigate, although there may be some transferrable information.

The majority of sites investigated are from the USA. The fish species reported on are not therefore directly relevant to the fish species in the UK. They are, however, from similar families and therefore with applicable sensitivities to behavioural stimuli (Normandeau Associates 2012). The physiology and swimming capabilities of many of the fish species investigated are also comparable with some UK fish species.

The majority of studies investigated the efficacy of the behavioural deterrents at deflecting fish and other aquatic biota away from the intake. Very few studies discuss the cost of installing, operating and maintaining the systems. The safety of operating and maintaining the systems is rarely addressed, especially for nuclear power plants where continued cooling water supply is of vital importance for the safe running of the plant. Equally there are very few studies that discuss the feasibility of installing the behavioural deterrent technologies in a range of environments and for different sites.

The studies generally discuss the efficacy of single technologies in isolation. In practice, however, BAT requires the operation of a combination of different technologies including physical and behavioural solutions. The operation of behavioural deterrent solutions and physical technologies such as FRR systems are closely interlinked and it is difficult to separate out the 2 protection technologies in the literature. The efficacy of any behavioural deterrent, for example, in particular for delicate pelagic fish species may influence the subsequent efficacy of the FRR system. Behavioural deterrents are also often more effective for the delicate pelagic fish species for which survival rates in an FRR system are observed to be relatively low.

The efficacy of the different behavioural deterrent systems from the literature included in this report is variable depending on:

- site-specific conditions
- the specifics of the technology being investigated
- the environment and size/type of the abstraction
- the target species

Systems in general have been demonstrated to be more effective for clupeids than other species given their greater hearing sensitivity.

Flow is often cited as the limiting factor in the effectiveness of acoustic deterrents and turbidity is often cited as the limiting factor to the effectiveness of light deterrents. The protection of a range of fish species may therefore require the operation of a combination of different entrapment deflection and/or exclusion technologies.

The majority of studies available are dated pre-2010 and were therefore available for consideration within Environment Agency (2010), with most being cited within this document. Although there are a few studies that post-date 2010, these do not provide any significant new information that would indicate that a change to the BAT given in Environment Agency (2010) should be recommended.

3.1.4 International expert input

The international experts consulted indicated that studies by the British Energy Estuarine and Marine Studies (BEEMS) and the USEPA were likely to be the most important sources of available data on fish behavioural deterrents. This concurs with the evidence review conducted in Sections 3.1.3 and 3.2.3, which identified and considered the relevant studies from these sources since the Environment Agency (2010) review. Reviews conducted by Rolf Hadderingh at the Dutch energy consultancy company, KEMA, also provide data on the behavioural screening of cooling water intake systems. The German Federal Environmental Foundation (DBU) recently funded an assessment of the application and effectiveness of acoustic devices for the protection of fishes.

A number of the international experts identified that there is likely to be an additional body of evidence on fish behavioural deterrents from studies conducted for developers and operators that are not in the public domain or available for consideration as part of this review. But while a number of additional specific studies are likely to have been undertaken to test fish behavioural deterrents, these studies are only likely to serve to enhance the detail and specificity of the broad conclusions rather than change them.

No additional evidence on the effective operation, maintenance and reliability of fish behavioural deterrent systems was identified by the international experts for the scale of intake required for a new nuclear power station.

No additional evidence was identified on the ability to site and install suitable fish behavioural deterrent systems in onshore and offshore environments.

It was noted that the maintenance requirements of behavioural deterrent systems are significant for offshore marine intakes – given the risk of storm, debris and shipping damage – and it is often unclear if a system is actually operating as designed.

It was also noted that, for nuclear safety reasons, any fish behavioural deterrent system should have sufficient redundancy, back-up power supplies and maintenance planned to safeguard the continuous and efficient operation of the system. This is needed to avoid the potential for ingress of large numbers of fish causing blockages of the cooling water system, which could have potential operational and safety risks.

Feedback from the international experts on the effectiveness of fish behavioural deterrents further highlighted that the systems were only effective for specific species in specific hydrodynamic and water quality environments. No fish behavioural deterrent systems are effective for reducing the entrainment of eggs, larvae or very juvenile fish, and reduction of impingement is generally only demonstrated to be effective for specific species rather than wider assemblages. The main conclusion of USEPA (2014b) is that fish behavioural deterrent technologies alone are not considered capable of reducing

overall impingement or entrainment to acceptable levels at once-through cooled power plant, but that they could form part of a suite of protective technologies.

Ultrasound is the only behavioural deterrent that the experts are aware of that has been used as permanent and full-scale system for repelling fish at cooling water intake systems in the USA. This technology was installed at the James A. Fitzpatrick Nuclear Power Plant (Lake Ontario, NY) to reduce the entrainment of alewife and was found to be >80% effective. Sonic and infrasonic sound systems have also been investigated during laboratory and pilot-scale field studies for the deterrence of fish at cooling water intake systems. The results of these studies have not supported the use of low frequencies for sound deterrence at cooling water intake systems in the USA.

Recommendations for future application of fish behavioural deterrents from the international experts included:

- the need to design deterrents to be effective under operational and environmental extremes
- the need to design and construct any systems such that adaptation and improvement can be implemented to optimise the effectiveness of the intake as and when improvements are available over the lifetime of the project

3.1.5 Evidence scoring for fish behavioural deterrent systems

The evidence scoring results for fish behavioural deterrent systems are presented in Table 3.3.

Table 3.3 Evidence scoring for fish behavioural deterrent systems

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Fish protection at cooling water intake structures: A technical reference manual – 2012 Update. EPRI (2013)	Report	5	3	3	**Quality of information source** The report is a recent review of available literature on fish protection technologies and their biological performance for use at power plant cooling intake structures. It has a large body of case studies and empirical evidence to draw on, including those from nuclear power plant examples. The literature reviewed is largely historic, with the majority of papers dating back to the early 1990s, it therefore pre-dates Environment Agency (2010). **Applicability of evidence** The examples are predominantly based in the USA with different species targeted, and largely on power plants and hydroelectric projects. Several case studies of behavioural deterrent applications at nuclear power plants are discussed such as strobes and acoustics. **Strength of conclusion** The report as a whole gives evidence with clear conclusions of efficacy of practice within each study, but no comparison between technologies is provided as a summary. The studies reviewed focus on the efficacy of behavioural deterrents with little evidence provided on operation and maintenance.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Pickering Generating Station – Field testing of behavioural barriers for cooling water intake structures - test site 1. Patrick et al. (1988).	3	3	5	**Quality of information source** Technical report for EPRI published in a conference proceedings. The study is 20 years old and was conducted at an experimental open water test facility on Lake Ontario. **Applicability of evidence** The species targeted were adult alewife, which are not found in the waters around the UK, though they are similar to some UK species. A single species was targeted in the experiment. However, the study was for a nuclear power station and at a scale comparable with new nuclear plants in the UK. **Strength of conclusion** There is empirical evidence with clear conclusions as to the impact of the hammer device, demonstrating that there was a consistent negative behavioural response. As such the strength of the conclusion is high.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	San Onofre Nuclear Generating Station – Designing a light-mediated behavioral barrier to fish impingement and a monitoring program to test its effectiveness at a costal power station. Jahn and Herbinson (2000).	5	1	3	**Quality of information source** This paper is peer-reviewed and therefore the quality of the information is assessed as high. **Applicability of evidence** Applicability is low as the project involved laboratory testing rather than field testing, and thus is not directly comparable to the UK new nuclear industry. **Strength of conclusion** Some conclusions are drawn and appear to be supported by statistical analysis, but some of the work is noted as being inconclusive.	**Medium (9)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Roseton Generating Station – Field testing of behavioral barriers for fish exclusion at cooling-water intake systems. Matousek et al. (1988a).	5	3	5	**No access to full document** **Quality of information source** This is a peer-reviewed paper based on experimental field-based evidence, and as such a high quality information source. **Applicability of evidence** Although based on a fossil fuel steam electric generating station, the flow of 41.4m^3 per second is comparable with that of large-scale nuclear sites. The study was also carried out in saline waters and thus a similar environment to marine/coastal nuclear power stations. **Strength of conclusion** Although statistical measures were used with an overall effectiveness index calculated, the authors deemed that the observed results could have happened by chance (that is, they were not statistically significant). This critical and transparent analysis suggests a high confidence level in terms of the strength of the conclusion.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Roseton Generating Station – Biological evaluation of behavioral barrier devices at a power plant intake located on the Hudson River. Matousek et al. (1988b).	5	3	5	**No access to full document** **Quality of information source** This is a peer-reviewed paper based on experimental field-based evidence, and as such is a high quality information source. **Applicability of evidence** Although based on a fossil fuel steam electric generating station, the flow of 41.4m^3 per second is comparable with that of large-scale nuclear sites. The study was also carried out in saline waters and thus a similar environment to marine/coastal nuclear power stations. **Strength of conclusion** Although statistical measures were used with an overall effectiveness index calculated, the authors deemed that the observed results could have happened by chance (that is, they were not statistically significant). This critical and transparent analysis suggests a high confidence level in terms of the strength of conclusion.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Roseton Generating Station – 1986 and 1987 year class report for the Hudson River estuary monitoring program. LMS Engineers (1989).	3	3	5	**No access to full document** **Quality of information source** This is a report from an engineering company for a developer, but is based on well-documented expert judgement and experimental field-based evidence. **Applicability of evidence** Although based on a fossil fuel steam electric generating station, the flow of 41.4m^3 per second is comparable with that of large-scale nuclear sites. The study was also carried out in saline waters and thus a similar environment to marine/coastal nuclear power stations. **Strength of conclusion** Although statistical measures were used with an overall effectiveness index calculated, the authors deemed that the observed results could have happened by chance (that is, they were not statistically significant). This critical and transparent analysis suggests a high confidence level in terms of the strength of conclusion.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Fort Halifax Hydroelectric Station – 1993 Studies of downstream fish passage at Fort Halifax hydro-electric station Sebasticook River, Maine. Environmental Consulting Services et al. (1994).	3	3	5	**No access to full document** **Quality of information source** This is a report from an engineering company for a developer, but is based on well-documented expert judgement and experimental field-based evidence. **Applicability of evidence** Although based on a hydroelectric station, the flow is of a sufficient volume (24.1m^3 per second) to be relevant. The species targeted – Atlantic salmon and American shad and alewife (clupeids) – are partly applicable to UK marine/estuary species. **Strength of conclusion** There was conclusive evidence that strobe lighting did not affect behaviour, which was asserted to be due to turbidity.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Annapolis Tidal Generating Station – Effectiveness of a fish protection scheme in repelling or diverting fish in the intake-forebay of the Annapolis Tidal Power Station. McKinley and Kowalyk (1989).	5	3	5	**No access to full document** **Quality of information source** This is a peer-reviewed published report based on experimental field-based evidence. **Applicability of evidence** For light deterrent: Though based on a tidal generating station rather than a conventional power station intake, the tidal environment is applicable to this study. The clupeid species targeted (alewife, blueback herring and American shad), though not directly relevant, are transferrable to UK fish species. For sound deterrent: Though based on a tidal generating station rather than a conventional power station intake, the tidal environment is applicable to this study. The large amount of data across so many species and taxa allows a general stance to be determined and the wider scale can be applicable to UK marine / estuary species. **Strength of conclusion** For light deterrent: Clear conclusions were drawn from the 2 test phases, giving direction of impact and with different methods for calibrating the findings (visual observations and hydroacoustic data). For sound deterrent: There were clear conclusions as to the efficacy of the acoustic fishpulser.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Lake Borrevann, Norway; Tihange Nuclear Power Plant, River Muese, Belgium – Reactions of cyprinids to infrasound in a lake and at the cooling water inlet of a nuclear power plant. Sonny et al. (2006).	5	3	5	**Quality of information source** This is based on a scientific paper from 2006, which is supported by empirical and statistical evidence. There was a substantial body of data - 1,301 fishes, made up of 4 families and 15 species were recorded. **Applicability of evidence** This is based on 2 studies; one of which was field tests at an operational, full-scale cooling water intake for a nuclear power plant on the River Meuse in Belgium. However, limnophilic cyprinids made up 93.2% of the data and are not therefore, directly relevant to the UK unless lake sites are chosen. Individuals of other species, including European silver eel and chub were sampled, but in much smaller quantities. **Strength of conclusion** Statistical analysis of echogram data demonstrated a clear avoidance effect, through differences between corridors upstream of infrasound sources and those downstream. A critical discussion of the study method highlighted that key parts of the infrasound unit did occasionally break down during prolonged continuous operation (approximately more than one week) and that technical improvements of its design were required.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Salem Generating Station – Developments in the use of infrasound for protecting fish at water intakes. Taft et al. (1996). Sonic Fish Deterrence: EPRI/Alden Laboratory's experience. Taft and Brown (1997).	5	5	5	**Quality of information source** Peer-reviewed paper on experimental cage and field-based evidence at a nuclear power station. Findings were presented to EPRI at a workshop in 1995. Robust statistical analysis of data was carried out, which displayed both positive and negative impacts of the acoustic device. **Applicability of evidence** This study was based on field tests within a nuclear power facility intake based in a marine coastal environment – Salem shares an artificial island in the Delaware Bay with the Hope Creek Nuclear Power Plant. The species of note, though largely US based in their distribution, are comparable as clupeids, crab species, and the study covered a wide range of species (48 taxa). **Strength of conclusion** Clear conclusions were drawn from the 2 test phases, giving the direction of the impact and with different methods for calibrating the findings. Effectiveness indices were calculated to allow robust conclusions to be drawn on the efficacy of the acoustic deterrents, giving the direction and magnitudes of each species under the test scenarios.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Arthur Kill Generating Station – Evaluation of underwater sound to reduce impingement at the Arthur Kill Station. Consolidated Edison Company of New York (1994).	3	1	5	**No access to full document** **Quality of information source** This report of the field studies at Arthur Kill is an unbiased report which, while it has been cited in peer-reviewed articles since, the original is inaccessible. **Applicability of evidence** The applicability of the study is low, as while it has comparable habitat conditions, it is a cage study. The species are relevant to UK studies, with bay anchovy found in shallow tidal areas with muddy bottoms and brackish waters, and able to tolerate a wide range of salinities, while alewife are anadromous clupeids. **Strength of conclusion** The strength of the conclusion was medium – with clear conclusions as to the responses produced for each species but no measure of the magnitude of impact	**Medium (9)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Ultrasound deterrence: Alewife at a nuclear generating station in New York. James A. Fitzpatrick Power Plant – Dunning (1997). Alewives Avoid high-frequency sound. Dunning et al. (1992). Response of Alewives to high-frequency sound at a power Intake on Lake Ontario. Ross et al. (1993). Reducing Impingement of Alewives with high frequency sound at a power plant on Lake Ontario. Ross et al. (1996).	5	3	5	**Quality of information** These studies of the phased approach are peer-reviewed papers based on experimental data and supported by robust statistical analysis. **Applicability of evidence** The study focused on a working nuclear power station and had permanent installation studies to draw on. It also has a relevant species to the UK (alewife, anadromous herring family) but it comprises cage studies and the field studies are based in a lake environment. **Strength of conclusion** The strength of the conclusion was high – with clear conclusions as to the responses produced for each species.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Doel Nuclear Power Plant – Field evaluation of a sound system to reduce estuarine fish intake rates at a power plant cooling water inlet. Maes et al. (2004).	Report	5	5	5	**Quality of information** The quality of this paper is high; it is a well-cited paper based on field trials targeted towards a specific aim – to look at how sound systems reduce estuarine fish impingement. It is supported by robust statistical analysis. Although several of the authors are manufacturers of the fish deterrent system being trialled, it is a peer-reviewed document with other authors. **Applicability of evidence** The applicability of this study is high as all primary aspects of the evidence are based on similar parameters. The study is based on the Doel Nuclear Power Plant in Belgium, with similar flows to potential nuclear stations. It is set within European waters, targeting relevant species to UK environments and the field studies were carried out in a coastal estuarine environment; it thus addresses salinity and turbidity. **Strength of conclusion** The strength of the conclusion is high – with clear conclusions on the direction and magnitude of the impact and efficiency of the device. The authors also looked critically at the results and at the reliability of their results by comparing them with other power station cooling water intakes. They highlighted trials of the same system at the Hartlepool Power Station, which resulted in similar results – effectiveness for clupeids 60–80%; other species with swimbladder 54%, while non-swimbladder species was reduced by only 16% (A.W.H. Turnpenny, J.M. Fleming, K.P. Thatcher and R. Wood, personal communication), thus providing confidence and strength to their conclusions.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Hydropower and pumped-storage hydropower studies: Lakeside Engineering (1996). Nestler et al. (1998). Nestler et al. (1995). Nestler et al. (1992). Northrup, D. & T. (1997). Pickens, J. L. 1992. Ploskey et al. (1995). RMC Environmental Services and Sonalysts (1993). SWETS (1994).	Reports	5	3	3	**Quality of information source** The quality of the information sources is high as the majority are peer-reviewed journals or published reports or conference proceedings. As such the evidence is based on well-documented expert judgement and any uncertainties can be identified and managed. The studies are not targeted at nuclear power, but appear to be robust with some evidence of statistical analysis. **Applicability of evidence** The applicability of the evidence is medium, as all the studies are based on hydroelectric stations within a river environment. However, the flows and species considered may provide useful data for the UK context. **Strength of conclusion** The strength of conclusion is medium – there are conclusions on the direction of the impact but measures of magnitude are lacking in the studies and the detail of statistical analysis presented is limited.	**Medium (11)**

The effects of strobe light and sound behavioural deterrent systems on impingement of aquatic organisms at Plant Barry, Alabama. Baker (2008).	Report	5	3	5	**Quality of information source** The study appears to be robustly designed and extends over more than 30 weeks. The devices were assessed by monitoring rates of fish and invertebrates entrained in each intake (control versus treatment) throughout the study period. Additional evidence on the behavioural response of fish in relation to the deterrent devices was gathered using hydroacoustic (DIDSON and Biosonic) devices installed at each intake. **Applicability of evidence** The evidence and conclusions of the study are deemed to be of medium applicability to the UK context. The data are robust in that they were collected from an operational power station of a comparable scale to UK power stations (30 m^3 per second abstraction flow). However, the power station is located at the upstream end of the tidal limit of the Mobile River in a predominantly freshwater environment and is thus of limited relevance to estuarine and particularly offshore installations in the UK. In addition, none of the fish species entrained in the study are native to UK waters and therefore the findings may be of limited ecological relevance, though inferences could be made (for example, comparisons of hearing and/or light sensitivity between the entrained species and UK species). **Strength of conclusion** The report draws clear conclusions from the data, stating that there was no evidence to suggest that either of the deterrent devices evaluated were capable of reducing the entrainment rates of any fish species monitored during the study. Ultimately, the report concludes that, on the basis of the results, the 2 devices assessed would not be a viable technology option for compliance with the US Clean Water Act.	**High (13)**
Evaluation of Strobe Lights for Reducing Fish Impingement at	Report (entrainment	5	3	5	**Quality of information source** The study provides robust data from an established organisation and is supported by statistical analysis.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Cooling Water Intakes. EPRI (2008).	and laboratory studies)				**Applicability of evidence** The evidence and conclusions of the study are deemed to be of medium applicability to the UK context. The data are robust in that they are collected from an operational power station, as opposed to laboratory or theoretical studies and therefore account for confounding factors that a laboratory study cannot consider. However, the Cumberland Fossil Power Plant abstracts water from a freshwater river and is thus of limited relevance to estuarine and more so offshore installations in the UK. In addition, none of the target fish species are native to UK waters and therefore the deterrent efficiencies may be of limited ecological relevance, although inferences could be made (for example, based on comparisons of hearing ability between the entrained target species and at-risk UK estuarine/marine species). **Strength of conclusion** The conclusions of the entrainment study are clearly documented, with the authors deeming that the performance of the strobe units was neither consistent nor substantial enough for them to be considered a cost-effective mitigation measure for reducing entrainment into cooling water abstractions.	

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Trials of an acoustic fish deterrent system at Hartlepool Power. Turnpenny et al. (1995).	Report	3	5	3	**Quality of information source** The study is not peer-reviewed and was commissioned by a developer. It does, however, have a clearly documented methodology and is supported by statistical analysis. The quality of information source is therefore assessed as medium. **Applicability of evidence** The evidence and conclusions of the study are deemed to be of high applicability to the UK context, as the study is based on a UK nuclear power station in an estuarine environment. **Strength of conclusion** The conclusions are clearly documented but uncertainty is not clearly presented.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Investigation into minimising fish entrainment at Environment Agency pumping stations, Phase 2; Permit-to-pump trial and preliminary findings of a combined acoustic and strobe fish scarer test. Styles et al. (2015).	Report	5	3	3	**Quality of information source** The technical report is from an established organisation in the industry and is based on empirical data. **Applicability of evidence** The study is based on pumping stations in the UK. The conditions are validated, with relevant fish species (though not specified in the summary document) and similar regulatory paradigms, but has no data that refer to particular stations and none are of the scale or type of new nuclear plants. **Strength of conclusion** The strength of the conclusion was medium; there are conclusions about the lack of impact of behavioural devices, but there is no measure of the magnitude, efficacy or any discussion of the statistical methods used to determine these outcomes within the study. Furthermore the authors noted that the conclusions were based on just one replicate and as such more replicates are required for a confidence in this assessment.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Investigation into minimising fish entrainment and mortality at Environment Agency pumping stations, Phase 1. Bolland et al. (2012).	Report	5	3	3	**Quality of information source** The technical report is from an established organisation in the industry and is based on empirical data. **Applicability of evidence** The study is based on pumping stations in the UK. Conditions are validated, with relevant fish species (though not detailed within the document) and similar regulatory paradigms. However, the scales of abstraction are not clear. **Strength of conclusion** The strength of the conclusion was medium; there are conclusions about the lack of impact of behavioural devices, but there is no measure of the magnitude, efficacy or any discussion of the statistical methods used to determine these outcomes within the study. Furthermore, the study of behavioural deterrents was carried out on just one day. This is discussed within the report, which notes that further testing over a range of environmental conditions and seasonal and operational scenarios is required for increased confidence in any conclusions.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Lambton diverts fish and saves millions. OPG Power News (2005).	Report	1	1	1	**Quality of information source** The quality of this news article is low. The evidence is not well-documented and there is no indication whether partiality is managed, no review process and it is published in OPG Power News in 2005, suggesting potential bias. OPG Power News is from OPG, which operates and develops power generation assets in India. There is no target aim to be answered and no statistical basis for the evidence. **Applicability of evidence** The applicability of this study is low, as it is based on a coal-fuelled power plant located on the St Clair River on Ontario, and while gizzard shad is a clupeid, there is no other mention of any other fish species, scales of abstraction or the conditions under which the study was carried out. **Strength of conclusion** The evidence draws conclusions as to the efficacy of the diversion system, but confidence and uncertainty are not discussed. There are no robust statistical analyses to appraise and the method of determining efficacy is not discussed. The quote of being '90% effective' gives no reference to scales of measurement, baselines or practice.	**Low (3)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
In-situ tests of sound-bubble-strobe light barrier technologies to prevent range expansions of Asian carp. Ruebush et al. (2012).	Report	5	1	5	**Quality of information source** This study is peer-reviewed with statistical analysis, which is discussed critically in the discussion. **Applicability of evidence** The applicability Is low, because while the technologies are directly relevant to this synthesis, the study looks at creating a barrier on Quiver Creek in Illinois which does not have a comparable flow to those of nuclear power stations. The species are primarily American freshwater river species, not marine. Few aspects of the evidence are based on similar paradigms, but the efficiency of the technology is well covered. It is also an in situ field-based study conducted in a natural and dynamic environment, which is more appropriate for drawing conclusions applicable to this project. **Strength of conclusion** The evidence draws clear conclusions as to the efficacy of the technologies and also discusses the uncertainty with the results – such as any negative influences on non-target fishes, or the lack of relying on this barrier as an absolute method for preventing upstream movement.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Evasive responses of American shad (*Alosa sapidissima*) to ultrasonic stimuli. Plachta and Popper (2003).	Report	5	1	3	**Quality of information source** The article is a peer-reviewed paper in a scientific journal and thus has been peer-reviewed. There is evidence of robust statistical analysis, and as such the paper is a high quality information source. **Applicability of evidence** The applicability is low, because while clupeid species are comparable, there is no direct investigation of potential acoustic deterrent technologies. It is also set within tank trials rather than in comparable field or high flow environments. **Strength of conclusion** The strength of conclusions is medium, as they discuss the parameters to which responses are visible in shad species but do not give a measure of efficiency.	**Medium (9)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Allis shad (*Alosa alosa*) exhibit an intensity-graded behavioural response when exposed to ultrasound. Wilson et al. (2008).	Report	5	1	3	**Quality of information source** This relatively recent article (2008) is a peer-reviewed paper in a scientific journal and thus has been peer-reviewed. There is evidence of robust statistical analysis with detailed methods used (for example, Student's *t*-test on the correlation coefficient, $p < 0.05$), and as such the paper is a high quality information source. **Applicability of evidence** The applicability is low, because while clupeid species are comparable, there is no direct investigation of potential acoustic deterrent technologies. Although there is potential within the study to use ultrasound frequencies to deter these fish, it has not been used at a scale comparable with those at nuclear power stations. It is also set within tank trials rather than in comparable field or high flow environments. **Strength of conclusion** The strength of conclusions is medium, as they discuss the parameters to which responses are visible in shad species. It is demonstrated that they have a behavioural response to the selected ultrasound frequencies, no a measure of the efficiency or magnitude of the impact is given.	**Medium (9)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Effectiveness of a high-frequency-sound fish diversion system at the Annapolis Tidal Hydroelectric Generating Station, Nova Scotia. Gibson and Myers (2002).	Report	5	5	5	**Quality of information source** As a peer-reviewed journal article with detailed methods and statistical analysis, this is a high quality information source. It details how environmental parameters are incorporated into the modelling. There are targeted aims for the study with comparison with other evidence and literature in the field. **Applicability of evidence** The applicability is high, with comparable scales of abstraction to nuclear power stations (the authors compared the study with the Salem Nuclear Generating Station) and similar environments (estuarine, tidal environments). In addition, the conditions and species of note are clupeids, which are comparable to those found in the UK. Although regulatory paradigms are different, they can be transferrable to the UK context. **Strength of conclusion** The strength of conclusions is high, as they discuss the parameters and give measures of efficacy and magnitude. There is a discussion as to the future of these findings within a practical management context and direct reference to use in power stations.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Downriver passage of juvenile blueback herring near an ultrasonic field in the Mohawk River. Dunning and Gurshin (2012)	Report	5	3	3	**Quality of information source** As a peer-reviewed journal article with detailed methods and statistical analysis, this it is a high quality information source. However, it should be noted that the study was funded by the New York Power Authority. **Applicability of evidence** The study is comparable with a similar species to those found in the UK, with a similar scale of abstraction at the Crescent Hydroelectric Project (the entrance to the turbine channel is more than 10 times wider than the intakes at the Arthur Kill and Fitzpatrick power stations). As such a medium applicability is suggested. **Strength of conclusion** The strength of conclusions is medium, because while they discuss the parameters and give diversion rates for the study, there are a lot of caveats with limitations about design and other factors that may have influenced the conclusions. There is discussion about confidence in the results; for example, the authors debate that the significantly higher than expected number of juvenile blueback herring that migrated downriver at the main channel downriver site could be attributable to factors other than a reaction to ultrasound, including habitat preference, depth preference or water turbulence near the entrance to the turbine channel. They also discuss how this poses a challenge in evaluating behavioural barriers at sites.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
2011 Georgiana Slough non-physical barrier performance evaluation project report. California Department of Water Resources (2012).	Report	5	3	5	**Quality of information source** The project has many contributors ranging from environmental consultancies (Hanson Environmental Ltd, AECOM Technical Services, Normandeau Associates Inc.), technology companies (Hydroacoustic Technologies Inc.) and organisations (California Department of Water Resources, US Geological Survey). The project has a vigorous scientific approach and multiple review processes (as detailed in the report) by established organisations – National Marine Fisheries Service, US Fish and Wildlife Service, US Geological Survey peer review, and a final review by the California Department of Water Resources. The evidence is targeted towards set aims and hypotheses, with a robust and detailed statistical analysis that takes into account variables. There is also discussion of future directions. **Applicability of evidence** The field studies are based in large river environments not at an intake or power station, but the species used could be transferrable to UK species. **Strength of conclusion** There are clear conclusions on the direction of the impact, with measures of magnitude given for different evaluation metrics. There is critical analysis of the outcomes and the report gives future scope for further studies to address some of the variables not controlled in this study.	**High (13)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

3.1.6 Evidence review conclusions for fish behavioural deterrent systems

The review found that there are technologies available that can be operated at intakes comparable with the size of nuclear power plants, including acoustic and light based systems in isolation and combined. However, the majority of the studies were carried out at sites in onshore environments with few in offshore environments, in particular with the harsh coastal or estuarine conditions that could be experienced by new UK nuclear plants.

Drawing on a range of expert sources, the majority of evidence available on behavioural deterrent systems focuses on the effectiveness of systems to deflect fish and other aquatic biota. There is limited information available on the installation, operation and maintenance of the systems. The installation, operation and maintenance of behavioural deterrents in harsh offshore environments will therefore be reliant on manufacturer and third party designs and theoretical information. Further information, including research and development, is likely to be required to satisfy the nuclear safety requirements of behavioural deterrent technologies for offshore situations.

Few studies have been reported on since 2010 that are publicly available for this review, and as such there is limited new evidence since the 2010 cooling water options report (Environment Agency 2010) that can be considered. The conclusion therefore remains that behavioural deterrent systems could represent an important mitigation against the impingement effects on fish for new UK nuclear power plants. However, the efficiency of such systems will depend on the technology, target species, intake/screen design, abstraction rate and environmental conditions. In addition, the design and realised efficiencies of protection will need to be assessed on an individual site basis, especially over the long-term operation of the site.

Reported efficiencies differ by technology, species and installation. Careful technology selection and design will be required at an early stage in a project, depending on the key target species, environmental conditions (especially turbidity and flow given identified limitations in the effectiveness caused by this) and individual station designs to ensure effective deflection. The majority of reported studies involve US target fish species. However, many of these fish species are comparable in terms of physiology, response to behavioural stimuli and swimming ability to UK target fish species. Generally, deterrents were found most effective for clupeid species, with variable success reported for other species.

Given the likely need for a bespoke design of any behavioural deterrent proposed for a cooling water intake for a new nuclear power station, there will be inherent uncertainties within the reported operational and deterrence efficiencies of any system prior to its detailed design and in situ testing. These uncertainties should be considered when assessing the effectiveness of a behavioural deterrent as a mitigation measure to reduce entrapment of aquatic biota.

Furthermore, the need to integrate behavioural deterrent designs with nuclear safety requirements will also require consideration at an early stage of project development if a behavioural deterrent is proposed as a mitigation measure for a new nuclear power station.

The reduction in aquatic biota entrapment into an intake often requires the implementation of a number of protection measures, including both behavioural and physical screening technologies. A combination of techniques is therefore likely to be required to reduce entrapment, and their individual and overall performance can be dependent on one another. Therefore it is important to assess the feasibility and

efficacy of the cooling water system as a whole rather than as its constituent parts and without an understanding of the potential implications of the linkages between them.

Further site-specific evidence for each installation will be required to be able to determine that suitable behavioural deterrent systems are effective for use in reducing entrapment of aquatic biota at cooling water intake systems of nuclear power stations. This is because, among other factors, there is variability in the hydrodynamic conditions that may be experienced at each intake depending on their geographic location (around the UK and also between coastal and estuarine environments) that may influence effectiveness. There is also variability in intake configuration and scale that may require bespoke behavioural deterrent solutions to be designed. Each of these factors therefore needs to be assessed on an individual basis, with evidence provided for their effectiveness.

3.1.7 Subject area scoring for fish behavioural deterrent systems

The subject area scoring results for fish behavioural deterrent systems are presented in Table 3.4.

Table 3.4 Subject area scoring for fish behavioural deterrent systems

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance	Comments/justification	Overall confidence (total score)
Evidence on the ability to site and install available and suitable systems in onshore and offshore environments with consideration of nuclear safety requirements	3	3	3	**Quality of evidence base** There is limited information available on the process and feasibility of installation of different behavioural deterrent systems. A number of case studies are available in onshore environments, but information on offshore installations is lacking. Available data are from a variety of sources, including peer-reviewed papers and technical site reports. Much of the information is dated, with little evidence post 2010. **Applicability of evidence** Case studies are available from nuclear power plants as well as other water intakes of comparable size. The majority of studies are from onshore sites with few offshore sites comparable with the new UK nuclear industry. The lack of evidence for offshore harsh environments may require further evidence or research and development to satisfy nuclear safety requirements for installation in these circumstances. **Degree of concordance** Evidence suggests that behavioural deterrent technologies are available that can feasibly be installed at onshore nuclear power plants. However, insufficient evidence from existing installations is available for offshore sites and decisions would need to be based on manufacturer design information.	**Medium (9)**

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance	Comments/justification	Overall confidence (total score)
Evidence on effective operation, safe maintenance and reliability of a system in onshore and offshore environments and at the scale required for a new nuclear power station in the UK and over the lifetime of the station	3	3	3	**Quality of evidence base** There is limited information available on the operation, maintenance and reliability of different behavioural deterrent systems. Case studies are available from onshore installations, but evidence from offshore installations – especially at the scale of new nuclear plants – is lacking. Available data are from a variety of sources including peer-reviewed papers and technical site reports. Much of the information is dated, with little evidence post 2010. **Applicability of evidence** Case studies are available from nuclear power plants as well as other water intakes of comparable size. The majority of studies are from onshore sites, with few offshore sites comparable with the new UK nuclear industry. The lack of evidence for offshore harsh environments may require further evidence or research and development to satisfy nuclear safety requirements and to understand the reliability and feasibility of maintenance of installations in these circumstances. **Degree of concordance** Evidence suggests that behavioural deterrent technologies are available that can feasibly be operated and maintained at onshore nuclear power plants. However, insufficient evidence from existing installations is available for offshore sites and decisions would need to be based on manufacturer information. Further information is likely to be required to ensure that technologies can be effectively operated and maintained within some environments and circumstances to satisfy nuclear safety requirements.	**Medium (9)**

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of concordance	Comments/justification	Overall confidence (total score)
Evidence that systems are effective for fish protection in onshore and offshore environments under different environmental conditions	3	3	3	**Quality of evidence base** Available data are from a variety of sources including peer-reviewed papers and technical site reports. Much of the information is dated, with little evidence post 2010. Data are from a range of studies, including laboratory investigations but predominantly operating systems at intakes. Evidence sources include primary reports as well as synthesised data. Studies vary in length from short test cases to longer term installations over 1 or 2 years. Information on the efficacy of continued operation over the life of a development does not appear to be available. **Applicability of evidence** Case studies are available from nuclear power plants as well as other water intakes of comparable size. The majority of studies are from onshore sites with few offshore sites comparable with the new UK nuclear industry. The UK new nuclear industry may use intake and physical screen designs that are not directly comparable to the existing evidence base. The target fish species from the majority of studies are from the USA. However, several the species are of comparable physiology to key UK fish species. **Degree of concordance** Evidence suggests that behavioural deterrent technologies could be effective for the protection of fish at new nuclear power plants depending on the technology, environmental conditions, intake design and target species. Further information is likely to be required for offshore installations operating in harsh environments to ensure that they will be effective and that design efficiencies are realised for installations over the long term.	**Medium (9)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

3.2 Decisions on cooling waters taken by other environmental regulators

3.2.1 Introduction

This section reviews changes to the international policy and legislative context for cooling water intake systems of coastal and estuarine new nuclear power stations since publication of the 2010 cooling water options report (Environment Agency 2010), and specifically what is considered to be 'best available' for use outside of the UK, to inform the approach to defining BAT for new nuclear power stations in the UK.

The decisions taken by other environmental regulators in relation to cooling water intake systems for power generation and other industries are evaluated, along with the evidence that these decisions have been based on. Cooling water intake systems covering direct cooling (or once-through cooling) and both wet and dry indirect cooling methods are considered.

The BREF (European Commission 2001) set out that BAT for industrial cooling water intake systems within the European Union was a site-specific solution balancing:

- process and site requirements
- reduction of direct energy consumption
- reduction of water consumption
- reduction of heat emissions to water
- reduction of entrainment
- reduction of emissions of chemical substances to water
- reduction of emissions by optimised cooling water treatment
- reduction of emissions to air
- reduction of noise
- reduction of leakage and microbiological risk

Following this advice, Environment Agency (2010) concluded that once-through cooling systems could represent BAT for use for cooling water intake systems for new nuclear power stations subject to 'current best planning, design and operational practice and mitigation methods being put in place'.

The recent scoping study on methods to reduce the impact on biota from cooling water intakes (Environment Agency 2018) sourced available literature on biota protection measures but did not consider whether the overall approach of once-through cooling could be BAT or the current position in the USA adopted by the USEPA. There have been recent publications and statements from the USEPA on restricting the use of direct cooling in favour of recirculating cooling. The basis of this regulatory approach by the USEPA is examined in this review for its applicability to UK situations and any other implications of relevance. Information from other international regulatory approaches was also sought.

3.2.2 Documents reviewed

National Pollutant Discharge Elimination System – Final regulations to establish requirements for cooling water intake structures at existing facilities and amend requirements at Phase I facilities (USEPA 2014a)

This document sets out the Final Rule by the USEPA for new and existing facilities that abstract water for the purposes of cooling. It gives an overview of the Final Rule and the litigation history leading to it, as well as presenting an economic analysis of the rule. While it also provides a brief description of the rationale for the rule, this is supported by limited evidence, which is generally left to the supporting documentation to the rule. As such, its value as a piece of evidence beyond its setting out the USEPA's current position is limited.

Programmatic biological opinion on the USEPA's issuance and implementation of the Final Regulations Section 316(b) of the Clean Water Act (US Fish and Wildlife Service and National Marine Fisheries Service 2014)

This document presents the USEPA's supporting biological opinion to the Final Rule reviewed above. It provides numerous studies and evidence related to the species of fish and shellfish potentially impinged and entrained through cooling water intake systems, and also on the effects of entrainment and impingement on the species (specifically in Appendix C), but limited evidence is provided that is post 2010.

Economic analysis of the Final Regulations addressing cooling water intake structures for new facilities (USEPA 2001)

This document provides an economic analysis of the Final Rule. In Section 11, it specifically quantifies impingement and entrainment impacts and potential benefits in the USA, collating datasets from a large number of existing operations and surveys.

Technical Development Document for the Final Section 316(b) Existing Facilities Rule (USEPA 2014b)

Section 6 of this document discusses the range of technological options available to facilities to achieve compliance with the Final Rule. It also presents an initial analysis of the likely effectiveness of the technologies to reduce impingement and entrainment. More widely, a justification is provided within the document for the costing methodology and development of the standards.

Fact Sheet: Final Regulations to establish requirements for cooling water intake structures at existing facilities (USEPA 2014c)

This short fact sheet provides a summary of the USEPA Final Rule.

Riverkeeper v. EPA (Riverkeeper I) – 358 F.3d 174, 181 (2nd Circuit, 2004)

This document is the court judgement for the legal case known as Riverkeeper I, in which various challenges were made to the USEPA regulatory position. The ruling prompted the development of the Final Rule by the USEPA. It provides the rationale for the judgement, but

this is supported by limited evidence in the document. As such, its value as a piece of evidence beyond providing resolution to the decision made by the court is limited.

Riverkeeper, Inc. v. EPA (Riverkeeper II) – 475 F.3d 83, 91 (2nd Circuit, 2007)

This document is the court judgement for the legal case known as Riverkeeper II, in which various challenges were made to the USEPA regulatory position. The ruling prompted the development of the Final Rule by the USEPA. The document provides the rationale for the judgement, but this is supported by limited evidence. As such, its value as a piece of evidence beyond providing resolution to the decision made by the court is limited.

Entergy Corp. v. Riverkeeper, Inc. et al., S. Ct. No. 07-588 et al. (Supreme Court, 2008)

This document is the Supreme Court judgement for Entergy Corp. v Riverkeeper, Inc., in which various challenges were made to the USEPA regulatory position. The ruling prompted the development of the Final Rule by the USEPA. It provides the rationale for the judgement, but this is supported by limited evidence in the document. As such, its value as a piece of evidence beyond providing resolution to the decision made by the court is limited.

Commentary on Riverkeeper II (Gersen 2008)

This document is a commentary on the court judgement for Riverkeeper II made in 2007, in which various challenges were made to the USEPA regulatory position. The ruling prompted the development of the Final Rule by the USEPA. As such, its value as a piece of evidence beyond providing resolution to the decision made by the court is limited.

Tradeoffs between once-through cooling and closed cycle cooling for nuclear power plants (EPRI 2012)

This report provides substantial evidence and case studies on the impingement and entrainment of fish and shellfish species at cooling water intake systems. It was written in response to the development of the USEPA Final Rule and considers alternative fish protection technologies to reduce impingement and entrainment.

Do power plant impingement and entrainment cause adverse changes in fish populations? A review of the scientific evidence (EPRI 2011a)

This report provides substantial evidence and case studies on the impingement and entrainment of fish and shellfish species at cooling water intake systems. It was written in response to the development of the EPA Final Rule and considers significant primary data from cooling water intake systems at many scales and in different aquatic environments.

National and regional summary of impingement and entrainment of fish and shellfish based on an industry survey of Clean Water Act 316(b) Characterisation Studies (EPRI 2011b)

This report reviews the scientific evidence on whether the impingement and entrainment of individuals may have wider population level effects on various species. It provides numerous

case studies that cover a range of environments and scales of abstraction. These are all species-specific, but many are of relevant species or families of species present in the UK.

Impacts of entrainment and impingement on fish populations: A review of the scientific evidence (Barnthouse 2013)

This is a published paper from EPRI (2011a) – see above.

Efficient water management in water cooled reactors (IAEA 2012)

This report discusses international policies on cooling water use around the world.

Section 3.3.2 notes that some governments place restrictions on the amount of heat that can be discharged to water bodies or protect sensitive flora/fauna from the non-thermal effects of nuclear power plants. The Indian government, for example, specifies temperature limits for new generating facilities and the EU has thermal regulations for rivers within Member States.

The report discusses the USEPA's approach to the regulation of cooling water systems, but does not give any further examples from other countries on their approach to regulation of cooling water systems or the rationale for this.

The report concludes that, in areas where water availability is a concern or due to other environmental effects, the trend has been towards dry cooling systems or more water efficient cooling systems and away from once-through cooling systems.

3.2.3 Review synthesis

USA

The USEPA defines the best technology available (BTA) in this instance as ‘best technology available for minimizing environmental impact’ (USEPA 2014a). In regulations within the USA, the USEPA identifies the BTA that is economically achievable for that industry and sets regulatory requirements based on the performance of that technology. Facilities do not have to install the technology identified by the USEPA, but they do have to achieve the regulatory performance standards that were developed based on the technology. The facility may use any technology that meets the regulatory performance standard.

This differs from the UK situation, where under the EU Integrated Pollution Prevention and Control Directive (96/61/EC) (IPPC Directive), the Environment Agency is obliged to consider, for designated installations, whether the technologies and techniques used by the developer would be BAT in each case rather than assessing against a performance standard. Box 3.1 sets out how the IPPC Directive defines BAT.

Box 3.1: Definition of BAT in the IPPC Directive

BAT is defined in Article 2(11) of the IPPC Directive as:

> 'the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole'.

Article 2(11) goes on to clarify further this definition as follows:

- **techniques** includes 'both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned'
- **available** techniques are 'those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator'
- **best** means 'most effective in achieving a high general level of protection of the environment as a whole'

The 2010 cooling water options report noted that use of once-through cooling as BTA by the USEPA had been challenged by the pressure group Riverkeeper, Inc. (Environment Agency 2010, p. 2). This challenge progressed and, in 2014, the USEPA published its Final Rule in the Federal Register to establish BTA requirements for cooling water intake systems at existing facilities and new facilities (EPA 2014a). The Final Rule came after a number of subsequent litigation proceedings:

- Riverkeeper v. EPA (Riverkeeper I) – 358 F.3d 174, 181 (2nd Circuit, 2004)
- Riverkeeper, Inc. v. EPA (Riverkeeper II) – 475 F.3d 83, 91 (2nd Circuit, 2007)
- Entergy Corp. v. Riverkeeper, Inc. et al., S. Ct. No. 07-588 et al. (Supreme Court, 2008)

The Final Rule establishes broad requirements for the cooling water intake systems at both existing and new nuclear power stations as described below; for further details, see USEPA (2014a).

BTA for new facilities

The Final Rule established 2 compliance 'tracks' for new facilities.

Under Track I, new facilities that withdraw ≥10 million gallons per day (about 0.5m^3 per second) must meet 3 requirements.

> 'First, the intake flow of the cooling water intake structure is restricted, at a minimum, to a level commensurate with that which could be attained by use of a closed-cycle recirculating cooling system. Second, the design through-screen intake velocity is restricted to 0.5fps [feet per second]. Third, the total quantity of intake is restricted to a proportion of the mean annual flow of a freshwater river or stream, or to a level necessary to maintain the natural thermal stratification or turnover patterns (where

present) of a lake or reservoir, except in cases where the disruption is beneficial, or to a percentage of the tidal excursions of a tidal river or estuary' (USEPA 2014a, p. 48316).

Furthermore, under Track I, if there are endangered or threatened species stressed by a facility's intake structure, then it may have:

> 'to select and implement additional design and construction of operational measures to address impingement mortality and entrainment if these measures are inadequate to protect the species'.

Under Track II, there is the opportunity for the facility to demonstrate to the permitting authority that:

> 'the technologies at a new facility will reduce the level of adverse environmental impact to a comparable level to what would be achieved by meeting the Track 1 requirements for restricting intake flow and velocity. In making this demonstration, the regulations allow a facility to rely on a combination of measures in addition to technology controls for reducing impingement and entrainment to achieve results equivalent to the Track I intake flow and velocity requirements' (USEPA 2014a, p. 48316).

Under Track II, the use of restoration measures (for example, 'restocking fish and improving the surrounding habitat to offset the adverse effects that would otherwise be caused by operating the intake structures') by the facility is not authorised when demonstrating compliance with the performance standard.

Under both tracks, the USEPA may:

> 'establish less stringent alternative requirements for a facility if compliance with the Phase I standards would result in compliance costs wholly out of proportion to those the EPA considered in establishing the Phase I requirements, or would result in significant adverse impacts on local air quality, water resources, or local energy markets' (USEPA 2014a, p. 48316).

BTA for existing units at existing facilities

To achieve compliance with the impingement mortality standard, an existing unit must comply with one of the following 7 alternatives (USEPA 2014a, p. 48321).

1. Operate a closed-cycle recirculating system.
2. Operate a cooling water intake structure that has a maximum through-screen design intake velocity of 0.5 feet per second.
3. Operate a cooling water intake structure that has a maximum through-screen intake velocity of 0.5 feet per second.
4. Operate an offshore velocity cap that is installed before 14 October 2014.
5. Operate a modified travelling screen that the USEPA Director determines is the BTA for impingement reduction.
6. Operate any other combination of technologies, management practices and operational measures that the USEPA Director determines is the BTA for impingement reduction.
7. Achieve the specified impingement mortality performance standard (a 12-month impingement mortality performance of all life stages of fish and shellfish of no more than 24% mortality, for all non-fragile species that are collected or retained in a sieve with maximum opening dimension of 0.56 inches after holding for 18–96 hours).

To achieve compliance with the entrainment standard, the USEPA must establish the BTA entrainment requirement for an existing unit on a site-specific basis.

BTA for new units at existing facilities

To achieve compliance with the impingement mortality and entrainment standard, a new unit at an existing facility must achieve one of 2 compliance alternatives (USEPA 2014a, p. 48322).

1. The owner or operator of the facility must 'reduce actual intake flow at the new unit, at a minimum, to a level commensurate with that which can be attained by the use of a closed-cycle recirculating system'.
2. The owner or operator of the facility must demonstrate to the USEPA Director that it 'has installed, and will operate and maintain, technological or other control measures that reduce the level of adverse environmental impact from any cooling water intake structure used to supply cooling water to the new unit to a comparable level to that which would be achieved through flow reductions commensurate with the use of a closed-cycle recirculating system. Entrainment mortality reductions must be equivalent to 90 percent or greater of the reduction that could be achieved through compliance with the first standard'.

In addition, the USEPA may:

> 'establish alternative entrainment requirements for new units when compliance with the new unit entrainment standards would result in compliance costs wholly out of proportion to those the EPA considered in establishing the requirements at issue, or would result in significant adverse impacts on local air quality, local water resources other than impingement or entrainment, adverse impacts on threatened and endangered species, or local energy markets' (USEPA 2014a, p. 48322).

Any USEPA-specified alternative must achieve a level of performance as close as practicable to the requirements under Track I or Track II of the new facilities standard.

For new or existing units at existing nuclear facilities, the Final Rule also includes a provision that if compliance would conflict with a nuclear safety requirement, following consultation with the Nuclear Regulatory Commission, the Department of Energy or the Naval Nuclear Propulsion Program, then the EPA must establish BTA requirements that would not result in a conflict with the safety requirement. This does not apply to new facilities, for which the Phase I rule applies and does not make allowance for any exemptions. The USEPA anticipates that this provision would be implemented as follows:

> 'Initially, the [USEPA] Director will draft a permit and will share the draft permit with the owner or operator of the nuclear facility. Upon reviewing the draft permit, the owner or operator will determine whether in their view a conflict with a safety requirement established by the Nuclear Regulatory Commission, the Department of Energy or the Naval Nuclear Propulsion Program exists. If a conflict exists, the owner or operator should communicate the conflict to the NRC, Department or Program and the Director. In all cases, whether a conflict exists or not, the Director should notify the NRC, Department or Program and the owner or operator of the facility that he or she wishes to informally confer regarding the permit. Such interactions should be scheduled, conducted and documented. Where a conflict is identified, the Director would make a site-specific BTA determination' (USEPA 2014a, Section VIII.E.7, p. 48373-48374).

Other international information

In terms of wider international legislation relating to cooling water intake systems and the impingement and entrainment of biota, no additional relevant legislation has been identified. The EU (through the Water Framework Directive 2000/60/EC) and India (through the Environment (Protection) Act 1986 (as amended)) have thermal limits for cooling water intake systems and nuclear power stations, but no countries were identified as having legislation to manage or limit the entrainment and impingement of biota.

Supporting evidence for international decisions

Rationale for the USEPA Final Rule

A number of supporting documents to the Final Rule were published by the USEPA (USEPA 2001, US Fish and Wildlife Service and National Marine Fisheries Service 2014, USEPA 2014b, USEPA, 2014c). EPRI also published a number of studies in advance of the Final Rule. These were in response to its development and probably reflecting ongoing discussions with the USEPA (EPRI 2011a, EPRI 2011b, EPRI 2012, Barnthouse et al. 2013).

The review of the Final Rule, the supporting documents, the EPRI reports and the litigation proceedings listed above, and the commentary on the litigation proceedings (Gersen 2008), found a clear justification that the compliance requirements established by the Final Rule are for the purposes of reducing the total numbers of impinged and entrained fish and shellfish individuals. The evidence provided within these documents for use in the UK is scored in Section 3.2.5.

Although the Final Rule clearly favours the use of closed-cycle recirculating systems due to their benefits in reducing losses of total numbers of impinged and entrained fish, it is carefully worded so as to not exclude the use of once-through cooling systems for any facility. This is providing that the facility can implement sufficient mitigation to demonstrate a similar amelioration of losses of total numbers of impinged and entrained individuals as a closed-cycle recirculating system (to 90% of the amelioration offered by a closed-cycle recirculating system) from an ‘unmitigated’ open intake. This 90% level was determined through the litigation proceedings and subsequent judgements. As noted above, there are further exemptions also available within the Final Rule in terms of disproportionate cost and environmental and energy market effects for both new and existing facilities, and in terms of nuclear safety for existing facilities.

History of the USEPA Final Rule

The USEPA Final Rule addresses Section 316(b) of the 1972 Clean Water Act, which introduced the National Pollutant Discharge Elimination System (NPDES) permit program. NPDES regulates point sources of pollution, including power plants with thermal and other point source discharges. Section 316(b) requires that the location, design, construction and capacity of cooling water intake structures reflect the BTA for minimising adverse environmental impacts.

The Section 316(b) regulations published by the USEPA in 1976 were successfully challenged by a group of utilities (Appalachian Power Co. v Train, 10 ERC 1965 (4th Cir. 1977)) and so the USEPA withdrew them in 1979. A coalition of environmental groups filed a lawsuit in 1993 against the USEPA over their failure to re-enact Section 316(b) regulations, and a consent decree was agreed in 1995 (Cronin v. Browner, 898 F. Supp. 1052 (S.D.N.Y. 1995)), which directed the USEPA to take final action in relation to Section 316(b) regulations. This initial lawsuit against the EPA, headed by the Hudson Riverkeeper campaign group – and the subsequent consent decree – featured the issue of the

entrainment and impingement of fish within cooling water intake systems, and was a prominent factor in the development of the Final Rule by the USEPA.

Achieving compliance with the USEPA Final Rule

The Technical Development Document (USEPA 2014b) presents an analysis of impingement mortality reduction and entrainment reduction estimates for technologies including reductions to intake velocities, barrier nets, travelling screens, offshore intakes and variable speed pumps. The USEPA pointed out that this was only an initial analysis and so it is anticipated that any operator would prepare a detailed evaluation of the performance of relevant technologies at the site in question. Using the figures quoted by the USEPA, however, it is possible to reduce impingement mortality and entrainment to a level of 90% of the reduction offered by use of a closed-cycle recirculating system through the currently available technologies evaluated. A once-through cooling system could still therefore, be considered to be the BTA within the USA without any need for consideration of, or application for, less stringent alternatives or exemptions.

Technologies considered by the USEPA for the reduction of impingement mortality and entrainment include:

- closed-cycle recirculating systems or partial closed-cycle cooling
- variable speed pumps
- seasonal outages (including standard maintenance outages that are specifically scheduled to avoid a biologically sensitive period)
- certain impingement technologies that reduce the number of organisms exposed to the intake structure (for example, diversions, louvers, barrier nets)
- intake location
- behavioural technologies (for example, light or sound barriers)
- fine mesh screens with a mesh size of $\leq$2mm
- water reuse or alternate sources

The Final Rule specifically considers reductions in **total numbers** of individuals to be the requirement for compliance, rather than reductions in the **proportion of populations** of species impinged and entrained, and this was supported by the Riverkeeper II decision. The USEPA justifies its position 'because impingement and entrainment are primary, harmful environmental effects that can be reduced through the use of specific technologies' and that 'where other impacts at the population, community and ecosystem level exist, these will also be reduced by reducing impingement and mortality' (Riverkeeper, Inc. v. EPA (Riverkeeper II) – 475 F.3d 83, 91 (2nd Circuit, 2007)).

The USA operates a rule-based and prescriptive approach to the regulation and compliance of cooling water intake systems. This approach therefore lends itself to establishing the requirements, as it does with regard to total numbers versus proportion of populations. This is because the need to set an inflexible 'rule' means that the USEPA has to set a rule that can apply to all operators and situations, and all operators must adhere to it.

The authors of this report consider that the drawback with the Final Rule promulgated by the USEPA is that solely seeking to reduce the total numbers of individuals impinged and entrained means that, even by complying with this rule, the impingement and entrainment may still result in an appreciable loss to the populations. With the Final Rule as currently adopted, this possibility would not be considered by the USEPA in any decision-making. Also, given the USEPA's adopted position through the litigation proceedings, an amendment

to the Final Rule to include consideration of both reduction in total numbers and ensuring no adverse population level effects is likely to be contested strongly.

The UK regulatory paradigm does not provide the same prescriptive, rule-based guidance for operators and so there is flexibility to promote and secure reductions in adverse environmental impact as far as possible on a project-specific basis. For any project, it is important to consider both total numbers of entrained and impinged individuals and also the implication of these total numbers to the relevant populations of the species and their structure, functioning, growth and productivity. Only in this way can the significance of wider community and ecosystem effects be understood for decision-making purposes.

This assessment is required within the UK regulatory paradigm, as projects are required to comply with:

- environmental impact assessment (EIA) regulations such as The Town and Country Planning (Environmental Impact Assessment) Regulations 2017 or The Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2017, which require the identification of the 'significant' environmental effects of a proposed development
- 'Habitats Regulations' including The Conservation of Habitats and Species Regulations 2017, which require that an 'appropriate assessment of the implications of the plan or project for that site in view of that site's conservation objectives'
- the Water Framework Directive, which requires Member States to achieve good ecological status or potential in surface water bodies, and to prevent the deterioration of surface water bodies from high status to good status
- the Marine Strategic Framework Directive and Marine Conservation Zones

It is therefore essential that the implications of entrainment and impingement are understood during the decision-making process in terms of whether it is significant under the EIA regulations, whether it will have any effect on the conservation objectives of sites designated under the Habitats Regulations, and whether it will cause a deterioration in status (or failure to achieve good status) in water bodies covered by the Water Framework Directive.

As such, the justification for the Final Rule set out by the USEPA is not entirely applicable to the UK situation, as applying it directly to the UK situation could lose some of the resolution and understanding in decision-making offered by the current UK approach.

Entrainment survival within the USEPA Final Rule

The USEPA continues to consider that entrainment through a cooling water intake system will result in zero entrainment survival and so reductions in entrainment numbers rather than in entrainment mortality is required by the Final Rule. This conflicts with cooling water options report (Environment Agency 2010), which presents evidence that many individuals survive entrainment.

The USEPA position was tested through Riverkeeper II. The court found that the US EPA acted within its discretion in assuming zero entrainment survival based on its explanation that 'it does not have sufficient data to establish performance standards based on entrainment survival for the technologies used as the basis for today's rule'. Riverkeeper II drew together an expert review panel to consider the available evidence on entrainment survival, and while they concluded that zero entrainment survival was unlikely, they could not conclude what level of entrainment survival was likely based on the available evidence to enable an industry-wide rule to be set.

An assumption of zero entrainment survival appears to have been set on a precautionary basis in the absence of sufficient evidence to define a value across the whole industry, rather than because there is categorical evidence that there will be no survival during entrainment.

As the UK does not follow the same rule-based regulatory processes, it is not required to set stringent and inflexible rules for the whole industry but can evaluate this matter on a project-specific, technology-specific, site-specific and location-specific basis. As such, it can consider the available evidence on entrainment survival and its applicability to each specific case in order to define what is considered to be a likely level of entrainment survival in that case. In many cases, this could be a range of potential values to capture the variability within the population and the uncertainty in the evidence base, but for many species is also likely to not be zero entrainment survival following the conclusions drawn by Environment Agency (2010).

3.2.4 International expert input

Thermal power plants in Germany (Karlsruhe Power Plant, Moorburg Power Plant and Irsching Power Plant) have been equipped with physical and electrical fish protection systems for the purposes of compliance with environmental regulation such as the Habitats Directive and the Federal Water Act (Wasserhaushaltsgesetz).

The international experts also identified a further piece of evidence from the Netherlands, where impingement and entrainment for new cooling water intakes was assessed and then checked (if required) by a monitoring programme. The only intake in the Netherlands currently required to mitigate for impingement and entrainment is the Eems CCGT power station near Groningen. A technical review related to the impingement and entrainment of fish (Bruijs 2007) is still used for the permitting of cooling water intakes in the Netherlands.

It was noted by the international experts that decisions made in Canada appear to be broadly similar to the approach taken by the USEPA, and that in the Netherlands site-specific evaluations are made leading to local decisions which are then supported by monitoring. In the Netherlands, the permitted impact level is <10% loss to the population, but this is acknowledged to be arbitrary and not based on scientific evidence.

The intakes in other countries were generally considered to be sufficiently comparable in terms of design configuration and intake flow to those in the UK to allow meaningful consideration of their approaches to addressing the impingement and entrainment of biota. In addition, the international experts noted that the decision-making framework in the USA and the EU gave consideration to the impingement and entrainment of biota, which concurs with the review synthesis in Section 3.2.3. It was noted by the international experts that there is generally a non-linear relationship between intake flow and impingement numbers, with a doubling of flow more than doubling impingement numbers. It was noted that entrainment is however less effected and generally increases in proportion to flow.

In relation to the implications of the regulatory approaches in other countries, the international experts highlighted the case of the Moorburg Power Station in Germany, which implemented a recirculating cooling water system rather than direct cooling and also a large-scale monitoring programme for the entrapment of fish.

In the USA and Canada, a number of developers have argued that by using the same intake to provide water for a repowered or newly developed station, they are not required to meet the Final Rule standards, but must meet the standards in place prior to the Final Rule.

The international experts considered that:

- the regulation of the impacts of impingement and entrainment in the USA was far ahead of that in the UK
- in other EU countries, the approaches vary widely with the impact often not considered in detail

3.2.5 Evidence scoring for international approach

The evidence scoring results for the international approach systems are presented in Table 3.5.

Table 3.5 Evidence scoring for international approach

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
NPDES – Final Regulations to establish requirements for cooling water intake structures at existing facilities and amend requirements at Phase I facilities (USEPA 2014a)	Report	1	1	1	**Quality of information source** There is limited justification of evidence or statements. Some studies are referenced, but these are of varying quality and not always targeted towards the case made by the USEPA. **Applicability of evidence** Evidence is predominantly from US waters and species, or from generic studies. No key individual studies are identified in this document which unequivocally demonstrate a significant adverse effect of once-through cooling and would trigger a paradigm shift in regulation in the UK. In addition, a weight of evidence of significant adverse effects of once-through cooling is not presented. **Strength of conclusion** Clear, evidence-based conclusions, with appropriate consideration of confidence and uncertainty are not discussed.	**Low (3)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Programmatic biological opinion on the USEPA's issuance and implementation of the Final Regulations Section 316(b) of the Clean Water Act (US Fish and Wildlife Service and National Marine Fisheries Service 2014)	Report	5	5	3	**Quality of information source** Evidence is based on a review of numerous peer-reviewed papers and grey literature reports by the USEPA. Statistical robustness is not clearly described or demonstrated. **Applicability of evidence** Evidence is based on varying scales and locations of abstractions, including marine/coastal environments, lakes and rivers. Fish species considered are all US species, but many are either also present in UK waters or have species from the same family present in UK waters. **Strength of conclusion** Clear conclusions are drawn following the review of the evidence on the direction of impact, but uncertainty and confidence are not explicitly discussed as well as population level implications of the impacts.	**High (13)**
Economic analysis of the Final Regulations addressing cooling water intake structures for new facilities (USEPA 2001)	Report	5	3	3	**Quality of information source** Evidence is a grey literature report from an established organisation reviewing US impingement and entrainment datasets. **Applicability of evidence** Evidence is provided relevant to coastal and estuarine nuclear power stations and can be transferrable to the UK situation. However, the document does not provide targeted evidence that can be transferred as reports only mean impingement and entrainment of US species in US waters rather than the implications of these. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented, but some confidence limits are suggested.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Technical Development Document for the Final Section 316(b) Existing Facilities Rule (USEPA 2014b)	Report	3	5	3	**Quality of information source** Evidence is a review of existing evidence from many sources by an established organisation. Screening and deterrent information relies heavily on EPRI (2013). **Applicability of evidence** Evidence is relevant to marine and coastal environments and to nuclear power stations, and is therefore transferable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented.	**Medium (11)**
Fact Sheet: Final Regulations to establish requirements for cooling water intake structures at existing facilities (USEPA 2014c)	Report	1	1	1	No relevant supporting evidence is provided by this document.	**Low (3)**
Riverkeeper v. EPA (Riverkeeper I) (2nd Circuit, 2004)	Report	5	1	1	**Quality of information source** Evidence is a court judgement report on the USEPA Final Rule. It is not peer-reviewed or supported by robust statistical analysis, but is assessed as high quality as it forms part of the US legal framework. **Applicability of evidence** Evidence reviews the US rule-based regulatory paradigm and proposed adjustments to it. It is therefore not directly transferable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented.	**Medium (7)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Riverkeeper, Inc. v. EPA (Riverkeeper II) – (2nd Circuit, 2007)	Report	5	1	1	**Quality of information source** Evidence is a court judgement report on the USEPA Final Rule. It is not peer-reviewed or supported by robust statistical analysis, but is assessed as high quality as it forms part of the US legal framework. **Applicability of evidence** Evidence reviews the US rule-based regulatory paradigm and proposed adjustments to it. It is therefore not directly transferable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented.	**Medium (7)**
Entergy Corp. v. Riverkeeper, Inc. et al. (Supreme Court, 2008)	Report	5	1	1	**Quality of information source** Evidence is a court judgement report on the USEPA Final Rule. It is not peer-reviewed or supported by robust statistical analysis, but is assessed as high quality as it forms part of the US legal framework. **Applicability of evidence** Evidence reviews the US rule-based regulatory paradigm and proposed adjustments to it. It is therefore not directly transferable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented.	**Medium (7)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Commentary on Riverkeeper, Inc. v. USEPA (Gersen 2008)	Report	1	1	1	**Quality of information source** Evidence is a commentary on a court judgement report on the USEPA Final Rule. It is not primary data or supported by robust statistical analysis. **Applicability of evidence** Evidence is a commentary reviewing the US rule-based regulatory paradigm and proposed adjustments to it. It is therefore not directly transferable to the UK situation. **Strength of conclusion** Evidence does not draw clear conclusions.	**Low (3)**
Tradeoffs between once through cooling and closed cycle cooling for nuclear power plants (EPRI 2012)	Report	5	5	3	**Quality of information source** Evidence is a grey literature report from an established organisation reviewing technological and environmental considerations, and is up-to-date and targeted towards the key questions. **Applicability of evidence** Evidence is relevant to coastal and estuarine nuclear power stations and is not species-specific, so can be transferrable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions but uncertainty and confidence are not explicitly discussed or addressed.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
	Do power plant impingement and entrainment cause adverse changes in fish populations? a review of the scientific evidence (EPRI 2011a)	5	5	5	**Quality of information source** Evidence is a grey literature report from an established organisation reviewing US impingement and entrainment datasets, and is up-to-date and targeted towards the key questions. **Applicability of evidence** Evidence is provided relevant to coastal and estuarine nuclear power stations, and can be transferrable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions; uncertainty and confidence are clearly documented.	**High (15)**
	National and Regional summary of impingement and entrainment of fish and shellfish based on an industry survey of Clean Water Act 316(b) Characterisation Studies. (EPRI 2011b)	5	5	3	**Quality of information source** Evidence is a grey literature report from an established organisation reviewing US impingement and entrainment datasets, and is up-to-date and targeted towards the key questions. **Applicability of evidence** Evidence is provided relevant to coastal and estuarine nuclear power stations, and can be transferrable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented.	**High (13)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Impacts of entrainment and impingement on fish populations: a review of the scientific evidence (Barnthouse 2013).	Report	5	5	3	**Quality of information source** Evidence is a peer-reviewed paper from an established organisation reviewing US impingement and entrainment datasets, and is up-to-date and targeted towards the key questions. **Applicability of evidence** Evidence is provided relevant to coastal and estuarine nuclear power stations, and can be transferrable to the UK situation. **Strength of conclusion** Evidence draws clear conclusions though uncertainty and confidence are not clearly documented	**High (13)**
Efficient water management in water cooled reactors (IAEA 2012)	Report	5	5	3	**Quality of information source** Evidence is grey literature, but from an established and objective organisation and is up-to-date. **Applicability of evidence** Evidence is provided relevant to nuclear power stations, but many are relating to areas under water availability stresses. **Strength of conclusion** Evidence draws clear conclusions, though uncertainty and confidence are not clearly documented	**High (13)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

3.2.6 Evidence review conclusions for international approach

This review of the evidence base surrounding the USEPA Final Rule did not identify a body of comprehensive studies and evidence that unequivocally demonstrate significant effects on fish species, populations or ecosystems as a result of entrainment and impingement through cooling water intake systems. Equally, however, it was unable to demonstrate that entrapment through cooling water intake systems does not cause a significant effect on fish populations.

There is insufficient evidence in the USA to determine, at a national level, whether entrapment through cooling water intake systems does or does not have a significant effect on aquatic biota populations. Therefore, the USEPA has taken a precautionary approach in its regulatory mechanisms by requiring mitigation for the effects of entrapment regardless of the predicted impacts on aquatic biota. This mitigation is in the form of entrainment reductions and impingement mortality reductions, with the standard required to be met of the entrainment and impingement mortality rates of a closed-cycle recirculating system.

Even with the precautionary approach adopted by the USEPA, risks to aquatic biota populations remain. A US power station could be considered compliant if it mitigates impingement mortality and entrainment levels to the standard. However, this reduced level of impingement mortality and entrainment may still potentially pose significant effects to species if they are particularly exploited or vulnerable to additional anthropogenic pressures.

Although the USEPA regulatory approach is relevant to the scale and nature of cooling water intake systems being proposed in the UK, and the regulatory approach is clearly developed to reduce impingement mortality and entrainment of aquatic biota, it is considered that there is insufficient evidence to adopt a similar regulatory position to the USEPA Final Rule in the UK. This is due to the regulatory paradigm currently adopted in the UK and the focus within UK legislation under the EIA Directive and Habitats Directive of identifying whether there are ‘significant’ effects on species. It is considered that the evidence, while potentially useful on a site- and species-specific basis for project-level assessments, is not sufficiently transferable to the UK regulatory paradigm to influence a wider BAT policy decision in the UK.

Many studies are available, and identified through this review, that document the numbers of individuals entrained or impinged through existing intakes of varying flows and designs. Two examples are US Fish and Wildlife Service and National Marine Fisheries Service (2014) and EPRI (2012), which between them contain many tens of individual studies. Some of these studies document a population level effect and others document no population level effect. It is apparent from these studies, however, that both numbers of entrained or impinged individuals and the subsequent population level effect is highly specific to the project location and design in question. The implication of entrainment and impingement through cooling water intake systems to fish and shellfish will be species-specific, and will depend as much on the underlying population structure and abundance as on the numbers of individuals being entrained or impinged.

This supports the current UK approach of using bespoke, project-specific assessments within the consenting process, as required by the EIA and Habitats directives. This bespoke assessment approach helps to mitigate the risk inherent within the USEPA approach of allowing inappropriate development to proceed.

There is little other evidence of limits to entrainment and impingement legislated for by other countries than the USA and Canada, with countries in Europe such as the Netherlands following a similar, bespoke, project-specific approach as the UK.

While it is considered appropriate to continue to utilise project-specific assessments for consenting purposes, the wider effects of multiple pressures on aquatic biota populations from, for example, multiple power stations, other anthropogenic developments or activities, also need to be understood to safely manage species populations. No studies have comprehensively assessed the cumulative effect of a number of marine/coastal power stations on marine or diadromous fish species populations, as may be the case in the UK where multiple power stations are operating and entraining and impinging fish in the same stock.

In conclusion, this review has not identified sufficient evidence through examination of the USEPA Final Rule (USEPA 2014a) and supporting evidence, and approaches in other countries to support an alternative position to that concluded by Environment Agency (2010). Once-through cooling systems therefore potentially still represent the 'best available technology' for use for cooling water intake systems for new nuclear power stations if 'best practice in planning, design, mitigation and compensation are followed'.

The fact that there is no systematic demonstration of detrimental population effects to fish and shellfish species from power stations from the past 60 years of operation indicates that it is not possible to apply a 'one-size fits all' approach to the regulation of these operations for their effects on fish and shellfish. Evaluation of each project on its own merits and against the latest technologies and evidence to determine what is 'best available' is appropriate for the UK regulatory context.

Each project should be considered on its own merits and with regard to the nature of the site and the fish and shellfish populations present, using the best available evidence. This should result in the design of an appropriate intake system that will not result in a significant adverse effect on fish and shellfish populations due to entrainment and impingement in the cooling water intake system.

3.2.7 Subject area scoring for international approach

The subject area scoring results for the international approach are presented in Table 3.6.

Table 3.6 Subject area scoring for international approach

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of Concordance	Comments/justification	Overall confidence (total score)
Are cooling water developments in other countries sufficiently comparable to the UK new nuclear industry for their regulatory decisions to be considered a relevant evidence base?	5	5	5	**Quality of evidence base** All the evidence relates directly to all cooling water intake systems with intake volumes >2 million gallons per day (or 0.1m^3 per second), with nuclear power stations directly discussed. Hence it is considered that there is sufficient evidence that the cooling water developments in other countries are comparable. **Applicability of evidence** All the evidence relates directly to cooling water intake systems with intake volumes >2 million gallons per day, with nuclear power stations directly discussed. Evidence for marine and coastal environments is also presented. **Degree of concordance** There is clear agreement by the industries that the regulatory decisions apply to include nuclear power stations.	**High (15)**
What are the rationales for decisions made in other countries (for example, compliance with environmental regulation, protection of specific fish species, non-fish related drivers) and are they comparable to the UK permitting framework?	5	3	3	**Quality of evidence base** The evidence is sufficient to determine that the rationale for the USEPA decision is for the protection of biota from impingement and entrainment for all fish species. However, there are some differences between regulatory frameworks that mean the decision is not directly transferable. **Applicability of evidence** There are some differences in regulatory frameworks between the USA and the UK that mean the decision is not directly transferable. **Degree of concordance** The evidence agrees that the rationale for the USEPA decision is for the protection of biota from impingement and entrainment for all fish species, but there is limited evidence presented on the transferability of this decision to the UK permitting regime. There is also insufficient evidence to determine that entrainment and impingement have significant effects on fish populations to support the transfer of this decision to the UK permitting regime.	**Medium (11)**

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of Concordance	Comments/justification	Overall confidence (total score)
Is there any evidence available on the implications of decisions made by other environmental regulators (for example, a reduction in new development applications, or objections from developers)?	1	1	1	**Quality of evidence base** No evidence of the implications of the USEPA Final Rule since its publication has been identified. **Applicability of evidence** No evidence of the implications of the USEPA Final Rule since its publication has been identified. **Degree of concordance** No evidence of the implications of the USEPA Final Rule has been identified.	**Low (3)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

3.3 Fisheries and other aquatic biota impact assessment

3.3.1 Introduction

The industrial cooling waters BREF (European Commission 2001) presents data on numbers of impinged and entrained biota from a selected number of power stations within Europe, but does not discuss any methods of contextualising the impacts to the wider population or ecosystem.

The Environment Agency (2010) cooling water options report does, however, discuss methods for putting numbers of entrained and impinged biota into context. The report discusses the EAV approach proposed by Turnpenny (1989), along with the habitat production foregone (HPF) approach (otherwise termed EALP) (Turnpenny 2002). It also presents methods of contextualising entrainment and impingement numbers against wider prey resources and fishery discards. These methods have traditionally been conducted for impingement and entrainment assessments for power stations in the UK, along with contextualising against the spawning stock biomass or species population abundance (BEEMS 2011).

The scoping study report (Environment Agency 2018) highlighted the use of individual-based models (IBMs) as a technique for assessing entrainment and impingement at cooling water intake systems. This report also notes the need to develop the monitoring of cooling water intake systems to consider such aspects as survival on FRR systems, fish deterrent effectiveness and impingement quantities. Finally, the report discusses the latest developments in EAV and EALP methodologies, including the development by Cefas of a model for relating mortality to length based on a von Bertalanffy Growth model (Metcalfe et al. 2016).

Impact assessments generally focus on the contextualisation of fish losses on stocks or populations. Relatively few studies consider other aquatic biota or wider ecosystem effects.

3.3.2 Documents reviewed

Extrapolating impingement and entrainment losses to equivalent adults and production foregone (EPRI 2004)

The report provides evidence on the use of 2 types of fish loss extrapolation models to minimise entrainment and impingement losses of fish and shellfish. In particular, it provides comprehensive guidance on the use of equivalent adult and production foregone models including proper model selection and model parameterisation, and an explanation of the uncertainties in the modelling results. The report illustrates the application of these models to calculate the number of adult fish required to produce the lost fish (for equivalent adult models) or to estimate the biomass that would have been elaborated by the group of fish lost, that is, production foregone (for production foregone models).

Framework for assessing fisheries productivity for the Canadian Fisheries Protection Program (Bradford et al. 2014)

This technical report describes a conceptual framework for assessing changes in fisheries productivity resulting from projects, works or activities that have the potential to affect fish or

fish habitat. This framework appears to be robustly defended when assessing changes in productivity caused by the residual effects of development projects when mitigation measures cannot be applied or cannot fully address a stressor.

Pathways of effects are presented as a tool for the identification and organisation of possible effects ('indicators') of a project on fish and fish habitats. The aim of this approach was to link pathways of effects to the productivity state functions of fisheries in order to specify causal relations between a change in habitat or environmental condition and a change in a component of productivity. Productivity assessments were described for 3 different types of projects based on the quantity, quality and degree of transformation and scale of the impact:

- projects that reduce habitat quantity
- projects that affect habitat quality
- projects that result in ecosystem transformation

Climate change and the green energy paradox: the consequences for twaite shad Alosa fallax *from the River Severn (Aprahamian et al. 2010)*

This paper used a population model developed for twaite shad *(Alosa fallax*) to simulate future scenarios for this species, taking into account future climate change and future infrastructure developments in their population range. The model was developed from data collected in the Severn Estuary. From this, a stock–recruitment relationship was developed using a traditional Ricker model (Ricker 1954). This was applied in practice to answer a number of research questions within the paper.

It is likely that a model of this nature can be adapted for use in assessments of impingement and entrainment at cooling water intake systems, given that it can incorporate the evaluation of pressures on populations from infrastructure.

*Modelling the response of the twaite shad (*Alosa fallax*) population in the Afon Tywi SAC to a modified temperature regime (Knights 2014)*

The population model described above was extended for use in the River Tywi, another river designated as a Special Area of Conservation (SAC) for twaite shad, in order to consider effects of changes in the temperature regime in this river. Additional Monte Carlo simulations and stochastic functions were added to the model to further understand the potential variability within the population and the uncertainty within the model parameters and input data.

It is likely that a model of this nature can be adapted for use in assessments of impingement and entrainment at cooling water intake systems, given that it can incorporate evaluation of pressures on populations from infrastructure.

Severn Tidal Power Feasibility Study: Strategic Environmental Assessment topic paper: Migratory and Estuarine Fish Annex 4 – migratory fish life cycle models (Knights et al. 2010)

To enable assessment of the effects on the fish receptor populations as a whole from the Severn Tidal Power plan alternatives, life cycle models were developed for key fish receptors (Atlantic salmon, twaite shad, river lamprey, sea lamprey and eel). These models were developed to enable mortality related to turbine passage – and where possible other

potential effects – to be integrated to assess the effects of Severn Tidal Power on the fish receptor populations.

Life cycle models for individual species were developed to predict population changes over the anticipated lifetime of a Severn Tidal Power plan alternative from the present day to 2140. In addition to baseline predictions, consideration was also given to potential future implications such as climate change and management initiatives designed to meet compliance targets such as favourable condition under the Habitats Directive.

Preliminary assessment of river flow impacts on salmon migration resulting from alternative hands off flows in simulated extreme drought scenarios (Milner et al. 2018)

This report describes the development of a population model for Atlantic salmon (*Salmo salar*) to investigate the recovery time of this species to very low water levels in the rivers Test and Itchen. It is likely that a model of this nature could be adapted for use in assessments of impingement and entrainment at cooling water intake systems, given that it can incorporate evaluation of pressures on populations from infrastructure.

Best practice in use of Ecopath with Ecosim food-web models for ecosystem-based management (Heymans et al. 2016)

Ecopath with Ecosim is a modelling complex that has been used since the 1980s to create mass-balanced models of marine and aquatic ecosystems (Pauly et al. 2000). Few such models have been used in a management context, but their application to understand the wider effects of actions or pressures on trophic levels is possible.

An applied model available for the North Sea (Mackinson et al. 2009) is being used by the International Council for the Exploration of the Sea to evaluate European Commission proposals for multiannual management plans for fisheries in the North Sea (STECF 2015). The following are described in STECF (2018) for the application of Ecopath with Ecosim models:

- diagnostics for thermodynamic and ecological principles
- principles when balancing the model
- comparing Ecopath models using ecological network analysis indices
- model calibration for dynamic simulations
- time series fitting and Monte Carlo simulations to address uncertainty in input parameters

Blade strike survival modelling for hydropower turbines

- ‘Comparison of blade-strike modelling results with empirical data’ (Ploskey and Carlson 2004)
- ‘Fish passage assessment of an advanced hydropower turbine and conventional turbine using blade-strike modelling’ (Deng et al. 2011)
- ‘Validation of a model to predict fish passage mortality in pumping stations’ (van Esch and Spierts 2014)

- ‘Assessing hydraulic conditions through Francis turbines using an autonomous sensor device’ (Fu et al. 2016)

These 4 documents present studies from the USA where investigations into operational hydropower and pumping stations were conducted to attempt to validate predictive models of turbine passage survival of fish. Initial blade strike and passage mortality models for various fish species were developed before experiments were performed at operational stations to gather empirical data on turbine passage survival.

The results of the predictive modelling and empirical data on turbine passage survival were compared in each case to understand the effectiveness of the initial modelling. This work has helped to refine methods of turbine passage survival assessment for this industry.

3.3.3 Review synthesis

Current impingement and entrainment assessment approaches

The initial task for any assessment of entrainment and impingement due to a cooling water intake system is the definition, calculation or estimation of the numbers of fish and shellfish that may be entrained or impinged at the cooling water intake system.

For new or existing UK power stations, use can be made of impingement and entrainment monitoring data at the site in question, or nearby sites if fish assemblages and design configurations are comparable. This approach has been followed for Hinkley Point C (BEEMS 2010) and Wylfa Newydd Nuclear Power Stations (Horizon Nuclear Power 2018).

Where historic site-specific or comparable impingement and entrainment monitoring data do not exist, it is possible to estimate them from fisheries survey data, collected in an appropriate manner (WFD-UKTAG 2014). This can be coupled with the development of bespoke encounter modelling tools such as IBMs following the approach used by Willis (2011) or other probabilistic techniques such as those set out by Hammar et al. (2015) and Schofield and Scorey (2017). Use of the Prediction of Inshore Saline Communities by Expert System (PISCES) (Seaby and Henderson 2009) can also be considered depending on the location and design of the cooling water intake system.

From the raw numbers of fish and shellfish/invertebrates impinged or entrained, the EAV, EALP, prey availability and comparison with the fisheries methods described in Environment Agency (2010) are often then used to place the figures into context of the wider populations and ecosystem for the purposes of decision-making.

The EAV concept was first introduced by Horst (1975) and still follows the same method today. Recent proposed developments in these methods have been suggested to account for some of the difficulties in determining parameters of the EAV model. One example is the BEEMS technical report by Metcalfe et al. (2016) which introduced the use of a general length–mortality relationship within an EAV model as a substitute for setting species-specific mortality rates at each life-stage – for which evidence can be scarce. However, these new methods need to be treated with caution and critically reviewed to account for the uncertainty within the relationship and the application of a general relationship at a species-specific level.

Monitoring and validation of impingement and entrainment assessments

One critical problem in using EAV and EALP models is that there is no independent means of verifying the accuracy of the results by using empirical data. By definition, equivalent adult losses and production foregone are theoretical quantities: estimates of the number of fish or

quantity of biomass that could have been produced, given the assumptions used to make the calculations. Thus, there is no way to measure these quantities and no way to independently validate the model projections. If the assumptions used in the models are wrong or the parameters inaccurate, the model projections will also be inaccurate. However, it is possible to screen model results for unrealistic projections by comparing the model's output with known or plausible rates of population change or to provide quantitative bounds on the uncertainties of those projections (for example, life cycle balancing).

The EAV and EALP metrics are purely theoretical and cannot be validated through the monitoring of cooling water intake systems. The focus of monitoring should therefore be on validating the raw numbers of fish and shellfish impinged and entrained at the cooling water intake system, and then comparing these numbers with the predicted numbers using consistent EAV or EALP methods.

Evaluation of impingement and entrainment predictions against actual numbers of impingement and entrainment occurs during operational monitoring. However, direct comparison between prediction and actual values, along with evaluation of the efficiency of the prediction method, is often not reported.

The available impingement and entrainment monitoring data from recently constructed cooling water intake systems for power stations, or other infrastructure (such as for wastewater treatment works), should be collated and compared with the impingement and entrainment predictions made for these projects during the consent/licensing process. This would enable the appropriateness of the prediction methods to be determined. Collation and publication of these data would also assist the industry by:

- enabling more accurate predictions of likely impingement and entrainment to be made in future projects
- allowing more confidence to be placed in future assessments during the decision-making process

These modelled versus empirical comparisons would have most value if undertaken for a number of coastal/estuarine sites in the UK. Ideally, a range of cooling water intake system design configurations could be used for such comparisons to provide a representative analysis for the possible locations and design configurations for future cooling water intake systems. A similar approach has been followed for other industries, such as for the blade strike survival modelling for hydropower turbines, whose approach has been tested and validated against actual turbines (Ploskey and Carlson 2004, Deng et al. 2011, van Esch and Spierts 2014, Fu et al. 2016).

Other techniques available for contextualising impingement and entrainment numbers

The methods described by Environment Agency (2010) and employed currently are useful indicators of the scale of potential effects from impingement and entrainment at cooling water intake systems in terms of both the raw numbers of individuals and the proportion of wider populations, where uncertainty within the methods is appropriately addressed. These generally provide annual losses to the population of individual species. However, there are other methods that can be employed to understand the implication of this pressure on fish species and the wider ecosystem – if considered to necessary given the scale of potential effects and the sensitivity of the species or wider ecosystem. The use of these approaches should be evaluated on a project-specific basis.

Life cycle modelling can be used to place the predicted annual losses to a species population into a multi-year context, or the context of the whole operational life of the power

station in question. This approach was used for the Severn Tidal Power Feasibility Study (Knights et al. 2010) for a number of diadromous fish species and subsequently for a number of other projects for these species (Knights 2014, Milner et al. 2018). These models allow long-term pressures on populations to be understood through evaluation of recovery rates, age structures, long-term population stability, reductions in population abundance, and extinction probability which cannot be explored using the EAV or EALP methods. These models, however, are complex to prepare and require an additional level of data and understanding of the life histories of species that may be difficult to source for some species.

As cooling water intake systems often impinge or entrain a mixture of fish species at predominantly egg, larval or juvenile ages, the effect of these losses through the wider food chain and to higher trophic levels may also need to be evaluated (in addition to life cycle modelling). This is particularly important where the fish assemblage as a whole is valued, or where key prey species are impinged or entrained in large numbers. Ecosystem modelling, such as Ecopath with Ecosim (Pauly et al. 2000), is an appropriate approach to explore for this purpose. Ecopath with Ecosim as a tool is open source ecosystem modelling software that has been in development for nearly 20 years; other similar approaches could also be developed.

Life cycle and ecosystem modelling have not traditionally been used to assess impingement and entrainment of power stations, but have been used for other projects and infrastructure where the effects on Natura 2000 sites or Marine Protected Zones and their species need to be considered. As such, for some species or fish assemblages it may be appropriate to utilise these models in relation to Habitats Regulations Assessments (HRAs) where an additional level of detail is required within the appropriate assessment.

3.3.4 International expert input

Although the international experts consulted identified that there is extensive literature available on the use of EAVs as a method of assessing the impacts of impingement and entrainment, they did not identify any new studies since the Environment Agency (2010) review. A paper by Newbold and Iovanna (2007) was highlighted. This describes a model for assessing the effect of impingement and entrainment on populations, which appears to calculate the estimated additional mortality caused by impingement and entrainment in addition to natural and other anthropogenic sources of mortality.

Feedback from the international experts indicated that there were a number of models and assessment methods available. However, they pointed out that:

- these could potentially be adapted and improved in the future in all cases
- adaptive management and development was essential for effective fish protection

Important limitations with the current suite of methods noted by the international experts were:

- the availability of reliable input data
- the sufficient consideration of population dynamics over time

The experts also highlighted that:

- biological modelling for predictive purposes is complex and difficult
- at present, models may only provide a relative assessment tool for choosing among technologies that reduce intake impacts rather than accurately predicting the magnitude of effects

- modelling of cumulative effects (that is, multiple power stations within vicinity of each other, or other impacts) was not sufficiently developed

In general, it was considered that the overall outcome of the application of assessment and modelling methods are that:

- there are temporal patterns of entrapment which reflect patterns of abundance in the water body
- the majority of fish impinged are juveniles

When predictive models are applied, numbers differ greatly from predictions for some species; this difference is driven by the temporal patterns of abundance and model input parameters. Models therefore need to account for the variability in abundance and other input parameters over time to more accurately predict impacts.

Impingement and entrainment is likely to vary between years and therefore a single impingement or entrainment number cannot be determined as it will be relative to the population status and also with variability due to wider population dynamics. The impacts of a project need to be presented as a range to account for the potential entrainment and impingement numbers in any given year.

3.3.5 Evidence scoring for fisheries and other aquatic biota impact assessment

The evidence scoring results for the fisheries and other aquatic biota impact assessment are presented in Table 3.7.

Table 3.7 Evidence scoring for fisheries and other aquatic biota impact assessment

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
A framework for assessing fisheries productivity for the Fisheries Protection Program (Bradford et al. 2014)	Report	5	3	3	**Quality of information source** This peer-reviewed research describes a conceptual framework for assessing changes in fisheries productivity due to projects, works or activities that have potential to affect fish or fish habitat. The framework appears to be robustly defended when assessing changes in productivity caused by the residual effects of development projects when mitigation measures cannot be applied or cannot fully address a stressor. Pathways of effects were described as a tool to identify and organise possible effects of a project on fish and fish habitats. The aim was to link pathways of effects to productivity state functions of fisheries to specify causal relations between a change in habitat or environmental condition and a change in a component of productivity. Productivity assessments were described for 3 types of projects: those that reduce habitat quantity, those that affect habitat quality and those that result in ecosystem transformation. **Applicability of evidence** A clear methodology on the applicability of this framework to complex projects is not presented. Therefore this evidence is deemed to be of medium applicability into the UK new nuclear industry. **Strength of conclusion** There are a number of issues that need to be resolved before the approach can be fully implemented (for example, the necessity of a combined assessment of effects on productivity from multiple stressors). As such, the strength of the conclusion is deemed to be medium for projects involving nuclear plants in the UK.	**Medium (11)**

Extrapolating impingement and entrainment losses to equivalent adults and production foregone (EPRI 2004)	Report	5	5	3	**Quality of information source** This document by an established organisation subject provides thorough guidance on the use of equivalent adult and production foregone models including proper model selection and model parameterisation, and an explanation of the uncertainties in the modelling results. **Applicability of evidence** The applicability of these models within the context of the new UK's power plants is high. Both types of models could be easily implemented if there is precise information and agreement on the main life history parameters for fish species sensitive to entrainment and impingement in the UK. These are likely to vary between different areas and information should be selected for each specific site. **Strength of conclusion** One critical problem in using these models is that there is no independent means of verifying the accuracy of the results using empirical data. By definition equivalent adult losses and production foregone are theoretical quantities: estimates of the number of fish or quantity of biomass that could have been produced, given the assumptions used to make the calculations. Thus there is no way to measure these quantities and no way to independently validate the model projections. If the model's assumptions are wrong, or the parameters inaccurate, the model projections will also be inaccurate. However, it is possible to screen model results for unrealistic projections by comparing the model's output with known or plausible rates of population change or provide quantitative bounds on the uncertainties of those projections (for example, life cycle balancing). It is feasible, however, to quantitatively assess the overall uncertainty of the models based on the uncertainty associated with each of the individual parameters in the model, and so the strength of conclusion is assessed as medium.	**High (13)**
Climate change and the green energy paradox: the consequences for	Report	5	5	5	**Quality of information source** This is a peer-reviewed paper based on direct empirical	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
twaite shad *Alosa fallax* from the River Severn, U.K. (Aprahamian et al. 2010)					evidence from the UK and supported by robust statistical analysis to understand uncertainty. **Applicability of evidence** The paper is based on UK fish species and applied under UK regulatory conditions. The activities assessed are not specifically power station impingement and entrainment, but the modelling approaches could be readily adapted to this type of assessment. **Strength of conclusion** The paper draws clear and quantitative conclusions on the direction and magnitude of impacts using the approaches, with confidence and uncertainty discussed and quantified using appropriate statistical routines.	
Modelling the response of the twaite shad (*Alosa fallax*) population in the Afon Tywi SAC to a modified temperature regime (Knights 2014)	Report	5	5	5	**Quality of information source** This document was produced by a subject expert for an established and unbiased organisation as an objective evidence report. Like Aprahamian et al. (2010) in the previous row, the work is based on direct empirical evidence from the UK supported by robust statistical analysis to understand uncertainty and builds on Aprahamian et al. (2010). **Applicability of evidence** The document is based on UK fish species and applied under UK regulatory conditions. The activities assessed are not specifically power station impingement and entrainment, but the modelling approaches could be readily adapted to this type of assessment. **Strength of conclusion** The document draws clear and quantitative conclusions on the direction and magnitude of impacts using the approaches, with confidence and uncertainty discussed and quantified using appropriate statistical routines.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Severn Tidal Power Feasibility Study – Strategic Environmental Assessment (SEA) Topic Paper: Migratory and Estuarine Fish Annex 4 – Migratory fish life cycle models (Knights et al. 2010)	Report	5	5	5	**Quality of information source** This document was produced by a number of experts on the subject for a government department as an objective evidence report. The work is based on direct empirical evidence from the UK supported by robust statistical analysis to understand uncertainty, and was accepted as part of government decision-making processes. **Applicability of evidence** The document is based on UK fish species and applied under UK regulatory conditions. The activities assessed are not specifically power station impingement and entrainment, but the modelling approaches could be readily adapted to this type of assessment. **Strength of conclusion** The document draws clear and quantitative conclusions on the direction and magnitude of impacts using the approaches, with confidence and uncertainty discussed and quantified using appropriate statistical routines.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Preliminary assessment of river flow impacts on salmon migration resulting from alternative hands off flows in simulated extreme drought scenarios (Milner et al. 2018)	Report	3	5	3	**Quality of information source** This document was produced by a number of experts on the subject for a utility company. The population modelling approach is not described in detail but is summarised briefly. Therefore further work would be required to understand the process followed and treatment of uncertainty. **Applicability of evidence** The document is based on UK fish species and applied under UK regulatory conditions. The activities assessed are not specifically power station impingement and entrainment, but the modelling approaches could be readily adapted to this type of assessment. **Strength of conclusion** The document briefly draws conclusions on the direction and magnitude of impacts using the approaches, with treatment of confidence and uncertainty also mentioned but not described in detail.	**Medium (11)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Best practice in Ecopath with Ecosim food-web models for ecosystem-based management (Heymans et al. 2016).	Report	5	3	5	**Quality of information source** This paper is peer-reviewed and describes procedures for developing ecosystem models in detail, and how to deal with uncertainty. **Applicability of evidence** The paper is not based on particular fish species but a wider North Atlantic assemblage (such as from the west coast of Scotland) which may be representative of more marine/coastal conditions. It would be possible to transfer this to an inshore or estuarine community in a similar manner however. The activities assessed are not specifically power station impingement and entrainment, but the modelling approaches could be readily adapted to this type of assessment to extend the current assessments undertaken. **Strength of conclusion** The paper discusses the treatment of confidence and uncertainty and the limitations of the models, including the availability of data as a critical driving factor in the appropriateness of the models.	**High (13)**
Appropriate assessment: Pembroke Power Station Environmental Permit. Report – final v 2.5 (Environment Agency 2011) Pembroke environmental monitoring: quantification of entrapment pressure (Jacobs 2017)	Report	5	5	5	**Quality of information source** These documents are by established organisations on the subject and are detailed in their methods and approaches. **Applicability of evidence** The documents are based on similar scales of projects in similar environments in the UK to that which may be encountered by a nuclear power station and so are therefore applicable. **Strength of conclusion** The documents discuss the treatment of confidence and uncertainty in the methodologies, and express results with appropriate descriptions of variability.	**High (15)**

Document	Piece of evidence	Quality of information source	Applicability of evidence	Strength of conclusion	Comments/justification	Overall confidence (total score)
Fish passage assessment of an advanced hydropower turbine and conventional turbine using blade-strike modelling (Deng et al. 2011) Assessing hydraulic conditions through Francis turbines using an autonomous sensor device (Fu et al. 2016) Comparison of blade-strike modelling results with empirical data (Ploskey and Carlson 2004) Validation of a model to predict fish passage mortality in pumping stations (van Esch and Spierts 2014)	Reports	5	3	5	**Quality of information source** These papers are all peer-reviewed scientific papers and so the quality of evidence is high. **Applicability of evidence** The papers are related to the hydropower industry and so are not directly comparable with the nuclear industry. However, they do directly relate to techniques for the validation of predictive modelling used within this industry and so have specific applicability for certain tasks rather than general applicability. **Strength of conclusion** The papers present the findings of the research clearly, comparing predicted outputs against validated outputs from experiments and trials on operational systems.	**High (13)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

3.3.6 Evidence review conclusions for fisheries impact assessment

This review of the evidence base surrounding the methods available for assessing the impingement and entrainment effects of cooling water intake systems of nuclear power stations on fish and biota populations found a number of appropriate modelling tools and techniques that could be utilised for a project. These include techniques to estimate raw numbers of fish and shellfish impinged or entrained, such as scaling of existing impingement and entrainment data or bespoke encounter modelling methods. Techniques to contextualise these raw numbers of fish into the implications for populations of species, both annually and over the operational life of the project (including EAV, EALP, life cycle and ecosystem modelling) were also identified.

EAV and EALP methods are established for use at power stations in relating annual entrainment and impingement numbers to a standard comparable metric. However, there are limits to the contextualisation offered by these methods, which further analysis could helpfully expand on for the purposes of HRAs and the assessment of the effects at ecosystem level. For example, established methods of reporting impingement and entrainment predictions (that is, annual rates) and contextualising using EAV and EALP methods do not consider the wider population implications of entrainment and impingement over a number of years, or changes across the ecosystem and trophic levels.

There are a range of methods available for use, but detailed guidance does not exist on which techniques should be used for a project in a given scenario (such as a project in a Natura 2000 site, Marine Protected Area, or an estuarine project versus a coastal project). Consistency of approach is likely to be an issue in assessments, as different projects will adopt different approaches. Furthermore, these methods have generally been utilised primarily for fish species, with less information and application available for effects on other aquatic biota.

Although available modelling tools are appropriate for use, the critical gap at present within the evidence process is the available data to parameterise each of the models for each species across the ecosystem under consideration. The modelling tools will therefore produce outputs of variable quality and with varying levels of confidence, which must be managed through the assessment process to ensure predictions are robust.

One approach could be to centralise the acceptable datasets for use within assessments to ensure each project uses a consistent set of data in certain areas of the assessment for comparability. This may, however, limit innovation and the use of the most recent scientific advances within assessments and so may not be appropriate for all modelling techniques. It will be essential for any future projects to collate the available information for the assessment of effects of entrapment and the assessment of effectiveness of mitigation early in the consenting process.

It is possible to collect some of the data necessary to build and run the impact models at a project-specific level, but many of the model parameters are biological information relevant to the wider population. Where this is the case, either research effort needs to be focused in these areas or it will be necessary to use appropriate bounding of the possible range of the parameters within the modelling frameworks and to carry it through to the modelled outcomes.

Furthermore, effort is needed to validate the available modelling tools to ensure that their predictive capacity is sufficient for the purposes of decision-making. This could be through comparison of post-construction monitoring with predicted impacts and potentially comparison of population models with more data-rich environments to

ensure they represent the characteristics of better known populations accurately. There are examples from other industries where validation of predictive models has occurred, such as for hydropower turbines (see Section 3.3.3) and these should be drawn on where possible when developing a validation approach.

Finally, as discussed in Section 3.2.6 in relation to the USEPA's regulatory approach, it has not so far been possible to unequivocally determine through monitoring programmes whether entrainment and impingement causes significant adverse effects on aquatic biota populations. This is likely to be primarily due to the statistical power of experimental designs, variability within datasets and practical difficulties in collecting data limiting the ability to draw statistically robust conclusions.

There may be opportunities to use more advanced modelling techniques to identify the potential for more subtle effects within wider ecosystems that may be less variable and able to be investigated more easily than monitoring wild fish populations. This would assist in the monitoring of project-level effects and the validation of predictive models.

Determination of the effects of entrapment of aquatic biota beyond reasonable scientific doubt, given the currently available evidence base, will require the systematic documentation and treatment of the variability and uncertainty in each step of the assessment process. This will ensure that the effects predicted can be suitably assessed with knowledge of the limitations of the methods and possible range of predicted outputs that could occur.

3.3.7 Subject area scoring for fisheries and other aquatic biota impact assessment

The subject area scoring results for the fisheries and other aquatic biota impact assessment are presented in Table 3.8.

Table 3.8 Subject area scoring for fisheries and other aquatic biota impact assessment

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of Concordance	Comments/justification	Overall confidence (total score)
Are models available to satisfactorily assess impacts from cooling water on fish stocks, including considering new intake and screen technologies, and long-term stock/ecosystem level implications?	3	5	3	**Quality of evidence base** There are a comprehensive suite of models available for assessing impingement and entrainment at cooling water intake systems developed both specifically for this purpose and also adapted from other uses. However, these have not been subject to validation or thorough literature/data reviews to parameterise them. **Applicability of evidence** Models are available, or can be adapted, to cover all the necessary industries, environmental conditions, intake/screen designs and fish species/stocks. **Degree of concordance** Modelling frameworks are available and suitable for the assessment of impacts from new nuclear cooling water at species and ecosystem level, and over the project lifetime for some species. For some species, models will need to be developed. The detail within these models will be site-specific and may be available at various levels of detail depending on the project.	**Medium (11)**

Are sufficient model input data and their associated uncertainties available for use?	3	1	3	**Quality of evidence base** Data availability will be on a site and project design specific basis, but there are likely to be some evidence needs for any model used that will be collated for a particular project. Uncertainty can be appropriately treated in all the models through a mixture of statistical procedures and routines to make robust predictions with associated confidence levels. **Applicability of evidence** Project-specific data to parameterise the models are likely to be needed in all cases, or uncertainty appropriately bounded. Key uncertainties are likely to cover behavioural responses of species, geographic distributions, population sizes and mortality rates. **Degree of concordance** Limited evidence is available on the appropriate way to manage and report uncertainty in a consistent manner, with evidence presenting uncertainty in predictions in a range of ways. The evidence needs for each model are, however, clearly and consistently described.	**Medium (7)**

Confidence criteria	Quality of evidence base	Applicability of evidence	Degree of Concordance	Comments/justification	Overall confidence (total score)
Are the available models validated with empirical monitoring data?	1	1	1	**Quality of evidence base** Limited coherent validation of any of the models (where it is possible to do so) has been undertaken and reported. **Applicability of evidence** Limited coherent validation of any of the models (where it is possible to do so) has been undertaken and reported, and so it is not possible to conclude that model outputs are representative of the industry, environmental conditions, intake location, scale of abstraction and screen design impacts. **Degree of concordance** Limited coherent validation of any of the models (where it is possible to do so) has been undertaken and reported, and so it is not possible to conclude that model outputs concord with monitoring data.	**Low (3)**

Notes: Red shading = Low score; amber shading = Medium score; green shading = High score.

4 Conclusions and recommendations

This report has reviewed the evidence that has become available relating to cooling water intake systems for new nuclear power stations since the Environment Agency's cooling water options report was published in 2010. The review has provided increased confidence in the state of the knowledge in 3 technical areas:

- fish behavioural deterrent systems
- evidence from the USEPA approach to cooling water intakes
- fisheries and other aquatic biota impact assessment

4.1 Conclusions

4.1.1 Fish behavioural deterrent systems

Fish behavioural deterrent technologies, including acoustic and light based systems, are available for operation with large volume cooling water systems. However there is little new information available since the Environment Agency 2010 report was published. In addition, few studies are available on the effectiveness of technologies operating in offshore environments. There is limited information available on installation, operation and maintenance of existing systems.

Reported efficiencies of existing fish deterrent systems differ depending upon the technology, key fish species, and individual site conditions. Behavioural deterrent systems could provide mitigation against the impingement effects on fish for new nuclear power plants in the UK if installed but the efficiency would be uncertain. Further site specific evidence may be required to determine the effectiveness and operability of a system in a particular location, and bespoke behavioural deterrent systems are likely to be required for each new nuclear power station site.The reduction in biota entrapment in a cooling water system often requires the implementation of a number of protection measures, including physical and behavioural technologies designed to work together. The effectiveness of a fish behavioural deterrent system may be dependent upon the overall protection system design.

4.1.2 Evidence from the USEPA approach to cooling water intakes

The USEPA decision-making process and decisions made in the EU and Canada are undertaken on comparable cooling water intake systems for the purposes of reducing the entrainment and impingement of aquatic biota. Based on the available evidence, however, the USEPA decision-making process is not at present directly transferrable to the UK situation. To do so would require significant further data collection and analysis to determine whether such an approach would be appropriate and compliant with existing UK legislation.

4.1.3 Fisheries and other aquatic biota impact assessment

A suite of modelling and assessment tools are available for assessing entrainment and impingement at cooling water intake systems. However, these tools are likely to require site-specific evidence and adaptation for use in all cases. Data to parameterise the tools are unlikely to be comprehensive for any project, and so uncertainty and variability will need to be accounted for within the models to enable robust and risk-based decisions to be made.

4.2 Recommendations

To further inform permitting decisions for new nuclear power stations, it is recommended that the evidence base available for the 3 topics examined by the review is developed and expanded through the following activities.

- Where a fish behavioural deterrent system is proposed for a project, evidence on its design, effectiveness and operational efficiency, and maintenance requirements should be provided by the developers/operators early during the permit determination process. This will ensure that the appropriateness of the system and its design can be fully evaluated. The evidence provided should consider:
  - the scale and location of the intake
  - the relevant species the system is seeking to deter
  - the links between the behavioural deterrent system and other protection technologies

  There may also be a need for further research into these aspects of fish behavioural deterrent systems.
- Developers/operators should be encouraged to share any evidence relating to behavioural deterrent systems that is not currently available. This will help to:
  - expand the evidence base for these technologies
  - determine their effectiveness and operational efficiency for a wider range of cooling water intake system design, scales and locations
- Contact should be made with the USEPA and the US power sector to identify any consequences to cooling water design and permitting resulting from the 2014 Final Rule.
- Work to further evaluate the significant body of data on the numbers of entrained and impinged individuals should be conducted to:
  - determine the effect of these losses to populations over time
  - understand the resilience of the relevant species to these losses

  These data could also be used to test the validity of predictive models.
- No studies have comprehensively assessed the cumulative effect of a number of marine/coastal power stations on populations of marine or diadromous fish species. Such an assessment should be made where multiple power stations are operating and entrapping fish in the same stock or population units.

- Collation of a central database of appropriate data for use in fisheries and other aquatic biota assessment methods and models would be of value to the whole industry. This would help to standardise assessments and to ensure consistent levels of quality are achieved. The database could be audited for robustness, with guidance provided on:
  - how to use the data
  - where appropriate uncertainties and variability exist
  - how to treat these when using the data

  This database could be maintained and updated on a regular basis to ensure it remains accurate and reflects the best available evidence.
- Consideration of which assessment methods and models to use would help to ensure that the appropriate level of detail is provided for each project's permit applications. This could include:
  - a description of the required confidence limits that predictions need to be presented at
  - the levels of effect for relevant species that are considered to be 'significant' in terms of the EIA regulations or 'adverse' in terms of the Habitats Regulations

  Consideration should also be given to the appropriate methods and models to be employed for relevant species and for designated sites and populations, with reference to appropriate datasets to use.
- To determine whether they can be obtained for inclusion in future assessments, further investigation should be made of evidence sources that:
  - are not currently in the public domain
  - are known about but were not available for review
  - are in draft form or unpublished

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List of abbreviations

AFD	acoustic fish deterrent
BAFF	bioacoustic fish fence
BAT	Best Available Techniques
BEEMS	British Energy Estuarine and Marine Studies
BREF	Best Available Techniques reference document
BTA	Best Technology Available
CCGT	combined cycle gas turbine
EALP	equivalent area of lost production
EAV	equivalent adult value
EIA	environmental impact assessment
EPRI	Electric Power Research Institute
FRR	fish recovery and return
HRA	Habitats Regulations Assessment
IBM	individual-based model
IPPC	Integrated Pollution Prevention and Control
NPDES	National Pollutant Discharge Elimination System [USA]
SAC	Special Area of Conservation
USEPA	United States Environmental Protection Agency
WFD	Water Framework Directive

Glossary

Clupeids	Fish of the Clupeidae family which includes herrings, shads and sardines.
Cyprinids	Freshwater fish of the Cyprinidae family.
Equivalent area of lost production (EALP)	Concept allows quantities of fish removed by power stations to be equated to the equivalent area of marine habitat being taken out of production for that species.
Equivalent adult value (**EAV)**	Concept puts catches via entrapment into the context of adult populations by estimating the likely future adult value of a juvenile fish had it avoided entrapment. This allows the biological value of fish at different ages to be compared.
Entrainment	The unwanted passage of fish at various life stages through a water intake.
Entrapment	Situation where fish and shellfish are unable to escape from the cooling water intake.
Habitat production foregone (**HPF)**	The cost of replacing the production lost ('foregone') by producing new, equivalent habitat; restoration that replaces the lost production.
Impingement	The physical contact of a fish with a screen (or other barrier structure) as a result of high intake velocities that do not allow the fish to escape.
Spawning stock biomass (SSB)	The combined weight of all individuals in a fish stock that are capable of reproducing.

Appendix A: International expertise questionnaire and responses

International Expert Input - A

1. Study Introduction

The UK Environmental Permitting Regulations 2010 require that all industrial processes that have the potential to cause pollution operate under permits, which are designed to protect the environment and reduce any pollution they may cause. The Environment Agency regulates permits for a variety of industrial processes including cooling water for new nuclear power stations. To effectively undertake this regulatory role it is necessary for the EA to continually review and evaluate the latest scientific evidence and consider how advances in technology and the decisions of other international environmental regulators should influence the thinking in permitting decisions. Some areas of technology and assessment for new nuclear cooling water systems have been identified as requiring further review.
For a review of current information on any subject, it is important to summarise and present the pertinent evidence within the available research which will help to identify issues, solve problems and promote evidence based decision making. This approach ensures that the science and evidence are appropriately weighted in the decision making process and for informing policy, and that the science used by Government is robust, relevant and of high quality. A review of the evidence needs to be open and transparent and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.
APEM Ltd has been asked to conduct an independent review of existing data and research sources on the following three key topics related to cooling water applications for new nuclear power stations, and to assess the confidence that can be placed in the existing evidence:

- Fish Behavioural Deterrent Systems;
- decisions on cooling waters taken by other environmental regulators; and
- advances in the ability to model impacts on fish stocks/ecosystem.

We are seeking input from experts with an international perspective of cooling water intakes to provide information and consideration on the three key topics under consideration as part of this study. We have detailed below some key questions on the three topics that the study aims to investigate, particularly considering the quality, applicability and concordance of the available evidence base.

We would appreciate it if you could provide responses to each of the questions detailed within the questionnaire below with justification provided for the responses in the form of examples, case studies and reports/papers that are in the public domain and could be made available for this evidence review. If a question does not fall in your area of expertise, please state this and leave blank. There is a section on each topic calling for thoughts and opinions on the current consensus regarding available evidence, particularly with regards to experience and information from international perspectives, and we would be grateful to hear any considered comments and thoughts on these aspects of biota protection in large scale cooling waters which you may wish to put forward.
The responses provided are likely to inform a published report and so we ask that all information provided is from openly published or available material. Where opinions are stated they will be noted as your own. Thankyou for your time in considering these topics in detail and we appreciate all feedback you can provide to this review.

2. Questionnaire

Question	Response
Name of participant	Marq Redeker
Organisation/affiliation	CDM Smith Consult GmbH, Düsseldorf, Germany
Experience in the cooling water industry	Limited experience in the cooling water industry. Detailed experience regarding other water uses, e.g. hydropower.
Any direct commercial interest with UK new nuclear developers which could be considered as a potential conflict of interest?	No
Topic 1. Fish Behavioural Deterrents	
Do you have any documents or information which would aid in the review of the evidence base on fish behavioural deterrents in relation to the following questions;	
I. Is there evidence relevant to the effective operation, safe maintenance and reliability of a fish behavioural deterrent system (e.g. acoustic, light, combined technology etc.) in onshore and offshore environments and at the scale (>15m^3s^{-1}) required for a new nuclear power station in the UK and over the lifetime of a power station (~40 years)?	As far as known the former and remaining nuclear power stations in Germany were/are equipped with mechanical (physical) barriers. It is known that behavioural deterrent systems (using light and electricity) were/are installed in large hydropower and thermal power plants in the Netherlands. These have been scientifically assessed by Hadderingh et al.: HADDERINGH, R. H. & H. D. BAKKER (1998): Fishmortality due to passage though hydroelectric power stations on the Meuse and Vecht rivers. - In: JUNGWIRTH , M. SCHMUTZ & S. WEISS (Hrsg.): Fish migration and fish bypasses. - Oxford (Fishing News Books), 315 - 328. HADDERINGH, R. H. & H. JANSEN (1990): Electric fish screen experiments under laboratory and field conditions. - In: Cowx, I. G. (Hrsg.): Developments in electric fishing, Cambridge (Fishing News Books), 266 - 280. HADDERINGH, R. H. (1978): Mortality of young fish in the cooling water system of Bergum power station. - Proc. International Association of Theoretical and Applied Limnology 20 (Kopenhagen, 7. - 14. 8. 1977), 1822 - 1836. HADDERINGH, R. H. (1982): Experimental reduction of fish impingement by artificial illumination at Bergum power station. - Int. Revue ges. Hydrobiol. 67, 887 - 900. HADDERINGH, R. H. (1993): Das Wegführen von Aalen von Wassereinlässen von Kraftwerken mit- tels Licht. - Vortrag 7. SVK Fischereiseminar, Januar 1993, Bad Godesberg. HADDERINGH, R. H., & A. G. SMYTHE (1997): Deflecting eels from power stations with light. - Paper presented at the "Fish passage workshop", May 6 - 8, 1997, Milwaukee, USA, 7 S. HADDERINGH, R. H., G. H. M. VAN AERSSEN, R. F. DE BEIJDER & L. J. VAN DER VELDE (1999): Reaction of silver eels to artificial light sources and water currents: an experimental defection study. - Regulated Rivers: Research and Management 15, 365 - 371. HADDERINGH, R. H., J. W. VAN DER STOEP & J. W. P. M. HABRAKEN (1992): Deflecting eels from water inlets of power stations with light. - Irish Fisheries Investigations Series A (Freshwater) 36, 80 - 89. HADDERINGH, R. H., KOOPS, F. B. J. & VAN DER STOEP, J. W. (1988): Research on fish protection at Dutch thermal and hydropower stations. - Kema Scientific & Technical Reports 6/2, 57 - 68. KEMA (1993): Reactie van licht op vis (laboratorium- experimenten), deel 2: paling (Salmo trutta trutta L.). - Arnhem/NL (KEMA), Rapport Nr. 63635-KES/ WBR 93-3109. KEMA (1994): Reactie van zeeforel (Salmo trutta trutta L.) op zeer lage lichtniveaus tijdens labora- toriumexperimenten. -Arnhem/NL (KEMA), Rapport Nr. 63863-KES/WBR 94-3120. KEMA(1998): Tegengaan van visinzuiging met strobos- coop lampen. Praktijkexperimenten bij de centrale Diemen. - Arnhem/NL (KEMA), Rapport Nr. KPG/ CET 98-5060.

		The German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt - DBU) recently funded an assessment of application and effectiveness of acoustic devices for the protection of fishes: https://forum-fischschutz.de/sites/default/files/webform/FuE_Untersuchung%20der%20M%c3%b6glichkeiten%20der%20Anwendung%20und%20Effektivit%c3%a4t%20verschiedener%20akustischer%20Scheucheinrichtungen%20zum%20Schutz%20der%20Fischfauna%20vor%20Turbinensch%c3%a4den_Labor_WKA_Jaegersdorf.pdf
II.	Is there evidence relevant to the ability to site and install available and suitable fish behavioural deterrent systems in onshore and offshore environments with consideration of nuclear safety requirements?	n/a
III.	Is there evidence that fish behavioural deterrent systems (e.g. acoustic, light, combined technology etc.) are effective for fish protection in onshore and offshore environments under different environmental conditions?	See references stated in I.)
IV.	General comments on knowledge base for this topic.	In Germany physical screens (with bypasses/fish-return facilities) are generally recommended for onshore (fresh)water abstractions. Behavioural deterrent/guidance systems efficiencies are regarded as site- & species-specific.
Topic 2. Decisions on cooling waters taken by other environmental regulators		

Do you have any documents or information which would aid in the review of the evidence base used to inform decisions on cooling waters taken by other environmental regulators in relation to the following questions;	
I. What current evidence on which international cooling water permitting decisions are based are you aware of in terms of overall regulation and individual site consenting? Is this evidence applicable to the UK new nuclear cooling water industry?	Germany has a long-standing history with regards to fisheries regulation. The Prussian Water Act (1916) already required fish protection facilities at water intakes. Today the Federal Water Act (*Wasserhaushaltsgesetz - WHG*) represents the legal framework for Germany (based on the WFD) and includes following requirements amongst others - § 34 Free Passage at barriers - § 35 Measures for protection of fish populations at hydropower plants Water and Fisheries legislation is specified by the 16 German States. Fish protection regulations exist in most States; mostly physical screens with a certain permissible spacing are prescribed:

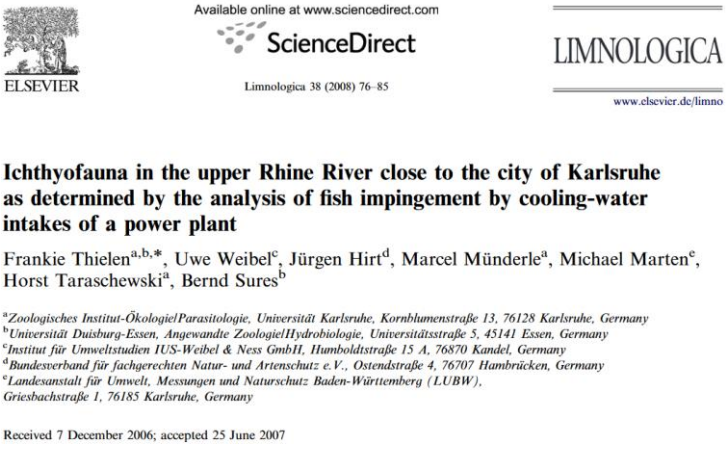
	Downstream passage requirement	Fish protection requirement *Screen spacing*	Upstream passage requirement	Environmental flow specification
Baden-Württemberg	X	X *10 mm in Salmon Rivers*	X	X
Bavaria	X	X	X	X
Saarland	X	X	X	
Rhineland-Palatinate	X	X *10 - 20 mm*	X	
Hesse	X	X *≤15 mm*	X	X
Thuringia	X	X *≤20 mm*	X	X
Saxony	X	X *≤20 mm*	X	X
Northrhine-Westfalia	X	X *≤20 mm* *≤15 mm in Eel Rivers* *≤10 mm in Salmon Rivers*	X	X
Lower Saxony	X	X *≤20 mm*	X	
Saxony-Anhalt	X	X	X	
Berlin	X	X *≤15 mm*	X	
Brandenburg	X	X *≤15 mm*	X	
Bremen	X	X	X	
Hamburg	X		X	
Schleswig-Holstein	X	X	X	
Mecklenburg-West Pomerania	X	X	X	

Fish protection at water abstractions/uses and downstream passage at hydropower plants has been a very contentious subject for the last 20+ years.
Therefore, the German Environment Agency (UBA) initiated the “Forum Fischschutz & Fischabstieg“ (Forum Fish Protection and Downstream Passage) for all stakeholders to

- develop a common & nationwide consistent understanding of the issue, and
- draw together requirements and solutions to establish and preserve fish populations based on the current state-of-the-art and knowledge.

Topics of the Forum are:

- Environmental policy framework
- Strategic and river basin related aspects

		- Technical measures and facilities for fish protection and downstream fishways - Applied population and behavioral biology - Efficiency and monitoring of measures and facilities for fish protection and downstream passage Timeline of the Forum: - 1st cycle from 2012 - 2014 - 2nd cycle from 2015 - 2018 Focus of the 1st cycle was on fish protection at hydropower facilities (there are ca. 7,600 hydrostations in Germany). Further info: https://forum-fischschutz.de/ https://forum-fischschutz.de/sites/default/files/How_to_Improve_Fish_Protection_and_Downstream_Migration_in_Rivers.pdf
II.	Are cooling water systems in other countries on which decisions have been made sufficiently comparable to the UK new nuclear industry for the regulatory decisions of the other countries to be considered a relevant evidence base for the UK permitting framework?	In recent years 3 large thermal power plants have been equipped with fish protection systems in Germany: - Drum-type screen system at Karlsruhe power plant RDK8 (Rhine River) - Geiger MultiDisc® at Moorburg power plant (Elbe River) - Electric barrier at Irsching power plant (Danube River) However, I have no background/details on the individual site consents. The following colleagues have been involved in the review/efficiency assessments of the facilities any may provide further information in consultation with their clients: - Moorburg power plant: Dr. Beate Adam (b.adam@schwevers.de) - Karlsruhe power plant RDK8: Dr. Uwe Weibel (weibel@weibel-ness.de)  Available online at www.sciencedirect.com ScienceDirect ELSEVIER Limnologica 38 (2008) 76–85 LIMNOLOGICA www.elsevier.de/limno **Ichthyofauna in the upper Rhine River close to the city of Karlsruhe as determined by the analysis of fish impingement by cooling-water intakes of a power plant** Frankie Thielen[a,b,*], Uwe Weibel[c], Jürgen Hirt[d], Marcel Münderle[a], Michael Marten[e], Horst Taraschewski[a], Bernd Sures[b] [a]*Zoologisches Institut-Ökologie/Parasitologie, Universität Karlsruhe, Kornblumenstraße 13, 76128 Karlsruhe, Germany* [b]*Universität Duisburg-Essen, Angewandte Zoologie/Hydrobiologie, Universitätsstraße 5, 45141 Essen, Germany* [c]*Institut für Umweltstudien IUS-Weibel & Ness GmbH, Humboldtstraße 15 A, 76870 Kandel, Germany* [d]*Bundesverband für fachgerechten Natur- und Artenschutz e.V., Ostendstraße 4, 76707 Hambrücken, Germany* [e]*Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), Griesbachstraße 1, 76185 Karlsruhe, Germany* Received 7 December 2006; accepted 25 June 2007 In my view the above facilities are comparable to the UK new nuclear industry.
III.	What are/were the rationales for cooling water regulatory decisions made in other countries	Compliance with environmental regulation (Federal (water and nature conservation acts) and State (water and fisheries) legislation), and protection of specific fish species (e.g. Habitats Directive). These are comparable to the UK permitting framework.

	(e.g. compliance with environmental regulation, protection of specific fish species, non-related drivers etc.) and are they comparable to the UK permitting framework?	
IV.	Is there any evidence on the implications of decisions made by other environmental regulators on cooling water systems (e.g. reduction in new development applications, objections from developers etc.)?	?
V.	General opinion on current knowledge base with respect to international approaches.	Fish passage (protection) efforts have largely focused on upstream passage in the past; fish protection systems and downstream fish passage technologies are much less advanced and are in need of research.
Topic 3. Advances in the ability to model impacts on fish stocks/ecosystem		
Do you have any documents or information which would aid in the review of the evidence base on advances in the ability to model impacts on fish stocks/ecosystem (e.g. entrainment/ impingement prediction techniques, EAV, EALP, SSB, life cycle modelling, ecosystem modelling)? in relation to the following questions;		

I.	Are models available to satisfactorily assess impacts from power station cooling water on fish stocks and aquatic ecosystems including considering new intake and screen technologies and long term stock/ecosystem level implications?	As far as known there are no models that assess the impacts from power station cooling water on fish stocks and aquatic ecosystems in Germany. Impacts on fish stocks have only been modelled for single hydropower plants or a chain of hydropower plants in a river, e.g. - Eel migration/protection in the Moselle River (https://iam.innogy.com/-/media/innogy/documents/ueber-innogy/innogy-Innovation-und-Technik/aalschutzinitiative-komrimierte-pdf-version.ashx) - Fish protection and downstream passage assessments for the Weser River (https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4197.pdf)
II.	Are sufficient model input data and their associated uncertainties available for use within power station cooling water impact fish stock/ecosystem assessments?	n/a but I would presume “no” even if adequate models were available
III.	Have any of the available models been validated with empirical monitoring data?	n/a
IV.	General opinion on evidence base for this topic at present.	n/a
Is there any further information which you think would be important to consider within this evidence base review in relation to the 3 key topics under consideration?		In my view, as yet, no country has found an entirely satisfactory solution to fish protection (i.e. for all species and life stages), especially where installations and high flow volumes (⇨ hydropower plants >50 m³/s) are involved. However, cooling water abstractions for nuclear/thermal power plants typically are a) smaller in volume and b) have low approach velocities. I believe these conditions favour the development of effective fish protection facilities both in onshore and offshore environments. Nevertheless, there are two principal issues associated with fish protection:

	1) Realistically it is impossible to provide protection for all life stages of fish, e.g. for larvae and fry. Therefore, prescribing specific aperture for physical barriers represents a conscious decision on which fish sizes / life stages one intends to protect, or not. This determination that essentially defines what proportion of fish need to be excluded to meet both environmental targets and water users objectives, is always a mutual compromise and controversially debated. 2) The technical and economical challenge with physical screens lies in their operation and maintenance (in particular cleaning and sediment management), and not in their design and installation. I feel fish protection best practice needs to allow an ongoing development/improvement. Adaptive management is essential. We need to learn from designs that work and have failed, develop suitable solutions and test these solutions at new sites. Such an approach will allow for the long-term advancement of fish protection technologies.
Do you consider the three topics to have sufficient evidence base to satisfactorily inform the decision making which will be required? Are there particular knowledge gaps to be addressed?	No, as mentioned above, fish protection technologies are less advanced than upstream passage solutions and are in need of research. The development and application of fish protection systems is complex, as account must be taken of biotic criteria (different species, varying swimming abilities, fish behaviour and life-stages), as well as site-specific abiotic conditions (e.g. flow patterns and water temperature).

International Expert Input - B

1. Study Introduction

The UK Environmental Permitting Regulations 2010 require that all industrial processes that have the potential to cause pollution operate under permits, which are designed to protect the environment and reduce any pollution they may cause. The Environment Agency regulates permits for a variety of industrial processes including cooling water for new nuclear power stations. To effectively undertake this regulatory role it is necessary for the EA to continually review and evaluate the latest scientific evidence and consider how advances in technology and the decisions of other international environmental regulators should influence the thinking in permitting decisions. Some areas of technology and assessment for new nuclear cooling water systems have been identified as requiring further review.

For a review of current information on any subject, it is important to summarise and present the pertinent evidence within the available research which will help to identify issues, solve problems and promote evidence based decision making. This approach ensures that the science and evidence are appropriately weighted in the decision making process and for informing policy, and that the science used by Government is robust, relevant and of high quality. A review of the evidence needs to be open and transparent and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.

APEM Ltd has been asked to conduct an independent review of existing data and research sources on the following three key topics related to cooling water applications for new nuclear power stations, and to assess the confidence that can be placed in the existing evidence:

- Fish Behavioural Deterrent Systems;
- decisions on cooling waters taken by other environmental regulators; and
- advances in the ability to model impacts on fish stocks/ecosystem.

We are seeking input from experts with an international perspective of cooling water intakes to provide information and consideration on the three key topics under consideration as part of this study. We have detailed below some key questions on the three topics that the study aims to investigate, particularly considering the quality, applicability and concordance of the available evidence base.

We would appreciate it if you could provide responses to each of the questions detailed within the questionnaire below with justification provided for the responses in the form of examples, case studies and reports/papers that are in the public domain and could be made available for this evidence review. If a question does not fall in your area of expertise, please state this and leave blank. There is a section on each topic calling for thoughts and opinions on the current consensus regarding available evidence, particularly with regards to experience and information from international perspectives, and we would be grateful to hear any considered comments and thoughts on these aspects of biota protection in large scale cooling waters which you may wish to put forward.

The responses provided are likely to inform a published report and so we ask that all information provided is from openly published or available material. Where opinions are stated they will be noted as your own.

Thankyou for your time in considering these topics in detail and we appreciate all feedback you can provide to this review.

2. Questionnaire

Question	Response
Name of participant	Steve Amaral
Organisation/affiliation	Alden Research Laboratory, Inc.
Experience in the cooling water industry	More than 25+ years of experience in the design and evaluation of fish protection technologies developed for use at cooling water intake structures (CWIS) and hydropower dams.
Any direct commercial interest with UK new nuclear developers which could be considered as a potential conflict of interest?	No.
Topic 1. Fish Behavioural Deterrents	
Do you have any documents or information which would aid in the review of the evidence base on fish behavioural deterrents in relation to the following questions;	Yes. Alden has an extensive library of fish protection literature that includes the design, evaluation, and application of fish behavioural deterrents. Additional time beyond what has been allotted for the completion of this survey would be required for Alden staff to compile a list of relevant literature and possibly provide electronic copies of key documents.
I. Is there evidence relevant to the effective operation, safe maintenance and reliability of a fish behavioural deterrent system (e.g. acoustic, light, combined technology etc.) in onshore and offshore environments and at the scale (>15m^3s^{-1}) required for a new nuclear power station in the UK and over the lifetime of a power station (~40 years)?	Ultrasound is the only behavioural deterrent I am aware of that has been used as permanent and full-scale system for repelling fish at CWIS in the US. This technology was installed at the James A. Fitzpatrick Nuclear Power Plant (Lake Ontario, NY) to reduce entrainment of alewife and was found to be greater than 80% effective. There may be one or two additional plants on the Great Lakes in either Canada or the US that also use ultrasound for repelling alewife. Sonic and infrasonic sound systems have also been investigated during lab and pilot-scale field studies for deterrence of fish at CWIS. The results of these studies have not supported the use of low frequencies for sound deterrence at CWIS in the US.
II. Is there evidence relevant to the ability to site and install available and suitable fish behavioural deterrent systems in onshore and offshore environments with consideration of nuclear safety requirements?	Because behavioural deterrents have only been investigated at a few CWIS, there is limited information on how their installation and operation are affected by nuclear safety requirements. However, I am not aware of any safety issues or concerns associated with the installation of sound deterrents at two nuclear power plants where they have been permanently installed (Fitzpatrick) or tested at the pilot-scale level (Plant Barry in Alabama, USA).
III. Is there evidence that fish behavioural deterrent systems (e.g. acoustic, light, combined	There is evidence that effectiveness behavioural deterrents will vary with species, site configuration, and/or environmental

	technology etc.) are effective for fish protection in onshore and offshore environments under different environmental conditions?	conditions. These issues are probably most relevant to behavioural deterrents which involve a visual reaction from fish (e.g., lights, air curtains). Environmental conditions are not expected to reduce effectiveness of sound deterrents.
IV.	General comments on knowledge base for this topic.	In North America, there are very few permanent installations of behavioural deterrents at cooling water intakes primarily due to most technologies being ineffective for a wide range of species and under a broad range of environmental and hydraulic conditions. Ultrasound deterrent systems have been installed at one CWIS (possible more) and one hydropower project to repel *Alosa* species in the clupeid family (e.g., American shad, alewife, blueback herring). Low frequency sound (sonic and infrasonic) systems have been evaluated at several sites (CWIS and hydro projects) and during laboratory and pilot-scale field studies, but results to date have not demonstrated levels of protection or effectiveness that would warrant installation of full-scale systems. Similarly, other behavioural stimuli (lights, electric deterrents, air curtains, turbulent flow inducers, etc.) have not demonstrated an ability to effectively repel a wide range of species at US power plants.
Topic 2. Decisions on cooling waters taken by other environmental regulators		
Do you have any documents or information which would aid in the review of the evidence base used to inform decisions on cooling waters taken by other environmental regulators in relation to the following questions;		Yes.
I.	What current evidence on which international cooling water permitting decisions are based are you aware of in terms of overall regulation and individual site consenting? Is this evidence applicable to the UK new nuclear cooling water industry?	In the US, Section 316(b) of the Clean Water Act is used by the US Environmental Protection Agency (EPA) to regulate CWISs with respect to mitigating entrainment and impingement using the Best Technology Available (BTA) to minimize Adverse Environmental Impact (AEI). In 2014, a new rule was instituted by EPA for the implementation of Section 316(b). The new rule focuses on specified reductions in entrainment and impingement mortality from site-specific baselines. Several options are provided for plant owners to comply with the requirements of the new rule. The approach taken by the EPA in the US could have applicability to new nuclear plants in the UK.
II.	Are cooling water systems in other countries on which decisions have been made	The new EPA rule for implementing Section 316(b) in the US was developed using available scientific information and data describing the

	sufficiently comparable to the UK new nuclear industry for the regulatory decisions of the other countries to be considered a relevant evidence base for the UK permitting framework?	magnitude and potential impacts of entrainment and impingement at CWIS and the effectiveness of available technologies, intake modifications, and/or operational changes to reduce entrainment and impingement (mortality). I believe the process by which the new Section 316(b) rule was developed in the US has applicability to the UK permitting framework and would provide a relevant evidence base for new UK nuclear plants. It is also likely that the design and operation of CWISs in the US are sufficiently similar to those in the UK so that using regulatory information from the US to address entrainment and impingement at new UK nuclear plants would be acceptable.
III.	What are/were the rationales for cooling water regulatory decisions made in other countries (e.g. compliance with environmental regulation, protection of specific fish species, non-related drivers etc.) and are they comparable to the UK permitting framework?	Section 316(b) regulatory decisions in the US are driven by the need to reduce impingement of juvenile and adult fish and entrainment of ichthyoplankton. That is, plant owners are required to minimize AEI using BTA. A the primary component of AEI that receives the most regulatory scrutiny is impingement and entrainment of fish and other aquatic organisms. Presences of federally-listed endangered and threatened species also can be a major issue at some CWIS. Because I am not familiar with the UK permitting framework, I cannot draw any comparisons between it and the US regulatory process.
IV.	Is there any evidence on the implications of decisions made by other environmental regulators on cooling water systems (e.g. reduction in new development applications, objections from developers etc.)?	Because of the new 316(b) rule and the information and data that were used to develop varying aspects of the rule, most new power plants in the US will be required to use closed-cycle cooling systems as the best technology available to minimize entrainment and impingement of fish.
V.	General opinion on current knowledge base with respect to international approaches.	There is a wealth of information on entrainment and impingement of fish at US CWIS, with respect to the development and implementation of regulatory requirements and methods for determining impacts and selecting and evaluating mitigation options (e.g., fish protection technology or operational approaches).
Topic 3. Advances in the ability to model impacts on fish stocks/ecosystem		This topic is outside of my area of expertise. However, I am aware that extensive modelling has been performed to predict entrainment and impingement effects on fish populations, as well as what the benefits of various mitigation approaches may be.

Do you have any documents or information which would aid in the review of the evidence base on advances in the ability to model impacts on fish stocks/ecosystem (e.g. entrainment/ impingement prediction techniques, EAV, EALP, SSB, life cycle modelling, ecosystem modelling)? in relation to the following questions;	
I. Are models available to satisfactorily assess impacts from power station cooling water on fish stocks and aquatic ecosystems including considering new intake and screen technologies and long term stock/ecosystem level implications?	
II. Are sufficient model input data and their associated uncertainties available for use within power station cooling water impact fish stock/ecosystem assessments?	
III. Have any of the available models been validated with empirical monitoring data?	
IV. General opinion on evidence base for this topic at present.	
Is there any further information which you think would be important to consider within this evidence base review in relation to the 3 key topics under consideration?	
Do you consider the three topics to have sufficient evidence base to satisfactorily inform the decision making which will be required? Are there particular knowledge gaps to be addressed?	Yes, using regulatory processes and actions in the US and other parts of the world, there should be sufficient evidence to inform the decision process in the UK with respect to potential CWIS impacts and appropriate mitigation.

International Expert Input - C

1. Study Introduction

The UK Environmental Permitting Regulations 2010 require that all industrial processes that have the potential to cause pollution operate under permits, which are designed to protect the environment and reduce any pollution they may cause. The Environment Agency regulates permits for a variety of industrial processes including cooling water for new nuclear power stations. To effectively undertake this regulatory role it is necessary for the EA to continually review and evaluate the latest scientific evidence and consider how advances in technology and the decisions of other international environmental regulators should influence the thinking in permitting decisions. Some areas of technology and assessment for new nuclear cooling water systems have been identified as requiring further review.

For a review of current information on any subject, it is important to summarise and present the pertinent evidence within the available research which will help to identify issues, solve problems and promote evidence based decision making. This approach ensures that the science and evidence are appropriately weighted in the decision making process and for informing policy, and that the science used by Government is robust, relevant and of high quality. A review of the evidence needs to be open and transparent and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.

APEM Ltd has been asked to conduct an independent review of existing data and research sources on the following three key topics related to cooling water applications for new nuclear power stations, and to assess the confidence that can be placed in the existing evidence:

- Fish Behavioural Deterrent Systems;
- decisions on cooling waters taken by other environmental regulators; and
- advances in the ability to model impacts on fish stocks/ecosystem.

We are seeking input from experts with an international perspective of cooling water intakes to provide information and consideration on the three key topics under consideration as part of this study. We have detailed below some key questions on the three topics that the study aims to investigate, particularly considering the quality, applicability and concordance of the available evidence base.

We would appreciate it if you could provide responses to each of the questions detailed within the questionnaire below with justification provided for the responses in the form of examples, case studies and reports/papers that are in the public domain and could be made available for this evidence review. If a question does not fall in your area of expertise, please state this and leave blank. There is a section on each topic calling for thoughts and opinions on the current consensus regarding available evidence, particularly with regards to experience and information from international perspectives, and we would be grateful to hear any considered comments and thoughts on these aspects of biota protection in large scale cooling waters which you may wish to put forward.

The responses provided are likely to inform a published report and so we ask that all information provided is from openly published or available material. Where opinions are stated they will be noted as your own.

Thankyou for your time in considering these topics in detail and we appreciate all feedback you can provide to this review.

2. Questionnaire

Question	Response
Name of participant	Paul Geoghegan
Organisation/affiliation	Normandeau Associates, Inc.
Experience in the cooling water industry	34 years
Any direct commercial interest with UK new nuclear developers which could be considered as a potential conflict of interest?	No
Topic 1. Fish Behavioural Deterrents	
Do you have any documents or information which would aid in the review of the evidence base on fish behavioural deterrents in relation to the following questions;	Yes
I. Is there evidence relevant to the effective operation, safe maintenance and reliability of a fish behavioural deterrent system (e.g. acoustic, light, combined technology etc.) in onshore and offshore environments and at the scale (>15m^3s^{-1}) required for a new nuclear power station in the UK and over the lifetime of a power station (~40 years)?	Yes
II. Is there evidence relevant to the ability to site and install available and suitable fish behavioural deterrent systems in onshore and offshore environments with consideration of nuclear safety requirements?	Yes
III. Is there evidence that fish behavioural deterrent systems (e.g. acoustic, light, combined technology etc.) are effective for fish protection in onshore and offshore environments under different environmental conditions?	Yes

IV. General comments on knowledge base for this topic.	Behavioural deterrents are site and species specific.
Topic 2. Decisions on cooling waters taken by other environmental regulators	
Do you have any documents or information which would aid in the review of the evidence base used to inform decisions on cooling waters taken by other environmental regulators in relation to the following questions;	Yes
I. What current evidence on which international cooling water permitting decisions are based are you aware of in terms of overall regulation and individual site consenting? Is this evidence applicable to the UK new nuclear cooling water industry?	Not aware of international cooling water permitting decisions.
II. Are cooling water systems in other countries on which decisions have been made sufficiently comparable to the UK new nuclear industry for the regulatory decisions of the other countries to be considered a relevant evidence base for the UK permitting framework?	Not aware of UK new nuclear industry. Is this fourth generation (MSR, pebble bed etc.) or new reactors like the AP1000?
III. What are/were the rationales for cooling water regulatory decisions made in other countries (e.g. compliance with environmental regulation, protection of specific fish species, non-related drivers etc.) and are they comparable to the UK permitting framework?	Not familiar with UK permitting framework.
IV. Is there any evidence on the implications of decisions made by other environmental regulators on cooling water systems (e.g. reduction in new development applications, objections from developers etc.)?	By “other” do you mean other than UK?
V. General opinion on current knowledge base with respect to international approaches.	My knowledge base on international approaches is not substantial.

Topic 3. Advances in the ability to model impacts on fish stocks/ecosystem	
Do you have any documents or information which would aid in the review of the evidence base on advances in the ability to model impacts on fish stocks/ecosystem (e.g. entrainment/ impingement prediction techniques, EAV, EALP, SSB, life cycle modelling, ecosystem modelling)? in relation to the following questions;	
I. Are models available to satisfactorily assess impacts from power station cooling water on fish stocks and aquatic ecosystems including considering new intake and screen technologies and long term stock/ecosystem level implications?	Yes
II. Are sufficient model input data and their associated uncertainties available for use within power station cooling water impact fish stock/ecosystem assessments?	Yes
III. Have any of the available models been validated with empirical monitoring data?	Not that I am aware of.
IV. General opinion on evidence base for this topic at present.	Models may only provide a relative assessment tool for choosing among technologies that reduce intake impacts.
Is there any further information which you think would be important to consider within this evidence base review in relation to the 3 key topics under consideration?	
Do you consider the three topics to have sufficient evidence base to satisfactorily inform the decision making which will be required? Are there particular knowledge gaps to be addressed?	You have not considered public opinion or economic impacts.

International Expert Input - D

1. Study Introduction

The UK Environmental Permitting Regulations 2010 require that all industrial processes that have the potential to cause pollution operate under permits, which are designed to protect the environment and reduce any pollution they may cause. The Environment Agency regulates permits for a variety of industrial processes including cooling water for new nuclear power stations. To effectively undertake this regulatory role it is necessary for the EA to continually review and evaluate the latest scientific evidence and consider how advances in technology and the decisions of other international environmental regulators should influence the thinking in permitting decisions. Some areas of technology and assessment for new nuclear cooling water systems have been identified as requiring further review.
For a review of current information on any subject, it is important to summarise and present the pertinent evidence within the available research which will help to identify issues, solve problems and promote evidence based decision making. This approach ensures that the science and evidence are appropriately weighted in the decision making process and for informing policy, and that the science used by Government is robust, relevant and of high quality. A review of the evidence needs to be open and transparent and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.
APEM Ltd has been asked to conduct an independent review of existing data and research sources on the following three key topics related to cooling water applications for new nuclear power stations, and to assess the confidence that can be placed in the existing evidence:

- Fish Behavioural Deterrent Systems;
- decisions on cooling waters taken by other environmental regulators; and
- advances in the ability to model impacts on fish stocks/ecosystem.

We are seeking input from experts with an international perspective of cooling water intakes to provide information and consideration on the three key topics under consideration as part of this study. We have detailed below some key questions on the three topics that the study aims to investigate, particularly considering the quality, applicability and concordance of the available evidence base.
We would appreciate it if you could provide responses to each of the questions detailed within the questionnaire below with justification provided for the responses in the form of examples, case studies and reports/papers that are in the public domain and could be made available for this evidence review. If a question does not fall in your area of expertise, please state this and leave blank. There is a section on each topic calling for thoughts and opinions on the current consensus regarding available evidence, particularly with regards to experience and information from international perspectives, and we would be grateful to hear any considered comments and thoughts on these aspects of biota protection in large scale cooling waters which you may wish to put forward.
The responses provided are likely to inform a published report and so we ask that all information provided is from openly published or available material. Where opinions are stated they will be noted as your own.
Thankyou for your time in considering these topics in detail and we appreciate all feedback you can provide to this review.

2. Questionnaire

Question	Response
Name of participant	Maarten Bruijs
Organisation/affiliation	Private
Experience in the cooling water industry	Having worked in the field since 2000 (for KEMA, DNV GL and Sweco), I have done projects on fish migration related to hydropower and organised/conducted field studies to investigate impact of I&E at cooling water intake systems, as well as R&D (fish deterrent systems) and consultancy (design reviews, general studies on cost-benefit of technical and operational measures to reduce I&E). As impartial consultant. I'm an international recognised expert in this field. See my CV attached for further information.
Any direct commercial interest with UK new nuclear developers which could be considered as a potential conflict of interest?	None (although part of my network)
Topic 1. Fish Behavioural Deterrents	
Do you have any documents or information which would aid in the review of the evidence base on fish behavioural deterrents in relation to the following questions;	I think best documents are already available through the BEEMS studies. Much information on systems is in grey literature and not readily available. Public data should already be available. The key conclusions are known already, more studies and information will not change the main conclusions, only confirm or make it more specific.
I. Is there evidence relevant to the effective operation, safe maintenance and reliability of a fish behavioural deterrent system (e.g. acoustic, light, combined technology etc.) in onshore and offshore environments and at the scale (>15m^3s^{-1}) required for a new nuclear power station in the UK and over the lifetime of a power station (~40 years)?	<u>Acoustic</u> The hearing of most fish is within the spectrum of human hearing, with max sensitivity in the sub-3kHz band width to low infra-sound frequencies. For most fish species with a swim bladder an efficiency of about 80% can be expected, with levels up to 90 – 100%. Sound with high frequency (120kHz) is efficient to deter herring like species. For a number of species high frequency acoustics are not efficient. As for the species specific response to different frequencies results vary greatly, and ongoing research is required to further develop/optimise the application for specific locations. The hydraulic conditions play an important role in the efficacy (escape options of fish). Not all systems are technically feasible, for example the infrasound system by ProFish was developed but too much technical issues. It's not on the market anymore.

		Any system used should have Proven Technology status (or at least Fit for Service when promising). Investment base should be sufficient field evidence, both regarding the efficacy as well as O&M). <u>Light</u> Light is applied in two ways: 1) enhances the ability of fish to orientate itself (trash rack, nearby structures of the intake) so it can maintain its position and prevent passive movement with the intake water. 2) depending on the light it will deter the fish within a certain range from the source, depening on the penetration distance of the light through the water. In highly turbid water distances are often too short for fish to react and swim away. <u>Combined technology</u> Application of light combined with acoustic often shows an improved effect. <u>Electric screens</u> Application of electric screens is not proven (no state-of-art nor proven technology!). systems are investigated for a long time, but there is no conclusive evidence (scientific) from field investigations that show an efficient application. Only in Germany the systems are applied at a variety of locations (see DWA, 2005 for status of investigations). Test results of field trials are not provided by the suppliers. Electric screens are much more species and length specific than is mentioned by the suppliers. Also, the efficacy for species and year classes depend on the conductivity of the water (salinity) and temperature (fish reaction) Conclusion: application of electric screens has a huge uncertainty, literature provides evidence electric screens provide a inconsistent fish deterrence. DO NOT USE!
II.	Is there evidence relevant to the ability to site and install available and suitable fish behavioural deterrent systems in onshore and offshore environments with consideration of nuclear safety requirements?	Most important aspects for nuclear safety is the availability of cooling water at all times. There are rare cases of fish blocking the entire system. If blockage mainly due to algal debris or jelly fish, as such debris management (and proper design of debris screening systems) is of more importance than prevention of the ingress of fish. The prevention of fish I&E is an ecological concern. Very large schools of fish, e.g. herring types, might in rare cases be able to block filter screens. These type of fish are sensitive to acoustic systems. For safety reasons any acoustic(/light) system should have sufficient redundancy and back-up power supply and maintenance should be frequently planned to safeguard the continuous

		and efficient operation of the system (prevent outages)
III.	Is there evidence that fish behavioural deterrent systems (e.g. acoustic, light, combined technology etc.) are effective for fish protection in onshore and offshore environments under different environmental conditions?	Yes, e.g. Doel NPP (Belgium). Most important aspect is the flow velocity and general hydraulic conditions in front of the intake. Any (acoustic) modelling to design the system should be done under a variety of operational and environmental conditions (extremes). Fish should be deterred at sufficient distance of the intake (<<0,5 m/s)
IV.	General comments on knowledge base for this topic.	Application of behavioural based deterrence systems and its efficacy is depending on local hydraulic conditions, species of concern and life stages. These are highly local specific whereby no general conclusions can be drawn on specific technical options. A thorough review of options and the local conditions is required. Also, measures should be economically feasible (e.g. BREF), so the cost of a measure is decisive in final field application, regardless the expected efficacy. The application of behavioural systems will enhance during the coming years. Any installation should be designed and constructed as such that changes can be made in order to optimise the efficacy when improvements are available. Most installations require high maintenance due to the harsh environment and materials of the system. The operational costs are to be considered and development of this aspect is as important as the efficacy to reduce I&E.
Topic 2. Decisions on cooling waters taken by other environmental regulators		
Do you have any documents or information which would aid in the review of the evidence base used to inform decisions on cooling waters taken by other environmental regulators in relation to the following questions;		**Netherlands** No official decisions as the impact of fish I&E is reviewed by a theoretic exercise and checked (if required) by a field monitoring. In all cases no additional requirements to prevent fish I&E are obligated to the power station operating companies (only one situation, Ems power station, however this location has a strongly reduced CW withdrawal (>50%), by which the ingress of fish is strongly reduced/installation is partly mothballed. A technical review was made by Bruijs for the Dutch Water authorities (Rijkswaterstaat) in 2007, it is still used. **Other EU countries** In most EU countries the legislation is not fully developed. Most often a monitoring program is required as part of the permit, monitoring

		population and I&E. The programs should be carried out over multiple years to get reliable insight (which happens in UK (e.g. Pembroke) and Germany (e.g. Moorburg), but often it is only during one year. In general the overall outcome of such studies are Entrapment that there are temporal patterns of entrapment which reflect patterns of abundance in the water body and the majority of fish impinged are juveniles. When prediction models are applied, for some species numbers differ greatly from predictions; driven by the above and model input parameters.
I.	What current evidence on which international cooling water permitting decisions are based are you aware of in terms of overall regulation and individual site consenting? Is this evidence applicable to the UK new nuclear cooling water industry?	See attached presentation for the Dutch situation. In other countries decisions are made in the planning/permitting process (i.e. Germany and UK). In the USA, the Clean Water Act is more strict, no monitoring efforts but simply changing the intake physically, or change to cooling towers, in order to reduce I&E by ~90%. In the Netherlands at each site an individual evaluation is made, leading to a local specific decision (it is not officially implemented in law yet!). However, in most cases a monitoring should take place.
II.	Are cooling water systems in other countries on which decisions have been made sufficiently comparable to the UK new nuclear industry for the regulatory decisions of the other countries to be considered a relevant evidence base for the UK permitting framework?	Germany, i.e. for new coal fired power stations Netherlands, i.e. for all (cooling) water abstractions These can be considered for the UK permitting framework. Other EU countries: not really developed, most often taken care of by local regulators
III.	What are/were the rationales for cooling water regulatory decisions made in other countries (e.g. compliance with environmental regulation, protection of specific fish species, non-related drivers etc.) and are they comparable to the UK permitting framework?	Impact on fish population and (local) specific species of concern. EU regulations are the basis of environmental law, i.e. WFD, Natura2000, IED (BREF). These are comparable with UK.
IV.	Is there any evidence on the implications of decisions made by other environmental regulators on cooling water systems (e.g. reduction in new development applications,	Germany, Moorburg power station: huge implication (recirculating system instead of once-through, and large scale monitoring of fish ingress)

objections from developers etc.)?	Most countries follow the BREF, when the intake design is conform BREF it is merely ok. However, the BREF is not very detailed on this matter and only gives some directions for design intake, screening systems and flow requirements (source for this information is KEMA which did a lot of work on this in the past).
V. General opinion on current knowledge base with respect to international approaches.	The approaches vary largely, often the impact is not taken too seriously or is based on the assumption (precaution principle), but not based on scientific evidence. In the Netherlands permitted impact level is <10% on population level, but arbitrary level (it is decided, not based on scientific evidence). The impact of cumulation (multiple abstractions nearby) is not yet developed.
Topic 3. Advances in the ability to model impacts on fish stocks/ecosystem	
Do you have any documents or information which would aid in the review of the evidence base on advances in the ability to model impacts on fish stocks/ecosystem (e.g. entrainment/ impingement prediction techniques, EAV, EALP, SSB, life cycle modelling, ecosystem modelling)? in relation to the following questions;	See attached.
I. Are models available to satisfactorily assess impacts from power station cooling water on fish stocks and aquatic ecosystems including considering new intake and screen technologies and long term stock/ecosystem level implications?	McCall, Newbold. All models depend on reliable input, sufficient knowledge of population dynamics over time, correct handling of assumptions, correct design of algorithms, sufficient consideration of all other population impacts, etc etc. This is a never ending development, all models become better in time, but modelling biology, especially fish populations is difficult. Current models will provide an improved insight and give directions to further consider technical options and there potential impact (but will never resemble reality).
II. Are sufficient model input data and their associated uncertainties available for use within power station cooling water impact fish stock/ecosystem assessments?	Lack of information on Life History aspects of species of concern is an issue for the applicability of models. Mostly only for commercial species sufficient information is available. Modelling cumulative effects (i.e. multiple power stations within vicinity of each other, or other impacts) is still not sufficiently available yet. Some try to use simplified assumptions, such as when half the water is abstracted, half the fish is drawn in (when CW reduction is an option…)

III. Have any of the available models been validated with empirical monitoring data?	Yes, but only for a limited number of species and situations.
IV. General opinion on evidence base for this topic at present.	Any model output fully relies on the input. Much of the input is based on assumptions. Monitoring data on populations is difficult to obtain due to limitations in catch methods and evaluation methods to calculate abundance (based on volume or area), a sufficient number of catch efforts throughout the year, for multiple years is required, but natural/seasonal changes and variation are only possible to elucidate by long term monitoring programs, which are rare.
Is there any further information which you think would be important to consider within this evidence base review in relation to the 3 key topics under consideration?	I send along a ppt from 2008 in which I proposed the Dutch water regulator (Rijkswaterstaat) to follow a Best Available Approach, rather than focussing on immediate evaluation of a BAT technology.
Do you consider the three topics to have sufficient evidence base to satisfactorily inform the decision making which will be required? Are there particular knowledge gaps to be addressed?	The application of a technical measure is local specific. Starting point is sufficient design/location of the intake and FRR systems. Hereafter evaluation of the I&E should take place to optimally apply the system. When a system is already planned and designed without knowledge of the real ingress and impact, it will never be easy to optimise and it takes more time and money to reach a satisfactory reduction of I&E.

International Expert Input - E

1. Study Introduction

The UK Environmental Permitting Regulations 2010 require that all industrial processes that have the potential to cause pollution operate under permits, which are designed to protect the environment and reduce any pollution they may cause. The Environment Agency regulates permits for a variety of industrial processes including cooling water for new nuclear power stations. To effectively undertake this regulatory role it is necessary for the EA to continually review and evaluate the latest scientific evidence and consider how advances in technology and the decisions of other international environmental regulators should influence the thinking in permitting decisions. Some areas of technology and assessment for new nuclear cooling water systems have been identified as requiring further review.
For a review of current information on any subject, it is important to summarise and present the pertinent evidence within the available research which will help to identify issues, solve problems and promote evidence based decision making. This approach ensures that the science and evidence are appropriately weighted in the decision making process and for informing policy, and that the science used by Government is robust, relevant and of high quality. A review of the evidence needs to be open and transparent and to make a judgement as to the strength and independence of the information provided and identify any omissions in the data.
APEM Ltd has been asked to conduct an independent review of existing data and research sources on the following three key topics related to cooling water applications for new nuclear power stations, and to assess the confidence that can be placed in the existing evidence:

- Fish Behavioural Deterrent Systems;
- decisions on cooling waters taken by other environmental regulators; and
- advances in the ability to model impacts on fish stocks/ecosystem.

We are seeking input from experts with an international perspective of cooling water intakes to provide information and consideration on the three key topics under consideration as part of this study. We have detailed below some key questions on the three topics that the study aims to investigate, particularly considering the quality, applicability and concordance of the available evidence base.
We would appreciate it if you could provide responses to each of the questions detailed within the questionnaire below with justification provided for the responses in the form of examples, case studies and reports/papers that are in the public domain and could be made available for this evidence review. If a question does not fall in your area of expertise, please state this and leave blank. There is a section on each topic calling for thoughts and opinions on the current consensus regarding available evidence, particularly with regards to experience and information from international perspectives, and we would be grateful to hear any considered comments and thoughts on these aspects of biota protection in large scale cooling waters which you may wish to put forward.
The responses provided are likely to inform a published report and so we ask that all information provided is from openly published or available material. Where opinions are stated they will be noted as your own.
Thankyou for your time in considering these topics in detail and we appreciate all feedback you can provide to this review.

2. Questionnaire

Question	Response
Name of participant	Richard Seaby
Organisation/affiliation	Pisces Conservation Ltd
Experience in the cooling water industry	I and my company have studies entrainment and impingement issues for 35 years both in the UK and overseas. I have worked on large and small industrial intakes both with and without fish protection technologies. I have also studied fish and invertebrate survival following impingement and the efficacy of fish deterrent systems in the UK and the USA. We maintain a huge resource of grey literature collected over the last 70 years. This is in part because we have a library of CEGB, CERL and other laboratories research literature from the 1950s onwards. I have been involved with legal issues relating to fish protection and the environmental damage of impingement and entrainment in the USA and Canada
Any direct commercial interest with UK new nuclear developers which could be considered as a potential conflict of interest?	Work at Hinkley point B sampling the fish, macro crustaceans and plankton as part of a 37 year long ongoing sampling program. Undertook the impingement and entrainment sampling for Sizewell and Hinkley new build teams between 2010 – 2014.
Topic 1. Fish Behavioural Deterrents	
Do you have any documents or information which would aid in the review of the evidence base on fish behavioural deterrents in relation to the following questions;	Most of the European studies undertaken on this subject are undertaken under client confidentially agreements, so reports are rare and negative results are even more unlikely to be released. The situation is a little different in the US, as the use of the legal system places many of these studies in the public domain. I will concentrate on the our experience in American system The US EPA has reviewed the subject several times in the past particularly in relation to the 316(b) regulations (that regulate the type and size of intake allowed). The EPA have generally been of the opinion that behavioural deterrents (sonic deterrents, lights etc) can be potentially useful for one or two species for impingement but do recognise the technologies as effective across a diverse fish community. I quote below from the EPA document about the fitting of behavioural technologies to existing power plant - Technical Development Document for the Final Section 316(b) Existing Facilities Rule EPA-821-R-14-002 May 2014 (**my emphasis added**) (https://www.epa.gov/sites/production/files/2015-04/documents/cooling-water_phase-4_tdd_2014.pdf) *6.6.5* *Behavioral Technologies*

		This category encompasses a wide range of technologies that utilize behavioral responses in fish to induce an avoidance response and prevent the organism from entering the intake structure. There are numerous examples: sound barriers, air bubbles curtains, strobe or colored lights, chain link walls, and electric barriers. See Chapter 4 of the 2004 Phase II TDD for additional information. *Generally speaking, behavioral technologies have shown some ability to reduce impingement. (**These technologies are not effective for entrainment.**) EPA analyzed data from a number of studies in developing the impingement mortality standards; see Chapter 11 of this TDD. However, the performance tends to be species-specific; for example, certain frequencies of sound are most effective for a certain fish species. **This characteristic makes these technologies difficult to employ on a wide scale, given that the goal of the final rule is to reduce impingement of all species.** Additionally, behavioral technologies are not widely used. As a result, EPA did not study this class of technologies any further* As shown above the 316(b) regulations also state the amount of entrainment allowed. Behavioural deterrents are ineffective in reducing entrainment. The main conclusion is that the US EPA does not consider behavioural technologies capable of reducing overall impingement or entrainment to acceptable levels at once through cooled power plant. It might form part of a suit of protective technologies.
I.	Is there evidence relevant to the effective operation, safe maintenance and reliability of a fish behavioural deterrent system (e.g. acoustic, light, combined technology etc.) in onshore and offshore environments and at the scale (>15m^3s^{-1}) required for a new nuclear power station in the UK and over the lifetime of a power	There are no installations that I know of that have been in operations close to 40 years. At the one site we study where a sound deterrent system is installed, the system does not reliably stop fish impingement as the station catches a species richness and number which is typical for the size and type of intake. The impingement is comparable to that at intakes with no sound deterrence. Pisces staff had early experience of light deterrent systems at Dungeness Nuclear Power Station and other facilities. At Dungeness the system was found to be unreliable and ineffective. In fact, it may have actually increased the rate of capture of sprat. I personally worked as part of the team testing sound deterrence at Hinkley Point B. The trial was unsuccessful and there were indications that the sound actually increased sprat impingement. There were problems with speaker reliability. I do not know of a system that is installed on an intake that is the size of those proposed at the new Nuclear builds.

	station (~40 years)?	In general, there is an appreciable engineering problem with the maintenance of lights and sound systems at intakes. This is far greater at offshore marine intakes. There is a constant risk of storm, debris and shipping damage and it is often far from clear at any one time if the system is actually operating as designed.
II.	Is there evidence relevant to the ability to site and install available and suitable fish behavioural deterrent systems in onshore and offshore environments with consideration of nuclear safety requirements?	No knowledge of nuclear safety documents
III.	Is there evidence that fish behavioural deterrent systems (e.g. acoustic, light, combined technology etc.) are effective for fish protection in onshore and offshore environments under different environmental conditions?	As part of the EPA analysis for the development of 316(b) EPRI undertook a wide ranging review of fish protection technologies https://www.epri.com/#/pages/product/000000003002000231 They reviewed many different studies and fish protection technologies including sound and light, finding that at best the systems deter a few species, at worst they had no effect. For example in the EPRI study (https://www.epri.com/#/pages/product/1014022) the effectiveness of lights and sound systems a freshwater power station in Alabama US were investigated. They tried the system both separately and in combination. The summary of the document states *"**There is no evidence that the impinged total fish numbers or impinged individual species numbers were reduced when the deterrent systems were operating**".* None of the behavioural systems have any effect on the entrainment of eggs, larvae or very juvenile fish. The numbers of entrained animals is often very high.
IV.	General comments on knowledge	Fish deterrent systems can work in particular locations and for particular species. It is seems to work best in situations where the requirement is to exclude a single species where this species is responsive to sound and where the fish and pass the intake once before moving on. A classic example

base for this topic.	would be diverting salmon from a hydropower station intake to a bypass channel. Where the entire community of fish is of concern, and is in constant exposure to the deterrent system, it appears that is much less effective. In most coastal communities of fish there are many species that appear to show little or no response to sound. These include several important commercial species, and some, such as eels, of conservation concern.
Topic 2. Decisions on cooling waters taken by other environmental regulators	
Do you have any documents or information which would aid in the review of the evidence base used to inform decisions on cooling waters taken by other environmental regulators in relation to the following questions;	I have listed some of many documents produced in the US with wide ranging reviews of this issue. There are many more that deal with particular plant or technologies. Most are available on line and we hold a large grey literature library of reports.
I. What current evidence on which international cooling water permitting decisions are based are you aware of in terms of overall regulation and individual site consenting? Is this evidence applicable to the UK new nuclear cooling water industry?	I have concentrated on the US regulations, but the Canadian system appears to be broadly similar.
II. Are cooling water systems in other countries on which decisions have been made sufficiently comparable to the UK new nuclear industry for the	The US intakes I have worked on are broadly similar to those found on UK stations in design and operation. The US regulations are compatible with the UK, as they take in the north east coast stations that catch similar species to our marine stations. Some of the species are the same, many are very similar.

	regulatory decisions of the other countries to be considered a relevant evidence base for the UK permitting framework?	
III.	What are/were the rationales for cooling water regulatory decisions made in other countries (e.g. compliance with environmental regulation, protection of specific fish species, non-related drivers etc.) and are they comparable to the UK permitting framework?	In the US the loss of animals to impingement and entrainment (I&E) at cooling water intake structures (CWIS) is considered harmful in a number of ways beyond the immediate death of the impinged or entrain animals. For example from the final ruling on 316(b) https://www.gpo.gov/fdsys/pkg/FR-2014-08-15/pdf/2014-12164.pdf "*In addition to direct losses of aquatic organisms from I&E, a number of indirect, ecosystem-level effects may also occur, including (1) disruption of aquatic food webs resulting from the loss of impinged and entrained organisms that provide food for other species, (2) disruption of nutrient cycling and other biochemical processes, (3) alteration of species composition and overall levels of biodiversity, and (4) degradation of the overall aquatic environment. In addition to the impacts of a single CWIS on currents and other local habitat features, environmental degradation can result from the cumulative impact of multiple intake structures operating in the same watershed or intakes located within an area where intake effects interact with other environmental stressors. Finally, although it is difficult to measure, the compensatory ability of an aquatic population, which is the capacity for a species to increase survival, growth, or reproduction rates in response to decreased population, is likely compromised by I&E and the cumulative impact of other stressors in the environment over extended periods of time.* The rule makers in the US also look at the benefit of the animals lost to the system both in direct terms – available to be fished, but also as part of protecting the ecology of the system. In the USA the regulations are such that new cooling water systems must be 80-90 percent protective as closed cycle cooling (ie cooling towers). Closed cycle cooling is considered as the standard to be met because it uses around 90-95% less water than once though cooling. There is generally a non-linear relationship with intake flows and impingement, were doubling the flow more than doubles the impingement. Entrainment is generally less effected and general increases in proportion to the flow. The other aspect that is given great importance is the protection of threatened and endangered species. For example, the impingement of sturgeon is an issue at numerous localities in freshwater and estuarine sites. At British sites eels have become a major concern. While

	there is some evidence that strobe lights may have some influence on adult eel impingement there is no behavioural technology known to me that is effective in reducing elver captures. Even if some behavioural technologies are partially effective, no known approach can reduce eel losses to negligible levels.
IV. Is there any evidence on the implications of decisions made by other environmental regulators on cooling water systems (e.g. reduction in new development applications, objections from developers etc.)?	There have been several court cases in the US and Canada where the developer has argued that by using the same intake to provide water for a repowered or newly developed station so that they can use the older standards.
V. General opinion on current knowledge base with respect to international approaches.	The US is well ahead in terms of regulation on the impact of impingement and entrainment the environmental standard of new build power plant.
Topic 3. Advances in the ability to model impacts on fish stocks/ecosystem	
Do you have any documents or information which would aid in the review of the evidence base on advances in the ability to model impacts on fish stocks/ecosystem (e.g. entrainment/ impingement prediction techniques, EAV, EALP, SSB, life cycle modelling, ecosystem modelling)? in relation to the following questions;	We have an extensive literature on the use of EAVs etc. This is a huge subject. We have been involved in the calculation and critical evaluation of EAV and other methods for more than 30 years.
I. Are models available to	No - PISCES a program written by my company can give a general idea of the likely numbers and composition of

	satisfactorily assess impacts from power station cooling water on fish stocks and aquatic ecosystems including considering new intake and screen technologies and long term stock/ecosystem level implications?	impinged species in UK waters, but does not measure any community level effect. The system bases it calculation on 10 mm screen, and would need updating to account for the finer mesh screens that are now more common. The translation of entrained fish numbers into impinged fish number with varying screen size is not trivial, as the body form of the fish can have a significant effect. There is very little peer reviewed data on the efficiently of many of the fish protection technologies, and none available on the size of intake that is being built at Hinkley.
II.	Are sufficient model input data and their associated uncertainties available for use within power station cooling water impact fish stock/ecosystem assessments?	
III.	Have any of the available models been validated with empirical monitoring data?	
IV.	General opinion on evidence base for this topic at present.	
Is there any further information which you think would be important to consider within this evidence base review in relation to the 3 key topics under consideration?		The behavioural influence and harm caused by heated discharges has not been considered. Issues such as interference with salmon migration have not been discussed and there is no behavioural technology I know of to reduce the effects of thermal impacts.

Do you consider the three topics to have sufficient evidence base to satisfactorily inform the decision making which will be required? Are there particular knowledge gaps to be addressed?	

Appendix B: Notes of workshop held on 28 April 2018

Meeting title:	**APEM P00002461 EA SC170021 Cooling Waters Workshop Minutes**
Date:	26th April 2018 Time: 10:30 Venue: Millennium Point, Birmingham
Attendees:	Environment Agency (EA) 9 staff APEM Ltd (APEM) 3 staff Natural Resources Wales (NRW) 1 staff Association of Inshore Fisheries and Conservation Authorities (IFCA) 1 staff Marine Management Organisation (MMO) 1 staff Natural England (NE) 2 staff
Apologies:	Environment Agency (EA) 7 staff, Marine Management Organisation (MMO) 2 staff, Centre for Environment, Fisheries and Aquaculture Science (CEFAS) 1 staff, Natural Resources Wales (NRW) 2 staff, Scottish Environmental Protection Agency (SEPA) 1 staff, Association of Inshore Fisheries and Conservation Authorities (IFCA) 1 staff.

Item:	Subject	Action
Introduction and background		
1.	**Welcome and introduction** The Environment Agency – Welcome	
2.	**Regulatory Views** Presentation provided by (EA_2) on; how a nuclear power station affects the environment, fish protection measures at nuclear power stations, permits and permissions and information available to support the decision making process. (EA_5) • Note, that wider than Hinkley point C it may not be possible to use low velocity intake heads and there may therefore, be requirements to use biocides. This may result in differences in the assessment. (EA_3) • Question on behalf of (EA_10) - is there any UK context legislative / policy change that would require us to review / change position on project. (EA_2) • We have overriding responsibility to protect the environment. Are we using the best available evidence? Our understanding around WFD changing, evolving. Even if no	

	HRA test, still need to meet framework requirement and use best available evidence. (IFCA) • Importance of Marine Coastal Act, public interest in marine conservation / protection, has shifted the way we approach things. Also important is 25 year environment plan – how to take the ecosystem into account. Also, 2 schools of thought – ICES stock assessment which is brilliant and valid, but also regional approach / formation of IFCAS, they bring a wider valid approach. (EA_6) • Underpinning requirement to bring most up to date evidence. It would be risky to be mobilising on back of policy shift. The right answer is we are always looking for best science regardless of policy change. (EA_1) • Comment that Hinkley C is driving this project and therefore required to bring knowledge gained into this project.	
3.	**Background to project, workshop aims & outline of the day** (EA_1) provided an overview of the project, the background of the 2010 engineering options report and the biota protection scoping report and how they fed into the selection of the 3 urgent issues that form the focus of this project.	
Break		
4.	**Identified literature for review** (APEM_2) provided an overview of the approach to identifying the key literature list, consultation with relevant industry (EDF and Fish Guidance Systems (FGS)), aims of the workshop to gather further information/feedback if available and summarised the current literature list. (NRW) • Pembroke Power Station fish deterrent system - have RWE been approached for information of efficiency, operation, maintenance etc.? Are they willing to share?	NT – to speak to RWE and see if there is any relevant information available in the public domain.

	○ (APEM_2) - response – nothing in public domain. ○ (EA_1) - Could potentially use this project as vehicle to get information. ○ (APEM_1) – there have been no 'on and off' test trials to understand its efficiency. (APEM_1) • Some identified documents aren't available for use in the study as they are too expensive to purchase or are not available in the public domain. (APEM_2) / (APEM_1) / (EA_8) / (EA_2) Explained discussion of Hinkley documents that could be useful to the project but that are not publicly available or are in the process of being revisited and may not therefore, be valid for inclusion. Not including new methods of fisheries impact assessment developed for the Hinkley project was considered to be the greatest limitation to the project from this information not being available. Discussions are under way with EDF as to whether method statements could be produced detailing the approaches used within the impact assessment without the need to present inputs and outputs. It is the approach and any commentary around its use, limitations etc. that are important for this project rather than the outputs. (EA_6) • Knowing what position on data access and uncertainty as such is important. Important to say this is what we've done and what we've got available, and important for future.	
5.	**Evaluation matrix for scoring quality of evidence** (APEM_1) provided an overview of the evidence matrix scoring method. Chief scientific guidance has been central point in terms of what to achieve, quality and confidence. (EA_8) / (NRW) • Discussion of FRR Pembroke systems, and link with AFD. Does one rely on the other? What is the effect of removing one on the protection of different species? (APEM_1)	EA – need to ensure that it is noted in the report that AFD and FRR are intertwined and difficult to separate.

	• Discussed how FGS have been consulted and that they had provided some additional papers for consideration however, they are limited t what is in the public domain. (NRW) / (EA_7) / (EA_1) / (EA_2) • Discussion of culturally different approaches (i.e. France framework, German non-nuclear approach, US regulators). (EA_4) • Discussion of terminology – e.g. cautionary principle (HabsRegs) if we have something with low level confidence, will immediately fail HABS. ○ (EA_9) – suggest numerical methods. ○ (APEM_1) – possible next step to develop methods. ○ (EA_9)- high levels of uncertainty required for use if nothing else available – have to use best evidence but acknowledge uncertainty. (APEM_1) / (EA_7) / (EA_4) • Discussion of careful wording around "decision" (Regarding slide 18/32, 2. Evaluation matrix for scoring key questions). • (EA_4) – Forward thinking with regards to legal process. • (APEM_1) – Need careful wording about scoring and what exactly is being assessed.	EA – will try and get more information on the policy decisions and guidance in the Netherlands, France and Germany. APEM – Request support from EA about terminology and HRA overlap to make as robust and clear as possible.
Discussion of topics including limitations and uncertainties for each		
6.	**Effectiveness of behavioural deterrent systems** (APEM_1) provided an overview of APEM's initial findings with regards to behavioural deterrents. Few studies detail operational maintenance or cost with the majority focusing on effectiveness. (EA_8) – Shoreham Report worth including. (APEM_1) / (EA_9) / (EA_1) / (EA_6) • Discussion of potential author bias if study and report undertaken by a deterrent manufacturer/promoter and importance of peer review process. • If document has been through the peer review process it will be considered to be unbiased as this should have been considered. Peer review process is considered to be scientific best practice. • Important for assessments of bias to be transparent and justified.	APEM - Need to provide transparent and justified assessments of bias potential.

	(EA_9) / (APEM_1) / (EA_4)
	• Discussion of performance of maintenance issues – a lot of efficiency discussion but less published data on safety / maintenance.
	• Studies likely to be site specific – e.g. Severn Estuary harsher than Doel, Pembroke very sheltered.
	• Engineering elements could contribute to survivability of equipment
	  ○ (EA_6) – requirement to comment on the paucity / sporadic availability of data surrounding upkeep, maintenance of technologies.
	
	(APEM_1) / (EA_2) / (EA_6) / (APEM_2)
	• Discussion on transferability of information - environment, scale of abstraction, industry, species
	• Need transparent and justifiable commentary on scoring of transferability of information to the nuclear power industry.
	
	(APEM_2) / (EA_4) / (APEM_1) / (EA_6) / (EA-2)
	• Discussion on availability of information on performance, operation and maintenance.
	• Information will be site and environment specific.
	• Limited site specific data available in the public domain.
	
	(APEM_1)
	• Discussion of bias in availability of data – i.e. technologies/installations that have had maintenance problems or have determined low efficiencies are unlikely to publish their results.
	  ○ (EA_8) – all can do is use scientific approach with what is available. New territory with a lack of direct applicable evidence and doing best with what's available.
	  ○ (NRW) – Important that that is clear in this – that you are highlighting evidence available for guidance in decision making.
		APEM - include comment on lack of data on maintenance/ safety data for technologies.

Lunch		
7.	**USEPA & other international evidence** (APEM_2) • Discussion of APEM findings on EPA Final Rule (2014), litigation challenges, and	

	decisions supported by significant quantity of documentation – both evidence for and against significant impacts of cooling water systems (US EPA, US FWS, US NMFS, EPRI). • Highlighted large review process – challenged in court three times, concluded that best available technology is either closed cooling or fish protection technologies that meet that level. • Have to demonstrate one of 7 tests – such as flow, fish protection technologies. • US EPA Final Rule (2014) requirements for cooling water systems of new facilities / new intakes at existing facilities, they have to meet one of two requirements: • (1) Reduce intake flow to a commensurate level of a closed-cycle recirculating system, and reduce intake velocity to below 0.5 feet/second Or • (2) Demonstrate that fish protection technologies used would reduce impingement mortality and entrainment to 90% of reduction achieved by (1). (EA_8) • Likely particular interests in the exemptions. (EA_9) • Criteria 2 doesn't seem to be equivalent to criteria 1. Why is one noticeably less than two? (EA_6) • Is there a weakness in expertise being applied to these criteria? What's the confidence from, where's the statistical robustness of "90%"? (EA_8) • Difficult to prove beyond reasonable doubt so onus on developer to demonstrate that fish protection measures would be nearly as effective. (APEM_2) • International expertise may be useful to look at where it is applied, how the rule is utilised and if there have been any implications for developers/developments. (APEM_2) / (EA_6) / (APEM_1) / (EA_1) / (EA_8) / (EA_2) / (EA_3) • Discussion on the feasibility of operating a nuclear power plant with a closed cooling system or under the strict requirements of criteria 1.	APEM – Include international experts within the review for insight into the USEPA ruling.

	• Issues of safety and cost with safety being a primary factor for the nuclear industry. (EA_3) / (EA_2) / (NE_1) • Discussion about need for development rather than research in blue-sky R&D. • Cost is strong driver in this. (APEM_2) • Looking to other countries - Limited evidence on policy and legislation. (EA_8) / (APEM-2) • Why has this ruling happened? Main driver entrainment rather than impingement? • Riverkeeper 2 setup a panel to look at entrainment mortality and although deemed unlikely to be 100% mortality determined there was insufficient evidence to who whether there population effects, precautionary approach of assumption of 100% mortality was therefore, adopted. (EA-6) • If we have budget time, it is important to have expert input from EPA comment on this if possible.	APEM – need to provide commentary on the evidence and conclusions for the 100% entrainment mortality aspect of the ruling. EA – to consider consultation with the EPA as part of the study.
8.	**Modelling approaches to impacts on fish stocks and ecosystems** (APEM_2) / (APEM_1) • Discussion on EAV / EALP modelling approaches, input parameters and quality, and uncertainties / assumptions at each stage (e.g. stock size). (APEM_2) • A lot of uncertainty in the fish science / data required for these models. If modelling the species assemblage have to rely on more generic data which needs to be treated in right way. Whilst the broad approach is valid, careful consideration of uncertainties and assumptions is needed at each step. (NRW) / (APEM_1) • Can the entrapment impacts modelled for Pembroke Power Station be compared with the empirical data collected since the plant has been in operation? • Is this information available in the public domain?	APEM – investigate whether any reports or data available on the impact model prediction vs empirical data for Pembroke Power Station.

	(IFCA) / (APEM_1)
	• Discussion of model validation
	  ○ (EA_6) – modelling science not well developed, instead verification science emergent area. Need to expose the predicament – lack of robustness issue and modelling tools needs investigation.
	  ○ (APEM_2)– Agreed, needs validating. Modelling fisheries is not a simple task.
	  ○ (APEM_1) – some steps been taken for hydropower industry e.g. Pacific Northwest Laboratory and validation of the blade strike model. Close similarities here so a similar approach could be adopted.
	
	(APEM_2) / (IFCA)
	• Difficult to build impact assessment models when don't have previous comparable data for the site, technology, operation type etc.
	• Few if any investigations on impacts of entrapment on the fish population, assemblage or ecosystem.
	• Hinkley and the Severn Estuary is the most studied site with some useful information however, it's difficult to identify station specific impacts over underlying effects.
	
	(APEM_2) / (EA-6) / (EA_4) / (EA_2) / (NRW)
	• Discussion of integrity - need to consider how the integrity of the information will be involved and how it will be used in terms of HRA / WFD / Salmon Fisheries Act (e.g. for NE / MMO).
	• What are the implications of emerging set of tools with limited validation and uncertain input data?
	• Assessment only as good as data available to inform it.
	• R & D may be required to develop modelling approaches and understand the input data requirements.
	
	(EA_3)
	• Requirement to understand uncertainty within assessments – e.g. understanding ranges of impacts from adoption of techniques such as the use of Monte Carlo simulation. Highlighting where uncertainty / risks lie is crucial.
	  ○ (EA_6) - Usefulness of models to highlight best placed effort useful, how best to invest.
	  ○ (NRW) - Whilst can't delay decisions, we need to apply best approach based
		APEM –mention similar models (such as hydropower blade strike) that has gone through a validation process, and use as an example for future approaches to entrapment assessments.

	on the evidence we have – the precautionary approach. (NRW) / (MMO) • What is the status of BEEMS – any is there any equivalent current sharing panel? BEEMS historical evidence used to be used – Bradwell etc. Linking to BEEMS, NTF, on strategic level is important going forward on specific issues in this emergent field. (IFCA) • 25 year plan / Hendry review all talked about a Tidal Authority. Could a similar Authority be set up for the nuclear power industry to aid cross company/project collaboration/knowledge sharing?	APEM – Include comment on cross company/project collaboration/knowledge sharing.
Review and Next steps		
9.	**Review of workshop findings**	

10.	**Next steps**
	
	(EA_1) / (APEM_1) / (EA_8)
	• Need for international experts to provide input to the review.
	• European view important also important in addition to US.. Dutch / German representatives being considered as part of the expert panel.
	  ○ (EA_8)- Pisces may have useful combined scientific / legal knowledge and of US / UK.
	• Approach given limited budget / time:
	  ○ (EA_6) – suggest set questions, include in review, and give reference response. A lot of value in a questionnaire to highlight perspectives.
	
	(EA_1)
	• Scoping report out soon.
	• Minutes of this meeting will remain private for first circulation.
	• EA make the decision on publication timescales.
	
	(APEM_1)
	• To (NRW) - Useful to have NRW notes on Wylfa, in terms of modelling approach adopted for the impact assessment etc.
	• (EA_2) to provide feedback on French policy.	

	(EA_1) • Discussion of WebEx Telecom. Likely high level of interest. Is it manageable? Aim is to achieve openness - the more open we are the more we are working for the protection of the environment. (EA_8) • Political / commercial / environmentally sensitive issues and interest – need to keep focused and direct to subject, given limited timescale. ○ (IFCA) – Blue planet effect – authority / stakeholders more engaged. Have to be very careful - is a shift in the way we view the environment, a move towards regional management, in inshore management, so whilst we've said before no legislative shift there is a mind shift and within the 25 year plan.	EA / APEM - WebEx Telecom set up with invite only participants.
11.	**AOB** (NE_1) • From NE point view, reassuring that the work is going on. (EA_6) • Mention of EPRI, there is Joint Environment Power Program for panel to consider – discussion of collective approach from different developers / developments. (EA_5) • Question regarding population modelling e.g. EAV / EALP. Seems to be different methods – production forgone and habitat production forgone, which cover slightly different things. More literature may be available.	APEM – to look at whether to add life stage modelling to the review for the fisheries impact assessment aspect.
Workshop close & refreshments		