Application of a Comprehensive Framework for Assessing Alternative Cooling Water Intake Structure Technologies under Section 316(b)

By Donald Galya, P.E., James Jolley, P.E., David Urban, P.E., Joan Tracey ENSR International and Jacob Scheffer, Entergy Nuclear Generation Company

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Introduction

Section 316(b) of the Clean Water Act requires a demonstration that the location, design, and capacity of cooling water intake structures (CWIS) use the best technology available (BTA) to minimize adverse environmental impacts. Direct environmental impacts of a CWIS typically are considered to include entrainment (passage of aquatic organisms into a cooling system) and impingement (immobilization of organisms against an intake screen). In addition, there is a potential for effects on water resources, noise, air quality, aesthetics, and navigation.

The currently evolving regulatory framework for Section 316(b) includes new performance standards and requirements for demonstrating compliance. U.S. EPA's upcoming 316(b) regulation for existing facilities will likely contain a provision for performing a cost-benefit analysis to justify selection of a CWIS technology for site-specific applications. The cost-benefit analysis in the draft 316(b) regulation focuses on evaluating monetary costs associated with various alternative CWIS or BTA controls compared to the benefits of a reduced level of impingement and entrainment. This paper discusses an application of a comprehensive assessment framework performed as part of a recent 316 Demonstration (ENSR, 2000) for the Pilgrim Nuclear Power Station (PNPS), a coastal power station with a once-through cooling water system and shoreline CWIS. This framework includes practical feasibility and engineering assessment measures in addition to monetary costs and environmental benefits.

Power Station Description

PNPS is located in Plymouth, Massachusetts on the northwest shore of Cape Cod Bay approximately 38 miles southeast of Boston, Massachusetts (See Figure 1). The station consists of one boiling water reactor and associated steam-electric and auxiliary systems. The licensed capacity of PNPS is 670 MWe. PNPS uses seawater in a once-through cooling system to remove heat through the condenser. Seawater is drawn from Cape Cod Bay into the cooling system by two circulating water pumps, each with a capacity of 155,500 gpm.

Seawater for cooling water and service water at PNPS is drawn through a constructed inlet embayment and into the CWIS. The embayment is created

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by two large breakwaters, which effectively separate the embayment from the open ocean as indicated in Figure 2. The PNPS CWIS consists of wing walls, a skimmer wall, vertical bar racks, and vertical travelling screens (See Figure 3). Two concrete wing walls guide flow into the intake. The skimmer wall removes floating debris. Bar racks, constructed of 3-inch by 3/8-inch rectangular bars with three-inch openings, intercept large debris. The 10-foot wide vertical traveling screens remove aquatic organisms and small debris. Dual level spray washing is used to clean the traveling screens. A low-pressure spray removes organisms and a subsequent high-pressure spray above removes debris.

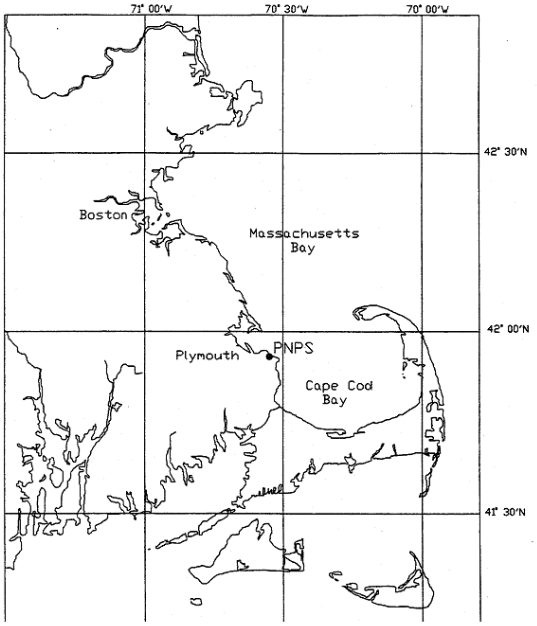

Figure 1

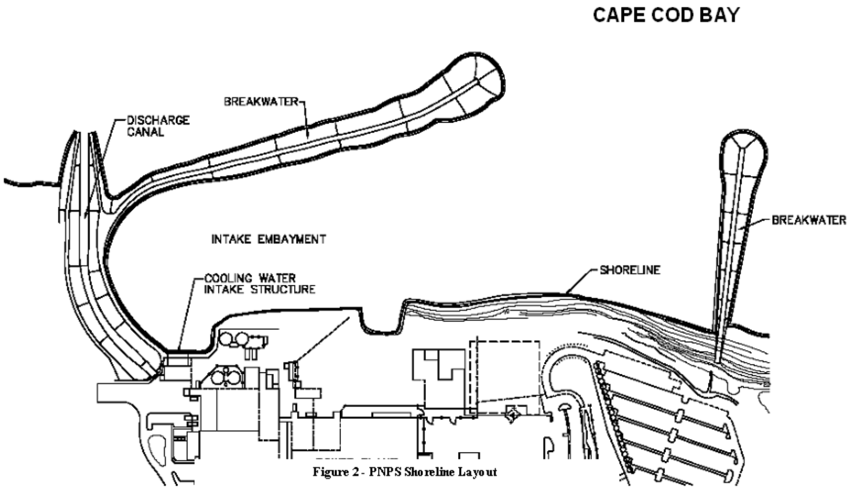

Figure 2 - PNPS Shoreline Layout

Figure 2

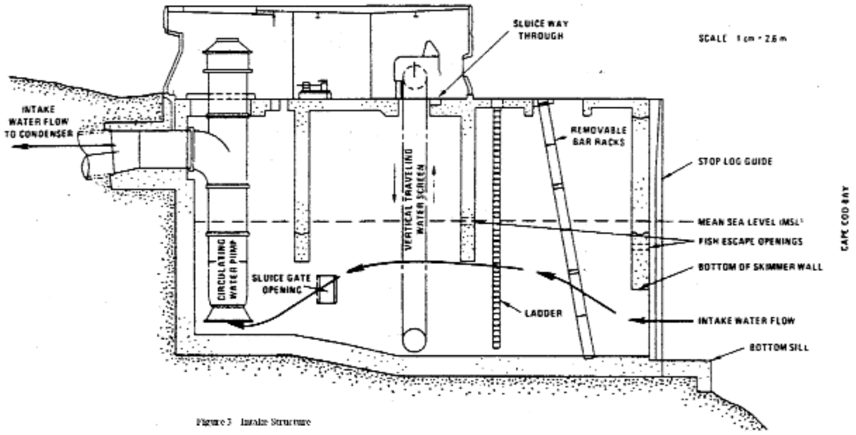

Figure 3 Intake Structure

Figure 3

Spray wash discharge is routed back to the bay via a concrete sluiceway. Fish escape openings are located in the skimmer walls and at each end of the intake structure.

Impact Assessment of Existing CWIS

A series of analyses was performed to assess impacts of the existing CWIS. Data for this impact assessment were collected from several decades of monitoring studies that have been performed since the early 1970s. Based on these data, specific Representative Important Species (RIS) were selected for detailed analysis. The impact assessment consists of an evaluation of the RIS-specific and overall impacts of the CWIS and the related thermal discharge. An evaluation of the CWIS impacts on Essential Fish Habitat (EFH) species was also performed. RIS were assumed to be representative of EFH species in the detailed assessment and the primary study conclusions were based on assessed potential effects on RIS.

Impingement and entrainment effects were assessed based on impingement and entrainment rates measured in monitoring studies. These results indicate that Atlantic silversides, rainbow smelt, and alewife are the most likely species to be affected by impingement, and winter flounder and cunner are those most likely to be affected by entrainment. These species, as well as American lobster and Irish moss, were included on the RIS list and were quantitatively evaluated in the impact assessment. Adult fish losses were determined from entrainment rates using the Equivalent Adult methodology outlined by Goodyear (1978). Also, supplemental detailed field and impact analysis studies of winter flounder entrainment were performed to evaluate the percentage of winter flounder larvae entrained by PNPS compared to that transported through the Cape Cod Bay system. Thermal impacts were assessed using a combination of field thermal surveys, thermal modeling, comparison of the thermal plume temperatures with species thermal tolerance values, and observations of thermal plume effects on the benthic community.

The cumulative impacts on RIS of impingement, entrainment, and thermal discharges were determined by estimating mortality rates compared to species populations (i.e. conditional mortality rate) and/or commercial catches. The results of the impact assessment analysis with respect to conditional mortality for the RIS are summarized in Table 1.

Based on this assessment, it was concluded that the PNPS CWIS and thermal discharge has not caused an adverse impact to the integrity of the population of any RIS, or to the aquatic ecosystem of Cape Cod Bay. Conditional mortality from entrainment or impingement is generally less than one percent and in all cases - even under the most conservative assumptions and conditions - is less than five percent. The potential exists for exclusion of biota from a relatively small area of habitat in the thermal plume. However, there has been no observed mortality of fish and no evidence of adverse effects on fish populations from the thermal plume.

Table 1: Summary Impact Assessment for Existing CWIS

RIS	Entrainment Conditional Mortality	Impingement Conditional Mortality	Thermal Conditional Mortality
Winter flounder	< 1%	0.2%	0%
Rainbow smelt	0.00001-3%	0.5-2.5%	0%
Cunner	0.26%	0.02-3.1%	0%
Alewife	0.00005%	0.02%	0%
Atlantic silverside	0.01%	0.005%	0%
American lobster	0.001%	0.2%	0%
Irish moss	0%	0%	2%

Alternative CWIS Technology Assessment

A comprehensive list of BTA technologies was considered to determine whether any technology is feasible, appropriate, and cost-effective for the reduction of CWIS effects. Technologies considered include behavioral barriers, diversion devices, an offshore intake structure, wedgewire screens, fine mesh screens, Gunderboom fabric barrier system, cooling towers (mechanical, natural draft, and dry cooling), variable speed pumps, and cooling water bypass. In addition, habitat restoration and fish stocking were considered as mitigation strategies. Each of these alternatives was evaluated in comparison to the existing cooling system with respect to the following assessment measures:

- **Cost:** The capital cost and present value of the annual operation and maintenance (O&M) cost were determined. The capital cost includes the purchase, and installation of new equipment, or the retrofit of existing equipment. O&M costs include the additional costs to operate and maintain the new/retrofitted equipment. The cost of lost generation was included in the capital cost to account for construction outage and in O&M costs to account for decreased thermal efficiency. To obtain a single value for cost comparison purposes, a present value of annual O&M costs was calculated based on a 30 year period at an interest rate of 7%.
- **Technical feasibility:** Assessment of technical feasibility involved an analysis of the difficulties associated with the construction, operation, and maintenance of the alternative. The availability of the necessary equipment and skilled workers to build and operate the alternative were considered.
- **Reliability:** Reliability assessment involved analysis of the alternative's consistent ability to deliver water to the cooling system while reducing impingement and entrainment. The assessment considered maintenance requirements to prevent corrosion or fouling and to clean and repair elements of the technology.
- **Adverse effects:** Adverse impacts, other than on aquatic ecology,

were considered, including water resources/supplies, noise, air pollution, aesthetic, and navigation effects.

- **Safety Concerns:** The ability of the alternative technology to reliably deliver cooling water continuously to the power station was considered. This is critical for the safe operation of a nuclear power station, such as PNPS. Issues related to safety of the plant, its operating staff and the surrounding community subject to oversight by the NRC were of primary concern in this evaluation.
- **Benefits/Effectiveness:** The benefit of the alternative technology was based on its potential effectiveness in reducing impingement and entrainment of selected species, with consideration of the overall effect on the aquatic ecosystem, including an estimate of the anticipated change in populations.

The alternative technology evaluation consisted a two phase effort: (1) a screening level assessment to exclude technologies determined to not be feasible under at least one of the criteria and to select technologies for detailed analysis and (2) a detailed analysis of selected technologies using the evaluation criteria. The various technologies considered are discussed below. The evaluation is summarized on Table 2.

Behavioral Barriers

Barriers that use a behavioral response of fish to avoid entry into the intake flow include sound barriers, light barriers, air bubble curtains, chains and cables, and electrical barriers. During the screening evaluation, all behavioral barriers were determined to not have demonstrated effectiveness for a wide range of species and environmental conditions. Sound generating devices, air bubble curtains, electrical barriers, and chain and cable barriers were eliminated from further consideration.

Despite concerns about broad-based effectiveness, a strobe light type barrier system was retained for detailed evaluation as representative of behavioral barriers for the purpose of comparison with other BTA technologies. This system, which would be constructed at the front of the intake, would include strobe lights, a metal support structure, power supply, controllers, and power cables.

Diversion Devices

Diversion devices are physical structures, such as louvers and barrier nets, which are intended to guide fish away from and out of the intake flow. In the screening analysis louvers were determined to be potentially more effective than barrier nets and were retained for detailed evaluation. For this alternative, louvers, or a series of evenly spaced, vertical slats, would be placed across the entrance to the intake embayment at an angle so that fish would continue in the direction of the ambient current and away from the intake embayment. The

louvers would be constructed of material compatible with the marine environment (i.e. polyethylene plastic slats on stainless steel frame).

Offshore Intake Structure

An offshore submerged intake structure was included in the detailed alternative technology evaluation. The offshore intake would be located in Cape Cod Bay approximately one mile away from PNPS at a depth of approximately 36 feet. It was assumed that tunneling would be required for intake construction. The potential for fish impingement would be minimized by using an intake velocity of 0.5 fps and a velocity cap to create horizontal flow.

Wedgewire Screen System

Wedgewire screen is constructed of wire with a triangular cross section so that the surface of the screen is smooth while the screen openings widen inwards. A staggered array system of approximately 15 tee shaped cylindrical wedgewire screens of one-mm slot size was evaluated. Each screen would be approximately 84 inches in diameter and 23 feet long. The screens would be cleaned periodically with an automatic compressed air system. In order to place the screens in an area where the current is sufficient to prevent burial from sedimentation, the intake system would be located outside the embayment approximately 1500 feet north of the existing intake.

Fine Mesh Screens

The existing traveling screens at PNPS are constructed of stainless steel wire mesh, with ¼ inch wide, ½ inch tall spacing. A CWIS alternative with a screen mesh spacing of less than one millimeter was evaluated because of its potential for reduction in entrainment. Approximately 12 ten-foot wide travelling screens would be required to maintain the required cooling water flow and an intake velocity of 0.5 fps. The screens would be operated continuously to prevent excessive accumulation of debris and organisms. The screens would be mounted in an entirely new intake structure constructed in front of the existing structure. The existing intake structure would remain in place as a backup to the new system. Bypass gates would be installed to direct flow around the new structure in case of blockage.

Gunderboom Fabric Barrier System

The Gunderboom system is a double panel, full water depth fabric curtain suspended from flotation billets at the water surface and secured in place by an anchoring system. The system includes mooring lines, ballast chain, anchoring system and an automated compressed air cleaning system. The 1500-foot long Gunderboom filter system would be installed across the intake embayment. In order to provide protection for the system during coastal storms, a wave barrier system would be located outside the embayment entrance.

Cooling Towers

Three types of cooling towers systems were evaluated in detail: mechanical draft and natural draft evaporative cooling towers, and a dry cooling tower. Because minimal fresh water supply is available at PNPS, it is assumed that the evaporative cooling systems would use salt water. The use of either the mechanical or natural draft towers would reduce the cooling water withdrawal from the bay from 321,000 gpm to 19,000 gpm. The mechanical draft tower would consist of a 420-foot long, 125-foot wide, 50-foot tall tower. The natural draft alternative would include a 580-foot tall, 480-foot diameter tower. Either would include a new water circulation system and a booster pump located at the tower. The dry cooling tower would consist of one 90-cell condenser with fans covering 680 feet by 190 feet in area and requiring a power demand of 10 MW. No water withdrawal would be needed for station cooling with the dry tower. For each of the cooling tower alternatives (but to a greater degree for the dry tower), the efficiency of the power plant would be reduced and additional fuel would be required to produce the same amount of power.

Variable Speed Pumps

The use of variable speed pumps would allow a reduction in cooling water flow during periods of peak entrainment and impingement. For this alternative, it was assumed that the variable speed pumps would be adjusted to decrease the flow by 25% over a four-month period each year. This alternative would require replacement of the existing single speed drive with an adjustable speed drives on each of the two circulating water pumps. The reduction in flow through the condensers could cause condenser tube fouling which would result in decreased thermal efficiency in the turbines, might require condenser replacement, and could increase thermal discharge effects. An on-line condenser tube cleaning system is included in the alternative to alleviate potential tube fouling. The reduced flow would result in a loss in efficiency as well as a potential loss in generating capacity.

Cooling Water Bypass

This alternative would reduce the cooling water flow rate through station condensers and add a corresponding amount of bypass flow into the discharge canal. There would be higher delta T value in the condensers, but a similar flow rate and delta T to the design value in the discharge canal. The reduction in flow rate through the condensers could result in reduced entrainment losses. This assumes that mortality in the discharge canal would be less than that in the station condensers. Diversion of 25% of the normal cooling water flow over a four-month period each year was assumed. Because of the higher delta T in the condensers, a loss in plant efficiency as well as potential limitations on generation capacity were included in the evaluation.

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Table 2: Alternative BTA Evaluation Summary

BTA Alternative	Cost (Capital plus O&M)	Feasibility/ Reliability Issues	Potential Adverse Effects	Safety Issues	Benefits/ Effectiveness
Behavioral Barrier Strobe Lights	$$	None	Potential fish attraction to lights	None	Potential impingement reduction for some species
Diversion Device Louvers	$$	Potential clogging of louver spaces	Navigation issues	None	Potential impingement reduction for some species
Offshore Intake Structure	$$$$	Complex construction and maintenance	Benthic impacts, Navigation issues, potential I&E increase for some species	None	Potential I&E reduction for some species
Wedgewire Screens	$$$	Potential clogging of screens	Benthic impacts, Navigation issues	Cooling water flow limitation	No impingement, potential entrainment reduction
Fine Mesh Screens	$$$$	Potential clogging of screens	None	Cooling water flow limitation	Potential entrainment reduction, but survivability uncertain
Gunderboom Fabric Barrier	$$$	Potential storm damage, clogging	Navigation issues	Cooling water flow limitation	I&E reduction for all species
Evaporative Cooling Towers	$$$$$	Construction involving existing cooling system	Fogging, icing, salt drift, noise, aesthetics	None	I&E reduction for all species
Dry Cooling Tower	$$$$$	Construction involving existing cooling system	Noise	None	I&E reduction for all species
Variable Speed Pumps	$$$$$	Construction involving existing cooling system	None	None	I&E reduction during spawning period
Cooling Water Bypass	$$$$$	Construction involving existing cooling system	None	CWIS changes require NRC approval	I&E reduction during spawning period
Mitigation	$	None	None	None	Increase in winter flounder and rainbow smelt populations

$	Less than $1M
$$	$1M-$10M
$$$	$10M-$50M
$$$$	$50M-$100M
$$$$$	Greater than $100M

Mitigation

To offset declines in rainbow smelt populations and potential impingement losses at PNPS, a habitat enhancement and restoration project was initiated. The project involved the removal of downed trees and other obstructions leading up to the river spawning grounds, placement of trays filled with sphagnum moss to provide artificial spawning substrate, and stocking of wild smelt eggs (Lawton et al., 1999). Continuation of this project was considered as a mitigation alternative.

Stocking of winter flounder was another mitigation alternative that was considered. Under this alternative, fish would be raised at a waterfront hatchery and released into Cape Cod Bay when approximately 5 months old. A successful pilot hatchery program has been conducted (Marine Research Inc., 2003).

The BTA alternatives evaluation indicated that several of the alternatives could result in decreased impingement and entrainment. However, all the alternatives, except for mitigation, would involve significant issues associated with other adverse effects, feasibility, reliability, nuclear plant safety, effectiveness, and/or extremely high costs.

Conclusion

The results of the analysis indicated that the existing CWIS does not adversely affect the aquatic ecosystem. While several of the BTA alternative technologies could decrease impingement and entrainment, all would be costly and involve other adverse effects, feasibility, reliability, or nuclear plant safety issues. It was concluded none of the technologies provide benefits that outweigh the costs and other issues. The results of the evaluation indicated that the benefits of the mitigation measures considered (e.g., winter flounder fish hatchery, and rainbow smelt fish passage/habitat restoration) outweigh the cost, would have a positive effect on the ecosystem, and would not result in adverse effects or involve other issues. Based on this evaluation, it was also concluded that the existing CWIS represents BTA but that mitigation measures would be appropriate.

In summary, achieving compliance with the Phase II Section 316(b) rule has the potential to be a long, challenging, and expensive process. ENSR believes that careful planning and innovative evaluation of the elements of the rule are likely to help minimize the costs of compliance. This paper provides some general recommendations for cost-effective rule compliance. We recognize that implementation of these recommendations must account for a variety of site-specific factors and we would welcome the opportunity to discuss further the issues at your facility(ies).

About the Authors

Don Galya, P.E. (978-589-3188; dgalya@ensr.com) has 30 years of experience in managing and conducting hydrothermal, water quality, aquatic biology, water resources, discharge permitting, and related studies for electric power facilities. He specializes in managing complex, controversial projects and developing innovative strategies to comply with Clean Water Act Section 316(a) and (b), NPDES, and other environmental requirements for power facilities. He has managed or performed over 100 permitting projects and technical studies for electric power facilities throughout the United States.

Dave Urban, P.E. (978-589-3087; durban@ensr.com) is the Manager of Wastewater Engineering at ENSR's Westford, MA office. In his 28 years of experience, he has managed and conducted numerous projects in wastewater and stormwater characterization, permitting, treatment plant design, and 316 (a) and (b) evaluations. He has been involved in projects in a wide variety of industries, including petroleum and petrochemical, manufacturing, pharmaceutical, manufacturing, food processing, metal plating, pulp and paper, and electric utility industries.

Jim Jolley, P.E., (978-589-3093; jjolley@ensr.com) has led environmental and water permitting efforts for a variety of power plants worldwide during the past 17 years. His work includes developing NPDES permit applications, evaluating alternative intake technologies to reduce impingement and entrainment as part of Section 316(b) demonstrations, and developing cost estimates for each alternative 316(b) technology.

Joan Tracey (978-589-3127; jtracey@ensr.com) is a marine ecologist with specialization in benthic and water column multi-media sampling and analysis. Ms. Tracey's recent project experience includes the field programs and/or impact analysis to support the New Bedford Harbor long term monitoring effort, the Long Island Sound EIS, and the Pilgrim Nuclear Power Plant 316 (a)&(b) demonstration.

Jacob Scheffer is the Environmental Manager at the Pilgrim Nuclear Power Station. Among his responsibilities is to ensure the facility's compliance with environmental regulations.

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