Trials and tribulations of fish recovery and return

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Abstract

Recent regulatory Best Available Technology (BAT) guidance in England and Wales supports the use of fish recovery and return (FRR) systems at thermal power station cooling water intakes as part of fish protection measures. New guidance on eel (*Anguilla anguilla*) screening to meet the latest regulatory requirements also proposes possible modification of existing travelling band and cup screens at raw-water pumping stations for FRR as a means of eel screening. While FRR technology has been available for many years, its use and operational experience are still quite limited, and there are few existing examples that would meet current BAT guidance. Operators trying to introduce FRR are having to push the boundaries of existing knowledge to meet BAT standards. Some of the issues are explored and solutions discussed.

Keywords: band screen, drum screen, power station, fish recovery and return, FRR, best practice.

1 Introduction

Thermal power stations, which include nuclear and fossil-fuelled plants, abstract huge amounts of water for rejection of waste heat, necessitated by fundamental constraints set by the laws of thermodynamics [1]. A tower-cooled station or small, once-through-cooled, combined-cycle, gas turbine (CCGT) station, for example, will abstract a few cubic metres per second, while the latest proposed nuclear stations will require up to 125 $m^3 s^{-1}$ of seawater. The water is first passed through travelling band- or drum-screens, having mesh openings typically between 5 and 10 mm, although more recently there has been a trend towards smaller mesh sizes. This prevents debris, typically comprising a mixture of fish, weed and other aquatic biota, from entering and potentially blocking the small-

WIT Transactions on State of the Art in Science and Engineering, Vol 71, © 2013 WIT Press
www.witpress.com, ISSN 1755-8336 (on-line)
doi:10.2495/978-1-84564-849-7/010

bore tubes of the condensers. On older power stations, the debris, which has been impinged and then washed off the screens at the top of their rotation cycle, is usually drained, put into skips and sent to landfill; in a few cases, the debris is macerated and discharged to sea.

In the 1970s, the potential impact on fish stocks of cooling water (CW) screen fish impingement was recognised and measures to allow their return to the source water body began to be considered. In the UK, a primitive fish return arrangement was built into the (then) new Oldbury-on-Severn power station in an attempt to recover salmonid smolts. It was largely ineffective and was superseded by a manual operation involving station staff using buckets. In the 1980s, the new Sizewell B PWR nuclear station was provided with the capability to return screened debris, including fish, shrimps and other biota, back to sea but no special provision was made for reducing handling damage to fish. Tests of fish survival nonetheless indicated that a significant proportion of fish and crustaceans could be returned live and in good condition, whilst dead or moribund fauna could at least be returned to the food web [2]. Since then, a number of newer power stations have been required under the conditions of their water abstraction licences to provide various biota protection measures, including fish return. In 2005, the Environment Agency [3] published guidance on Best Practice for fish recovery and return (FRR) systems, based on a review of international experience. This has application with respect to any type of raw water abstraction where physical screening is required to protect a downstream process. Further Environment Agency guidance has since been issued with particular focus on large power stations [1] and for the protection of European eel (*Anguilla anguilla*) [4; see also paper by Aprahamian *et al.*, this volume]. The term ‘fish recovery and return’, or FRR, as opposed to just ‘fish return’ has been coined to emphasise the importance of promoting the physiological recovery of fish before putting them back into the wild.

The implementation of Environment Agency Best Practice guidance is a matter for individual developers and operators, and recent experience has identified a number of issues. The aim of this paper is to review the biological and engineering background to FRR systems and to describe the current state of play in the UK.

2 FRR systems design

2.1 Screen meshes

FRR systems currently used at power stations in the UK are elaborations of the band- or drum-screens primarily provided to protect condenser systems. A standard condenser will have hundreds of tubes and the heat transfer efficiency is vital to the overall performance of the power plant. Tube diameters are typically 20-25 mm. It is usual practice today to have screen openings no larger than one-third of the condenser tube internal diameter [1]. Thus meshes typically have 5–6 mm square openings. Older stations may have larger mesh sizes of 8–10 mm. Choosing a mesh size for FRR must strike a balance between recovering and returning to sea the largest amount of fish and other biota possible, while not incurring excessive risk of blockage. In France, the small ‘rose-de-mer’ jellyfish (known here as ctenophores or ‘sea gooseberries’) have blocked the finer (3 mm) drum-screens used at some nuclear plants, causing emergency shut-down [1], whereas at UK nuclear stations equipped with larger screen meshes, these small jellyfish have been able to pass through the screens, allowing the stations to continue operating. The latest Environment Agency guidance [4] requires consideration to be given to use of finer fish screens with openings as small as 1–2 mm, where glass eels or elvers (juveniles of *Anguilla anguilla*) are present, but it is unlikely that this would be feasible for a nuclear operator, owing to the very high costs and safety risks associated with forced shutdowns, should a blockage occur. On the other hand, it has been shown that >50% of elvers can be expected to survive entrainment passage through a typical once-through power station cooling system [5].

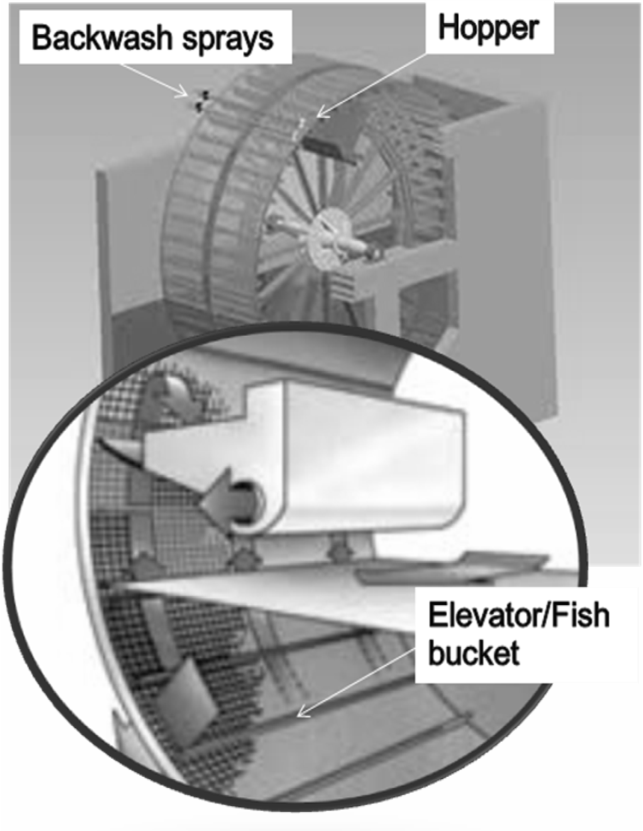


Figure 1: Schematic of (upper) drum-screen and (lower) band-screen, modified for FRR. (Key: A – mesh panel; B – fish bucket; C, F – low-pressure sprays; D, F, K – spray bars; J – high-pressure spray; G – wash-off trajectory; H – fish launder; L – debris launder.)

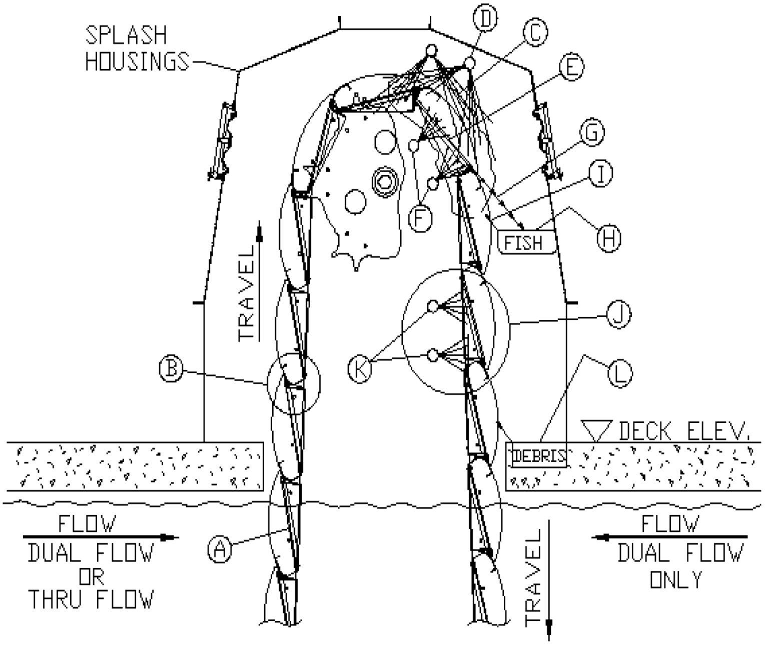


Figure 1: Continued.

The other main requirement for the mesh of a screen modified for FRR is that the material should be smooth and fish-friendly. Stainless steel woven meshes are commonly used, although plastic materials are equally or more suitable from the fish handling aspect.

An operational requirement for FRR screens is that the meshes are kept in motion continuously. This is not standard industry practice with band-screens, which are normally held static until partial blockage is detected from the head difference across the screens. As band-screens, unlike drum-screens, have many articulating parts, holding them stationary for long periods reduces mechanical wear. Under these conditions, fish could be pinned against the screens for hours, greatly increasing mortality. Maintenance costs on band-screens used for FRR are therefore likely to be higher. However, even on drum-screens, main bearing wear is related to speed of rotation and engineers prefer lower speeds. Current Environment Agency guidance specifies a minimum rate of screen travel of 1.5 metres per minute.

So far, no specific recommendations have been made concerning flow velocities through screen meshes. Low velocities help fish to avoid impingement but unless fish are able to swim out of the intake back to sea this only prolongs their retention within the screenwell. It may be argued that rapid impingement and removal is best, certainly for offshore tunnel intakes where the fish would have no chance of escape.

2.2 Fish buckets

The screen meshes on band-screens are formed into articulated panels on a continuously rotating vertical belt and chain assembly (Figure 1). In operation, material becomes impinged on the mesh panels, they are raised vertically from the water and, as the panel passes over the upper sprocket, spray-jets backwash the debris from the panels. To prevent impinged material from sliding back down the face of the screen and into the water, each panel is fitted with an elevator ledge or 'bucket', into which the material drops, allowing it to be lifted and removed. In FRR designs, the bucket is intended to retain water, so that fish are not left dry. The shape of the bucket profile is critical and designs have been developed (Figure 2b, c; [6]) which ensure that the water passing over the top of the bucket and on through the screen does not create a rotating flow within the buckets which would otherwise scour out the contents (Figure 2a).

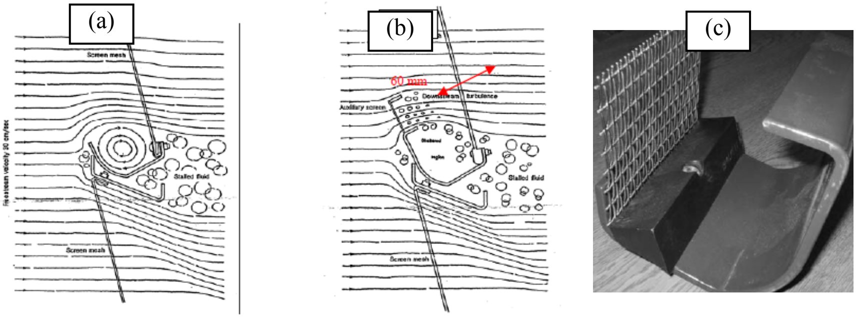


Figure 2: Fish bucket design: (a) unmodified bucket with unwanted rotational flow; (b) improved bucket profile: source: [6]; (c) example of fish bucket profile (courtesy Ovivo, UK).

Fish buckets for drum-screens are necessarily of a different shape. Whereas band-screen buckets remain in the vertical position as they are raised from the water, those on drum-screens follow the arc of rotation and will have rotated through 90 degrees or so (depending on the tidal level in the screenwell) by the time the buckets reach the wash-off point at the top. Thus, there is more opportunity for fish to be tipped out prematurely. However, the bucket is not fully inverted at this point and the bucket profile is therefore designed to encourage emptying (Figure 3).

While fish buckets of both types appear to work well for most species, recent Environment Agency guidance [1, 4] has drawn attention to the risk of recycling larger, sinuous species, such as eels and lampreys. Although these species are normally regarded as physically tough, adult eels are often observed to have low survival rates and sometimes exhibit injuries, such as external sores and spinal fractures. This is most likely as a result of fish writhing and falling back out of the buckets during the elevation phase, the process being repeated until they are eventually removed. Where chlorine or other biocides are used, this would also

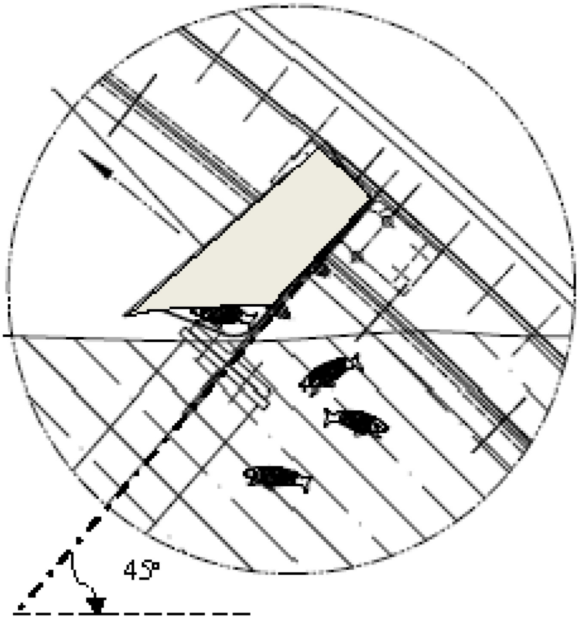


Figure 3: Fish bucket detail from drum-screen at tipping point.

have the effect of prolonging toxic exposure. Owing to the sensitive conservation status of eels and lampreys in Europe, it is therefore now incumbent on developers to demonstrate that the design used where these species are present performs efficiently. As yet, no specific performance criteria have been set out and this area merits research.

A potential issue when fitting water-retaining fish buckets to large drum-screens has been raised by one developer. Their concern is that the weight of water on the rising half of the screen will cause an imbalance, causing excessive bearing wear and other mechanical problems. It has been suggested that a potential solution would be to use buckets with drain holes but to spray water onto the rising face of the screen to keep fish wetted. The viability of this option is yet to be proven but it illustrates the kind of issues that developers are having to deal with in trying to meet emerging Environment Agency guidance.

2.3 Backwash sprays, hoppers and launders

At or near to the top of the screen's rotational cycle, material is backwashed from the screens by water spray jets, which blast off impinged debris from the reverse direction. Traditionally, on standard debris screens these have been high-pressure jets operating at ≥ 3 bar pressure. Such high pressures have been shown to injure fish and crustaceans [1] and so FRR systems precede the high-pressure wash with a low-pressure (≤ 1 bar) spray to flush off delicate organisms. These are collected in a hopper and the wash-water then flushes them through into the return troughs (known as 'launders'). Most systems have separate launders for biota and trash, the former conveying the fish and other biota back to the water body of origin (source water) and the second set transferring trash to collecting skips for disposal. The separation between biota and trash is not 100% efficient and some organisms such as crabs and shrimps are able to cling onto the meshes until forced off by the high-pressure spray. Where crustaceans are likely to be caught in large quantities, the option of combining both sets of launders into the fish return discharge should be considered. Environment Agency guidance [1] indicates that return of screening residues to sea is normally acceptable, provided that the process is continuous, rather than intermittent.

The efficiency of collection of fish, other biota and debris is high for band-screens, as the emptying range of the buckets within the rotational cycle is narrow, being just below the tipping point of the buckets as they ride over the upper drive sprocket. In drum-screens, especially those of large diameter (>10 m in some cases), the emptying range occupies a greater arc of the circle. It has been observed at some stations that a considerable number of fish fall out beyond the range of the hopper and are consequently recycled within the screening system (Figure 4). Hopper dimensions need to be large enough to deal with this, not only for efficient FRR operation but for debris removal generally.

From the hoppers, the water carrying fish, other biota and debris enter the launders, which are open channels or troughs, carrying them towards the point of return to the source water body. Figure 5 shows a typical layout schematic.

Launders need to incorporate a number of key design features. Most important is that they are smooth to prevent injury to fish. Any roughness, including welded joints, can cause small-scale turbulence that allows algal growth to develop in daylight, this then trapping twigs and other debris, on which fish become snagged. Minimum recommended launder width is 0.3 m for individual screen branches, and 0.5 m for main return conduits. Horizontal bend radius is kept large to assist free flow, a minimum radius of 3 m being preferred [1]. Where this is not possible, e.g. when retrofitting existing pumphouses with limited space, enlarging the launder width to 0.5 m will help. Launder slope is limited to 2% on main runs, especially in advance of bends, where excessive acceleration of flow will cause overtopping. Vertical bends should also be swept, as sharp angular drops will cause flow to separate from the launders. All-in-all, these criteria simply reflect good hydraulic design practice.

2.4 FRR discharge back to source

Returning fish and biota back to the source water body can create a number of design challenges. Critical requirements are as follows:

- Fish and biota should be hydraulically separated from the intake flow to prevent re-entrapment.
- The return point should not be in an area of natural flow where the organisms will rapidly disperse, and not in a backwater area where they may become targets for predators.

- The return point should be a metre or so below the lowest natural water level (e.g. below lowest astronomical tide in tidal waters) to avoid discharging onto a drying area where fish might become stranded.

Figure 4: Fish collecting on temporary scaffold boards installed inside an operating drum-screen. The fish seen here have emptied from the buckets only after passing the collection hopper and would normally have fallen back into the screenwell and been recycled through the screening system.

Hydraulic separation from the intake flow can be achieved either by discharging beyond a topographical feature such as a headland or by studying tidal flows from charts or 2-D hydraulic model outputs. The use of particle-tracking features, available within some numerical hydraulic models, can be helpful for this purpose. Physical drogue-tracking trials at the site in question may also be considered.

Return lines can be in the form of open launder troughs or pipes, or even bored tunnels but, whichever is used, adequate provision must be made for cleaning. Fouling in open launders arises not only from material being carried (weed, fish and other biota, sticks, shell debris, plastics, etc.) but also can result from growth

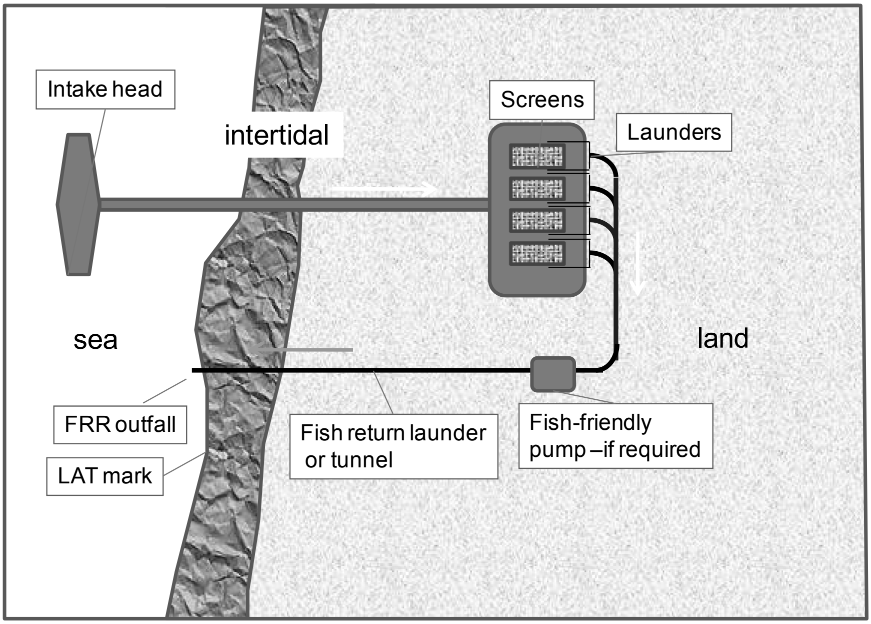


Figure 5: Schematic layout for FRR system, showing intake point.

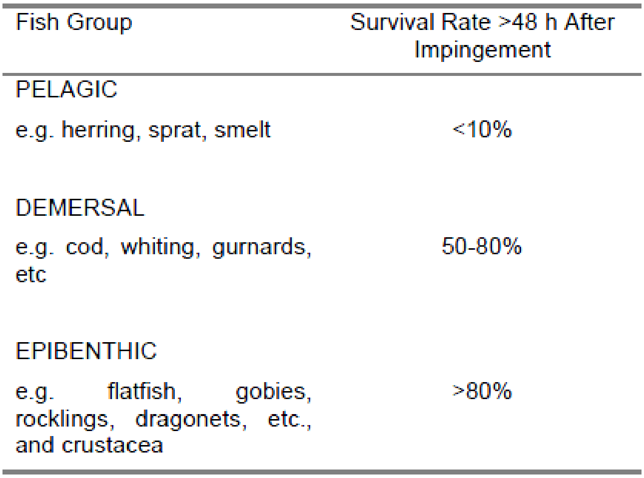
of algae, particularly at points of roughness and turbulence. Attached growth in troughs can be controlled by excluding light with covers, and this also avoids bird and mammal predator access. Algal fouling is not a problem where pipes and tunnels are used but suitable safe access for rodding/pigging must be included in the design. Operators at Great Yarmouth power station (RWE Npower, Norfolk) report trouble-free operation of a tunnel-type fish return system since its commissioning in 2002, with cleaning having been carried out only 2–3 times to date (G.J. Cribb, pers. comm.).

Where the return point is located a long distance from the CW pumphouse, it will be necessary to ensure that there is sufficient fall to maintain the discharge flow. In some cases it will also be necessary to elevate the inshore end of the return line to allow it to pass above a sea wall. In either case, a variety of fish pumps are available to provide the required lift without damaging fish. These include several proprietary Archimedean screw pumps and helical screw pumps, widely used in aquaculture but which have also been thoroughly tested in fish conservation schemes at engineering facilities [4]. Figure 5 shows where in the return line fish lift pumps might be located.

3 FRR within the overall context of abstraction mitigation

The success of FRR systems differs according to the physical robustness of the fish species and lifestages concerned. Delicate pelagic fishes, such as herrings, sprats and shad, as well as salmonid smolts, have loosely attached scales and generally do not survive any form of mechanical handling. In normal life these fish keep clear of the river or sea bed and solid structures and are known as ‘thigmophobic’ (avoiding touch). At the other end of the spectrum are ‘thigmophilic’ fishes, epibenthic species that normally live in contact with the river or sea bed, including flatfishes, rock-pool and reef fishes and eels. In between, fall a wide variety of demersal fishes, such as sea bass (*Dicentrarchus labrax*) and members of the cod and whiting family (Gadidae). Environment Agency guidance [3] shows the expected survival rates for these groups of fish in the passage of FRR systems (Table 1).

Table 1: Typical fish survival reported from studies of drum- or band-screens with simple modifications for fish return (e.g. with fish buckets, low-pressure sprays and continuous screen rotation) [3].



Fish Group	Survival Rate >48 h After Impingement
PELAGIC	
e.g. herring, sprat, smelt	<10%
DEMERSAL	
e.g. cod, whiting, gurnards, etc	50-80%
EPIBENTHIC	
e.g. flatfish, gobies, rocklings, dragonets, etc., and crustacea	>80%

It is clear from this that FRR is only a partial solution and that other measures would be required to protect the majority of pelagic and some demersal fishes. Environment Agency guidance [1, 3], proposes therefore that where FRR techniques are applied to provide abstraction mitigation at power station intakes, this should be supplemented by other measures, the main one being:

- Selecting an intake location away from any important fish spawning and nursery areas and away from known fish migration routes;
- Ensuring that low abstraction velocities (<0.3 ms^{-1}) are maintained so that fish are not forcibly drawn in by excessive current velocities;
- Fitting fish deterrent devices such as acoustic fish deterrents (AFDs) and/or strobe lights.

AFDs work in a complementary fashion to FRR systems, as thigmophobic fish are generally highly sensitive to acoustic stimuli, therefore this technology pairing meets BAT (best available technology) requirements for coast- and estuary-sited cooling systems.

4 Additional stress factors

As well as the obvious stresses associated with mechanical handling of fish, factors such as biocide toxicity and pressure changes during passage through inlet tunnels have the potential to limit FRR success.

Most coastal power stations use chlorine (as sodium hypochlorite) as a biocide, injected into the cooling system at one or more points to prevent mussel growth. At concentrations commonly used (typically a target concentration of 0.2 ppm at the condenser inlet), toxicity to fish is relatively low, provided the exposure time is less than about 6h (Figure 6). Also, treatment is normally confined to the warmer months when mussel growth is greatest, being stopped when water temperature falls below 9–10°C. Traditionally this has been from May to October but with warming in recent years this period is becoming longer.

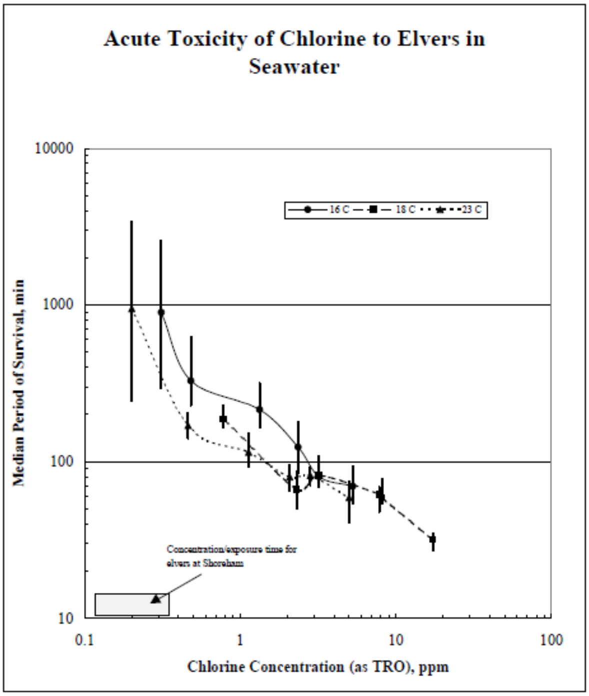


Figure 6: Median period of survival of elvers versus chlorine concentration at three water temperatures. The vertical bars are 95% confidence limits. The shaded rectangle in the lower, left-hand corner indicates the design exposure time/concentration for Shoreham CCGT power station [7].

Fish entrapment in CW intakes is usually greatest in the cooler months and therefore the risk of chlorine exposure is reduced. Environment Agency advice [1, 4] is to avoid dosing chlorine upstream of any FRR facility, but this may be unrealistic where long inlet tunnels are used and may be at risk of blockage by marine fouling. The Agency guidance therefore allows that upstream dosing may be permitted where it can be shown by a suitable risk assessment that fish recovery will not be harmed. So far, no protocol for such a risk assessment has been established but it will be necessary, for example, to consider the lethal toxic risk of the biocide to the key species and lifestages that are likely to be present during the dosing season. It may also need to consider any sublethal effects that might disorientate or affect motility such that they would be more vulnerable to predations after being returned to the wild. In reviewing toxic risk, a key factor may be the length of time for which fish stay in the intake and screenwell area before recovery.

Examination of Figure 6 reveals that, in the case shown for elvers (*Anguilla anguilla*), any retention beyond around 6h would increase the lethal risk and therefore knowing the clearance rates for different species is critical to any risk assessment. Further work is required on this matter.

Pressure-related stress in CW inlet tunnels is associated chiefly with deeply buried tunnels. Fish passing through deep tunnels are subjected to unnaturally rapid forced changes in hydrostatic pressure, which can cause over-expansion and rupture of the swim bladder in teleost fishes. The problem has been noted for example at Thameside stations where tunnels descend to around 20 m below water level. The use of deep tunnels should therefore be avoided, where possible, although this is likely to be determined by geophysical factors in most cases and therefore uncontrollable. Nevertheless, pressure effects should be accounted for in mitigation efficiency estimates prepared as part of any environmental impact assessment.

5 Future developments

Fish return technology is relatively new on the UK scene but will be widely used in future developments. As a result of European environmental law (principally the Habitats Directive and the Water Framework Directive), the present generation of nuclear and CCGT power plant developments will necessitate much design innovation and elaboration by cooling water plant design engineers. On the other hand it provides an unprecedented window of opportunity to get it right. This is likely to necessitate much interaction between fisheries specialists and design engineers at the planning and detailed design stages, a degree of risk-taking by designers, operators and regulators, some preliminary laboratory or flume-scale testing and much follow-up monitoring and refining of designs.

While fish return systems have been developed so far solely for power station applications, there would appear to be good opportunities for this technology in other applications. Many hundreds of raw water abstractions from rivers and lakes are currently operated by water companies in the UK and those supplies that feed directly into water treatment plants are mostly filtered using band-screens or small drum- ('cup') screens. Where thigmophilic species, such as eels, are the prime target for protection, modifying these screens for FRR should be considered. This is likely to require changing the elevators to a suitable fish bucket design, installing return launders to discharge recovered fish at a point downstream of the intake and providing low-pressure backwash with adequate flushing flow to carry fish back to the river. Where this is feasible, it could avoid substantial capital investment associated with installing completely new fish-friendly intakes and screens.

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