

## ALDEN

### Experience and Qualifications for Nuclear Power Plant Studies

January 9, 2009

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## **Introduction**

Founded in 1894, Alden is the oldest continuously operating hydraulic laboratory in the United States and one of the oldest in the world. From the early days of hydropower development and aviation, through World Wars I and II, and into the modern world defined by environmental needs, Alden has been a recognized leader in the field of fluid dynamics consulting, research and development.

In the 21st Century, Alden is a vibrant, growing organization consisting of engineers, scientists, biologists, and support staff in five specialty areas. Much of our work supports the power generating, manufacturing, and process industries. We occupy 32 acres in Holden, Massachusetts, containing numerous offices, laboratory buildings, computer and support facilities. Our on-site instrumentation, carpentry, and machine shops provide the specialty fabrication and data acquisition systems needed to support our wide range of complex and multifaceted projects. We also maintain an office in Fort Collins, Colorado to better serve our clients in the Pacific Northwest and on the west coast.

Alden has been performing regulatory hydraulic and environmental analysis work for the nuclear industry since the first major construction boom in the 1970's. From supporting the Nuclear Regulatory Commission directly with development of NUREG's to testing of sump strainers for plants to Clean Water Act compliance advising, Alden has become a trusted name in the nuclear community.

A major strength of Alden's offering is the ability to perform combined physical and numeric modeling (or "hybrid modeling") on projects. Both types have their strengths and weaknesses, and the ability to leverage them in an integrated fashion provides the best product for our customers at the lowest cost. As an example, a computational model of a larger domain may provide boundary conditions to be used in a physical model covering a smaller region. Additionally, if the validity of a computational model is proven with a physical model, various geometric configurations can be investigated in the computational model at a reduced cost and project duration.

## **Categories of Nuclear Power Projects**

Below is a general classification of projects conducted by Alden for the Nuclear Industry, along with a description of the work and a list of plants or projects.

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## Generic Safety Issue (GSI) 191: PWR Emergency Core Cooling System (ECCS) Performance Concerns.

High Energy Line Breaks (HELBs) inside nuclear reactor containment are recognized as challenges to Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) nuclear power plant sump strainers. The collateral damage to insulation, fireproofing, coatings, and other miscellaneous materials causes shredding, and the debris can be transported during the event. If washed towards the recirculation pumps, this debris could potentially impede the performance of the Emergency Core Cooling System (ECCS).

Alden has teamed with leaders in the industry to test sump strainers being designed for individual plant retrofits. To evaluate transport of material towards the sump and the potential for degradation in performance of the ECCS, Alden uses Computational Fluid Dynamics (CFD) in collaboration with debris generation modeling to predict the volume of material transported to the sump screens. This debris volume is then used in full scale laboratory tests to determine head loss across the screen under design flow rates.

The laboratory sump strainer tests employ a flume facility measuring 34 ft. by 10 ft. by 6 ft. tall with a 4 ft. deep pit at one end, which can accommodate multiple full scale strainer modules. Head loss performance of the modules under different insulation debris loading conditions is evaluated. The internal walls of the flume are adjusted to reproduce prototypical approach flow velocities and velocity gradients such that the transport of insulation debris to the strainer modules is accurately represented. A three-port isokinetic sampling system is integrated into the downstream piping for measuring debris bypass.

### Selected Plant List:

- Point Beach Units 1 and 2
- Turkey Point Units 3 and 4
- St Lucie Units 1 and 2
- Seabrook
- Watts Bar
- Sequoia
- Palisades
- Wolf Creek
- Calloway
- Kewaunee

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- South Texas Project
- Comanche Peak
- US APWR
- Oconee
- Japanese PWR Fleet

## BWR Sump Performance Evaluation

The models of reactor containment sumps are designed based on Froude similarity to include the sump and surrounding area with all the structures and piping which would influence the approach flow. In deciding the geometric scale, due considerations of simulation of flow patterns, vortexing, and possible scale effects due to viscous and surface tension forces are given. Testing to observe flow patterns, formation and type of vortices, and pre-rotation and swirl effects is undertaken for the various operating conditions including restrictions due to screen blockage. Evaluation of inlet loss coefficients for the various conditions is made to verify available NPSH. If necessary, vortex suppressors or other design modifications are derived and tested.

Studies on possible scale effects, involving high temperature-high velocity testing techniques derived by Alden researchers, were conducted to allow projection to prototype performance. Early work in this area culminated in the development of two NUREG documents: NUREG/CR-2758, (“A Parametric Study of Containment Emergency Sump Performance”, July 1982) and NUREG/CR-2759 (“A Parametric Study of Containment Emergency Sump Performance: Results of Vertical Outlet Sump Tests,” October 1982).

## Selected Plant List

- Beaver Valley
- Bellefonte
- D.C. Cook
- McGuire
- Catawba
- Millstone
- North Anna
- Salem
- Seabrook
- Shearon Harris

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- St. Lucie
- Three Mile Island
- V.C. Summer
- Washington Public Power Supply System, Nuclear Project No. 1

## BWR Suppression Pool Debris Testing

The pool dynamic conditions associated with the high-energy phase of a MLOCA are usually referred to as "chugging." Chugging occurs when water re-enters the down comers as a result of decreasing steam flow, thereby condensing steam. Alden conducted a parametric study sponsored by the NRC to investigate and provide insight into debris transport in a BWR suppression pool following a LOCA.

A 1 to 2.4 scale model was designed and constructed to simulate a segment of a Mark I BWR suppression pool. The model was constructed of steel with the appropriate lower curvature. The tank sidewalls of the segment were made of Plexiglas to provide complete visibility of the debris in motion. Turbulent chugging associated with steam-water oscillations (condensation oscillations) during depressurization of the primary system was simulated in these tests by including four 10-in. (0.25-m) diameter downcomers fitted with pistons. One of the downcomers was constructed of Plexiglas to facilitate visualization of debris transport. The spacing between the downcomers and their clearance with respect to the floor were also scaled. The front and back walls were spaced one-half the distance to the next pair of downcomers in either direction. Hence, the water volume of the tank per downcomer was scaled to the volume per downcomer of a typical BWR Mark I suppression pool.

Parametric tests were conducted to examine a variety of test conditions. The test parameters included the type, form, and quantity of insulation debris tested; the quantity of sludge tested; and the period and amplitude of the downcomer piston chugging.

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## Intake Structures

There are a number of hydraulics problems related to intake structures at nuclear power plants, including both cooling water intakes and internal storage tank withdrawals.

From an environmental perspective, the 316 (b) rule of the Clean Water Act has required a number of plants to install traveling water screens in order to keep fish from being entrapped in the cooling water system. Alden has performed both partial and full scale testing of these devices under plant specific conditions and channel geometry in order to ensure proper hydraulic performance.

Some plants have to struggle with sediment and debris in the body from which they withdraw water. The resulting fouling can translate into enormous expenses when frequent shut-downs are required to clear the system. Designing effective means of keeping sediment and debris away from intakes is not an intuitive engineering process, but sometimes requires a significant physical and computational modeling effort. Alden's combined expertise in this regard has helped plants to improve performance and be more profitable.

Operation of fresh water intakes in northern regions is complicated by the accumulation of frazil ice on the intake which can rapidly and unexpectedly shut down the intake facility. To address this problem, some plants will regularly back-flush warm discharge water through alternating intakes during the winter months. Such an operation must ensure that the warm discharge water does not re-circulate through the active intakes. Alden has performed CFD simulations of intakes under warm back-flush conditions to assist in their design.

Another major concern is the hydraulic performance of circulating and /or cooling water intakes. Unsatisfactory hydraulic performance can include objectionable vortex formation, excessive pre swirl at the pumps, non-uniform velocity distributions, air ingestion and sedimentation or debris accumulation. Adverse hydraulic conditions can affect pump performance and cause damage to pumps resulting in premature failure and /or maintenance issues. Additionally, excessive sediment or debris can cause problems with heat exchanger performance downstream. Alden regularly performs physical model studies of circulation and cooling water pump intakes, investigating overall hydraulic performance under varying external conditions as well as looking into the possibility of vortex formation.

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Air ingestion must be also carefully avoided during the withdrawal of water in storage tanks for emergency systems. In response to recent Nuclear Regulatory Commission (NRC) Component Design Bases Inspection (CBDI) issues, many US nuclear power stations have been required to demonstrate that vortex allowances were properly determined for various safety related storage tanks. In many cases, the licensees failed to consider a vortex allowance, or they applied an inappropriate vortex methodology. Alden has performed a series of test programs for plant owners in order to address these concerns.

## Selected Plant List

- Traveling Screen Hydraulics
  - DC Cook
  - Oyster Creek
  - Turkey Point
- Sedimentation and Debris Issues
  - Oyster Creek
  - Fort Calhoun
- Frazil Ice Management
  - Point Beach
- Pump Hydraulics / Vortexing
  - Oyster Creek
  - Calvert Cliffs
  - Arkansas Nuclear One
  - Indian Point Nuclear Power Station
  - McGuire
  - Peach Bottom
  - Perry Cooling Tower Intake
  - Qinshan
  - Seabrook
- RWST/BWST/CST Tank Drawdown Vortexing Tests
  - DC Cook
  - VC Summer
  - McGuire
  - Catawba
  - Oconee

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- Clinton
- Byron
- Braidwood
- Seabrook

## Plant Discharge Structures – Thermal Discharge Modeling

Rule 316(a) of the Clean Water Act regulates thermal discharge from thermal electric power plants, dictating how much temperature rise can occur over a given surface area of a water body. Mixing of the discharge plume is of critical importance, and Alden's computational modeling, physical modeling, and field service expertise have been used extensively by the nuclear community to design site-specific outfalls and to demonstrate compliance.

Of related interest, chemical biocides have been used by many plants to minimize bio-fouling of the cooling water system. For once-through cooling, it is necessary to ensure proper species mixing at the outfall so that the biocide concentration is sufficiently low at the outfall to minimize the ecological impact of the operation.

### Selected Plant List

- TVA Browns Ferry
- DC Cook
- Millstone
- Connecticut Yankee
- Tanners Creek
- Chalk Point
- Oyster Creek
- J.A. Fitzpatrick
- Yorktown
- Rosewood
- Indian Point
- Martin's Creek
- Seabrook
- Cayuga

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- Campbell
- Charleston
- Hanford
- Ao Phai
- Castle Creek
- Charleston
- Jamesport
- Map Ta Phut
- Mercer
- Palisades
- Seabrook Nuclear
- Basic Research Grant (NSF)

## Plant System Hydraulics

Alden's modeling and design experience has been leveraged for a variety of internal nuclear plant system hydraulics, in addition to the GSI-191 and tank draw-down work described above.

For raw water biocide usage, not only is turbulent mixing at the outfall important, as described above, but the biocide must also mix properly immediately downstream of the injection in order to avoid organism growth effectively. The condenser tube sheet inlet box has been of particular interest, because it is desirable to attain a similar biocide concentration in each condenser tube. CFD is an ideal tool for analyzing and designing a tube sheet inlet box for optimal mixing.

Also of concern in tube sheets is plant debris fouling. Alden has used full scale physical hydraulic modeling to determine what size debris will flow into a heat exchanger tube sheet.

Air can sometimes become entrapped in critical safety system piping over time. This air can then become entrained during emergency operation and hinder performance. Current computational modeling techniques cannot handle the complex free surface and dispersed multiphase flow physics involved in this problem, and Alden has performed full scale hydraulic modeling of such a system in order to assess the extent of the air entrainment and to assist in engineering mitigation tactics.

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Flow and pressure transients are initiated in nuclear power plant closed conduits due to changes such as opening or closing of valves, startup, shutdown, or trip-out of pumps and startup and load-rejection of turbines. Usually, transients produce the maximum and minimum pressures to which pipelines are likely to be subjected, and an analysis of transients for the various planned or accidental operating conditions of the piping system is essential to design the system and to verify its capability to withstand the extreme conditions. Alden has developed numerical models for transient analysis to predict both the water hammer (elastic pressure propagation) and surge pressures (mass oscillations), as the case may require.

## Selected Plant List

- Condenser Tube Sheet Inlet Box Design and Debris Mitigation
  - Fitzpatrick
  - McGuire
- Air Accumulation in Critical System Piping
  - McGuire
- Transients/Water Hammer Analyses
  - Seabrook
  - Manchester Power Station
  - VC Summer

## Summary

Since the advent of widespread nuclear power in the United States, the NRC and plant operators alike have come to Alden for modeling, design, and field services applied to solving flow problems both internal and external to the plant. As major relicensing efforts and new plant construction occur in the coming years, Alden is poised to help plant owners address regulatory concerns and a new generation of hydraulics challenges.