Attachment 5

Electrical Distribution Model Output Reports

Section 1:	**ETAP Results Evaluation**
Section 2:	**One Line Diagrams**

Purpose:

This attachment is provided to model the anticipated electrical distribution system required to support the conversion of Indian Point Units 2 and 3 to a closed loop condenser cooling water configuration using ETAP 7.0.0C electrical analysis software. This analysis will account for the expected electrical parasitic losses due to the new components required for the proposed cooling towers. The following documents are included in this attachment (for Indian Point 2 and Indian Point 3):

- 138kV One Line Distribution with short-circuit contributions
- One Line Distribution for 6.9kV and below with expected parasitic loads
- ETAP Load Flow results for Full-Load Hybrid Operation and Wet Load Operation
- ETAP Short Circuit results showing fault contributions from each bus

Methodology:

Analytical evaluations for the anticipated distribution system required to power the proposed cooling towers were done by the use of ETAP 7.0.0C. The ETAP model that was used in the 2003 study was converted from ETAP version 4.0.4C to the latest version, 7.0.0C. The converted model was used as the basis for this analysis and modified to incorporate the changes included in this study. For the model incorporated in this study, the grid impedance could not be obtained from transmission analysis of the Buchanan 138kV line and therefore the grid impedance from the previous study will be used as shown in Table 1. Short-Circuit and Load Flow analyses were performed to project the plant available short-circuit contributions and estimate the power demand using load flow and voltage drop case runs for the proposed towers. The evaluations are presented as ETAP output reports with the following configurations:

Load Flow

- Load Flow and Voltage Drop of the tower fan and circulating water pumps at full-load representative of the Hybrid Operation of Wet Fans, Dry Fans, and Booster Pumps. This configuration is the most conservative case as it incorporates all loads running simultaneously. Results for this configuration are shown in the Load Flow reports under the "Full Load" case run.
- Load Flow and Voltage Drop of the tower fan and circulating water pump loads at the reduced load representative of wet cycle fans and circulating water pumps only. Results for this configuration are shown in the Load Flow reports under the "Wet Load" case run.

Short Circuit

- Short Circuit contributions for the Buchanan-138kV Bus are based on the grid short-circuit ratings from 2003 along with the contribution from the loads downstream of the 138/6.9kV transformers. The short-circuit ETAP results for the Buchanan-

138kV bus are shown on page 73 of the ETAP Short-Circuit output report and are included in the One Line Distribution shown on page 4 of this analysis.

- Short-Circuit contributions with each bus faulted for Unit 2 and Unit 3 proposed cooling tower loads (6.9kV and lower). This configuration also shows contributions from parasitic loads (booster pumps, wet fans, and dry fans) as well.

Table 1: Short-Circuit ratings for Buchanan 138kV utility

	MVAsc	X/R	kAsc
3-Phase	3998	31.25	16.726
1-Phase	1132	11.84	4.736

Assumptions:

The software model was developed and run using the following assumed parameters:

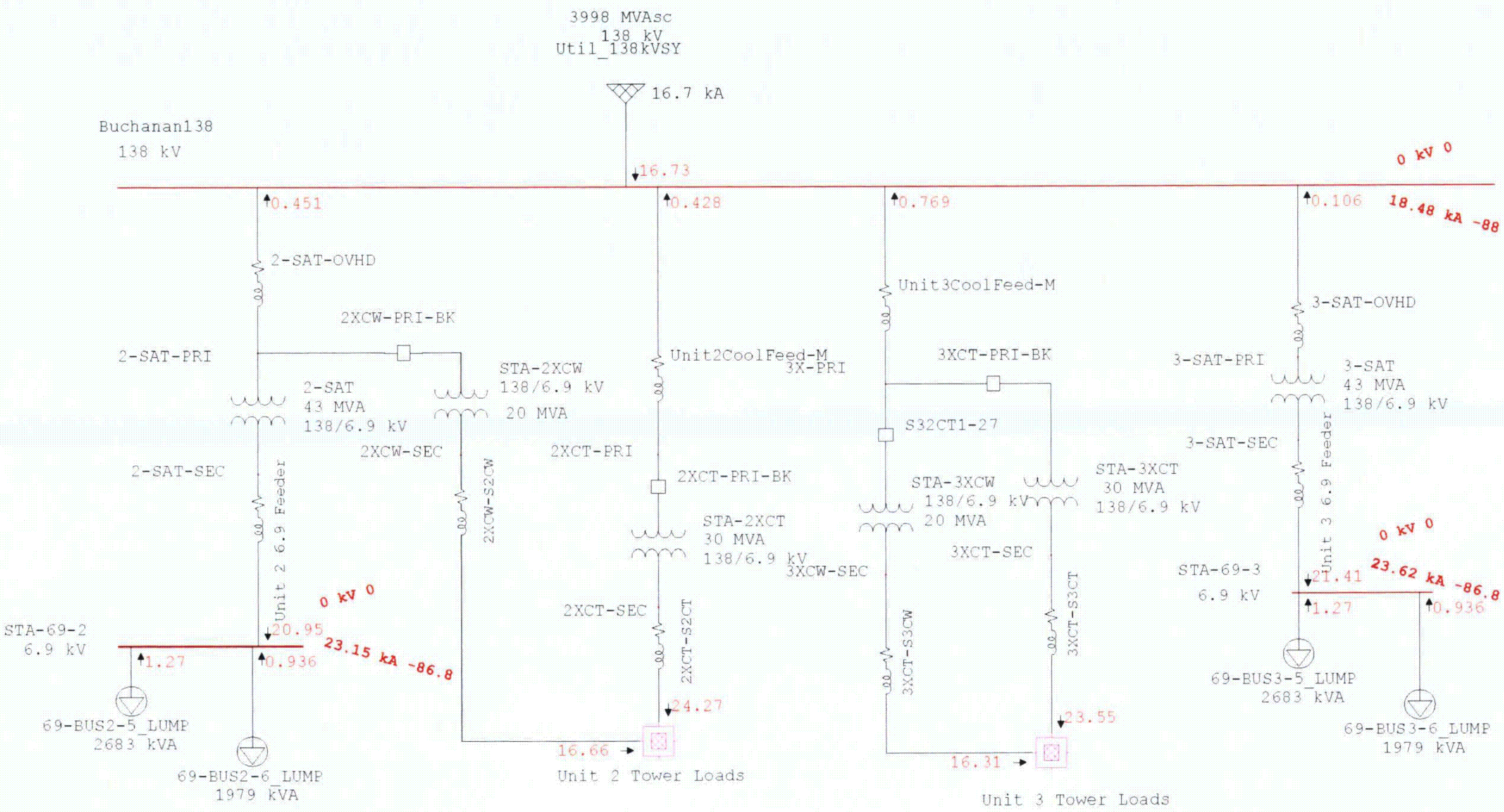
- Motors, cables, and transformer characteristics were sized based upon preliminary vendor information of tower configuration and required horsepower. Subsequent analytical parameters were assumed based upon the standard or typical values available in the software database for the input size of each component.
- The 138kV Buchanan Substation parameters including grid voltage, short-circuit rating, and impedance is taken from the previous study done in 2003. It is anticipated that the grid impedance did not change from 2003 to 2009 and it is expected to improve, therefore the grid ratings used in this analysis are conservative and acceptable for this study.
- The fans for dry cycle cooling were either assumed to be on at full load (350HP) during nominal conditions, or off during wet cycle only conditions. Reduction in parasitic load due to the variable speed dry cycle fan motors is not considered directly in this analysis, rather, it is accounted for in the percent of the time the tower is assumed to be in either full load or wet cycle only conditions.

Results:

The voltage drop and load flow output reports show that both cases (Wet Load and Full Load) are within the positive and negative 10% range for the rated bus voltages per the recommendations of IEEE 241-1990. This includes the alerts shown for the Full Load and Wet Load configurations which show bus voltages above and below the bus rated values.

The short-circuit analysis results for all faulted buses is shown starting on page 73 of the Short-Circuit output in Section 4. The one-line diagram on page 4 shows the fault contribution for the 138kV Buchanan line down to the 6.9kV buses and Unit 2 and 3 tower loads distribution. Reviewing the one line diagrams, the current load on the faulted buses by IPEC is 16.73 kA. The additional loads added by conversion to closed-loop cooling would increase this load by 1.75kA, or approximately 10%. Per discussions with site personnel, the faulted bus has a capacity on the order of 60kA, supplying significant margin against a short-circuit event. Due to the magnitude of this margin, and due to the relatively small increase of load, no modifications to the switchyard would be expected by conversion of IPEC to closed-loop cooling; however, additional electrical distribution analysis would be required in the detailed design phase to completely ensure adequate margin is present.

One-Line Diagram - IP-138kV (Short-Circuit Analysis)



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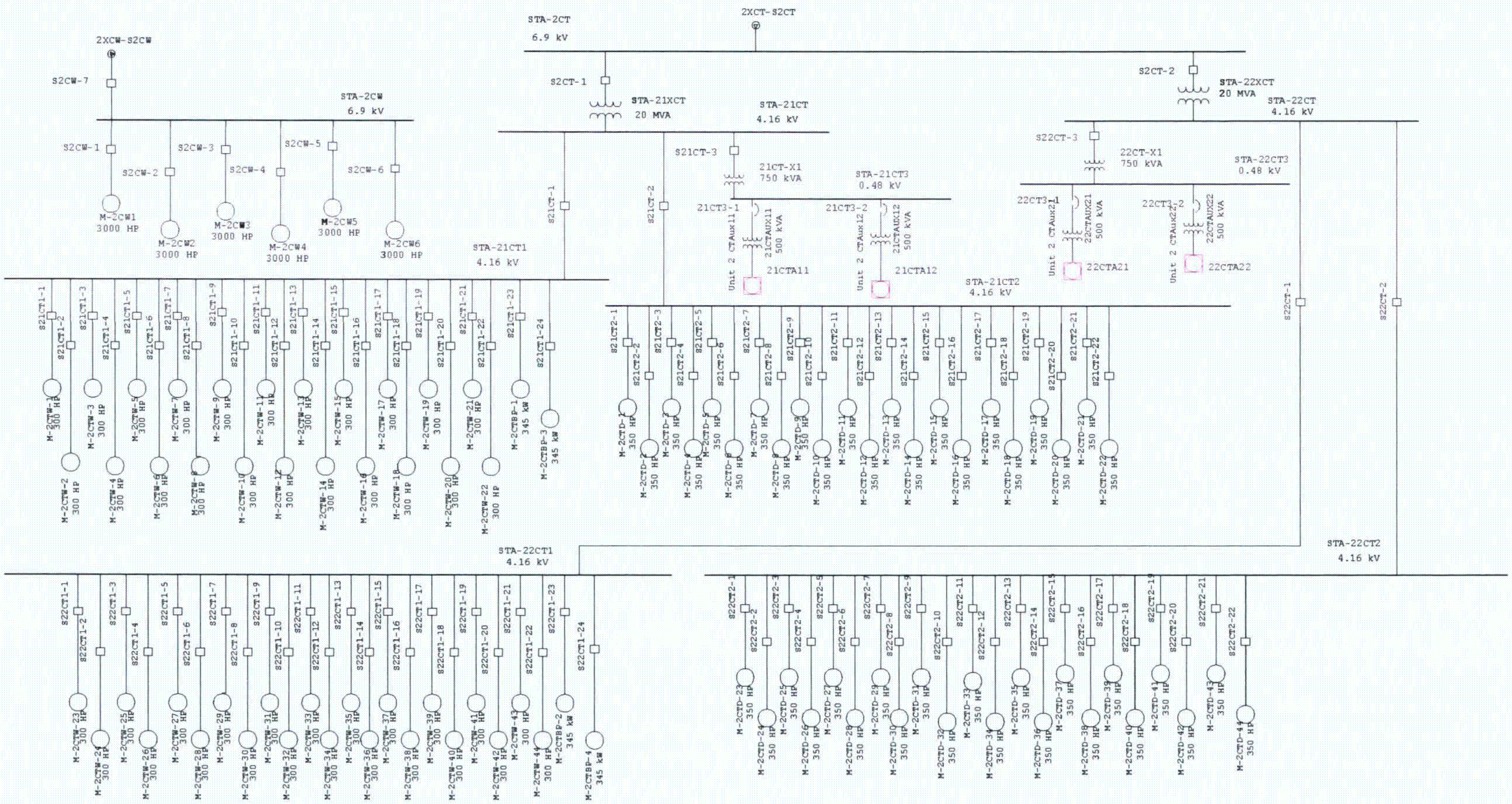
One-Line Diagram - IP-138kV=>Unit 2 Tower Loads (Edit Mode)



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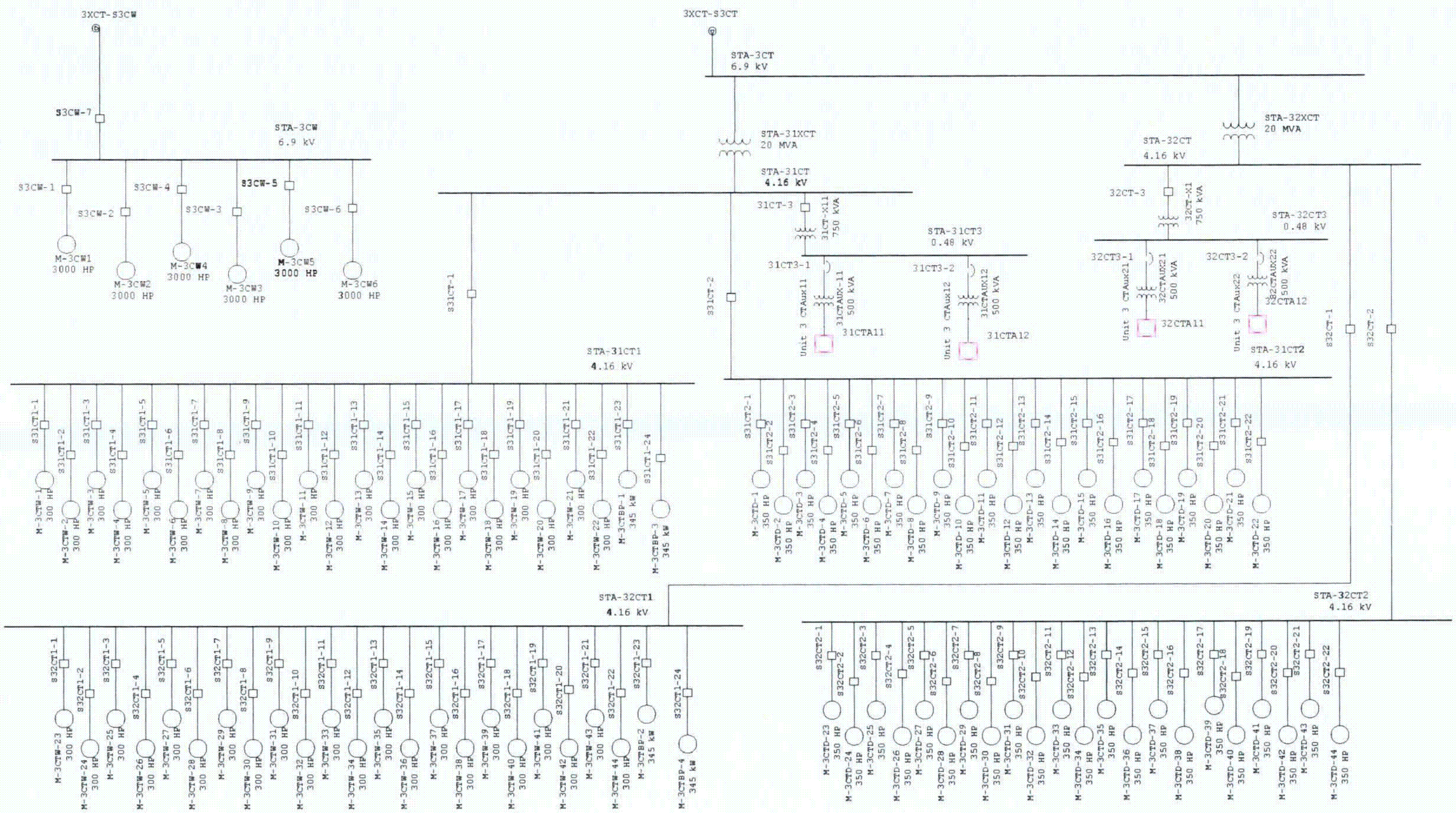
One-Line Diagram - IP-138kV=>Unit 3 Tower Loads (Edit Mode)



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Attachment 6

Feasibility Evaluation of Relocating the Algonquin Gas Transmission Pipelines

Spectra Energy Transmission, LLC

Thomas L. Stanton, Jr.
Associate General Counsel

Spectra Energy Transmission, LLC
890 Winter Street, Suite 300
Waltham, MA 02451

Tel. 617-560-1378
Fax. 617-560-1587

Spectra Energy.

November 24, 2009

VIA COURIER

John C. Englander, Esq.
Goodwin Proctor LLP
Exchange Place
Boston, MA 02109

Re: Pipeline Relocation Evaluation

Dear Mr. Englander:

I am responding to your letter to Reginald D. Hedgebeth, General Counsel of Spectra Energy Corp ("Spectra Energy") dated June 10, 2009 (the "Letter"). The Letter included a number of exhibits and requested information on behalf of your client, Entergy Nuclear Indian Point 3, LLC ("Entergy"), concerning the evaluation of a possible relocation of certain pipeline facilities. The requested relocation would accommodate the construction and operation of a cooling tower by Entergy at the Indian Point Unit 3 Nuclear Power Station (the "Site") located in Buchanan, New York. Since receiving the Letter, representatives of Spectra Energy have had discussions with you and Entergy representatives, and have exchanged information necessary for Spectra Energy to provide its preliminary evaluation of the possible relocation.

As a preliminary matter it is appropriate to describe the existing pipeline facilities that are lawfully located with permanent easements across the Entergy property at the Site. The pipeline facilities and easements are owned by Algonquin Gas Transmission, LLC ("Algonquin"). Algonquin is an indirect wholly-owned subsidiary of Spectra Energy and is an interstate natural gas transmission company authorized to construct and operate its facilities under the jurisdiction of the Federal Energy Regulation Commission ("FERC"). The design, construction and operation of its high pressure facilities are exclusively governed by the United States Department of Transportation ("US DOT").

Algonquin Facilities

Since 1952, Algonquin has owned and operated a natural gas pipeline system extending from an interconnection with Texas Eastern Transmission, LP at a point near Lambertville, New Jersey, and traversing the states of New

Jersey, New York, Connecticut, Rhode Island and Massachusetts to a point near Boston, Massachusetts where it interconnects with Maritimes & Northeast Pipeline, L.L.C. Algonquin's customers are various interstate pipelines, natural gas distribution companies, natural gas marketers, municipalities and electric generating facilities throughout the states it crosses. A general pipeline system map showing the location of the Algonquin facilities is enclosed and referenced as Exhibit A.

Algonquin utilizes its system capacity of approximately 2.5 billion cubic feet per day to serve approximately fifty (50) percent of the natural gas demand in New England. Because of this significant level of service to this region, the Hudson River crossing area located at the Site is considered by Algonquin as a critical site/location for its facilities. The "critical" characterization of this particular area is emphasized to impress upon you that the throughput of these facilities *cannot* be interrupted. If a relocation was required, the construction of new pipeline facilities and the interconnects with the existing facilities would have to be coordinated in a staged fashion and only during a service period that would accommodate a temporary outage. That process is discussed in further detail in this response.

The Algonquin facilities located at the Site are comprised of a twenty six (26) inch diameter and a thirty (30) inch diameter pipeline. The 26 inch pipeline operates at 674 pounds per square inch ("psi") of pressure while the 30 inch pipeline operates at 750 psi. These two (2) pipelines traverse approximately 2,500 feet of the Site within a sixty five (65) foot wide right-of-way to an area abutting the northwesterly property boundary on the western shoreline of the Hudson River ("Valve Site-14B"). At this location, a third twenty four (24) inch diameter pipeline was installed and tied into the two other pipelines along with valving and internal inspection facilities for all three pipelines[1] (collectively, the "Pipeline Facilities"). The third pipeline is necessary in the event there is an interruption of service with either of the other two pipelines crossing the Hudson River. The Pipeline Facilities are shown on an enclosed site plan hereinafter defined as the "Algonquin Site Plan".

Evaluation

We reviewed the "ALTA/ACSM LAND TITLE SURVEY" plan dated February 25, 2000 ("Land Title Plan") showing the location of the existing facilities at the site and the "SITE LAYOUT – Sketch 01" drawing ("Sketch 01") which shows the proposed location of cooling towers for the closed loop cooling system and in particular the proposed location of the Unit 3 Cooling Tower in proximity with the Pipeline Facilities. In order to properly align the location of the Pipeline Facilities in relationship to the location of the proposed Unit 3 Cooling

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[1] Internal inspection facilities permit the insertion and removal of electronic inspection devices at critical junctions along the pipeline. These electronic devices (a/k/a, smart pigs) travel within the pipelines recording data to evaluate the integrity of the pipelines as required by US DOT.

Tower, a field survey was recently performed to produce a plan showing an accurate location of the Pipeline Facilities at the Site. The electronic Sketch 01 data provided by you showing the location of the proposed Unit 3 Cooling Tower was overlayed on this recent survey plan. A general overview of all this information is shown on the "Site Overview – Valve Site 14B @ Indian Point" ("Site Overview") which is enclosed and referenced as Exhibit B. A more detailed plan with scaled drawings is also enclosed and entitled "Algonquin Gas Transmission, LLC - Site Plan - Indian Point Power Plant - Tract W-127, dated 11/03/09, Sheets 1,2 and 3" ("Algonquin Site Plan") and referenced as Exhibit C.

The evaluation and response is formatted along the questions raised in the Letter:

Q.1. Is it feasible to locate the Unit 3 Cooling Tower as shown on the Site Plan without relocating the Pipelines?

A.1. No. The Unit 3 Cooling Tower cannot be located as shown on the Site Plan without relocating the Pipeline Facilities.

As it is easily determined by viewing the Algonquin Site Plan (see Sheet 1), the proposed cooling tower would be located on top of the Pipeline Facilities. The proposed Unit 3 Cooling Tower would require the removal of a prodigious amount of rock to accommodate a concrete structure 168 feet in height with a diameter of 525 feet in a depression directly over where the Pipeline Facilities are currently located.

Q.2. Is it feasible to relocate the Pipelines to a location that would accommodate the Unit 3 Cooling Tower shown on the Site Plan? If so, where would Spectra propose to relocate the pipelines?

A.2. No. It would not be feasible to relocate the Pipeline Facilities to a location that would accommodate the Unit 3 Cooling Tower as shown on the Sketch 01 and the Algonquin Site Plan.

However, it may be possible to relocate the Pipeline Facilities in an area to accommodate the proposed cooling tower only if the Unit 3 Cooling Tower can be moved sufficiently far enough in a generally northeasterly direction (the "Relocated Cooling Tower") to accommodate the relocated right-of-way for the Pipeline Facilities. A further explanation follows.

Any relocation of the Pipeline Facilities is premised on the relocation provisions in the easements granted by Entergy's predecessor in interest for the Pipeline Facilities that cross the Site. The relocation obligation is therefore limited to the property boundaries on the parcel of land that is burdened with the Pipeline Facilities easements.[2] Additionally, possible pipeline relocation areas considered were limited by existing structures. Upon review of the location of existing structures on the Land Title Plan and the proposed structures shown on Sketch 01, if the Pipeline Facilities were to be relocated, that relocation could only be located towards the south and then in a westerly direction from the current location of Valve Site -14B. Because of the amount of area and significant rock removal necessary for the construction of the Relocated Cooling Tower, Spectra Energy would need to move the Pipeline Facilities, including an extension of the third pipeline, within a new right-of-way ("ROW") along the eastern property boundary of Parcel A. Based on the Spectra Energy spacing requirements for multiple line ROW's containing 3 high pressure pipelines, this new ROW would need to be one hundred (100) feet wide. The spacing distances between the pipelines and the proposed new ROW is more clearly shown on the Algonquin Site Plan and identified within the area bounded by the description "Edge of Proposed ROW".

To accommodate the construction of the proposed Relocated Cooling Tower, the relocated Pipeline Facilities would have to be constructed in this proposed ROW before any rock removal begins in the proximity of the proposed ROW. This would essentially place the relocated pipelines on a "shelf" along the eastern and southern sides of the Relocated Cooling Tower excavation area. For the purpose of this evaluation, Valve Site 14-B was relocated to an open area that may accommodate the necessary amount of area for the relocated Valve Site-14B as shown on Exhibit B, the Site Overview. It should be noted that this site was selected without the consultation of Entergy.

The relocated Pipeline Facilities would need to be constructed and tied-in to Algonquin's existing facilities in a staged manner during the months of June through September when the typical Algonquin system demands may allow for an approximate seven (7) day outage for each relocated pipeline to be tied-in and connected to Algonquin's existing system.

Q.3. How much time would be required to relocate the Pipelines?

A.3. The following table is a high level overview of the time required to relocate the Pipeline Facilities. Please note that this is a very preliminary timeline absent any detailed field work, facility design, agency consultation and without any detailed construction coordination concerns at the existing nuclear power facilities and/or in

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[2] This is identified as "Parcel A" on the Land Title Plan.

anticipation of any ongoing construction activity by the Site owner at that time.

Preliminary field work:	2 months
Facility design:	4 months
Permitting[3]:	14 months
Construction:	4 months
In-Service:	7 days for each pipeline (in sequence)
TOTAL	Approximately 24 months[4]

Q.4. Would constraints be placed on blasting or other excavation and site preparation activities near the Pipelines or the easement areas? Attached at Tab F is a copy of a document entitled Requirements for Construction on or Near Company Facilities, prepared by Spectra's predecessor Algonquin Gas Transmission Company and dated November 20, 1997 (the "Construction Requirements"). Entergy would appreciate Spectra's confirmation of whether the Construction Requirements remain in effect and whether new or additional policies or requirements have been adopted by Spectra that would govern these activities.

A.4. Please find enclosed the current version of "Requirements for Construction Near Company Pipelines, Date: 04/26/2008" and referenced as Exhibit D. These requirements are in effect. Also enclosed are two other documents that are instructive as to how to perform activities in proximity to Spectra Energy pipelines: "Blasting Near Pipelines, Date: 01/01/2007" and "Blasting Adjacent to In-Service Pipelines, Date: 01/01/2007". These are referenced as Exhibit E and F, respectively[5].

Assuming the Unit 3 Cooling Tower can be relocated, collectively, this information should provide a baseline of information and requirements for Entergy activities to be planned in order to avoid impacting the integrity of the relocated Pipeline Facilities for planned excavation activities in proximity to such facilities.

Since there is no specific blasting plan available to evaluate for the Relocated Cooling Tower and/or an excavation footprint for that

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[3] This includes application preparations (2 months) for a Prior Notice Filing to FERC (18 CFR § 157.208(b)) and the appropriate New York State filings.

[4] The preliminary timeline is approximately 24 months provided all activities are planned and executed to permit the 3 week tie-in to occur during the summer months (June – September).

[5] These two items were previously electronically forwarded to a member of your firm on October 26, 2009.

relocated site, we are unable to identify other specific blasting constraints concerning seismic ground vibration. However, to ensure the Relocated Pipeline Facilities will remain outside the zone of permanent ground displacement caused by blasting, a restrictive zone or "Blasting Offset" is required from the location of the nearest pipeline to edge of the excavated slope. This is essentially how close the edge of the blasting excavation may be located to the nearest pipeline. This distance should provide Entergy with a bench mark as to how far the Relocated Cooling Tower and the edge of its extensive excavation activities must be shifted to accommodate the relocated Pipeline Facilities.

To determine the Blasting Offset, the Spectra Energy standard which is based on US Bureau of Mines information, is for the pipeline to be outside of a 32-degree angle from the horizontal beginning at the bottom of the blast hole. The excavated slope appears to be approximately 45-degrees according to Sketch 01 information. The geometry of the excavation means that the distance from the top-of-slope for the excavation must be greater in areas where the excavation is deeper resulting in the required Blasting Offset from the top-of-slope to the nearest pipeline. This evaluation is shown in pictorial form on the attached drawing "Required Offset For Relocated ROW at Valve Site 14-B, Date: 11/23/2009" and referenced as Exhibit G.

The required Blasting Offset from the nearest pipeline is 46.8 feet (rounded to 50 feet). Consequently, this required offset adds another fifteen (15) feet to the northeasterly boundary of the Proposed Edge of ROW which is also described and shown as the "Required Offset for Blasting" on Exhibit C, the Algonquin Site Plan. The edge of the Required Offset for Blasting determines how close the edge of the excavation for the Relocated Cooling Tower may be located with respect to the nearest pipeline.

Q.5. What are the estimated costs of relocating the Pipelines? Would it be appropriate to assume that the cost to relocate each Pipeline would be 1/3 the cost of moving all three Pipelines?

A.5 Spectra Energy has performed a feasibility estimate which should be considered as a very preliminary estimate to relocate the Pipeline Facilities as shown on the Algonquin Site Plan. This current estimate is approximately $13,800,000 with an accuracy level of minus 25% to plus 40% ("Feasibility Estimate").

The basic assumptions around the Feasibility Estimate are primarily based on a desk top evaluation of the proposed Pipeline Facilities relocation and are comprised of design, permitting, material, labor and construction costs.[6]

It would not be appropriate to assume that the cost for relocating the Pipeline Facilities would be proportionately allocated 1/3 to each relocated pipeline. Although two (2) new pipeline segments are relatively the same length (approximately 1,100 feet), the third new pipeline would be approximately 2,600 feet. Additionally, apportioning the costs of the relocated valve site may not follow a simple formula based on the piping design necessary for each pipeline to operate independently and/or in conjunction with the other pipelines(s). Moreover, Spectra Energy believes the relocation cost obligations may include additional legal theories beyond a plain reading of easement language.

Q.6. What are the potential environmental impacts of relocating the Pipelines?

A.6. Spectra Energy has not performed the field work necessary to fully describe in detail an evaluation of the environmental impacts for relocating the Pipeline Facilities. However, the relocation scope as currently proposed is not significant in nature. It involves the construction of (i) approximately 1,100 linear feet of 2 new pipelines, (ii) approximately 2,600 linear feet of the new third pipeline, (iii) a new Valve Site-14B, and (iv) the removal of portions of the existing pipelines and Valve Site 14-B all within the Site which has been previously disturbed. Based on the impact type and minimal extent of potential impacts, an Environmental Impact Statement would not be anticipated. However, an environmental impact evaluation would be required to be performed in accordance with relevant issues outlined in 18 CFR Part 380.12 as part of the Prior Notice application that would be required to be filed with the FERC.

Q.7. Would service to Spectra's customers be interrupted during the relocation of the Pipelines?

A.7. As described previously, by tieing-in the relocated Pipeline Facilities in sequence sometime during the months of June through September and in conjunction with any other planned system outages, there should be little to no impact to the services of Algonquin's existing customers.

Q.8. Other than the costs to relocate the Pipelines, what other economic impacts (if any) would be associated with the relocation (e.g., impacts to Spectra's customers, price of natural gas delivered, etc.)?

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[6] This estimate would change if the relocated Valve Site-14B needs to be moved.

A.8. Other than the costs of the type and nature described in Feasibility Estimate and presuming that the construction and tie-in activities are executed as described in Answer 3, no other costs related to the construction of the relocated Pipeline Facilities are anticipated at this time. However, due to the significant amount and duration of rock removal (in excess of 30 months) by blasting, there would be additional costs after the installation of the relocated Pipeline Facilities. These costs would include field personnel and experts to monitor the relocated Pipeline Facilities throughout the Relocated Cooling Tower construction period. These costs cannot legitimately be estimated until such time there is a site specific blasting plan and construction schedule to evaluate.

I trust this response will be helpful in Proceeding as described in the Letter. Please do not hesitate to contact me if you have any questions.

Sincerely,

Thomas L. Stanton, Jr.

Cc: Reginald D. Hedgebeth, Esq.
Thomas B. Tirlia
Robert H. Fitzgerald, Esq. – Goodwin Proctor LLP

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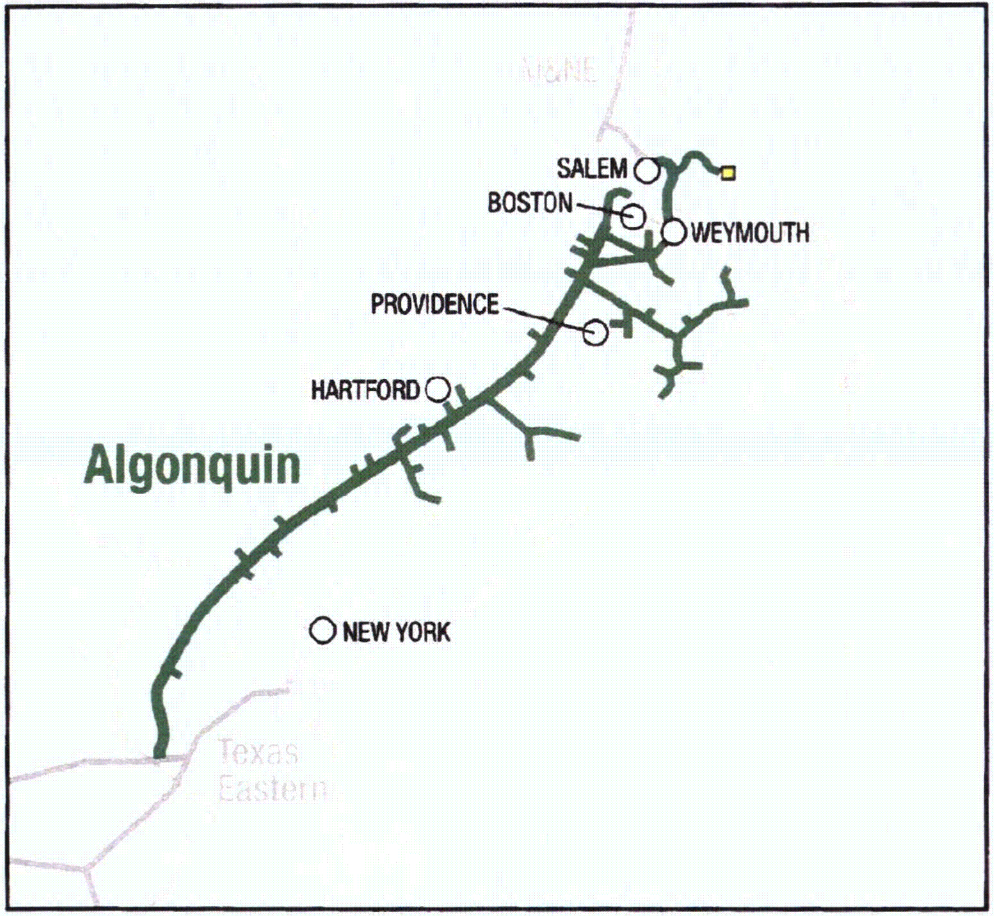
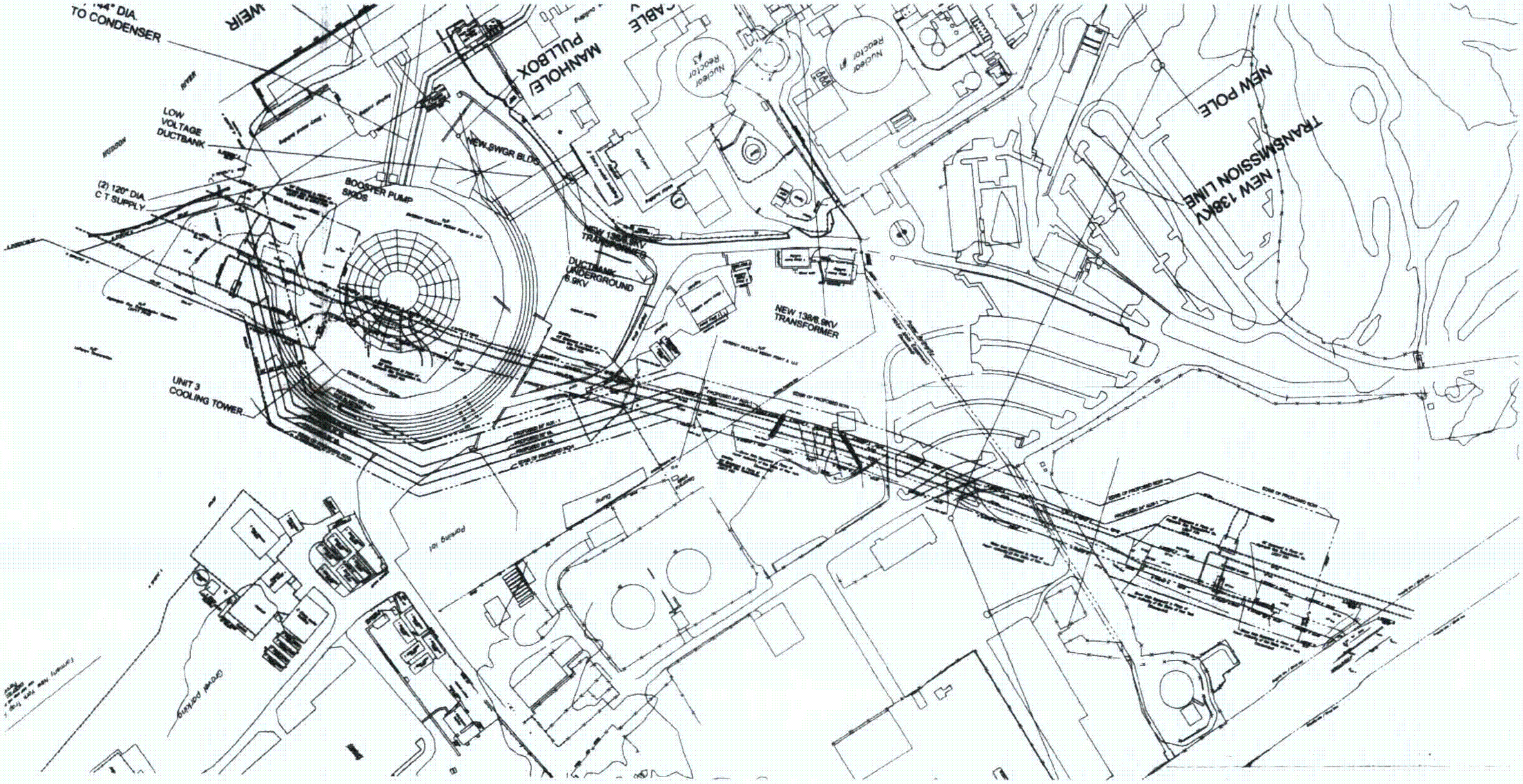
Enclosures

Algonquin Gas Transmission

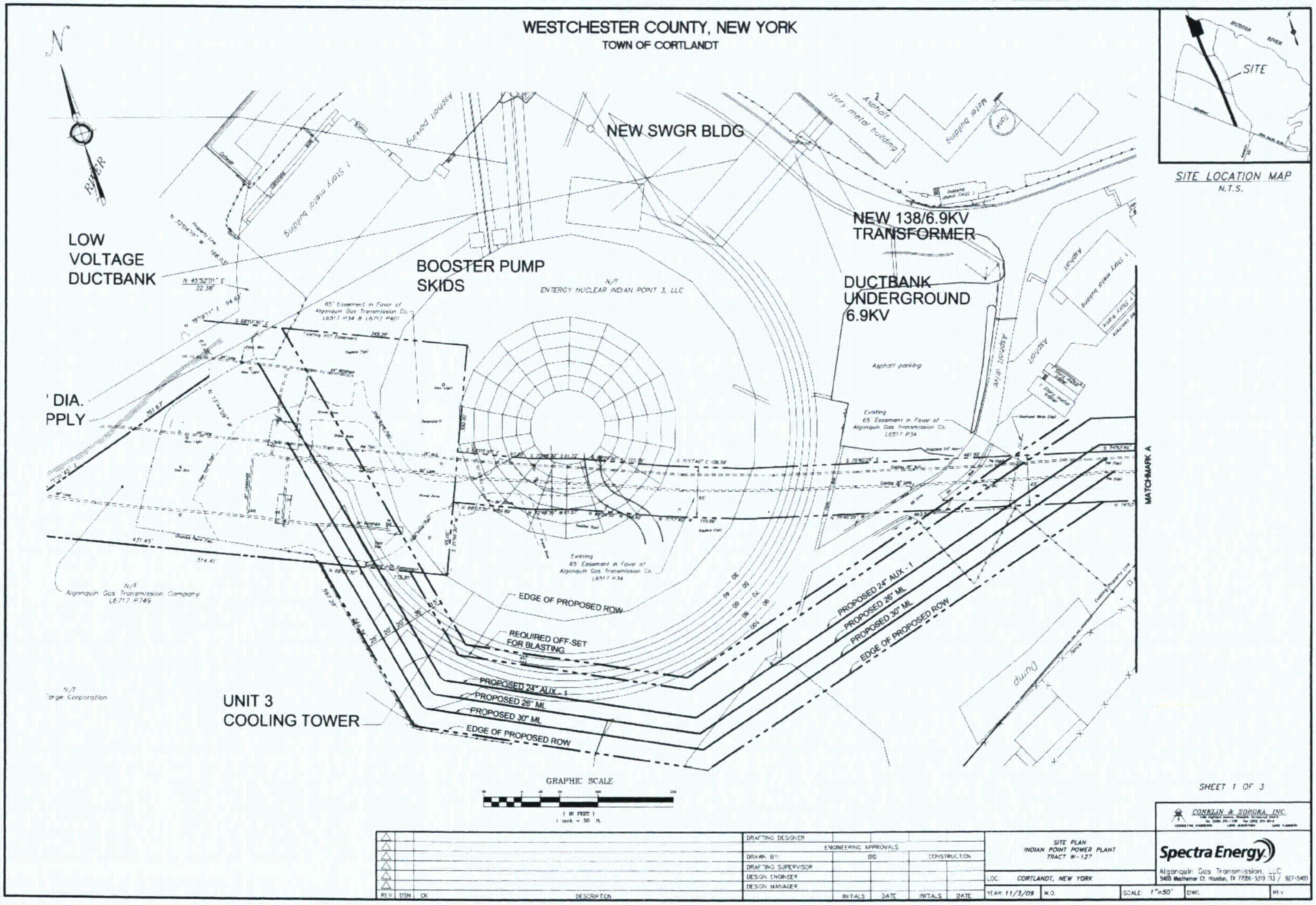


0901-15016 Feb-10-09



SITE OVERVIEW
VALVE SITE 14B @
INDIAN POINT

Exhibit C


WESTCHESTER COUNTY, NEW YORK
TOWN OF CORTLANDT
N
NEW SWGR BLDG
NEW 138/6.9KV TRANSFORMER
LOW VOLTAGE DUCTBANK
BOOSTER PUMP SKIDS
N/F ENTERGY NUCLEAR INDIAN POINT 3, LLC
DUCTBANK UNDERGROUND 6.9KV
' DIA. PPLY
Asphalt parking
Asphalt drive
Existing 65' Easement in Favor of Algonquin Gas Transmission Co. L6517 P34
N/F Algonquin Gas Transmission Company L6717 P749
EDGE OF PROPOSED ROW
REQUIRED OFF-SET FOR BLASTING
PROPOSED 24" AUX - 1
PROPOSED 26" ML
PROPOSED 30" ML
EDGE OF PROPOSED ROW
UNIT 3 COOLING TOWER
N/F Corporation
MATCHMARK A
SITE
SITE LOCATION MAP
N.T.S.
GRAPHIC SCALE
(IN FEET)
1 inch = 50 ft.
SHEET 1 OF 3
CONKLIN & SOROKA, INC.
DRAFTING DESIGNER
ENGINEERING APPROVALS
DRAWN BY:
BID
CONSTRUCTION
DRAFTING SUPERVISOR
DESIGN ENGINEER
DESIGN MANAGER
INITIALS
DATE
INITIALS
DATE
REV.
DSN
CK
DESCRIPTION
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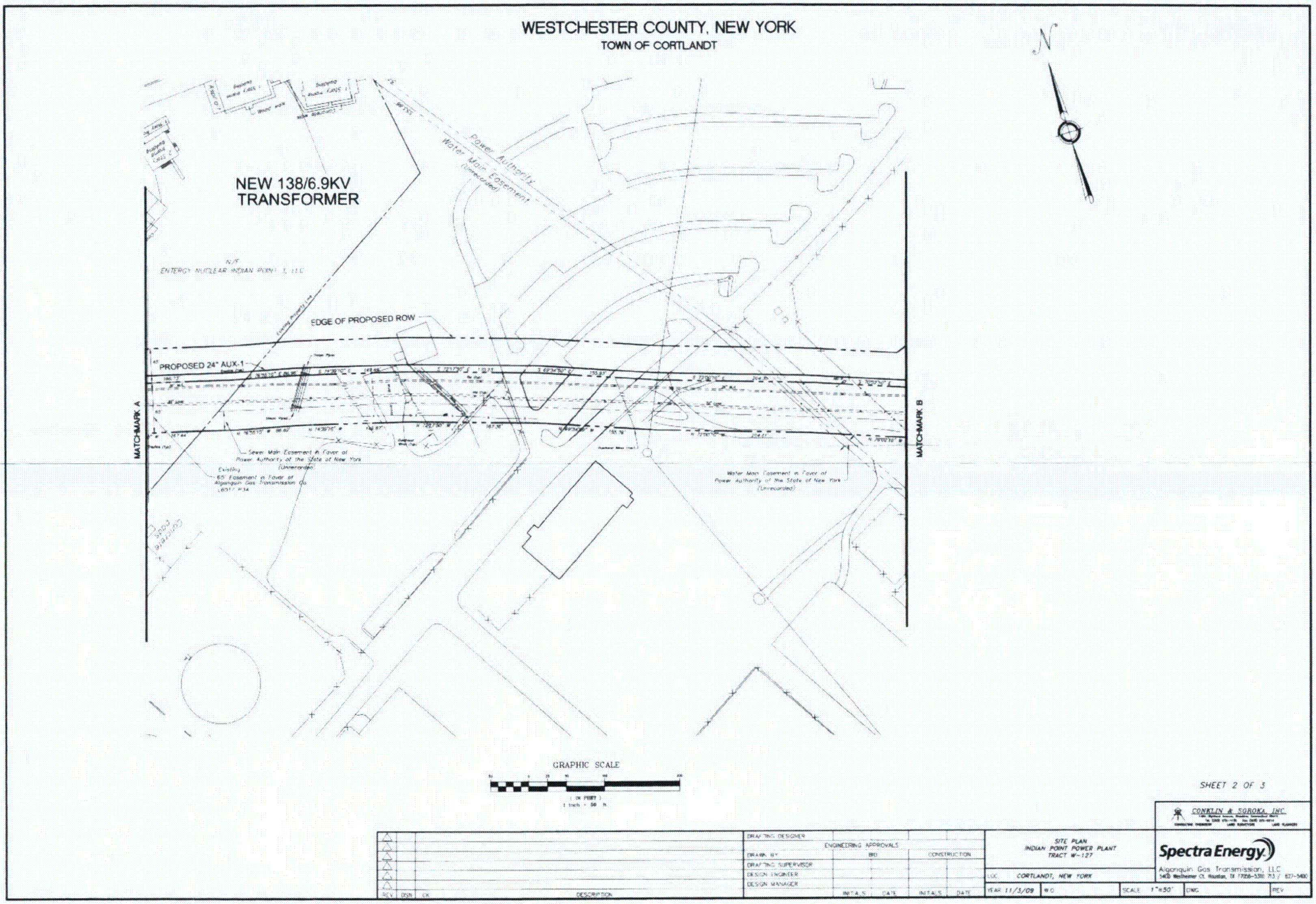
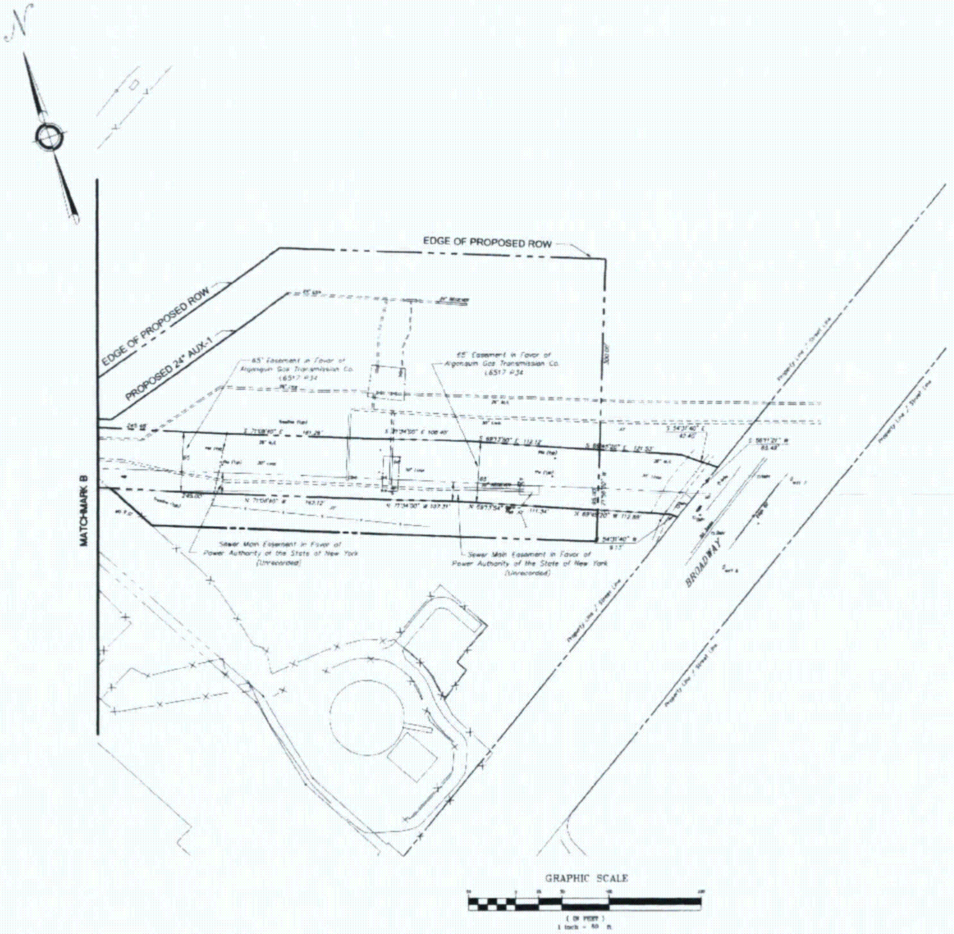
INDIAN POINT POWER PLANT
TRACT W-127
LOC. CORTLANDT, NEW YORK
YEAR: 11/3/09
W.O.
SCALE: 1"=50'
DWG.
REV.
Spectra Energy
Algonquin Gas Transmission, LLC
5400 Westheimer Ct. Houston, TX 77056-5310 713 / 627-5400


WESTCHESTER COUNTY, NEW YORK
TOWN OF CORTLANDT
N
NEW 138/6.9KV TRANSFORMER
N/F
ENTERGY NUCLEAR INDIAN POINT 3, LLC
Existing Property Line
Power Authority Water Main Easement (Unrecorded)
EDGE OF PROPOSED ROW
PROPOSED 24" AUX-1
MATCHMARK A
MATCHMARK B
Sewer Main Easement in Favor of Power Authority of the State of New York (Unrecorded)
Existing 65' Easement in Favor of Algonquin Gas Transmission Co. L631 P34
Water Main Easement in Favor of Power Authority of the State of New York (Unrecorded)
GRAPHIC SCALE
(IN FEET)
1 inch = 50 ft.
SHEET 2 OF 3
CONKLIN & SOROKA, INC.
DRAFTING DESIGNER
ENGINEERING APPROVALS
DRAWN BY
BID
CONSTRUCTION
DRAFTING SUPERVISOR
DESIGN ENGINEER
DESIGN MANAGER
INITIALS
DATE
REV
DSN
CK
DESCRIPTION
SITE PLAN
INDIAN POINT POWER PLANT
TRACT W-127
LOC. CORTLANDT, NEW YORK
YEAR 11/3/09
W.O.
SCALE 1"=50'
DWG.
REV
Spectra Energy
Algonquin Gas Transmission, LLC
5400 Westheimer Ct. Houston, TX 77056-5310 713 / 627-5400

WESTCHESTER COUNTY, NEW YORK

TOWN OF CORTLANDT



NOTES:

1. This map is intended to show Algonquin Gas Transmission Company's Easement Across Tract W-127 with respect to the proposed site improvements.
2. Bearings depicted are referenced to Magnetic North dated 10/29/09. Elevations depicted are from Proposed Site Plan provided by Spectra Energy.
3. Reference is made to the following maps:
    A. "ALTA/ACSM Land Title Survey prepared for Entergy Nuclear Indian Point 3, LLC., situate partly in the Village of Buchanan and wholly in the Town of Cortlandt, Westchester County, New York, Scale 1 inch = 100 feet, February 25, 2000, revised on May 4, 2000," prepared by Badey & Watson, Surveying & Engineering, P.C.
    B. "Right of Way for Pipeline Across the Property of Consolidated Edison Company, Dwg. # L-3616 A," scale 1" = 30', dated 08/11/64, revised 04/03/67, prepared by Algonquin Gas Transmission Co., Boston, Massachusetts.
    C. "Station Location: Indian Point, Property Survey and Ties to Traverse Stations, Dwg. # I.P.T. A-6-1 Rev., (Sheet #1 of 2)" no scale, dated 03/12/56, prepared by Consolidated Edison Co. of New York, Inc.
    D. "Situated in County of Westchester, Town of Cortlandt, County Block # 10341, County Sheet # 239, Plan Showing R.O.W. Across Property of K.C.O.R. Corporation to be Sold to Georgia Pacific Corporation, Town of Cortlandt, N.Y., Dwg. L-4609B" scale 1" = 50', dated 05/02/67, revised 04/04/68, prepared by Algonquin Gas Transmission Co., Boston, Massachusetts.
    E. "Composite A.G.T. Facilities, Indian Point, East Bank Hudson River, Dwg. L-4925A," REF. Consolidated Edison DWG. EO-13325A, A.G.T. DWGS. L-4598A - L3616A - L4619A - M761A - L4609B, BK 384, pg 18, scale 1" = 30', dated 04/08/68, rev 12/05/68, prepared by Algonquin Gas Transmission Company, Boston, Massachusetts.
    F. "Topographic Survey, East Bank of Hudson River Crossing (Valve 14B)," dated 08/01/07, scale 1" = 20', Spectra Energy, Algonquin Gas Transmission, LLC prepared by Conklin & Soroka, Inc., Cheshire, CT 06410.
    G. "Power Authority of the State of New York, Indian Point No. 3 Nuclear Power Plant, County of Westchester, Town of Cortlandt, Map No. 5, Parcel(s) No. 5," Sheet 1 of 1 Sheets, scale 1" = 100', prepared under the direction of the Power Authority of the State of New York.
4. Not all improvements or underground utilities are depicted on the map.
5. Algonquin Gas Transmission Easement is depicted utilizing the map referenced in Note 3B.
6. Property lines depicted are referenced to maps in Note 3A & 3D.
7. Staking of the existing gas lines was done by Spectra Energy personnel and field located by Conklin & Soroka, Inc.
8. The proposed valve site is a similar footprint of the existing MLV Site 14B with all associated appurtenances. The location of proposed site is shown without consultation with current landowners.

SHEET 3 OF 3

CONKLIN & SOROKA, INC.

DRAFTING DESIGNER				
ENGINEERING APPROVALS				
DRAWN BY	BID		CONSTRUCTION	
DRAFTING SUPERVISOR				
DESIGN ENGINEER				
DESIGN MANAGER				
	INITIALS	DATE	INITIALS	DATE

REV | DSN | CK | DESCRIPTION

SITE PLAN
INDIAN POINT POWER PLANT
TRACT W-127

LOC: CORTLANDT, NEW YORK

YEAR: 11/3/09 | W.O. | SCALE: 1"=50' | DWG | REV

Spectra Energy
Algonquin Gas Transmission, LLC
5400 Westheimer Ct. Houston, TX 77056-5310 713 / 627-5400

Guideline Name: ***Requirements for Construction Near Company Pipelines***	**Guideline Number: TG-010**	
	Date: 04/26/2008	**Page: 1 of 10**

1.0 PURPOSE

1.1 This guideline presents the requirements for construction in the vicinity of a Company pipeline(s) or pipeline right-of-way. These requirements are general in nature whereby specific circumstances may necessitate special considerations. The following areas are addressed.

- 1.0 Purpose
- 2.0 Company Notifications
- 3.0 General Requirements
- 4.0 Excavation and Blasting
- 5.0 Foreign Line Crossings

1.2 If any of the conditions stated in this document can not be satisfied, the Company representative shall be advised immediately.

2.0 COMPANY NOTIFICATIONS

2.1 The Company considers it essential that developers and contractors know the exact location and depth of the Company's pipeline(s) and requires that the pipeline(s) be shown on the contractor's plans.

2.2 The Company will field locate and stake its pipeline(s) at selected points in accordance with state and local requirements at no cost to the developer or contractor. However, the cost to excavate the pipeline and restore surface improvements (e.g., pavement, landscaping, sidewalks) shall be the responsibility of the developer or contractor. Note: A Company representative must be present during the excavation to expose the pipeline.

2.3 Copies of any proposed plans or drawings for road crossings within the pipeline right-of-way shall be submitted to the Company for review at least 30 days prior to the commencement of work.

2.4 The Company shall be given at least three (3) working days advance notice prior to the actual commencement of any work or excavation over or near its pipeline right-of-way so that the Company may locate its pipeline(s) and have a field representative present during excavation or construction activities.

2.5 In addition to complying with the above Company requirements, developers, contractors, utility companies, and landowners shall comply with the provisions of all state and/or local one-call regulations relating to excavation and demolition work in the vicinity of underground facilities.

3.0 GENERAL REQUIREMENTS

3.1 No buildings, structures or other obstructions may be erected within, above or below the pipeline right-of-way. If requested, the Company will furnish pipeline easement information which describes the pipeline right-of-way width.

3.2 Wire type, stockade, decorative and similar type fencing that can be easily removed and replaced may cross the pipeline right-of-way at or near right angles.

3.3 Planting of trees is not permitted on the pipeline right-of-way.

3.4 Planting of shrubs, bushes or other plants associated with landscaping on the pipeline right-of-way is subject to Company approval and shall not exceed 4 feet in height.

3.5 No drainage swells and no reductions in grade are permitted on the pipeline right-of-way. Limited additional fill may be deposited with prior written approval from the Company.

3.6 A Company representative shall give prior approval for heavy equipment to cross the Company pipeline(s) at any location. Minimum cover and other requirements will be determined by the Company on an individual basis.

3.7 Parking areas should be planned so as to avoid covering the pipeline right-of-way if possible.

3.8 No roads, foreign lines, or utilities may be installed parallel to the pipeline within the pipeline right-of-way.

3.9 All foreign lines, roads, electrical cables and other utilities shall cross the pipeline right-of-way at an angle at or near right angles, if practical.

3.10 If, in the sole judgement of the Company, the third party's proposed plans necessitate the installation of casing pipe and/or other alterations to protect the Company's pipeline(s), the third party may be required to pay the Company the estimated cost prior to the Company beginning the alterations. Once the actual costs have been incurred and tabulated by the Company, the Company and the third party shall settle any cost variances.

4.0 EXCAVATION AND BLASTING

4.1 Excavation operations shall be performed in accordance with the guidelines set forth below.

4.1.1 When a contractor excavates near Company pipelines, the Company representative shall be on site at all times to locate the pipeline(s), to determine the depth of cover before and during the excavation (see Section 2.4) and to witness the excavation and backfilling operations. The contractor shall not perform any excavation, crossing, backfilling or construction operations unless the Company representative is on site. **The Company representative shall have full authority to stop the work if it is determined that the work is being**

performed in an unsafe manner.

4.1.2 Excavation by a third party backhoe or other mechanical equipment shall not be permitted within the Company pipeline right-of-way until an excavation plan has been reviewed and approved by the Company representative. The excavation plan may be a written document produced by the contractor or a verbal discussion between the contractor and the Company representative. As a minimum, the excavation plan shall include but not be limited to the following:

- Backhoe set-up position in relationship to the pipeline
- Need for benching to level backhoe
- Required excavation depth and length
- Sloping and shoring requirements
- Ingress/egress ramp locations
- Minimum clearance requirements for mechanical equipment
- Verify bar has been welded onto backhoe bucket teeth and side cutters have been removed
- Pipeline location and depth
- Spoil pile location
- Compliance with OSHA regulations

4.1.3 The use of mechanical equipment in the vicinity of Company pipelines shall be directed by the Company representative in accordance with Company procedures and applicable dig-safe laws. Hand tools shall be used to complete the final excavation of the pipeline inside the "restricted" mechanical equipment limits of the excavation.

4.1.4 Federal regulations require that the Company's pipe be inspected whenever it is exposed. OSHA regulations pertaining to excavations must therefore be met to ensure the safety of the Company representative who must enter the excavation.

4.2 Blasting operations shall be performed in accordance with the minimum guidelines set forth below. Consult TG-111, "Blasting Adjacent to In-Service Pipelines" for more detailed information.

4.2.1 The Company shall be advised of any blasting proposed within 200 feet (500 feet for large scale quarry-type blasting) of its facilities. No blasting is permitted within the pipeline right-of-way, and no blasting shall occur outside the pipeline right-of-way if the Company determines that such blasting may be detrimental to its facilities.

4.2.2 The Company reserves the right to require that the party responsible for blasting furnish a detailed blasting plan at least three (3) working days prior to blasting to allow for evaluation and to make arrangements for witnessing the blasting operation. Blasting codes shall be followed in all cases.

5.0 FOREIGN LINE CROSSINGS

5.1 All buried foreign lines shall be installed as noted below and as stated in Sections 3.8 and 3.9, as appropriate.

5.1.1 Foreign lines shall be installed below the Company's pipeline(s) with a minimum of 12" of clearance except as noted in Section 5.1.2. Additional separation may be required in marshy areas or other areas where the 12" of clearance would have a potential to cause future problems.

5.1.2 If the normal crossing requirements present undue difficulties, foreign lines may be installed above the Company's pipeline(s) with prior approval from the Company representative. All such lines shall be installed with a minimum of 12" of clearance. The Company will not be responsible for any damage or required repairs which are caused by the Company's operating and maintenance activities when foreign lines are installed above the pipeline(s). Protective measures such as a concrete encasement, ditch marking tape, and/ or above ground markers may be required as deemed necessary by the Company representative.

5.1.3 Suitable backfill shall be placed between the foreign line and the Company's pipeline(s).

5.1.4 The installation of test leads (two No. 12 THW black insulated solid copper wires) attached at the point of crossing for corrosion control monitoring may be required for metallic foreign lines as directed by the Company representative. Test wires shall be routed underground and terminated at a point specified by the Company.

5.2 The following requirements shall be met for fiber optic cables which encroach upon the pipeline right-of-way.

5.2.1 High capacity fiber optic cable shall be installed in a rigid non-metallic conduit or covered in 6-8" of concrete which has been colored with an orange dye extending across the entire pipeline right-of-way.

5.2.2 The fiber optic cable shall be installed a minimum of 12" below the Company's pipeline(s) across the entire width of the pipeline right-of-way, unless approved by the Company representative.

5.2.3 Orange warning tape shall be buried a minimum of 18" directly above the fiber optic cable across the entire width of the pipeline right-of-way, where practical.

5.2.4 The fiber optic cable crossing shall be clearly and permanently marked with identification signs on both sides of the pipeline right-of-way.

5.3 The information listed below shall be furnished to the Company for all proposed electrical cables which will encroach upon the pipeline right-of-way.

- Number, spacing and voltage of cables
- Line loading and phase relationship of cables
- Grounding system
- Position of cables and load facilities relative to pipeline(s)

5.4 Specific installation requirements for cables carrying less than 600 volts shall be determined by the Company on a case by case basis.

5.5 The following installation requirements shall be met for electrical cables carrying over 600 volts but less than 7,600 volts. The Company will determine the installation procedures for electrical lines carrying voltages over 7,600 volts on a case by case basis.

5.5.1 The electrical cable shall be installed in a rigid non-metallic conduit covered in a minimum thickness of 2" of concrete which has been colored with a red dye extending across the entire pipeline right-of-way.

5.5.2 The electrical cable shall be installed a minimum of 12" below the Company's pipeline(s) across the entire width of the pipeline right-of-way, unless approved by the Company representative.

5.5.3 Each phase conductor should be surrounded with a spirally wound, concentric neutral conductor. The neutral may be within the outer cable jacket.

5.5.4 Red warning tape shall be buried a minimum of 18" directly above the electric cable across the entire width of the pipeline right-of-way, where practical.

5.5.5 The electric cable crossing shall be clearly and permanently marked with identification signs on both sides of the pipeline right-of-way.

5.6 Overhead power line and telephone line installations shall be reviewed by the Company on an individual basis. As a minimum requirement, overhead lines shall be installed with a minimum clearance of 25 feet above the grade of the pipeline right-of-way. The installation of poles will not be permitted on the pipeline right-of-way.

Spectra Energy Transmission

Standard Operating Procedures
Volume 1 - PIPELINE

Procedure Name: ***Blasting Near Pipelines***	**Procedure Number: 1-6030**	
	Date: 01/01/2007	**Page: 1 of 3**

Introduction

This procedure describes third party blasting operations.

This SOP contains the following sections:

- Protection of Pipelines from Blasting Operations

Frequency

As required.

Responsibility

Region Technical Management, unless otherwise noted.

	ACTION	RESPONSE/REMARKS
Protection of Pipelines from Blasting Operations	**OBTAIN** details from the party responsible for the blasting and **PERFORM** an analysis to ensure the safety of the pipeline.	*Area Management will do this when blasting operations are to occur within 200' of an in-service Company pipeline, or within 500' in the case of large-scale quarry-type blasting.*

NOTE:

All blasting operations conducted in the vicinity of in-service Company pipelines shall be evaluated and conducted in accordance with this SOP and **TG-111, "Blasting Adjacent to In-Service Pipelines"**.

Obtaining a Blasting Plan	• **ENSURE** that the party performing the blasting completes a Blasting Plan Submittal (**Form #7T-230**). • **COMPLETE** the Blasting Near Pipelines (**Form #7T-231**) and send it to Region Technical Management along with the Blasting Plan Submittal Form (**Form #7T-230**).	*Area Management is responsible for these action items.*
	REQUEST the blasting plan enough in advance to allow for evaluation and to make arrangements for witnessing the operations (3 business days).	
Evaluating the Blasting Plan	**REVIEW** all pertinent information in accordance with the existing policy regarding blasting operations.	*Region Technical Management is responsible for this action item.*

<table>
<tr><th></th><th>ACTION</th><th>RESPONSE/REMARKS</th></tr>
<tr><td></td><td colspan="2">NOTE:
The evaluation may determine one of the following:
• Acceptability of the proposed blasting plan at current operating conditions.
• Closest distance to the pipeline at which the blasting plan may be used at current operating conditions.
• Highest safe pressure at which the pipeline may operate with the proposed blasting plan.</td></tr>
<tr><td><i>Inspecting the Blasting Operations</i></td><td>OBSERVE the blasting operations, including the drilling and loading of the blast holes. This is only required if the evaluation has indicated that deviations from the Blasting Plan may endanger the pipeline.</td><td><i>If Region Technical Management determines that observation is required, Area Management will ensure that the Blasting Plan is followed and will shut down the job if there is any unapproved deviation from the Blasting Plan.</i></td></tr>
<tr><td><i>Blasting on the Pipeline Right-Of-Way</i></td><td>DO NOT ALLOW blasting on the pipeline right-of-way unless it is conducted for the benefit of the Company under direct supervision of a Company representative or unless otherwise approved by the Director, Pipeline Integrity - Houston.</td><td></td></tr>
<tr><td></td><td colspan="2">NOTE:
Seismographic monitoring criteria, such as peak particle velocity, have been found to give a very poor correlation with the stress imposed in pipelines from blasting.</td></tr>
<tr><td><i>Additional Safety Measures</i></td><td>DETERMINE the need to take additional safety measures during or after the blasting which may include manning of valves bracketing the section, or reducting the operating pressure.</td><td><i>Area Management is responsible for this action item after consulting with Region Technical Management.</i></td></tr>
</table>

ACTION	RESPONSE/REMARKS
IF damage is suspected, **CONDUCT** leakage surveys in accordance with **SOP #1-6020, "Leakage Surveys Utilizing Gas Detection Equipment"**.	

1.0 BACKGROUND AND PURPOSE

This guideline provides methods for evaluating Blasting Plans and for ensuring the safety of existing high pressure natural gas pipelines during blasting. It is designed to protect pipelines from blasting damage through: 1) controlling the pipe stresses caused by the seismic ground vibration, and 2) limiting the minimum distance between the explosive charges and the in-service pipeline to ensure the pipeline is not within the zone of rock fragmentation and displacement.

This guideline is intended as an aid to, not a replacement for, sound engineering judgment. An alternative stress analysis method may be used if technically justified and with the approval of the Region Director, Technical Operations in which the blasting will be performed. **Under no circumstances should the methods presented in this guideline or its companion spreadsheet be used by anyone not familiar with their basis, applications, and limitations.**

This guideline includes the following sections:

App. B References
App. C Specific Energy Release of Various Explosives
App. D Forms

Blasting involves a number of extremely complex phenomena. Accurate prediction of the blasting-induced stress in a pipeline and the pipeline's ability to withstand that stress requires knowledge of:

- Amount, type, and pattern of explosives used and delay between charges
- Offset between charges and pipeline, and relative grade between the two and on the far side of the pipeline
- Pipe diameter, wall, yield strength, and operating pressure
- Pre-existing stress state of the pipeline
- Any anomalies in the pipe or deviations from nominal specifications
- Competence of the rock in which the explosives are placed, including presence and orientation of any cracks or fissures
- Configuration and physical characteristics of the soil and rock through which the vibrations will propagate
- Conditions of the soil immediately surrounding the pipeline and the pipe-soil interface
- Presence and details of any strata which may reflect vibrations to the pipeline

The calculations in this guideline use only the first three (solid) bullet items listed above, as these are the only variables which can be readily determined. Actual induced pipeline stress can be shown to correlate fairly well with the values predicted by the equations; however due to the unknown factors it can be expected to vary significantly from the predictions. Because of the potentially devastating effects of a pipeline failure, it is only prudent to select a formula which provides an upper limit to the range of measured stress levels, and then impose a factor of safety. That is the approach taken in this guideline.

This guideline is based upon a series of blasting studies conducted between 1975 and 1990 by Southwest Research Institute (SWRI) for the AGA's Pipeline Research Committee (now Pipeline Research Council International). The predictive tools developed by the AGA studies were refined during field testing performed by Texas Eastern in conjunction with SWRI and Battelle during preparation for a major looping project. A proposed method for evaluating Blasting Plans, based upon the AGA results and the Texas Eastern testing, was presented by Alan Lambeth at the annual AGA conference in 1993. A study by the U.S. Bureau of Mines published in 1994 involved much larger charges than those used in the AGA and TE studies. While the authors of the 1994 study proposed a less conservative approach to protecting pipelines, their data seem to corroborate the suitability of the methods proposed by Lambeth to conservatively predict stresses imposed on pipelines by blasting. Interested readers are referred to Appendix B, References.

This guideline should be used in the following manner:

1.1 Verify the applicability of the guideline to a particular blasting situation per Section 2.

1.2 Obtain a complete Blasting Plan, per Section 3, from the party responsible for the blasting operations. See Section 1.9, below, if there is no Blasting Plan.

1.3 Assemble and review the input variables listed in Sections 4.1, 4.2, and 4.3. This information should be in the Blasting Plan and its accompanying form when sent in from the field. Review the information to verify it is both complete and reasonable.

1.4 Evaluate separately each combination of pipeline conditions (diameter, wall thickness, pipe grade, pressure, class location) identified as being in the area of the blasting against each combination of blasting parameters (agent, charge weight, delay, charge hole spacing, offset from the pipeline) identified in the Blasting Plan:

1.4.1 Calculate the intermediate geometric values and the powder factor per Section 4.4.

1.4.2 Select values for the adjustment factors listed in Section 4.5.

1.4.3 Calculate the predicted stress due to blasting, stress due to combination of blasting and pressure, and the allowable stress level by the methods in Section 4.6.

1.5 If the predicted stress due to the combination of blasting and pressure exceeds the allowable stress level, select an option or combination of options from Section 5 (increased offset, reduced pressure, increased stress factor).

1.6 If blasting is to be conducted within 25′ of a pipeline, review it per Section 6 in addition to the above methods.

1.7 Notify the person submitting the Blasting Plan and the appropriate Area Office of the results of the analysis. Notification should be written (letter, fax, or email) and contain sufficient detail that it cannot be misinterpreted.

1.8 Monitor blasting activities as noted in Section 8.

1.9 If asked to provide blasting restrictions without a Blasting Plan, explain the Blasting Plan review process to the requesting party. On occasion it may be necessary to provide some details on blasting parameters without the benefit of a Blasting Plan; this should be done in accordance with Section 7.

2.0 BLASTING APPLICATIONS

The following sections describe the applications for this guideline.

2.1 BLASTING COVERED BY THIS GUIDELINE

This guideline should be used for analyzing the effects of buried explosives on buried pipelines. Types of applicable blasting include mining operations, quarry excavations, trench excavation for new pipelines, seismic surveys, highway construction, and other types of construction. The guideline can only be used when the variables discussed in Section 4.0 are known. In some cases it may be possible to make conservative estimates.

2.2 DISTANCE OF BLASTING FROM PIPELINE

Where "normal" blasting operations, such as for construction, are to occur within 200 feet of an in-service pipeline, a Blasting Plan should be analyzed. In the case of large-scale blasting such as that used in quarrying, blasting within 500 feet - or more at the discretion of the Region Technical Staff - requires analysis of a Blasting Plan. For blasting within 25 feet of an active pipeline, refer to Section 6.

2.3 UNDERGROUND FUEL GAS EXPLOSIONS

There are devices on the market which detonate an underground fuel-air or fuel-oxygen mixture to kill rodents in their burrows. These are of particular concern because burrowing rodents often establish underground chambers in contact with the warm pipeline. Even if the fuel mixture does not completely fill the burrow, the burrow will direct the shock wave to the pipeline. Explosions in burrows should not be permitted if the burrow entrance is closer to the right of way than the target species' maximum normal burrow length. A sample calculation is provided in Appendix A; in general the analysis should be based on the following:

2.3.1 The burrow is assumed to be the maximum length and diameter that can be expected for the target species.

2.3.2 Amount of explosive is the amount of fuel gas (in pounds) which will completely fill the burrow in a stoichiometric mixture with the oxidizer being used (air or oxygen).

2.3.3 Specific energy release of the explosive is the heating value of the fuel gas, taken from standard references and converted to calories per gram. Two heating values are usually listed for fuel gases. The higher heating value includes the energy released if the water generated by combustion is condensed. Since this doesn't happen, use the lower heating value.

2.3.4 Because the burrow can direct the force of the explosion, the entire charge is treated as if it's located at the portion of the burrow closest to the pipeline. Since this distance is not generally known, it should be assumed that the burrow runs straight toward the pipeline and is the maximum length that can be expected for the target species.

2.4 SEISMIC BLASTING AND ISOLATED CHARGES

Powder factor calculations determine the amount of rock to be broken per pound of explosive used. If this value is too low, energy that would have been absorbed by breaking rock can be transmitted to the pipeline. This is allowed for by increasing the predicted stress on the pipeline. In the case of a single charge or a series of charges separated widely enough that their effects do not interact, powder factor calculations become meaningless. Since the synergistic effect of multiple closely-spaced charges does not occur in this case, the powder factor compensation factor, F_p, should be set to 2 unless there is a relief surface close to the charge(s). The delay time factor, F_t, should be set to 1 because multiple charges are not interacting. The blasting calculation spreadsheet will set both of these factors automatically if the ideal powder factor, PF_i, is set to zero to indicate individual or widely-spaced charges.

3.0 REQUEST FOR A BLASTING PLAN

All blasting within the distance limits discussed in Section 2.2 must be in accordance with a Blasting Plan which has been reviewed and accepted by the Company. The Blasting Plan should be requested by the Area with sufficient time to allow for evaluation and to make arrangements for witnessing the blasting operations if necessary. When making the request, the Area should provide the responsible party with a copy of **Form #7T-230**. The responsible party is to return the completed form to the

Area, at which time the Area will review the form to confirm that all required information has been provided. The Area should complete **Form #7T-231** and forward both completed forms to the Region Office for analysis.

4.0 ANALYZING THE BLASTING PLAN

Once the completed Blasting Plan is received by the Region Office, the Region Technical Staff is to analyze the Plan to determine its acceptability. Each combination of pipeline inputs (4.1), geometry inputs (4.2), and blasting inputs (4.3) requires separate evaluation. This can require an enormous amount of calculation; an Excel blasting calculation spreadsheet is available to simplify the process but it is important that the person performing the calculation understands the underlying processes and the meaning and implications of the variables. The blasting calculation spreadsheet is an internal document; neither it nor printouts from it should be provided to outside parties.

The following variables are used to determine acceptability of a Blasting Plan:

Drop = Drop in grade over "run" feet (ft)
C = Clearance from pipe to theoretical area of ground displacement caused by blasting (ft)
D = Outside diameter of the pipeline (in)
D_{CP} = Depth of bottom of charge below center of pipe (ft)
D_P = Depth of center of pipe below grade (ft)
D_t = Distance grade remains level on far side of pipeline from blasting (ft)
E = Young's Modulus of Elasticity (psi)
F_C = Confinement factor; stress multiplier

F_D = Blasting design factor (% of S)

F_H = Soil backing factor; reduces effective wall thickness when backing is relatively small

F_L = Delay time factor; charge weight multiplier

F_P = Powder factor compensation factor; stress multiplier

F_W = Weight adjustment factor based on level of inspection

G = Difference between grade at pipeline and grade at nearest blast hole (ft)

G_C = Depth below grade of bottom of nearest charge including subdrill (ft)

H = Distance from pipeline center to surface in direction opposite from the blasting charges (ft)

H_C = Height of charge column (ft)

H_P = Pipe depth of cover (ft)

n_S = Specific energy release of the explosive (cal/gm)

P_a = Actual operating pressure (psig)

P_C = Charge spacing within a row of blasting charges (ft)

P_m = Maximum operating pressure (psig)

P_R = Spacing between rows of blasting charges (ft)

P_T = Thickness of rock to be blasted (ft)

P_W = Maximum permitted operating pressure (psig) for a given value of "W" and other parameters

PF = Powder factor (lb/yd^3)

PF_i = Ideal powder factor for a given blast (lb/yd^3)

Run = Run over which grade drops by "drop" feet (ft)

R = Horizontal offset from pipeline center to charge (ft)

R_c = Distance between pipeline center and nearest point on charge column (ft)

R_h = Distance between pipeline center and bottom of charge (ft)

S = Yield strength of the pipe metal (psi)

t = Wall thickness of pipeline (in)

W_d = Maximum charge weight per delay (lb)

W_h = Maximum charge weight per hole (lb)

ρ_P = Density of pipe material (lb/ft^3)

ρ_S = Density of soil or rock (lb/ft^3)

σ = Hoop stress due to both blasting and pressure (psi)

σ_a = Allowable stress due to blasting and pressure (psi)

σ_b = Stress due to blasting vibrations (psi)

τ_d = Delay time between charges (ms)

4.1 PIPELINE INPUTS

D = Outside diameter of the pipeline (in): From Web Map, Alignment Sheets, or similar records. For smaller diameters, use the actual outside diameter per API 5L (example: for a 12″ line D = 12.75). Because coatings (including concrete) do not add significant strength to the pipeline, do not include coating thickness.

E = Young's Modulus of Elasticity: Use 29,500,000 psi (as used in development of the SWRI equation) for steel.

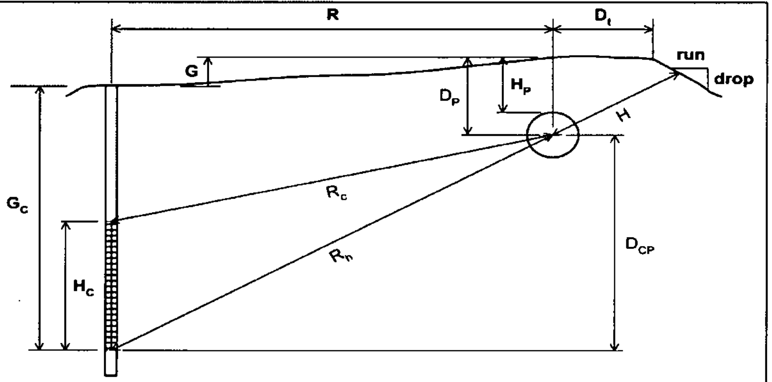
P_a = Highest anticipated pressure in the pipeline at the location where blasting is to be performed (psig): The most conservative approach is to use the highest allowable pressure (MAOP or DMOP). A lower value may be used, based upon operating conditions including pressure gradient. See Section 5.3 if using a value of P_a less than P_m.

P_m = Maximum operating pressure (psig): Either the Maximum Allowable Operating Pressure (MAOP) or the Dispatching Maximum Operating Pressure (DMOP)

S = Yield strength of the pipe metal (psi): Usually estimated as Specified Minimum Yield Stress (SMYS) and obtained from Web Map, Alignment Sheets, or similar records. When using these records, keep in mind that locations of changes in SMYS may be inexact. If the records indicate a change in pipe specifications nearby and the exact location of the change cannot be confirmed by field measurement, analyze the Blasting Plan for each combination of wall thickness and grade in the area.

t = Thickness of pipe wall (in): Get the specified wall thickness value from Web Map, Alignment Sheets, or similar records. If practical, take ultrasonic measurements to confirm the wall thickness. The value of t should be the smallest measured thickness, but no greater than the specified thickness. When relying on records with no field verification, keep in mind that locations of changes in wall thickness may be inexact. If the records indicate a change in pipe specifications nearby, analyze the Blasting Plan for each combination of wall thickness and grade in the area.

ρ_F = Density of pipe material: Use 490 lb/ft^3 for steel.



Geometric variables - Inputs in bold

4.2 GEOMETRY INPUTS

Drop = Grade drop over "run" feet - may be negative (ft)

D$_t$ = Distance grade remains level on far side of pipeline from blasting (ft)

Run = Run over which grade drops "drop" feet (ft)

Note:

The above three variables are intended to describe the behavior of the grade on the side of the pipeline opposite from the blasting, in order to determine the value of H. The grade remains essentially level for a distance D$_t$ away from the blasting. It then drops at an average rate of "drop" feet over a run of "run" feet. If the ground is rising, the value of "drop" is negative. If there is no level ground as measured perpendicular to the pipeline, the value of D_L is zero. These values should be provided by the field personnel on the form which accompanies the Blasting Plan form. If this simplified description does not adequately describe the behavior of the grade, the field personnel should send a dimensioned sketch to the person performing the analysis, who will determine the correct value of H.

H_C = Height of charge column (ft), measured from bottom of lowest charge in column to top of highest charge. This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

H_P = Pipe depth of cover (ft), measured from grade to top of pipe by probing or excavation. This value is provided by the field personnel on the form which accompanies the Blasting Plan form. If this depth varies, the range of depths should be provided by the Area, and the person performing the analysis should evaluate the blast at both the deepest and shallowest depths to determine the limiting case.

G = Difference in grade at pipeline relative to nearest blast hole (ft): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided and that it appears correct. Note that if grade at the pipeline is lower than at the blast holes, G is negative.

R = Horizontal offset distance from the centerline of the in-service pipeline to the nearest explosive charge (ft): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

G_C = Depth below grade of bottom of nearest charge (ft): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided. Note that blast holes may be drilled below the level of the charges to aid in rock breakage; this should not be included in G_C. In many cases the bottom of the explosive column is below the bottom of the desired excavation. This subdrilling is included in G_C, but is not included in powder factor calculations.

4.3 BLASTING INPUTS

n_s = Specific energy release of the explosive (cal/gm) for comparison with the explosive used in the SWRI equations: This value should be provided as part of the Blasting Plan but is often omitted. If the Blaster cannot provide this information, it may be available from cut sheets or from the internet. If the relative weight strength (RWS: specific energy relative to standard ANFO at 912 cal/gm) is available, the specific energy release is:

$$n_s\left({}^{cal}\!/_{gm}\right) = \frac{\mathrm{Re}\,lativeWeightStrength}{100} \times 912\,{}^{cal}\!/_{gm}$$

Note that the specific energy of ANFO can vary significantly, depending on how it is formulated and how the energy release is measured.

If bulk strength and density are available, the specific energy release is:

$$n_s\left({}^{cal}\!/_{gm}\right) = \frac{BulkStrength\left({}^{cal}\!/_{cc}\right)}{Density\left({}^{gm}\!/_{cc}\right)}$$

Density in grams per cubic centimeter (gm/cc) is equal to the specific gravity relative to water.

The following two factors, P_C and P_F, describe an array of charge holes. The array does not have to be aligned with the pipeline, and the charges may be aligned with one another or staggered. Either dimension may be chosen as the charge spacing within rows, with the other being the row spacing, however in general the number of rows should be less than the number of charges in a row. These values should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

P_C = Charge spacing within a row (ft) - Use:

- For single or widely spaced charges: See Section 2.4
- For blasting with charges close enough to interact: Distance between holes

P_R = Spacing between rows of charges (ft)

Note:

If there is only one row of interacting charges, set P_R equal to P_C. If using the blasting calculation spreadsheet, setting P_R to zero or number of rows to 1 will have the same effect.

P_T = Thickness of rock to be blasted (ft): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided. The person performing the analysis should compare this value to H_C, the height of the column of charges, to determine whether it accurately reflects the thickness of rock to be removed by the blast. P_T will typically be about the same as or slightly greater than H_C, although in some applications, blasters may load all of the charges in the bottom of the hole to lift and break the rock. The rock thickness does not include the thickness of any soil placed above the rock to prevent flyrock and does not include any subdrilling of the blast holes below the intended ditch bottom.

PF_i = Ideal powder factor for a given blast (lb/yd^3): Powder factor is the number of pounds of explosive used to remove a cubic yard of rock. The ideal powder factor varies depending on the rock being blasted and the geometry of the shot. Larger powder factors are required for stronger rock than for weaker rock, and trench blasting with one or two rows of charges requires larger powder factors than do extended areas such as basements or parking lots. For some extremely strong rock, powder factors as high as 5 lb/yd^3 may be required for adequate breakage. A qualified Blasting Engineer (not associated with the party performing the blasting) may be able to provide guidance in selecting the appropriate value for PF_i. In general, however, the following can be used for ideal powder factor:

- Trench blasting: $PF_i = 3\ lb/yd^3$
- Area blasting: $PF_i = 1\ lb/yd^3$

If using the blasting calculation spreadsheet, setting PF_i or the number of rows to zero will indicate to the program that an individual charge is being evaluated.

W_d = Maximum charge weight per delay (lb): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

W_h = Maximum charge weight per hole (lb): Often, but not always, the same as W_d. Sometimes multiple holes are fired simultaneously by a single delay, more rarely a hole may be divided into multiple delays by "decking". W_h should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

ρ_s = Density of soil or rock located between the blast and the pipeline (lb/ft^3). Soil density is to large extent a function of its water content. Rock densities may be obtained from geology or blasting references. Generally igneous rocks such as basalt and granite have the highest densities and sedimentary rocks such as shale and sandstone have the lowest. A higher value is more conservative.

Typical values to use are:

- Default value: 200 lb/ft^3
- Soil only: 100 - 120 lb/ft^3
- Rock only: 140 - 200 lb/ft^3

τ_d = Delay time between charges (ms): This value should be provided by the party performing the blasting as part of the Blasting Plan; the field personnel passing the form on to the person doing the evaluation should confirm that the information is provided.

4.4 CALCULATED INTERMEDIATE VALUES

D_P = Depth of center of pipe below grade (ft)

$$D_P = H_P + 0.5 \times D \times (1ft/12in)$$

D_{CP} = Depth of bottom of charge below center of pipe (ft)

$$D_{CP} = G_C + G - D_P$$

R_C = Distance from the center of the pipeline to the nearest point on the charge column (ft)

$$H_C < D_{CP} \quad : R_c = \sqrt{(D_{CP} - H_C)^2 + R^2}$$
$$H_C \geq D_{CP} \quad : R_c = R$$

R_h = Distance from the bottom of the nearest charge to the center of the pipeline (ft)

$$R_h = \sqrt{D_{CP}{}^2 + R^2}$$

H = Distance from center of the pipeline to the ground surface or free face in the direction opposite from the bottom of the blasting charges on the same line as R_h (ft).

$$D_t \geq \frac{D_P \times R}{D_{CP}} \quad : \quad H = \frac{D_P \times R_h}{D_{CP}}$$

$$0 \leq D_t < \frac{D_P \times R}{D_{CP}} \quad :$$

$$\frac{drop}{run} + \frac{D_{CP}}{R} > 0 \quad : \quad H = \frac{R_h}{R}\left[D_t + \frac{D_P - \frac{D_{CP} \times D_t}{R}}{\frac{drop}{run} + \frac{D_{CP}}{R}}\right]$$

$$\frac{drop}{run} + \frac{D_{CP}}{R} \leq 0 \quad : \quad H = \infty$$

In the last case, where H is infinite, the ground on the far side of the pipeline is rising at the same rate as or faster than the line from the bottom of the charges through the center of the pipe. H can be set to an arbitrarily large value such as 100'.

Sometimes the sketch at the beginning of this Section and on the blasting information form will not adequately describe the behavior of the grade on the far side of the pipeline from the blasting.

If this is the case the field should send a dimensioned sketch indicating how the grade behaves to the person performing the analysis, who will determine the appropriate value of H to use in the calculations.

PF = Powder factor (lb/yd^3): Powder factor is the number of pounds of explosive (normalized to ANFO) used to remove a cubic yard of rock:

$$PF = \frac{W_h \times {}^{n_s}\!/_{912} \times 27\,{}^{ft^3}\!/_{yd^3}}{P_R \times P_C \times P_T}$$

In the case of trench blasting with two rows of explosive (charges aligned or staggered), the rock breaking effect tends to extend about a foot outside of each row. In this case, the powder factor is:

$$PF = \frac{W_h \times {}^{n_s}\!/_{912} \times 27\,{}^{ft^3}\!/_{yd^3}}{\left({}^{P_R}\!/_{2} + 1ft\right) \times P_C \times P_T}$$

Powder factor should always be calculated, since the values submitted with Blasting Plans are often different from those calculated by this method.

4.5 ADJUSTMENT FACTORS

F_C = Confinement factor: Highly confined rock is more difficult to break during blasting and can transmit higher seismic ground vibration, whereas a relief surface or "free face" (an open area where no rock exists) reduces confinement by allowing rock to move more freely and results in much lower transmitted ground vibrations.

Based upon results of the Company blasting study and other sources on blasting, the following factors should be used:

- Where blasting is conducted with free faces in the rock which allow the rock to move laterally away from the blast: $F_C = 1.0$
- For blasting in confined rock formations where lateral movement of the rock during blasting is restricted (typical for trench blasting or opening shots on larger areas): $F_C = 2.0$

Note:
For trench blasting near existing pipelines, a free face should be created at one end of the rock area prior to blasting by mechanically excavating an open trench up to the rock area, and the shot sequence should proceed from the face. However, trench blasting is still considered a confined rock application and should be evaluated as such.

F_D = Blasting design factor taking into account stress due to both pressure and blasting. F_D is based upon the pressure design factor F, which for this purpose is the greater of the value prescribed by DOT (F_{DOT}) in 49CFR192.111 for the Class Location (0.72, 0.60, 0.50, or 0.40), or the value obtained by Barlow's formula for the pipe at MAOP:

$$F = \max\left[F_{DOT}, \frac{P_m \times D}{2 \times S \times t} \right]$$

F_D should not normally exceed 115% of F or 78%, whichever is greater. For grandfathered pipe with F greater than 78%, F_D should not exceed F:

- $F < 0.68 \ : \ F_D \le 1.15 \times F$ (115% of 0.68 is 0.78)
- $0.68 \le F \le 0.78 \ : \ F_D \le 0.78$
- $F > 0.78 \ : \ F_D \le F$

The value of F_D may have to be set lower than the limits above, based upon the engineering judgment of the person responsible for the analysis and taking into account the hydrostatic test pressure, the possibility of defects, the condition and type of the girth and seam welds, and other considerations from Section 5.4 which may impact the pipeline's susceptibility to damage. Section 5.4 also discusses circumstances in which F_D may be set higher than the limits above.

F_H = Soil backing factor for deep blasts:

$$\frac{R_h}{H} \le 4 : \ F_H = 1.0$$

$$\frac{R_h}{H} > 4: \quad F_H = \frac{H}{R_h} + \frac{\rho_p \times t}{12 \times \rho_s \times R_h}$$

The F_H factor was derived from SWRI's analysis of four blasts performed for Dow Chemical at an R/H ratio of about 14. The stress prediction formula which worked well at R_h/H ratios between approximately 1 and 3 significantly underestimated the effect of the Dow Chemical blasts. SWRI hypothesized that under blasting conditions, a mass of soil between the pipe and the charge moves with the pipe, as does a mass of soil on the far side of the pipe. When there is relatively little soil mass backing the pipe (high value of R_h/H) the pipe would tend to move more, resulting in higher pipe stress. SWRI derived a correction factor for the Dow Chemical blasts based on both R_h/H (which was constant) and on R_h (which varied due to changes in offset distance). Knowing that the factor did not apply to R_h/H between 1 and 3 but did apply at an R_h/H of 14, they conservatively recommended that it be applied to all blasts with R_h/H greater than 4.

As R_h increases with a constant H, F_H drops abruptly from 1 to about 0.25 at $R_h/H = 4$ and then decreases gradually toward (but never reaching) zero. The resulting stress multiplier ($F_H^{-0.385}$) jumps from 1 to about 1.7, then increases without bound as the R_h/H ratio increases. Based on SWRI's hypothesis that the increase in stress is due to reduced mass backing the pipe, it is questionable whether the F_H factor is applicable for large values of H – for example if R_h is 100′ and H is 20′. Hopefully future research will resolve this issue.

F_H and F_L are empirical corrections based on analyses of separate data sets. They should not be used together. If conditions for F_L are met, F_H should be set to unity regardless of R_h/H:

$R > 200'$ $\underline{\text{and}}$ $D_{CP} > 100$ $\underline{\text{and}}$ $\tau_d < 17$ ms: $F_H = 1.0$

F_L = Factor for large explosive weight per delay at a great distance from the pipeline, with deep columns of explosive (approximately 120 feet) and delay intervals less than 17 ms,

$R > 200'$ $\underline{\text{and}}$ $D_{CP} > 100$ $\underline{\text{and}}$ $\tau_d < 17$ms:
$F_L = 1 + 0.009 \times (R - 200)$

Otherwise: $F_L = 1.0$

F_P – Factor to compensate for high or low powder factor: If the actual powder factor is significantly higher than the ideal, excessive vibrations may be transmitted to the pipe. On the other hand, actual powder factors significantly lower than the ideal may result in insufficient rock breakage. Since rock breakage absorbs energy, too small a charge may result in excessive vibration being transmitted to the pipe.

$$\frac{PF}{PF_i} > 120\% \quad : \quad F_P = \frac{PF}{1.2 \times PF_i}$$

$$\frac{2}{3} \le \frac{PF}{PF_i} \le 120\% \quad : \quad F_P = 1.0$$

$$\frac{PF}{PF_i} < \frac{2}{3} \quad : \quad (1) \text{ or } (2)$$

(1) Blasting in confined rock:

$$F_P = \sqrt{\frac{2/3 \times PF_i}{PF}}$$

(2) Blasting with relief surfaces:

$$F_P = 1.0$$

The calculated stress is multiplied by F_P. It does not make physical sense that this factor should increase without limit; the value of F_P should be limited to no more than 2. The blasting calculation spreadsheet applies this limit automatically.

F_t = Delay time factor: If the time interval between charges is too low, the vibrations from sequential blasts may overlap. If the interval is too high, rock breakage may be inadequate, resulting in excessive vibration being transmitted rather than absorbed. The F_t factor compensates for this effect by doubling the effective charge weight. Testing has indicated that this effect is not present at large offsets or when there are free faces.

The appropriate delay range for any given situation may be determined by consulting with a qualified Blasting Engineer (not connected with the party doing the blasting) familiar with the type of blasting being performed. As a default, use the range 17 ms - 35 ms as acceptable.

R_h < 100′ and F_C > 1.0:

- $\tau_d < 17$: $F_t = 2.0$
- $17 \leq \tau_d \leq 35$: $F_t = 1.0$
- $\tau_d > 35$: $F_t = 2.0$

Otherwise:

$F_t = 1.0$

F_W = Safety factor applied to the charge weight to reflect whether blasting is closely inspected by a qualified Blasting Inspector (see Section 8.3).

- If a qualified Blasting Inspector working for the Company has observed the holes being loaded and is assured that the Blasting Plan is being scrupulously followed: $F_W = 1.0$
- If there is no qualified Blasting Inspector onsite or if the Blasting Inspector does not

personally witness the holes being loaded:

$F_W = 1.2$

4.6 PIPELINE STRESS

σ_b = Stress imposed in a pipeline by blasting vibrations (psi)

$$\sigma_b = 4.44 \times F_C \times F_P \times F_L \times E \times \left(\frac{W_d \times F_W \times F_t \times n_S / 912}{\sqrt{E \times t \times F_H} \times R_c^{2.5}} \right)^{0.77}$$

The origin of this formula is discussed in Section 1.0.

σ = Hoop stress in a pipeline due to combination of blasting and internal pressure (psi)

$$\sigma = \sigma_b + \frac{P_a \times D}{2 \times t}$$

σ_a = Allowable stress in a pipeline due to blasting and internal pressure (psi)

$$\sigma_a = F_D \times S$$

If $\sigma_a \geq \sigma$, blasting-induced stresses are acceptable.

5.0 IF THE BLASTING PLAN IS NOT ACCEPTABLE

If the Blasting Plan as submitted is not acceptable by the analysis in Section 4 ($\sigma > \sigma_a$), the following options should be considered:

5.1 INCREASED BLASTING DISTANCE

A Blasting Plan which is not acceptable at the nearest proposed blasting distance is probably acceptable at some greater distance. Because increasing the offset distance changes the geometry, determining the minimum offset may require an iterative process:

Calculate acceptable blasting stress level:

$$\sigma_b = \sigma_a - \frac{P_a \times D}{2 \times t}$$

Calculate R based on this stress level:

$$R = \left(\frac{W_d \times F_W \times F_i \times {}^{n_s}\!/_{912}}{\sqrt{E \times t \times F_H}} \right)^{0.4} \times \left(\frac{4.44 \times F_C \times F_P \times F_L \times E}{\sigma_b} \right)^{0.52}$$

Recalculate R_h based on new value of R
Recalculate H based on new values of R and R_h
Recalculate F_H based on new values of R, R_h, and H
Recalculate F_L based on new value of R
If F_H or F_L has changed, recalculate R based on the new value(s) and repeat.

The blasting calculation spreadsheet has a macro function activated by Ctrl-Shift-H to calculate the minimum acceptable value of R.

5.2 REDUCED CHARGE WEIGHTS

The party performing the blasting may choose to submit a revised Blasting Plan which uses smaller charges, to reduce the allowable distance. Note that using reduced charges at the same charge spacing and depth will reduce the powder factor, which may affect the adjustment factor F_P. See Section 7.0 in regard to providing charge weights to the Blaster.

5.3 REDUCED OPERATING PRESSURE

It may be possible to allow a Blasting Plan to be used at a pipeline pressure less than MAOP. This should only be done in coordination with Gas Control and if the blasting schedule is flexible enough to allow for delays due to pressure higher than anticipated at the time of blasting. If pressure gradient is taken into account, the possibility that blasting may occur at a time of low flow (little or no gradient) should be considered. The following is the maximum pressure allowed at the blasting location without modification of the Blasting Plan:

$$P_W = \frac{2 \times t \times (\sigma_a - \sigma_b)}{D}$$

5.4 INCREASED STRESS FACTOR

The value F_D was set in Section 4.5, limiting stress due to pressure and blasting to 115% of the stress at MAOP, with a maximum of 78% of SMYS or the stress at MAOP. On occasion it may be necessary to exceed these limits. In those cases, a thorough review of the factors listed below should be performed. As part of this review, serious consideration should be given to a site visit by the person performing the analysis. Based on the review and the engineering judgment of the person performing the analysis, the value of F_D may be set as high as the Class Location Factors permitted in TG-110 for road crossings: 85% in Class 1 locations, 79% in Class 2, 73% in Class 3, or 67% in Class 4.

Factors to consider before increasing value of F_D:

- Pipe specifications
- Current pipeline operating pressure
- Type of pipeline girth and seam welds
- Tested stress level
- Pipeline operating history
- Known, suspected and historical defects/corrosion
- In-line tool records
- Site and soil conditions
- Stress due to surface loading
- Potential for existing stress due to construction methods, soil overburden, settlement
- Other information regarding the integrity of the pipeline that may impact the pipeline's susceptibility to damage
- Other factors noted during site visit by the person performing the analysis

6.0 EVALUATION OF CLOSE-IN BLASTS

The following additional limitations apply for blasting at distances of less than 25 feet from the pipeline. These criteria were extrapolated from a 1970 US Bureau of Mines Study on cratering in granite, and refined based on a 2004 failure investigation.

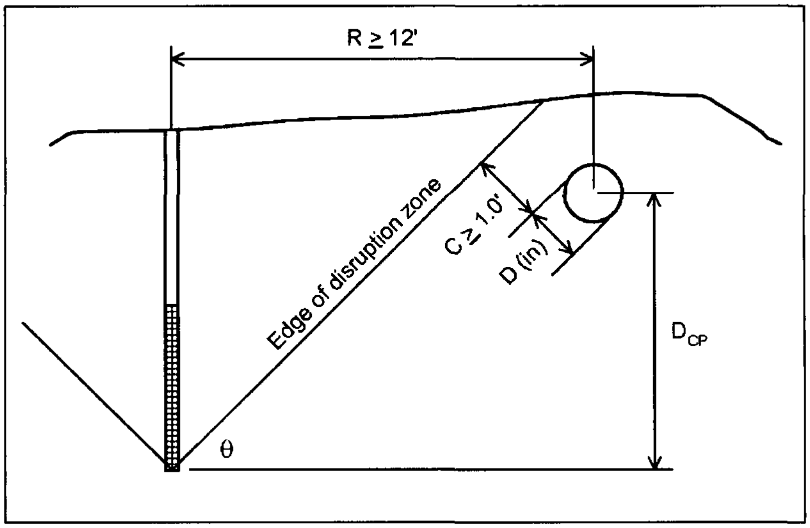
6.1 BLASTING ON PIPELINE RIGHT-OF-WAY

Blasting should not be allowed on the pipeline right-of-way except when conducted for the benefit of the Company and under the supervision of a Company representative or qualified Blasting Inspector familiar with the Company's blasting requirements.

6.2 MINIMUM OFFSET FROM BLAST HOLES TO PIPELINE

No blast holes should be loaded at an offset of less than 25 feet from the centerline of an in-service pipeline except in cases where precise measurements are taken to ensure that the pipeline will have at least one foot of Clearance (C) from the theoretical area surrounding the blast hole in which the ground could be permanently deformed by the blast under worst case conditions.

This theoretical area is a conical shape originating at the bottom of the blast hole and extending out at an angle up to the ground surface as depicted in the illustration below.



The clearance C can be calculated by:

$$C = R \times \sin\theta - D_{CP} \times \cos\theta - \frac{D}{24}$$

with D in inches and the other dimensions in feet, and where θ is the angle from the horizontal of the theoretical zone of permanent disruption.

The angle θ is taken to be 32°, except in the following special circumstances:

- Charge weight per delay does not exceed 0.9 times the ordinary maximum allowable charge weight <u>and</u>
- Charge weight per delay in pounds must not be greater than effective hole depth in feet, divided by 2.5 lb/ft (Example: for 15-ft hole depth,

maximum charge no greater than 15 ft / 2.5 lb/ft = 6 lb).

If both of these conditions hold, the disruption zone angle θ may be taken to be 45°.

If the calculated clearance C would be less than 1 foot, the minimum offset distance must be increased accordingly. The minimum offset R to achieve 1 foot clearance is:

$$R = \frac{1ft}{\sin\theta} + \frac{D}{24 \times \sin\theta} + \frac{D_{cp}}{\tan\theta}$$, or:

- θ = 32°: $R = 1.887ft + \frac{D}{12.718} + 1.6 \times D_{cp}$
- θ = 45°: $R = 1.414ft + \frac{D}{16.971} + D_{cp}$

When blast holes are angled from the vertical, this can have the effect of directing the disruption from the blast in one direction (the surface acts as a free face, allowing movement in that direction). For this reason, blast holes within 25 feet of an existing pipeline must be drilled vertically or angled away from the pipeline as the hole gets deeper.

In all cases, the absolute minimum offset R is 12 feet.

7.0 ESTIMATING BLASTING LIMITS WITHOUT A PLAN

It is not the Company's responsibility to dictate charge weights to the party performing the blasting. Selecting the correct parameters for a safe and successful blast requires considerable expertise and involves considerable liability. This work should be left to the blasting experts. However, parties who will be contracting for work which will involve blasting near the pipelines often need to know for budgeting purposes approximately what limitations will be imposed, long before a Blasting Plan is developed. These parties will not be familiar with pipeline operating conditions and the effects of blasting on in-service pipelines. As a result, a preliminary list of blasting limitations may need to be provided by the Company.

In some cases, a single maximum charge weight for a known offset distance will suffice, or possibly a scaled distance may be specified. In other cases, the blasting limitations should include a tabulation of maximum allowable charge weights at various offset distances from any pipelines in the vicinity of potential blasting operations. The pipeline specifications, operating pressure, and class location must be considered in developing the tabulation.

A charge weight which should be acceptable as part of a properly developed Blasting Plan can be calculated by:

$$W_d = \frac{R^{2.5} \times \sqrt{E \times t}}{F_W \times {}^{n_S}\!/_{912}} \times \left[\frac{\sigma_a - \dfrac{P_m \times D}{2 \times t}}{F_C \times 4.44 \times E} \right]^{1.3}$$

If the horizontal distance to the pipeline is not known, a minimum 0.4-factor scaled distance (see Section 9.5) may be calculated by:

$$SD_{0.4} = \frac{R}{{W_d}^{0.4}} = \left(\frac{F_W \times {}^{n_s}\!/_{912}}{\sqrt{E \times t}} \right)^{0.4} \times \left(\frac{F_C \times 4.44 \times E}{\sigma_a - \frac{P_m \times D}{2 \times t}} \right)^{0.52}$$

Note that these formulas omit some of the adjustment factors, as they cannot be determined until a Blasting Plan is reviewed. F_W should be set to 1.2; an exception would be a Company project when it is made clear that unless a qualified Blasting Inspector (per Section 8.3) can confirm compliance, charges must be reduced by 20%. F_C should be set to 2.0 for trench blasting or where it is uncertain whether free faces will be present.

Since the blasting plans are unknown, the initial tabulation of allowable charge weights should be based upon conservative assumptions such as pressure at MAOP and an explosive with a relatively high specific energy, n_S, such as 1050 calories per gram (high end for commercial gels). This basis and all other qualifications should be communicated along with the calculated charge weight or scaled distance. Where allowable charge weights are very low and may inhibit successful blasting, the potential for reducing operating pressure during blasting should be investigated for possible adjustment of the allowable charge weights.

When transmitting the calculated maximum charge weight or minimum scaled distance to the requesting party, it is very important to clarify in writing that the value is approximate and being provided as a service; a properly designed Blasting Plan which meets that limit should prove acceptable.

The party selected for the project will then be requested to submit a detailed Blasting Plan for review by the Company to ensure that the Company criteria have been met. The contractor's Blasting Plan should clearly define the proposed charge weight limits, the type of explosives to be used along with their properties, etc. A "typical" plan is not acceptable, unless specific defined limits are included in the plan. Site specific Blasting Plans should be requested for locations with extreme rock confinement, such as large creek crossings.

No blasting is allowed until a complete Blasting Plan has been reviewed and accepted by the Company as meeting the Company criteria.

8.0 REQUIREMENTS DURING BLASTING

When the Blasting Plan evaluation indicates that the pipeline could be adversely affected if the blasting requirements are not followed, a qualified Company representative or Blasting Inspector should be present during blasting operations.

8.1 Responsibilities

The Company representative or Blasting Inspector should carefully review the Blasting Plan, confirm that the Blaster has a copy of the Blasting Plan, monitor the loading of explosives, and otherwise observe the blasting activities.

8.2 Qualifications of Company Representative

The Company representative should be familiar with this Technical Guideline and with the applicable SOPs, and should be able to perform the responsibilities listed above.

8.3 Qualifications of Blasting Inspector

In addition to the above requirements, a Blasting Inspector must be qualified by training and experience to inspect all facets of the blasting process and to verify that the Blasting Plan is being followed. An independent Inspector does not report to the party or company being inspected.

9.0 MISCELLANEOUS BLASTING ISSUES

9.1 Distribution of Explosive in Blast Hole

Although no specific requirements should be made, blasters should be encouraged to spread the explosive charges throughout the blast hole rather than loading all of the charge in the bottom of the hole. A slightly higher concentration near the bottom of the hole may be preferable due to the greater confinement. Proper distribution of the charges in the holes should result in lower stress levels since better rock fragmentation minimizes the residual energy remaining to cause vibrations and because the explosive is spread out and less concentrated.

9.2 Explosive Sensitivity

Some explosives are more sensitive to impact than others, and this can result in simultaneous ignition of adjacent holes where the delay caps were planned to fire at different intervals. As a result, a minimum hole spacing of three feet should be used where the sensitivity of the explosive is not known.

9.3 Considerations for Blasting in Water

The results of the Company's blasting tests provide no evidence that additional considerations should be made for blasting in water to compensate for possible simultaneous initiation of charges or for additional stresses that may be caused by the incompressible fluid. As a result, these guidelines apply to charges which are set off in water with no adjustments necessary.

9.4 Peak Particle Velocity

Blasters are familiar with designing shots to meet peak particle velocity (PPV) limits and with monitoring PPV to confirm that blasting vibrations are acceptable. PPV is readily measured, is recognized by regulatory agencies, and correlates fairly well with damage to buildings. Multiple studies, however, indicate that PPV correlates poorly to blasting-induced stress in pipelines. As a result, peak particle velocity limits are not imposed by this guideline and PPV monitoring is not required for protection of the pipeline. Blasters may wish to monitor PPV for their own purposes.

9.5 Scaled Distance

Blasters frequently use the concept of scaled distance. This is based on the principle that a given charge at a certain distance will have approximately the same effect as a larger charge at a larger distance, or a smaller charge at a smaller distance. The most commonly used form of scaled distance, based on the observation that vibration strength diminishes approximately as the square of the distance, is the distance in feet divided by the square root of the charge in pounds. A 9-lb blast at 60 ft has the same scaled distance, 20 $ft/lb^{0.5}$, as a 4-lb blast at 40 ft, and if square root scaled distance is valid should have approximately the same effect. Cube root scaled distance ($ft/lb^{0.333}$) is used for some blasting applications. Scaled distance is often reported in units of feet, making it difficult to tell what factor is being used in the scaling. The formula for blasting stress used in this guideline (Section 4.6) includes the charge weight divided by distance raised to the power 2.5, suggesting that scaled distance may be used if the units are $ft/lb^{0.4}$. The 0.4-factor scaled distance for a 9-lb blast at 60 feet would be:

$$SD_{0.4} = \frac{R}{W_a^{0.4}} = \frac{60 ft}{(9 lb)^{0.4}} = 24.9\, ft/lb^{0.4}$$

The equivalent charge at 40 feet would be:

$$W_{eq} = \left(\frac{R}{SD_{0.4}}\right)^{2.5} = \left(\frac{40 ft}{24.9\, ft/lb^{0.4}}\right)^{2.5} = 3.27 lb$$

This is significantly less than the equivalent charge at 40 feet calculated using square root scaled distance.

Scaled distance should only be used as an approximation; because of the other factors in the stress formula, a blast may be rejected even though it has the same 0.4 - factor scaled distance as one that is acceptable.

Appendix A: Sample Calculations

A1 BLASTING FOR HOUSE CONSTRUCTION; MANUAL CALCULATION

A1.1 Blasting Plan

A Contractor will be blasting to prepare basements for new home construction. The Blasting Plan indicates that he will be using 5 - 10 lb of ANFO (ammonium nitrate & fuel oil) per hole with an 8-ms delay between holes. Holes will be 12 - 14 feet deep plus 2′ subdrill, and will be spaced on a 3′ x 4′ grid. He will be removing 4 - 11 feet thickness of rock; rock thickness will be equal to explosive column height. Closest hole will be 30′ from the pipeline, which is 20″ x .312″ X-52 at 656 MAOP with 36″ cover in a Class 3 Location. Grade at nearest hole is 2′ higher than at pipeline; grade drops at 1:10 (V:H) on the far side of the pipeline from the blasting after a 10′ section of flat ground. It does not appear from the Blasting Plan that adequate lateral expansion room (a "free face" per Section 4.5) is provided for the blasting near the pipeline.

A1.2 Analyze The Largest Charge At The Closest Approach

D = Outside diameter of the pipeline: 20 in

E = Young's Modulus of Elasticity: 29,500,000 psi

P_a = Highest anticipated pressure in the pipeline: 656 psig

P_m = Maximum allowed pressure in the pipeline: 656 psig

S = Yield strength of the pipe metal: 52,000 psi

T = Thickness of pipe wall: 0.312 in

ρ_p = Density of pipe material:490 lb/ft^3

Drop = Grade drop over "run" feet: 1 ft

D_L = Distance grade remains level on far side of pipeline: 10 ft

Run = Run over which grade drops "drop" feet: 10 ft

H_C = Height of charge column: 11 ft

H_P = Pipe depth of cover: 3 ft

G = Grade at line relative to grade at nearest blast hole: -2 ft

R = Horizontal offset distance from pipeline to charge: 30 ft

G_C = Depth below grade of bottom of nearest charge including subdrill: 16 ft

n_S = Specific energy release of explosive (std for ANFO): 912 cal/gm

P_C = Charge spacing within rows: 3 ft

P_R = Spacing of charge rows: 4 ft

P_T = Thickness of rock to be blasted: 11 ft

PF_i = Ideal powder factor for area blasting: 1 lb/yd^3

W_d = Maximum charge weight per delay: 10 lb

W_h = Maximum charge weight per hole: 10 lb

ρ_S = Density of soil or rock between blast and pipeline: 200 lb/ft^3

τ_d = Delay time between charges: 8 ms

$$D_P = H_P + 0.5 \times D \times (1ft/12in) = 3 + 0.5 \times 20/12 = 3.833 \quad \text{(ft)}$$

$$D_{CP} = G_C + G - D_P = 16 + (-2) - 3.833 = 10.167 \quad \text{(ft)}$$

$$R_c = R = 30 \quad \text{(ft) because} \quad (H_C = 11) \geq (D_{CP} = 10.167) \quad \text{(ft)}$$

$$R_h = \sqrt{D_{CP}{}^2 + R^2} = \sqrt{10.167^2 + 30^2} = 31.676 \quad \text{(ft)}$$

$$H = \frac{R_h}{R}\left[D_t + \frac{D_P - \frac{D_{CP}\times D_t}{R}}{\frac{drop}{run}+\frac{D_{CP}}{R}}\right] = \frac{31.676}{30}\left[10+\frac{3.833-\frac{10.167\times 10}{30}}{\frac{1}{10}+\frac{10.167}{30}}\right] = 11.628$$

(ft) because $0 \le (D_t = 10) < \left(\frac{D_P\times R}{D_{CP}} = \frac{3.833\times 30}{10.167} = 11.311\right)$

and $\left(\frac{drop}{run}+\frac{D_{CP}}{R} = \frac{1}{10}+\frac{10.167}{30} = 0.439\right) > 0$

$$PF = \frac{W_h \times {}^{n_s}\!/_{900} \times 27\,{}^{ft^3}\!/_{yd^3}}{P_R\times P_C\times P_T} = \frac{10\times {}^{912}\!/_{900}\times 27}{4\times 3\times 11} = 2.073 \quad (\text{lb/yd}^3)$$

F_C = 2.0 because of lack of lateral expansion room.

$$F = \max\left[F_{DOT}, \frac{P_m\times D}{2\times S\times t}\right] = \max\left[\frac{656\times 20}{2\times 52{,}000\times .312}, 0.50\right] = \max[0.404, 0.50] = 0.50$$

$F_D = 1.15\times F = 1.15\times 0.50 = 0.575$ because $(F = 0.50) < 0.68$ and there are no known issues with this pipe to cause F_D to be set lower.

$F_H = 1.0$ because $\left(\frac{R_h}{H} = \frac{31.676}{11.628} = 2.72\right) \le 4$

$F_L = 1.0$ because (R > 200′ and D_{CP} > 100 and τ_d < 17 ms) is not true.

$F_P = \frac{PF}{1.2\times PF_i} = \frac{2.073}{1.2\times 1} = 1.728$ because $\left(\frac{PF}{PF_i} = \frac{2.073}{1} = 207\%\right) > 120\%$

$F_t = 2.0$ because (τ_d = 8) < 17 and (R_h = 31.676) < 100′ and (F_C = 2.0) > 1.0

$F_W = 1.2$ because the Company does not hire Blasting Inspectors for third-party projects.

$$\sigma_b = 4.44 \times F_C \times F_P \times F_L \times E \times \left(\frac{W_d \times F_W \times F_t \times n_S/900}{\sqrt{E \times t \times F_H} \times R_c^{\,2.5}} \right)^{0.77}$$

$$= 4.44 \times 2 \times 1.728 \times 1 \times 29{,}500{,}000 \times \left(\frac{10 \times 1.2 \times 2 \times 912/900}{\sqrt{29{,}500{,}000 \times 0.312 \times 1} \times 30^{2.5}} \right)^{0.77}$$

$$= 15{,}790 \quad \text{(psi)}$$

$$\sigma = \sigma_b + \frac{P_a \times D}{2 \times t} = 15{,}790 + \frac{656 \times 20}{2 \times 0.312} = 36{,}816 \quad \text{(psi)}$$

$$\sigma_a = F_D \times S = 0.575 \times 52{,}000 = 29{,}900 \quad \text{(psi)}$$

$$(\sigma_a = 29{,}900) < (\sigma = 36{,}816)$$

Blasting-induced stress is not acceptable.

A1.3 <u>Increased Blasting Distance</u>

To calculate the minimum acceptable distance for this Blasting Plan:

$$\sigma_b = \sigma_a - \frac{P_a \times D}{2 \times t} = 29{,}900 - \frac{656 \times 20}{2 \times 0.312} = 8{,}874$$

$$R = \left(\frac{W_d \times F_W \times F_t \times {}^{n_s}\!/_{900}}{\sqrt{E \times t \times F_H}} \right)^{0.4} \times \left(\frac{4.44 \times F_C \times F_P \times F_L \times E}{\sigma_b} \right)^{0.52}$$

$$= \left(\frac{10 \times 1.2 \times 2 \times 912/900}{\sqrt{29{,}500{,}000 \times 0.312 \times 1}} \right)^{0.4} \times \left(\frac{4.44 \times 2 \times 1.728 \times 1 \times 29{,}500{,}000}{8{,}874} \right)^{0.52}$$

$$= 40.7 \quad \text{(ft)}$$

$$R_h = \sqrt{D_{CP}{}^2 + R^2} = \sqrt{10.167^2 + 40.7^2} = 41.95$$

$$H = \frac{R_h}{R}\left[D_t + \frac{D_P - \dfrac{D_{CP} \times D_t}{R}}{\dfrac{drop}{run} + \dfrac{D_{CP}}{R}}\right] = \frac{41.95}{40.7}\left[10 + \frac{3.833 - \dfrac{10.167 \times 10}{40.7}}{\dfrac{1}{10} + \dfrac{10.167}{40.7}}\right] = 14.24$$

$F_H = 1.0$ because $\left(\frac{R_h}{H} = \frac{31.676}{14.24} = 2.22\right) \leq 4$ - unchanged

$F_L = 1.0$ because (R > 200′ <u>and</u> D_{CP} > 100 <u>and</u> τ_d < 17 ms) is <u>not</u> true - unchanged

F_H and F_L have not changed so a second iteration is not needed; Minimum offset for this Blasting Plan is 41′

A1.4 <u>Reduced Operating Pressure</u>

To calculate the maximum acceptable operating pressure for this Blasting Plan (at the originally proposed distance):

$$P_W = \frac{2 \times t \times (\sigma_a - \sigma_b)}{D} = \frac{2 \times .312 \times (29{,}900 - 15{,}790)}{20} = 440 \quad \text{(psig)}$$

A2 UNDERGROUND FUEL GAS EXPLOSIONS; SPREADSHEET CALCULATION

A2.1 Blasting Description:

A farmer wants to control groundhogs on his property by using a device which detonates a propane-oxygen mixture in the burrow. What is the minimum distance he must keep from the pipeline?

A2.2 Analysis:

The chemical reaction for combustion of propane in oxygen is:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Propane's volumetric proportion of the fuel-oxygen mixture filling the burrow is:

$$B_{fuel} = \frac{1C_3H_8}{1C_3H_8 + 5O_2} = \frac{1}{6} = 16.67\%$$

Note that if air was used instead of oxygen, there would be an additional 3.773 volumes of nitrogen for each volume of oxygen.

Fuel gas density can be obtained from standard references, or estimated from the ideal gas law. The density of propane at 60°F and atmospheric pressure is:

β_{fuel} = 0.1196 lb/ft^3

Internet research reveals that groundhog burrows can be 30 feet long, and are about 10 inches in diameter:

$$V_{burrow} = L \times \frac{\pi \times d^2}{4} = 30ft \times \frac{\pi \times (10in)^2}{4} \times \frac{1ft^2}{144in^2} = 16.36ft^3$$

So the quantity of explosive is:

$$W_d = V_{burrow} \times B_{fuel} \times \rho_{fuel} = 16.36ft^3 \times 16.67\% \times 0.1196 lb/ft^3 = 0.326lb$$

Specific energy release is the lower heating value for propane:

$$n_s = LHV = 19{,}807\frac{Btu}{lb} \times 0.5556\frac{cal/gm}{Btu/lb} = 11{,}004\frac{cal}{gm}$$

The values for the other blasting input factors are set as follows:

G = Grade at line relative to grade at nearest blast hole (ft): Set to zero

H_C = Height of charge column (ft): Set to approximate diameter of burrow (1 ft in this case)

R = Horizontal offset distance from the centerline of the in-service pipeline to the nearest explosive charge (ft): This will be the distance from the pipeline to the burrow entrance, minus the maximum expected length of the burrow (30′ in this case)

G_C = Depth below grade of bottom of nearest charge (ft): Set this to the depth of the bottom of the pipe (H_P + D/12)

P_C, P_R, P_T, PF_i, W_h = These values are used solely to calculate the factor F_P, which compensates for high or low powder factor. This type of blasting is in dirt instead of rock, so powder factor is not an issue. If calculating manually, ignore these variables and set F_P to 1. If using the blasting calculation spreadsheet, set PF_i to zero to indicate an isolated blast.

ρ_S = Density of soil or rock located between the blast and the pipeline (lb/ft^3) - Set to 120 lb/ft^3 to reflect the fact that rodent burrows are found in soil, not rock

τ_d = Delay time between charges (ms): Irrelevant to a single charge shot. Assign F_T a value of 1; on the spreadsheet setting PF_i to zero does this.

F_C = Confinement factor: Set to 2 to reflect confined charge

The following page shows the spreadsheet with these values entered. The Ctrl-Shift-H macro was used to determine that the blasting is acceptable for this particular pipeline at a closest approach of 37.8 feet. This means that the closest burrow entrance must be at least 38 feet + burrow length = 68 feet from the pipeline.

This spreadsheet is only to be used by persons familiar and comfortable with TG-111

LINE: Sample calculation of underground fuel gas explosion

LOCATION: somewhere

PIPELINE INPUT:
Cl = 1 - Class Location Area
Pm = 1170 - Maximum Allowable Operating Pressure (psig)
Pa = 1170 - Actual Operating Pressure - at point & time of blast (psig)
D = 24 - Pipe Outside Diameter (in)
t = 0.375 - Wall Thickness (in)
S = 52,000 - SMYS (psi)
E = 2.95E+07 - Modulus of Elasticity (psi)
rhoP = 490 - Pipe Density (pcf)

GEOMETRY INPUT:
R = 37.8 - Horiz Offset Dist. (ft) **(Ctrl-Shift-H to get minimum)**
Gc = 5 - Depth below grade of Bottom of Charge (ft)
Hc = 1 - Height of charge column (ft)
Hp = 3 - Cover to top of pipe, ft
G = 0 - Grade at line relative to grade at nearest charge, ft (<0 if line lower)
Dt = 100 - Level distance past pipeline (ft)
run = 25 - Horizontal component of slope past Dt (ft)
drop = 1 - Vertical component of slope past Dt (ft)

BLASTING INPUT:
ns = 11004 - Specific Energy Release (cal/gm)
Wd = 0 326 - Actual Charge Weight per Delay (lbm/delay)
Wh = 0.326 - Actual Charge Weight per Hole (lbm/hole)
td = 27 - Delay Time Interval (ms)
Pt = 0 - thickness of rock to be blasted, ft
Pc = 0 - blasting charge spacing within row (ft)
Pr = 0 - spacing of rows of blasting charges (ft)
PFi = 0 - Ideal PF (3 for trench; 1 for large area: 0 for isolated or widely-spaced shots)
conf = confined - Type of blast confinement
insp = no - Qualified Blasting Inspector verifies Plan being followed?
rhoS = 120 - Soil Density (pcf)

INTERMEDIATE VALUES:
Dp = 4.00 - Depth of Pipe Center (ft)
Dcp = 1.00 - Depth of bottom of charge below center of pipe
Rc = 37.80 - Distance from center of pipe to nearest point on charge column, ft
Rh = 37.81 - Distance from center of pipe to bottom of nearest charge, ft
H = 120 42 - Distance pipe center to surface on same line as Rh, ft
PF = #DIV/0! - Powder Factor (lb/yd3)
F = 0.72 - Pressure design factor (per DOT or Grandfathered)

ADJUSTMENT FACTORS:
Fc = 2.0 - Confinement factor
Fd = 0.78 - Blasting design factor (blasting + pressure)
Fh = 1.00 - Factor for low backing ratio
FL = 1.00 - Factor for large, deep column charges at great distance
Fp = 2.00 - Factor for high/low PF
Ft = 1.00 - Factor for high/low delay time
Fw = 1.2 - Factor for who is inspecting

RESULTS:
Distance between pipe & displacement zone = 25.0 ft
Stress from internal pressure = 72.0% of SMYS
Additional Stress from Blast = 3120 psi = 6.0% of SMYS
Actual Stress Level = 78.0% of SMYS
Allowable Stress Level = 78.0% of SMYS
Allowable Operating Pressure = 1170 psig

BLASTING IS ACCEPTABLE

Appendix B: References

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Hopler, Robert (Editor): Blasters' Handbook, 17th Edition, International Society of Explosives Engineers, Inc., ISBN 1-892396-00-9, 1998

Lambeth, Alan: Blasting Adjacent to In-Service Gas Pipelines, American Gas Association Transmission /Distribution Conference, Orlando, FL, May 17, 1993

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Appendix C

Specific Energy Release of Various Explosives

Equivalent energy release ratios (N) for some typical explosives are:

Explosive	(N)
ANFO (94/6)	1.00
AN Low Density Dynamite	0.99
COMP B (60/40)	1.12
COMP C-4	1.12
HBX-1	0.83
NG Dynamite (40%)	1.05
NG Dynamite (60%)	1.12
Pentolite (50/50)	1.11
RDX	1.16
TNT	0.98

Equivalent energy release ratios (N) for some currently available explosives are:

Manufacturer	(N)
Apache Powder Company	
Dynagel 205/High Explosive Water Gel	1.04
Dynagel 209/High Explosive Water Gel	1.15
Dynaprime Booster/High Explosive Water Gel	1.15
Dry Hole Blasting Agents	
Carbamite P	1.02
Carbamite PB	1.02

Atlas Powder Company	
Atlas 7D/High Explosive Permissible	0.84
Emulsion	
Apex Bulk Emulsions	
Apex 200BA & 300BA Series:	
220 - 320	0.76
240 - 340	0.86
260 - 360	0.96
Apex 1200 Series - Bulk:	
1220	0.75
1240	0.87
1260	0.95
Apex 1300 Series - Bulk:	
1320	0.75
1340	0.87
1360	0.95
Coalites/Permissible for Underground Coal	
Coalite BP	0.53
Coalite 5P	0.81
Coalite 6Y	0.79
Coalite 5MR	0.91
Coalite 5U	0.84
Coalite 5LR	0.85
Coalite 8S	0.89
Coalite 8R	0.88
Gelcoalite Z	1.01
Extra Dynamite/General Purpose Ammonia	0.87
Dynamite	
Florigel 330	0.92
Gelmax/Semigelatin Dynamite	1.02
Giant Gelatin	0.95

Hi-Prime/Multi-Purpose Primer	1.12
Petrogel	1.08
PowerAn	
Bulk	1.05
Packaged PowerAn 300	0.93
Packaged PowerAn 500	0.89
Powermax 120/Cap-Sensitive Emulsion	0.75
Powermax 140/Cap-Sensitive Emulsion	1.05
Powermax 420/Cap-Sensitive Emulsion	0.77
Powermax 440/Cap-Sensitive Emulsion	1.07
Power Primer/High Energy Ammonia Gelatin	1.20
Seis Prim/High Velocity Seismic Explosive	1.07
Dupont	
Aluvite 1	1.21
Aluvite 2	1.46
Aluvite 3	1.18
ANFO HD	1.00
ANFO-P	1.00
Nilite 303	1.00
Tovex TR-2	1.05
Tovite	0.98
Ireco	
Energel - 200 Blasting Agent	0.82
Energel - 400 Series Blasting Agents	
400	0.75
410	0.80
420	0.91
430	0.99
440	1.09

450	1.17
Gelamite/Semigelatin Dynamites	
Gelamite 1, 1-X	0.82
Gelamite 2, 2-X	0.82
Gelamite 5, 5-X	0.91
Gelamite D(b)	0.91
Powergel D	0.97
Gelaprime F/Gelatin Dynamite	1.00
Hercodyne/365 Nonnitroglycerin High Explosive	0.91
Hercol and Hercon/Ammonium Nitrate Dynamites	
Hercol 2, 2-X	0.72
Hercol 4, 4-X	0.72
Hercol Bag	0.72
Hercon 2, 2-X	0.80
Hercon 3, 3-X	0.80
Hercomix 1/Blasting Agent	0.88
Unigel - Semigelatin Dynamite	0.86
Unimite - Ammonium Nitrate High Explosive	0.82
Independent Explosives Company of Pennsylvania	
Comsol 50	1.04
Comsol 166	1.06
Comsol 266	0.99
Comsol 300	1.06
Unitegel	1.03
Nitrochem Energy Corporation	
Dellek 10 Blasting Agent	1.04
ML-400 Slurry	1.00

ML-500 Blasting Agent	1.01
ML-600 Series Bulk Load Slurries	
ML-600	1.06 - 1.11
ML-600P	1.00 - 1.06
ML-700 Series - Small Diameter Slurry	1.00
ML-800 Series - Small Diameter Slurry	1.16
MS-80 Blasting Agents - Metalized Slurries	
MS-80-0	0.78
MS-80-5	0.95
MS-80-10	1.06
MS-80-15	1.29
MS-80-20	1.44
MS-80-25	1.58
Temprel - Blasting Agents - Metalized Dry Mixes	
Temprel 3	1.23
Temprel 6	1.45
Temprel 9	1.61
Temprel 12	1.78
Temprel 15	1.89
Tromax L - Series Blasting Agents	
Tromax 75L	1.51
Tromax 95L	1.68
Tromax 149L	1.88
Thermex Energy Corporation	
Detagel/High Explosive Water Gel	0.89
Detagel HS/High Explosive Water Gel	0.96

Detagel LD/High Explosive Water Gel	0.93
Slurran 805/Water Gel Blasting Agent	0.98
Slurran 806/Water Gel Blasting Agent	1.00
Slurran 915/High Explosive Water Gel	0.89
Slurran 916/High Explosive Water Gel	0.95

Appendix D: Forms

- Blasting Plan Submittal Form (Form #7T-230)
- Blasting Near Pipelines (Form #7T-231)
- Guidelines for Completing Blasting Plan Submittal Form

Guidelines for Completing
Blasting Plan Submittal Form

- Blasting Contractor: Name of the company doing the actual blasting.
- Technical Contact: This should be someone familiar with the Blasting Plan who can answer questions about the details of what will be done and provide any clarifications needed.
- Date and time of blast: If not precisely known, a range should be provided. At least 24 hours advance notice is required prior to loading the holes.
- Distance from blast holes to nearest pipeline. This is measured to the nearest point on the pipeline, from both the closest and the furthest blast hole.
    - ➢ Based on: How was this distance determined? If by GPS, indicate whether consumer or survey grade equipment was used.
- Grade at pipeline: What is the elevation difference between the ground directly above the nearest point on the pipeline, and the surface at the nearest blast hole?
    - ➢ Based on: How was this elevation difference determined?
- Thickness of rock to be removed: What range of rock thickness is intended to be removed? This will be the basis for the powder factor.
    - ➢ Based on: How was this thickness range determined?
- Rock confinement: If the blast design allows rock to move laterally, provide details on how this will be done.
- Type explosive: Manufacturer and product name. Attach a cut sheet if available.

Guidelines for Completing
Blasting Plan Submittal Form

- Specific energy release: This is essential. The plan cannot be reviewed without this information.
- Maximum charge weights:
  - ➢ For a given rock thickness range, what is the largest charge per hole and per delay which will be used?
  - ➢ What is the minimum distance to the pipeline at which this maximum charge will be used?
  - ➢ If only one distance is provided for a charge, that is the closest at which that charge may be used.
  - ➢ Worst case combinations of charge and distance should be provided.

Charge per hole	per delay	Distance to pipeline
10 lb	10 lb	50 ft - ____ ft
20 lb	20 lb	80 ft - ____ ft
____ lb	____ lb	____ ft - ____ ft

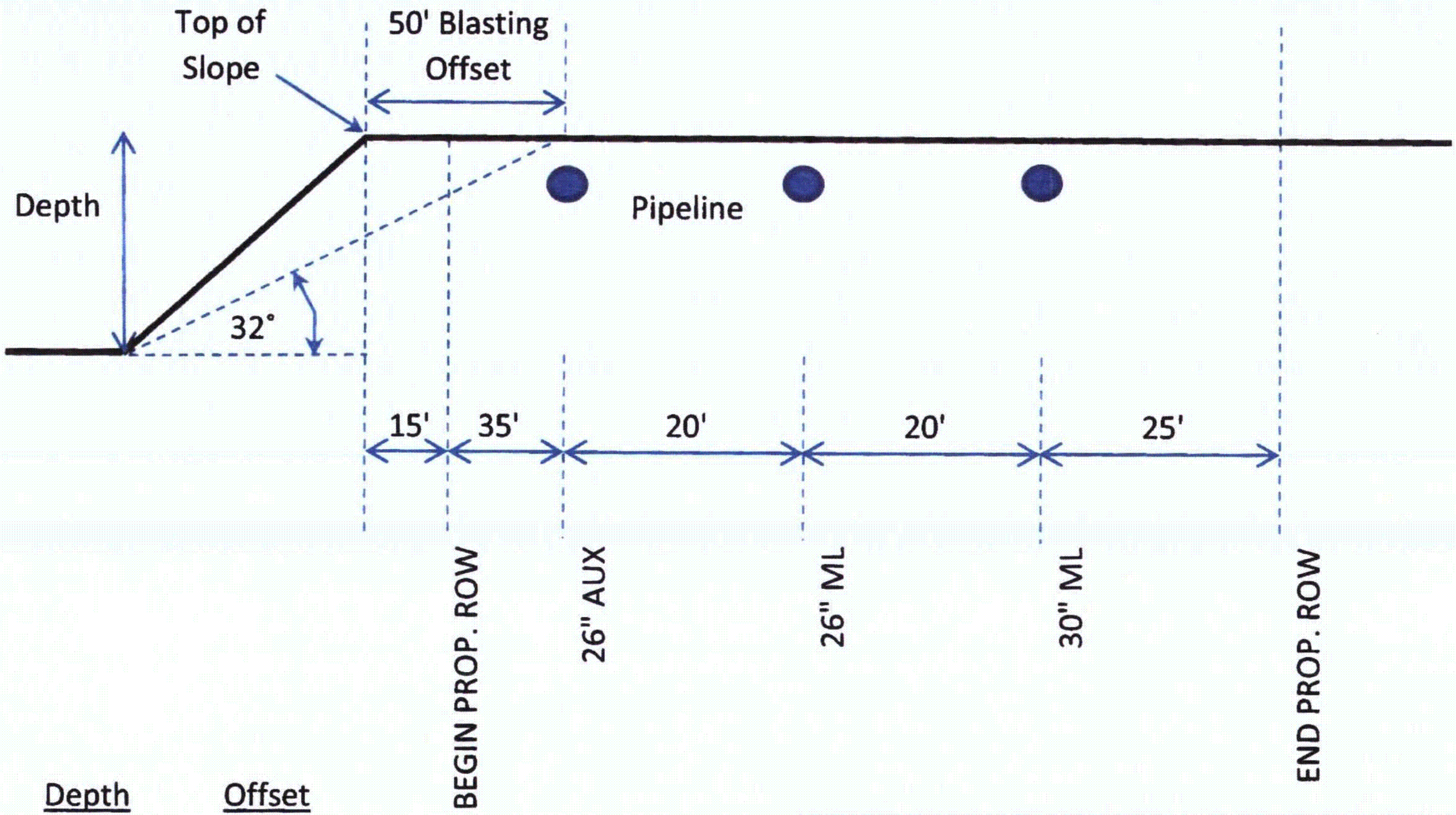
Charge weight example (assuming Blasting Plan is approved):

- ➢ No blasting allowed closer than 50′ from the pipeline.
- ➢ Maximum charge allowed 50′ - 79′ from the pipeline is 10 lb
- ➢ 20 lb maximum charges may be used at distances 80′ - 200′

Guidelines for Completing
Blasting Plan Submittal Form

- How will Blasting Contractor be monitoring the charge? How does Blasting Contractor know how much charge is going into each hole? (Not how the vibrations are being monitored.)
- Delay interval: shortest delay between any pair of charges.
- Holes per delay: Enter the number of holes firing within any 8-ms interval. If holes are decked, indicate as a fraction (1/2 indicates each hole has two decks firing at different times).
- Blast hole spacing: Include on the sketch if layout is not very simple.
- Hole depth: from ground surface to bottom of charges.
    - ➢ Subdrilling is included if charges will be placed below the desired bench or excavation level.
    - ➢ Do not include excess drilling that will be filled with stemming before charges are loaded.

  NOTE: Also provide depth of top of charge column.
- IMPORTANT: Attach a sketch showing blasting area and pipeline(s).
- Any deviation from this Blasting Plan as approved may result in shutting down the project:
    - ➢ Using lower charges or greater distances from the pipeline is OK as long as powder factor range is maintained.
    - ➢ Larger charges and/or closer to pipeline will not be allowed.



Depth	Offset
30	22.8
40	28.8
50	34.8
60	40.8
70	46.8

Algonquin Gas Transmission, LLC
Waltham, MA

**REQUIRED OFFSET FOR RELOCATED ROW
AT VALVE SITE 14-B
INDIAN POINT POWER PLANT, CORTLAND, NY**

Date: 11/23/2009	Scale: NTS	Rev: 0

Attachment 7

Precision Blasting and Rock Removal

Section 1:	**Blasting Feasibility Study for Conversion of Indian Point Units 2 and 3 to a Closed-Loop Cooling Water Configuration (Precision Blasting Services)**
Section 2:	**Breaker Program (Precision Blasting Services)**
Section 3:	**Blasting Program Insurance (Wortham Insurance and Risk Management)**

Attachment 7

Precision Blasting and Rock Removal

Section 1

Blasting Feasibility Study for Conversion of Indian Point Units 2 and 3 to a Closed-Loop Cooling Water Configuration

Prepared by Precision Blasting Services

BLASTING FEASIBILITY STUDY FOR CONVERSION OF INDIAN POINT UNITS 2 AND 3 TO A CLOSED-LOOP COOLING WATER CONFIGURATION

Prepared for

Enercon Services
Sam Beaver
500 TownPark Lane, Suite 275
Kennesaw, GA 30144-5509

Prepared by

Calvin J. Konya, Ph.D.
Precision Blasting Services
P.O. Box 189
Montville, OH 44064

February 2010

Executive Summary

The scope of work was to determine the feasibility, estimated duration and cost of blasting rock for the excavation related to the cooling tower configuration discussed in the Engineering Feasibility and Costs of Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration by Enercon Services, Inc. (Enercon Report), including blasting of rock trenches for the placement of the new 10 foot and 12 foot diameter piping for the closed loop cooling system (the trench excavation).

Preliminary blasting methods were determined, and charge weights were calculated, with vibration levels projected based on information available for similar rock types. The distances from the excavations to critical structures were determined, and vibration levels were calculated at these structures. The Indian Point Energy Center (IPEC) Updated Final Safety Analysis Reports (UFSAR) indicate that the Indian Point facility was built to safely withstand a seismic intensity of VII on the Modified Mercalli Scale. The operating basis earthquake (OBE)[1] would have a horizontal ground acceleration of 0.1 g. At an expected ground vibration frequency of 60 Hz, the 0.1 g acceleration translates to a peak particle velocity (PPV) of 0.1 inches per second, which is below standard blasting PPV limits. This vibration limit, as measured at each containment building, is therefore considered adequate to protect the structures and allow construction at the facility.

The drilling and blasting project would require ten rock drills and the project duration, if limited only by drill rate, would be 1.6 years. However, blasting at an operating nuclear reactor would be limited by additional site-specific considerations which are expected to increase the schedule duration by a factor of 2.5, as estimated in the Enercon Report. Therefore, the total project duration is expected to be approximately 4 years.

The volume of rock needed for excavation for the towers and tower bases would be 1,794,300 yd^3 for the two towers. The volume of rock of the trench excavation would be 94,600 yd^3. The total area of presplitting[2] on the perimeter of the excavation would be 61,080 yd^2. The estimated cost of drilling and blasting, a blasting consultant, and seismic monitoring are listed below:

	Rate	Quantity	Cost	
Cooling Towers Drilling and Blasting	\$15/yd^3	1,794,300 yd^3	\$	26,914,500
Trench Rock Drilling and Blasting	\$58/yd^3	94,600 yd^3	\$	5,486,800
Precision Presplitting	\$85/yd^2	61,080 yd^2	\$	5,191,791
Blasting Consultant	\$2,000/day	800 days	\$	1,600,000
Seismic Monitoring (6 seismographs)	\$26,140/month	34 months	\$	888,760
		Total	**\$**	**40,081,851**

Project duration and costs were also calculated independently for Unit 2 and Unit 3. This estimate does not include the cost of spoils removal or insurance for the project. As noted in Section 3 of this Attachment, obtaining insurance for the project is not assured.

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[1] Based on seismic analysis of the region, an OBE is defined as having a horizontal ground acceleration of 0.1 g and a vertical ground acceleration of 0.05 acting simultaneously at zero period. The nuclear steam supply systems were designed to be capable of continued safe operation in the event of an OBE.

[2] Presplitting controls excessive rock breakage beyond the desired edge of excavation. Lightly-loaded, closely-spaced blasts are pre-fired to fracture a plane across which radial cracks from the production blast cannot travel.

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1 Introduction

This Report assesses the feasibility of blasting rock for the excavation of the cooling towers proposed by the New York State Department of Environmental Conservation (NYSDEC) for IPEC Units 2 and 3 (collectively, the Stations, individually Unit 2 and Unit 3), including blasting of the rock trenches for the placement of the 10 and 12 foot diameter piping for the closed loop cooling system. This Report considers the vibration levels generated by expected blasting to determine whether the blasting could be done safely. To reach a feasibility determination, relevant seismology information concerning IPEC was obtained from the Updated Final Safety Analysis Report (UFSAR) [Ref. 11.5, Ref. 11.6]. Local blast vibration ordinances, as well as industry-standard blasting safety procedures, were also considered for determining vibration limits.

The Stations are designed to withstand an operating basis earthquake (OBE) with a horizontal ground acceleration of 0.1 g [Ref. 11.5, Ref. 11.6]. The 0.1 g limit and the corresponding seismic monitoring equipment at IPEC are designed to protect against and detect ground acceleration corresponding to earthquakes. Blasting would produce ground motion at higher frequencies and shorter durations than an earthquake; due to this difference, the 0.1 g acceleration limit applied to blasting would hold ground motion and peak particle velocities to conservatively low levels compared to the earthquake motion and velocities the Stations are designed to withstand. To protect sensitive nuclear facility equipment, the 0.1 g limit is considered appropriate for this Report. Therefore, a limitation of 0.1 g horizontal ground acceleration was used to develop the preliminary blasting plan. The effect of blasting vibrations on sensitive equipment throughout the facility would need to be carefully analyzed before a blasting limitation was finalized.

Based on the 0.1 g limitation, preliminary blasting methods were determined and charge weights were calculated. The vibration levels were projected with information in similar rock types. The distances from the excavations to the reactor containment buildings were determined and vibration levels were calculated at these structures. Along with the blast designs, a further task was to determine reasonable costs (in 2009 dollars) to accomplish the drilling and blasting.

2 Blasting Limitations for Indian Point

Limits for blasting operations at IPEC, based on vibration limits, were determined by several considerations: nuclear facility design, local ordinances, and onsite third-party natural gas pipeline restrictions.

2.1 Nuclear Facility Design

Vibration limits for the Stations correspond to the seismic design basis, i.e., the safety related equipment, components and structures of the plant were designed to withstand an earthquake of the highest intensity which can reasonably be predicted from geologic and seismic evidence developed for the site. The seismic design basis for the Indian Point facility is based on an earthquake of intensity VII on the Modified Mercalli Scale [Ref. 11.5, 11.6]. The maximum expected horizontal acceleration of ground motion for earthquakes of this intensity is about 0.15 g. Thus, the IPEC facility is designed to safely withstand a 0.15 g design basis earthquake (DBE).[3] Based on seismic analysis of the area, the OBE[4] for the Stations was defined as having a horizontal acceleration of 0.1 g and a vertical acceleration of 0.05 g acting simultaneously at zero period. The Stations were designed to be capable of continued safe operation in the event of an OBE.

The IPEC seismic design basis protects against ground acceleration corresponding to earthquakes, which is not directly equivalent to ground vibrations corresponding to blasting. An earthquake is a regional event with low frequency vibration which decays miles from the source, while blasting is a local event producing high frequency vibrations which rapidly decay in a matter of feet. Earthquake frequencies are generally less than 1 Hz while blasting frequencies for close proximity construction blasting are above 50 Hz. At the same measured particle velocity, the movement (displacement) of the earth is greater in earthquakes than in blasting, as shown in Table 2.1.

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[3] The DBE was selected to be the largest potential ground motion at the site based on seismic and geological factors and their uncertainties. In the case of the DBE, the Stations were designed to ensure that components required to shut the plant down and maintain it in safe shutdown condition do not lose their capability to perform their safety function [Ref. 11.5; Ref. 11.6].

[4] The OBE was selected to be typical of the largest probable ground motion based on the site seismic history. For the OBE loading condition, the nuclear steam supply systems were designed to be capable of continued safe operation [Ref. 11.5; Ref. 11.6]. On-site seismic monitoring equipment is triggered by a horizontal acceleration of 0.01 g to record vibrations caused by strong local earthquakes and provide retrievable data on the magnitude, duration, frequency and direction of seismic events [Ref. 11.8]. If the OBE horizontal acceleration of 0.1 g or vertical acceleration of 0.05 g is detected, an alarm in the Control Room initiates an abnormal operating procedure [Ref. 11.7].

Table 2.1 Comparison of Earthquake and Blast Vibration Displacement

MERCALLI MAGNITUDE	**RICHTER SCALE**	**PPV at 1 Hz (in)**	**DISP at 1 Hz (in)**	**DISP at 50 Hz (in)**
I	-1 to 3.5	0.002 to 0.35	0.0003 to 0.0557	6.37E-06 to 0.0011
II	3.5 to 5.4	0.35 to3.5	0.0557 to 0.5570	0.0011 to 0.0111
III	3.5 to 5.4	0.35 to3.5	0.0557 to 0.5570	0.0011 to 0.0111
IV	3.5 to 5.4	0.35 to3.5	0.0557 to 0.5570	0.0011 to 0.0111
V	3.5 to 5.4	0.35 to3.5	0.0557 to 0.5570	0.0011 to 0.0111
VI	3.5 to 5.4	0.35 to3.5	0.0557 to 0.5570	0.0011 to 0.0111
VII	5.4 to 6.0	3.5 to 6.3	0.5570 to1.003	0.0111 to 0.0200
VIII	6.1 to 6.9	7.0 to 17.7	1.114 to 2.810	0.0222 to 0.0563
IX	7.0 to 7.9	19.9 to 56	3.168 to 8.917	0.0634 to 0.1780
X	Over 8.0	Above 62.8	Above 10.000	Above 0.2000
XI	Over 8.0	Above 62.8	Above 10.000	Above 0.2000
XII	Over 8.0	Above 62.8	Above 10.000	Above 0.2000

The difference between earthquake and blasting vibration frequency also affects the relationship between ground vibration acceleration and PPV. For a given ground vibration acceleration, earthquake vibration would have a higher PPV than blast vibration. The equation to find the peak particle velocity corresponding to a given acceleration is as follows:

$$PPV = \frac{GA}{2\pi F}$$

where:

PPV = peak particle velocity in inches/second (in/s^2)

A = acceleration (g)

F = frequency (Hz)

G = gravitational constant (~386.1 in/s^2)

A comparison of the earthquake and the blast vibration PPV corresponding to OBE acceleration limits at IPEC is shown in Table 2.2. The IPEC facility is built on a bedrock foundation of Inwood marble (a crystalline metamorphic rock "made from" limestone with considerable heat and pressure). In dense limestone/marble, blasting would produce an expected vibration frequency of 60 Hz, as measured at the containment building [Ref. 11.13].

Table 2.2 Earthquake and Blast Vibration PPV Comparison

IPEC OBE Acceleration		**Earthquake Frequency**	**Blast Vibration Frequency**
		1 Hz	*60 Hz*
Horizontal	0.1 g	6.1 in/s	0.10 in/s
Vertical	0.05 g	3.1 in/s	0.05 in/s

Although the OBE vertical acceleration limit is only half that of the horizontal limit, the vertical component of blast vibrations dissipates with distance from the blast far more quickly than the horizontal component. This difference is due to the unrestricted motion of the free surface of the earth in the vertical direction. For the majority of the distances considered in this Report, vibration calculations show that the OBE horizontal acceleration would be limiting. In the Unit 2 pipe trench, blasting the 5-10 feet of trench closest to the Riverfront would be limited by the OBE vertical acceleration. The portion of the blasting affected by the vertical acceleration limit represents a small fraction of the total project. The blast plan would therefore be based on the horizontal acceleration limit, with additional measures implemented to meet the vertical acceleration limit in the small portion of Unit 2 trench near the Riverfront.

In addition to the difference in frequencies, earthquake and blast vibration occur over very different durations. An earthquake vibration typically occurs over a duration of seconds, whereas blast vibrations are measured in milliseconds. The shorter duration of blast vibrations could minimize the potential impact of blasting on equipment and sensors at IPEC.

Due to the differences between earthquake and blast vibration, the 0.1 g horizontal ground acceleration limit applied to blasting would hold ground motion and particle velocities to conservatively low levels compared to the earthquake motion and particle velocities the plant is designed to withstand.

On-site seismic monitoring equipment is designed to detect typical earthquake frequencies and accelerations and may not respond to blasting in the same manner due to the higher frequencies and shorter duration. It would be necessary to test the sensors before full-scale blasting operations commenced to ensure accurate operation.

2.2 Local Ordinances

New York State law and Village of Buchanan ordinances regulate blasting noise and vibration. The local ordinances that could impact the blasting project are shown in Table 2.3.

Table 2.3 Ordinances for the Village of Buchanan

Ordinances		
Code of the Village of Buchanan		
Chapter	119	Noise
	143	Quarrying and Blasting
	159	Soil Disturbances and Excavations
	203	Wetlands
	211	Zoning
New York State Department of Labor Regulations		
Part	23	Subpart 11. Use of Explosives
	39	Possession, Handling, Storage and Transportation of Explosives
New York State Code		
Rule	753	Protection of Underground Facilities

In Chapter 143, the Village of Buchanan specifies maximum PPV for vibration, and restricts blasting times and durations. Blasting hours are specified as Monday through Friday from 8 am to 7 pm, excluding holidays. However, blasting would not occur when these hours would be in darkness, in accordance with accepted, regulated industry practice. Therefore, in winter months blasting may be restricted to only eight hours per day rather than the eleven hours designated by this ordinance. The PPV limits are based on the frequency of the maximum vibration, as shown in Table 2.4. Vibration and airblast limits apply to the closest structures not owned by the entity or property conducting the blasting.

Table 2.4 Buchanan Quarry and Blasting Limits

<table>
<tr><th colspan="4">Buchanan - Chapter 143 - Quarrying and Blasting</th></tr>
<tr><td>Regulation</td><td colspan="2">Specifications</td><td>Notes</td></tr>
<tr><td>Blasting Hours</td><td>8am - 7pm</td><td></td><td>Limited to daylight hours</td></tr>
<tr><td>Blasting Days</td><td>M - F</td><td>Excludes public holidays</td><td></td></tr>
<tr><td rowspan="2">PPV Limits</td><td>0.75 in/sec</td><td>Frequencies < 40 Hz</td><td rowspan="5">PPV and overpressure limits apply to the closest structure or building not owned or used by the entity conducting the blast</td></tr>
<tr><td>2 in/sec</td><td>Frequencies ≥ 40 Hz</td></tr>
<tr><td rowspan="3">Overpressure Limits</td><td>131 dB</td><td>High pass filter of 0.1 Hz</td></tr>
<tr><td>128 dB</td><td>High pass filter of 2 Hz</td></tr>
<tr><td>125 dB</td><td>High pass filter of 6 Hz</td></tr>
</table>

Airblast attenuates with distance at a faster rate than ground vibration; therefore, if blast vibrations are at a safe limit, the overpressure on a properly designed blast would also be at a safe level. The Buchanan airblast limit of 131 dB can be met at the nearest off-site structure, a gypsum drywall manufacturing facility near the southwest IPEC property boundary.

2.3 Blasting Adjacent to In-Service Pipelines

The Algonquin Gas Transmission (Algonquin) pipeline crosses through the IPEC site to the south of Unit 3. The Algonquin pipeline would need to be relocated to accommodate the construction of the Unit 3 cooling tower. Spectra Energy Transmission, LLC (Spectra), owner and operator of the Algonquin pipeline, has proposed an allowable blasting offset as part of a preliminary relocation plan (Enercon Report, Attachment 6). Spectra Guideline TG-111 specifies a calculation to determine a maximum allowable charge weight based on distance from the pipeline. At the edge of the proposed blasting offset, 50 feet from the relocated pipeline, the maximum allowable charge weight would be 52.62 lbs.

2.4 Summary of Blasting Limits and Parameters

The blasting limits imposed by nuclear facility design, local ordinances, and the onsite gas transmission pipeline are summarized in Table 2.5. As discussed in the following sections, the most restrictive limitation for most of the excavation would be the 0.1 g horizontal ground acceleration limit. The vibration control techniques required to meet the horizontal acceleration limit, as measured at the containment building, would result in PPV and charge weights within the limits specified by Spectra Guideline TG-111 and the Village of Buchannan Code. Additional vibration control techniques beyond those employed to meet the horizontal acceleration limit would be necessary in only one location: the 5-10 feet of Unit 2 piping trench excavation adjacent to the Riverfront area. These additional measures would be required to meet the vertical ground acceleration limit and are described in the following sections of this Report.

Table 2.5 Vibration Limitations

Measurement Location	Limit	Reference
Containment Building	0.1 g	IPEC 0-AOP-Seismic-1. Horizontal. Freq. 2 to 25.4 Hz
	0.05 g	IPEC 0-AOP-Seismic-1. Vertical. Freq. 2 to 25.4 Hz
Alqonguin Pipeline	52.62 lbs/delay	Spectra Guideline TG-111. 50 ft from Pipeline.
Site Boundary	0.75 in/sec	Village of Buchanan Code, Chapter 143. Freq. < 40 Hz
	2 in/sec	Village of Buchanan Code, Chapter 143. Freq. ≥ 40 Hz

As discussed in Section 2.1, a blast plan designed in accordance with seismic acceleration limits would hold ground motion and particle velocities to conservatively low levels compared to those corresponding to an earthquake the plant is designed to withstand. Therefore, the seismic limits are considered appropriate for this preliminary evaluation. However, additional testing and analysis on the effects of vibration on individual components of the plant would be required to finalize a vibration limit. In addition, the background vibration due to the normal operation of the plant would need to be measured near sensitive components, for comparison to the proposed blasting vibration limits.

As further discussed in Section 3.1.2, the magnitude of ground vibration is a function of the distance from the blast. The minimum distance from the containment buildings to the blasting areas are shown in table Table 2.6, as determined by Enercon (Enercon Report, Attachment 2).

Table 2.6 Minimum Distances to Containment buildings

Unit	Component	Distance
2	Cooling Tower Excavation	510 ft
	Piping Trench	240 ft
3	Cooling Tower Excavation	440 ft
	Piping Trench	500 ft

The excavation quantities that may need blasting are shown in Table 2.7, as predicted by Enercon. To ensure adequate air flow, a circular clearing of 700 ft in diameter would be excavated around the towers to 30 ft elevation above mean sea level. The tower basin would require an additional 10 ft of excavation under the tower diameter of 525 ft.

Table 2.7 Excavation Quantities [yd^3]

Location	Unit 2	Unit 3	Both
Tower Clearing	693,100	940,800	1,633,900
Tower Basin	80,200	80,200	160,400
Piping Trenches	70,100	24,500	94,600
Total	**843,300**	**1,047,200**	**1,888,900**

3 Blasting Methods

3.1 Factors Affecting Blast Vibration

3.1.1 Principal Factors

There are two principal factors that affect the vibration level that results from detonation of an explosive charge: distance and charge size. Consistent with common sense, generally speaking, it is safer to be farther away from a blast, than to be near it, and a large explosive charge will be more hazardous than a small charge of the same type under the same conditions. The charge sizes that could feasibly be used for blast removal at Indian Point would be limited by the minimum distance from the blasting site to either containment building.

3.1.2 Charge-Distance Relationship

Extensive research has been conducted to determine the mathematical relationship between vibration level, charge size, and distance. This relationship is known as the Propagation Law, developed in the U.S. Bureau of Mines Bulletin 656 [Ref. 11.10]:

$$V = H\left[\frac{D}{W^{\alpha}}\right]^{\beta}$$

where:

V = Predicted particle velocity (in/s)

W = Maximum explosive charge weight per delay (lbs)

D = Distance from shot to sensor measured in 100's of feet (e.g., for distance of 500 feet, $D = 5$)

H = Particle velocity intercept

α = Charge weight exponent

β = Slope factor exponent

The values of α, β and H are determined by conditions in the area, rock type, local geology, thickness of overburden and other factors. The α, β and H values are slightly different for each component of the particle velocity. For the longitudinal or radial component, the law is numerically expressed as:

$$V_r = 0.052\left(\frac{D}{W^{0.5}}\right)^{-1.6}$$

Expressing D in feet instead of hundreds of feet produces a simplified approximation for this relationship:

$$V = 100\left(\frac{d}{\sqrt{W}}\right)^{-1.6}$$

where:
d = Distance from shot to sensor (ft)
W = Maximum explosive charge weight per delay (lbs)

The values of $\alpha = 0.5$ and $\beta = -1.6$ are fairly well fixed. The value of H can be highly variable from site to site and is influenced by many factors; therefore, H must be determined empirically through the ground calibration procedure discussed in Section 3.4. Ground calibration is used to determine a safe working value for the scaled distance, which is defined as distance in feet divided by the square root of the charge size per delay.

The DuPont Blaster's Handbook [Ref. 11.3] uses a higher value for H:

$$V = 160\left(\frac{d}{\sqrt{W}}\right)^{-1.6}$$

Obviously, the DuPont formula will give a higher value for the expected particle velocity. The approximate constant values stated by Bulletin 656 and the DuPont Handbook provide theoretical estimates of particle velocity; however, site specific measurements are needed to accurately characterize the effects of on-site blasting.

3.1.3 Charge Weight

The charge size that could be used for blast removal at IPEC can be estimated using the Propagation Law:

$$V = H\left(\frac{d}{\sqrt{W}}\right)^{-1.6} = H\frac{W^{0.8}}{d^{1.6}} \rightarrow W \approx d^{2}\left(\frac{V}{H}\right)^{1.25}$$

where:
V = Predicted particle velocity (in/s)
W = Maximum explosive charge weight per delay (lbs)
d = Distance from shot to sensor (ft)
H = Particle velocity intercept (160, Ref. 11.3)

At blasting vibration frequencies of 60 Hz and 40 Hz, the predicted maximum charge size per delay that could be used to meet the 0.1 g limit was calculated with respect to distance from the containment buildings as shown in Table 3.1.

Table 3.1 Pounds per Delay, Frequency and Distance

Distance	Explosive Pounds/Delay	
(ft)	For 60 Hz	For 40 Hz
240	5.69	9.45
250	6.18	10.25
300	8.89	14.76
350	12.11	20.10
400	15.81	26.25
440	19.13	31.76
450	20.01	33.22
500	24.71	41.01
510	25.70	42.67
550	29.89	49.62
600	35.58	59.06
650	41.75	69.31
700	48.42	80.38
750	55.59	92.28
800	63.25	104.99
850	71.40	118.52
900	80.05	132.88
950	89.19	148.05
1000	98.82	164.05

As shown in Table 2.6, the minimum distance from the Unit 2 cooling tower excavation to the containment building would be approximately 510 ft. The distance between the Unit 3 cooling tower excavation and the containment building would be approximately 440 ft. Assuming an expected blasting frequency of 60 Hz, the maximum allowable charge weights at the edge of the Unit 2 and Unit 3 tower excavation areas would therefore be 25.70 lbs/delay and 19.13 lbs/delay, respectively. Also shown in Table 2.6, the minimum distance from the Unit 2 piping trench excavation to the containment building would be approximately 240 ft. The distance between the Unit 3 piping trench excavation and the containment building would be approximately 500 ft. At an expected blasting frequency of 60 Hz, the maximum allowable charge weights at the edge of the Unit 2 and Unit 3 trench excavation areas would therefore be 5.69 lbs/delay and 24.71 lbs/delay, respectively. These maximum charge weight predictions were used to develop the blasting plan at IPEC, using a variety of vibration control methods to adhere to the maximum charge sizes calculated and limit blasting vibrations to the 0.1 g limit. Should the actual blasting frequency be lower than 60 Hz, more pounds per delay could be used to maintain acceleration less than 0.1 g.

3.2 Vibration Control

The Propagation Law provides a means of convenient, effective vibration control, allowing the prediction of vibration levels based on charge size and distance. Other techniques to control blast vibration have been developed to increase blasting efficiency and flexibility.

3.2.1 Delay Blasting

A delay cap allows a large explosive charge to be detonated as a series of small charges, rather than one large charge. Reduction in charge size can be made by the use of multiple delays. For example, the use of ten delays would reduce the effective vibration generating charge to one tenth the original charge.

Consider the following example:

A shot consists of 40 holes, 250 lbs. of explosive per hole with a total charge of 10,000 lbs. and is fired instantaneously. The probable vibration level can be calculated at a distance of 1,000 feet.

①①①①① ①①①①① ①①①①① ①①①①①

①①①①① ①①①①① ①①①①① ①①①①①

40 Holes Fired Instantaneously

$$V = 100\left(\frac{1000}{\sqrt{10000}}\right)^{-1.6} = 2.51 \text{ inch/sec}$$

This is a dangerously high particle velocity; two delays were introduced to reduce the vibration level. This divided the shot into two parts of 20 holes each, with 5,000 lbs. per delay.

MS2 ②②②②② ②②②②② ②②②②② ②②②②②

MS1 ①①①①① ①①①①① ①①①①① ①①①①①

20 Holes Fired Per Delay

$$V = 100\left(\frac{1000}{\sqrt{5000}}\right)^{-1.6} = 1.44 \text{ inch/sec}$$

If two more delays MS3 and MS4 were introduced, reducing the number of holes per delay to 10 and the charge per delay to 2,500 lbs., the probable particle velocity can be calculated.

MS3 ③③③③③ ③③③③③ ④④④④④ ④④④④④ MS4

MS1 ①①①①① ①①①①① ②②②②② ②②②②② MS2

10 Holes Fired Per Delay

$$V = 100\left(\frac{1000}{\sqrt{2500}}\right)^{-1.6} = 0.83\,\text{inch/sec}$$

Thus, a significant reduction in vibration level can be achieved by the use of delays. The effectiveness of delay blasting in reducing vibrations depends on the difference between particle velocity and propagation velocity, each discussed below.

3.2.2 Propagation Velocity vs. Particle Velocity

Propagation velocity is the speed at which a seismic wave travels through the earth from shot to sensor and beyond. The general range of values is from 1,000 to 20,000 ft/s. For a given area, the value is approximately constant.

Particle velocity is quite different. A rock particle vibrates in an elliptical orbit around a rest position. A simple example of particle motion and velocity is the motion of a fisherman in a dory. A passing speedboat generates a wave that passes under the fisherman, causing his boat to oscillate up and down. This is a particle motion. The speed at which it oscillates is particle velocity. Particle velocity is measured in inches per second (in/s), and is the parameter measured by the seismograph.

Delay blasting reduces ground vibration because the seismic wave generated by one delay has traveled a considerable distance due to its propagation velocity before the next delay has fired. The second seismic wave travels at the same propagation velocity as the first and can never catch up to the first. So the seismic waves or vibrations are separated. The following Figure 3.1 illustrates the process.

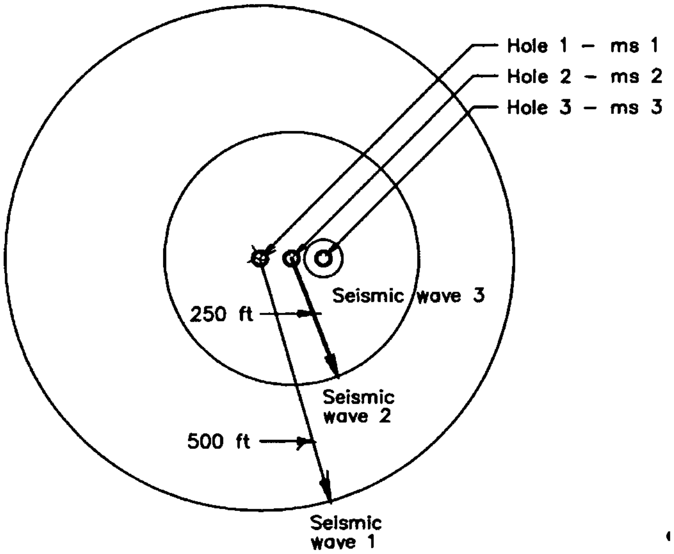

Figure 3.1 Seismic Waves from Delay Blasting

3.2.3 Charge Reduction

The maximum charge per delay may be reduced by decreasing the number of blastholes fired per delay. If the number of holes per delay cannot be reduced, then it may be possible to deck load the blastholes. Deck loading is accomplished by using drill cuttings or crushed stone to separate several decks of explosive loaded into the same hole. Each deck in the hole can then be fired individually at different delay times. Deck loading is more time consuming and expensive than shooting a single column of explosive in a blasthole. At IPEC, deck loading would be used in the locations nearest to the containment buildings. At greater distances, an entire blasthole could be fired.

3.2.4 Blast Design

The vibration level can be reduced by redesigning the blast so that less energy per hole is necessary to fragment the rock. This may require changing the hole spacing, the burden and even the hole size. A change in explosive may be helpful also.

3.3 Overbreak Control

Blasting techniques have been developed to control overbreak at excavation limits. Overbreak is defined as the excessive breakage of rock beyond the desired excavation limit. Three types of overbreak control methods have been developed: presplitting, trim blasting and line drilling.

Presplitting utilizes lightly-loaded, closely-spaced drill holes, fired before the production blast. The purpose of presplitting is to form a fracture plane across which the radial cracks from the production blast cannot travel. Secondarily, the fracture plane formed may be cosmetically appealing and allow the use of steeper slopes with less maintenance. Presplitting is a protective measure to keep the final wall from being damaged by production blasting.

Trim blasting is a control technique used to clean up a final wall after production blasting has taken place. The trim row of blastholes along a perimeter is the last to fire in a production blast and does not protect the stability of the final wall.

Line drilling is an expensive technique that can be used in conjunction with either presplitting or trim blasting to produce a cosmetically appealing final wall, under the proper geologic conditions.

The appropriate overbreak control technique for any project is selected based on the relative importance of stability and cosmetic considerations. For the IPEC excavation considered in this Report, presplitting would used to control overbreak and provide stability to the excavation limits.

3.4 Ground Calibration

Ground calibration should be done when entering a new area or starting a new project. As discussed in Section 3.1, the principal factors that affect vibration level are charge weight and distance. The relationship between vibration level, charge weight, and distance is determined by site-specific factors that influence the transmission of vibration, i.e., rock type, rock density, presence or absence of rock layering, slope of layers, nature of the terrain, blasthole conditions, and the presence or absence of water. The simplest way to evaluate these factors is by observation of the vibration levels generated. This is called ground or area calibration.

Ground or area calibration can be accomplished using data from a series of blasts. The on-site test uses the Propagation Law to design a test blast that is about 10% of the site-specific vibration limit. Designing the test blast to 10% of the vibration limit ensures that any error in the initial approximate values of α, β and H will not result in vibrations exceeding the determined limit. Seismic measurements of the vibrations resulting from the 10% test blast are used to determine the site-specific constants for use in the blasting plan. A minimum number of five test shots will serve as a starter, with more data added as additional shots are fired and recorded. The method synthesizes the many factors affecting vibration transmission and enables the operator to determine a safe working value for the scaled distance. Once the scaled distance is adequately determined, all shots should generate vibration levels less than the corresponding particle velocity.

3.4.1 Example Ground Calibration in Traprock (Diabase)

An example of site specific ground calibration is shown in Figure 3.2 for Traprock in New Jersey. The line on the graph is the ground vibration prediction line using the US Bureau formula. The 95% confidence line is the site specific prediction equation generated from actual data.

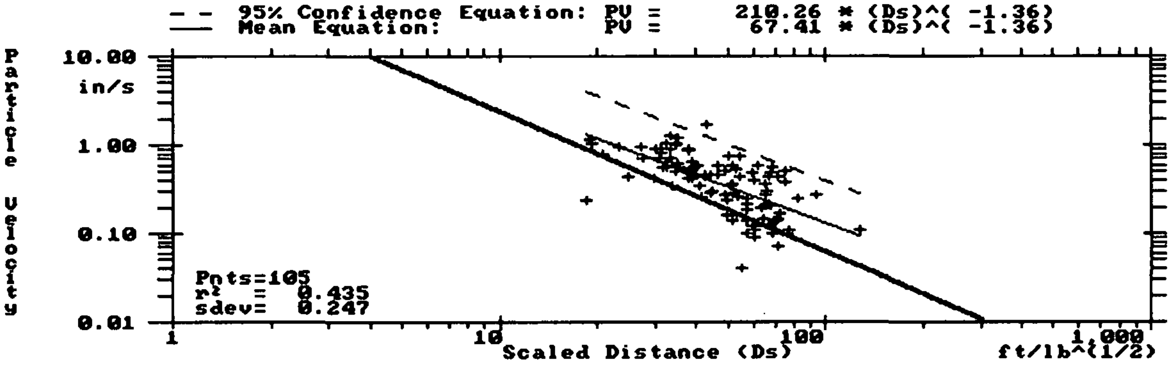

Figure 3.2 Site Specific Prediction Equation for Diabase

The 95% Confidence Equation at the top of Figure 3.2 can be used to predict different charge weights for specific vibration limits at different distances. An example set of predicted maximum charge weights that can be used at different distances to meet specific PPV limitations are shown in Table 3.2.

Table 3.2 Charge Weight/Delay, PPV at Specified Distances

DISTANCE (FT)	PPV			
	0.25 IPS	0.50 IPS	1.0 IPS	2.0IPS
330	5.3 lb	14 lb	41 lb	114 lb
960	45 lb	124 lb	346 lb	962 lb
1660	134 lb	372 lb	1035 lb	2880 lb

3.5 Vibration Standards

Vibration standards are the result of more than eighty years of research and investigation by concerned scientists. Standards have been developed for blasting near many types of structures, which can be generally classified as residential and industrial structures. Residential structures are the weakest type of construction, and represent the structure of highest concern under typical blasting circumstances. Industrial structures are typically stronger and can tolerate higher vibration levels. Nuclear facilities are among the most resilient of industrial structures and are specifically designed to withstand seismological incidents that could be reasonably expected.

3.5.1 Vibration Standards for Residential Structures

Vibration standards for residential structures are considered in this Report because they are the weakest structure for which substantial amounts of vibration data exist. Therefore, the vibration standards for residential structures are considered stringent and well-established.

The first significant investigation on residential structures was initiated by the U.S. Bureau of Mines in 1930, and culminated in 1942 with publication of Bulletin 442, Seismic Effects of Quarry Blasting. The "safe zone" vibration standards recommended by Bulletin 442 and subsequent programs are summarized in Table 3.3.

Table 3.3 Historical Development of "Safe Zone" Vibration Standards

Index	**Safe Zone (No Damage)**	**Equivalent PPV**		**Source**	
		40 Hz	**60 Hz**	**Year**	**Ref.**
Acceleration	< 0.1 g	< 0.15 in/s	< 0.10 in/s	U.S. Bureau of Mines, Bulletin 442 1942	11.14
Energy Ratio $ER = \left(\frac{a}{f}\right)^2$ where: a = acceleration (ft/s^2) f = frequency (Hz)	ER < 3	< 3.3 in/s		Journal of Boston Society of Civil Engineers 1949	11.1
Velocity	< 2.8 in/s			Water Power 1958	11.9
	< 2.0 in/s			Canadian National Research Council 1959	11.4
	< 2.0 in/s			U.S. Bureau of Mines, Bulletin 656 1971	11.10

Bulletin 656 synthesizes the work of a number of other investigators, in addition to the Bureau's own work. The "safe zone" vibration criterion was specified in Bulletin 656 as follows:

> The safe vibration criterion is based on the measurement of individual components. If the particle velocity of any component exceeds 2 in/s, damage is likely to occur.

In this specification, damage is defined as the development of fine cracks in plaster. The safe vibration criterion of 2 in/s has been widely adopted and remains the basis of many current regulations, including Chapter 143: Quarrying and Blasting of the Code of the Village of Buchanan (see Section 2.2). Bulletin 656 also specifies vibration criteria for three levels of damage, based on the results of other investigations, as summarized in Table 3.4.

Table 3.4 Vibration Criteria for Levels of Damage to Structures.

Threshold of damage	**Minor damage**	**Major damage**
(4 in/s)	(5.4 in/s)	(7.6 in/s)
opening of old cracks	fallen plaster	large cracks in masonry
formation of new cracks	broken windows	shifting of foundation-bearing walls
dislodging of loose objects	fine cracks in masonry	serious weakening of structure
	no weakening of structure	

The major damage zone correlates reasonably well with the beginning damage level for natural earthquakes.

In 1980, the U.S. Bureau of Mines reported on its most recent investigation of surface mine blasting in RI 8507 [Ref. 11.12]. Structural resonance responding to low frequency ground vibration, resulting in increased displacement and strain, was found to be a serious problem, underscoring the dependence of damage on frequency. Prior to this, the safe limit particle velocity was independent of frequency. Safe vibration levels as specified in RI 8507 are given in Table 3.5. These criteria are based on a 5% probability of damage.

Table 3.5 Safe Peak Particle Velocity for Residential Structures (RI 8507)

Type of Structure	f < 40 Hz	f > 40 Hz
Modern homes - drywall interiors	0.75 in/s	2 in/s
Older homes - plaster on wood lath for interior walls	0.50 in/s	2 in/s

Although more conservative safe vibration levels were specified in RI 8507 for low frequency vibrations, the standard 2 in/s limit was reconfirmed for vibrations above 40 Hz. Blasting vibrations at IPEC would be expected to be above 40 Hz.

3.5.2 Blasting Standard for Industrial Structures

Vibration standards for industrial structures can be divided into two groups: high level vibration structures and low level vibration sensitive components. Concrete structures and bridges are high level vibration structures. Blast vibration PPV and measured values of strain that produce various types of failure in concrete are given in Table 3.6 [Ref. 11.11].

Table 3.6 Failure in Concrete Due to Vibration

TYPE	STRAIN (μin/in)	PPV (in/s)
Static	140	20
Grout Spall	700	100
Skin Spall	1300	200
Cracking	2400	375

Concrete structures can withstand high levels of blasting vibrations; in fact, it is not uncommon for a portion of a concrete structure to be blasted away while leaving the remaining portion intact. Therefore, at the vibration limits considered in this Report, damage to concrete structures at IPEC due to blasting would be highly unlikely. Recently-poured (green) concrete structures, however, are sensitive to low levels of vibration. Guidelines for blasting vibration limits during the curing period are given in Table 3.7. The majority of blast removal at IPEC would likely be completed before any concrete was poured, regardless of this consideration; however, the final construction schedule would be designed to limit blasting near green concrete.

Table 3.7 Vibration Levels for Green Concrete

Time After Pour	PPV (in/s)
0 - 4 Hours	2.00
4 - 24 Hours	0.25
1 - 3 Days	1.00
3 - 7 Days	2.00
7 - 10 Days	5.00
> 10 Days	10.00

Precision blasting has been successfully conducted at nuclear facilities; unfortunately, the majority of these projects were completed decades ago and comprehensive records of the blasting plans are not readily available. A February 1979 article in Electrical World, entitled "Precision Blasting in Shadow of On-line Plant", describes precision blasting operations at Millstone Nuclear Power Station during the construction of Millstone Unit 3 [Ref. 11.1]. Blasting was successfully conducted within 900 ft of Unit 1 while the unit was online by limiting blasting vibration at Unit 1 to 1 in/sec PPV. The basis and/or development of this limit is not addressed in the article. The 1 in/sec limit used at Millstone is significantly higher than the 0.1 in/s limit considered in this Report, which may be due to site-specific conditions and procedures. A full analysis of the effects of blasting at IPEC would be required to finalize a site-specific vibration limit.

3.6 Human Sensitivity to Vibration

Human beings are remarkably sensitive to vibration. While damage may be avoided or minimized, vibration will be felt in practically all cases, with reactions ranging from curiosity and concern to fear, depending on conditions and information provided. Vibration is a fact of daily life, which one regularly experiences but rarely notices. This type of vibration has been designated cultural vibration. Generally, it elicits no reaction from the person affected. Vibration that contrasts sharply from the daily experience, as unusual, has been designated A-cultural. It is surprising, disturbing, and causes an acute awareness.

It is often difficult for the public to understand the magnitudes of vibration from blasting and relate this to normal environmental vibration which they sense every day. Since blast vibration is A-cultural, people become concerned about vibration levels from blasting while they are not concerned about the same vibration levels from cultural vibration which occurs every day in their lives. To put vibration in the proper perspective we can compare both the A-cultural and cultural vibration magnitudes. To do this in a simple understandable manner, we use the Konya Scale (where we can divide the vibration levels into 20 different classes). This class method can be used for both blast effects and separately for environmental vibration. The two charts can then be easily compared without confusion. Konya's Environmental Vibration Scale shows vibration levels from normal activities (Figure 3.3). Konya's Blast Effects Scale shows the PPV levels and the class numbers for human perception and potential damage which can result at high vibration levels (Figure 3.4).

ACTIVITY	SCALE																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WALKING	X	X	X	X	X															
TRAIN NEARBY	X	X	X	X	X	X														
WALKING ON WOOD FLOOR	X	X	X	X	X	X	X													
PILE DRIVING, PUNCH BARGE	X	X	X	X	X	X	X	X												
GARBAGE DISPOSAL	X	X	X	X	X	X	X	X	X											
JUMPING	X	X	X	X	X	X	X	X	X											
DOOR SLAMS	X	X	X	X	X	X	X	X	X											
POUNDING NAILS	X	X	X	X	X	X	X	X	X	X										
DAILY ENVIRONMENTAL CHANGE	X	X	X	X	X	X	X	X	X	X	X	X								
RIDING IN AUTOMOBILE	X	X	X	X	X	X	X	X	X	X	X	X	X							
PEAK PARTICLE VELOCITY	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.128	0.256	0.512	1.024	2.048	4.096	8.192	16.38	32.77	65.54	131.07	262.14	524.29

Figure 3.3 Konya's Environmental Vibration Scale™

EFFECTS	VIBRATION CLASS NUMBER																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PERCEPTION BY OLDER POPULATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PERCEPTION BY ALL					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WATER RIPPLES						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PIPES RATTLE						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LOOSE OBJECTS RATTLE						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CRACK EXTENSIONS IN PLASTER (INVISIBLE)											X	X	X	X	X	X	X	X	X	X
CRACK EXTENSIONS (VISIBLE)												X	X	X	X	X	X	X	X	X
NEW CRACK FORMATION (PLASTER)													X	X	X	X	X	X	X	X
FINE CRACKS IN MASONRY													X	X	X	X	X	X	X	X
BROKEN WINDOWS													X	X	X	X	X	X	X	X
CHIMNEY DAMAGE														X	X	X	X	X	X	X
LARGE CRACKS IN MASONRY WALLS														X	X	X	X	X	X	X
CRACKS IN CONCRETE WALLS																		X	X	X
CRACKS IN CONCRETE SLABS																			X	X
CRACKS IN MASSIVE CONCRETE																				X
PEAK PARTICLE VELOCITY	0.001	0.002	0.004	0.008	0.016	0.032	0.064	0.128	0.256	0.512	1.024	2.048	4.096	8.192	16.38	32.77	65.54	131.07	262.14	524.29
IN INCHES/SECOND																				
(THRESHOLD VALUES)																				

Figure 3.4 Konya's Blast Effects Scale™

The blasting vibration levels considered in this Report would be noticeable and may produce some slight rattling. On-site personnel would experience these effects during the daily 15-minute blasting period, described in Section 4.4. There is a slight potential that these effects could be experienced off-site near the Unit 3 tower excavation. A factory is located near the IPEC property line south of the Unit 3 excavation. The industrial nature of the nearest off-site environment would likely minimize any potential for noticeable effects of blasting. The distance from the excavation to the nearest residential areas would be approximately 1,000 ft; therefore, no noticeable blasting effects would be expected in these locations.

4 Assessment of Blasting Plan

The preliminary blasting plan for excavation at IPEC was developed, based on site-specific limitations and standard blasting techniques. Small-diameter blastholes and deck loading would allow blasting with the maximum charge weight per delay predictions of Table 3.1. The most restrictive limitation for most of the excavation will be the 0.1 g acceleration limit as measured at the containment building.

4.1 Cooling Tower Excavation

The expected volume of rock to be blasted for construction of the two cooling towers is a total of 1,794,300 yd^3 (Table 2.7). As discussed in Section 3.1.3, the maximum allowable charge weights at the edge of the Unit 2 and Unit 3 tower excavation areas closest to the containment buildings would be 25.70 lbs/delay and 19.13 lbs/delay, respectively.

A blasthole diameter of three inches, fully loaded with a 2.5 inch diameter explosive cartridge would contain less than 40 pounds of explosive. A charge weight of 40 lbs in each blasthole would allow holes closer than 650 ft to the containment building to be loaded and fired in two decks, as described in Section 3.2.3. At a distance of 650 ft or more from the containment buildings, an entire hole could be fired per delay of 8 milliseconds or more. A charge weight of 40 lbs per blasthole would also meet the 52.62 lbs/delay limit specified by Spectra Guideline TG-111 for blasting near the Algonquin pipeline. The maximum diameter of cartridged explosive to fit in a 3 inch diameter blasthole would be 2.5 inches. This explosive could be a dynamite, emulsion or water gel. No bulk explosive products would be used, to eliminate the potential for overloading the blastholes.

The rock around the towers would be presplit on 24 inch centers to maintain good excavation walls and eliminate overbreak beyond the desired perimeter.

4.1.1 Cooling Tower Blasthole Drilling

In calculating the number of drill feet, it must be noted that each hole is subdrilled two feet below the 20 feet of bench height. The blastholes shown in Table 4.1 are therefore 22 feet deep.

Table 4.1 Number of Blastholes and Drill Feet for Cooling Towers

Total Yd^3	Bench Height (ft)	Burden (ft)	Spacing (ft)	Yd^3 Per Hole	No. of Holes	Total Drill Feet
1,794,300	20	5	6	22.2	80,826	1,778,172

4.1.2 Blasting Pattern for Cooling Towers

The blasting pattern for the cooling towers would consist of three inch diameter blastholes loaded with 2.5 inch diameter explosive, explosive density 1.2 g/cc, powder factor 1.72 lb/yd^3, rock density 2.7 (hard limestone/marble/traprock), one hole per delay. All blasts will be covered with blasting mats (Table 4.2). Blasting mats must be used for cover of the blasting area to protect the electrical wires and any other structure which could be damaged by small pieces of flyrock.

The general production blasting pattern would consist of about 60 holes. Three to five hydraulic rock drills would work simultaneously at each cooling tower.

Blasting at cooling tower locations less than 650 feet from the containment buildings would be deck loaded, meaning that two separate charges would be placed in the blastholes and would be less than 19 pounds each. The two charges in the blasthole would be fired on different delay times to control ground vibration.

Table 4.2 Summary of Blasting Plan

Burden (ft)	Spacing (ft)	Bench Height (ft)	Subdrill (ft)	Stemming (ft)	Loading Density (lb/ft)	Pounds Per Hole
5	6	20	2	7	2.55	38.25

4.2 Trench Excavation

All trenches would be presplit on two foot centers with 3 inch diameter blastholes. The highest powder factor (amount of explosive needed per cubic yard of rock) required for trench blasting would be 3 to 3.5 pounds per cubic yard. This would require a blasting pattern drilled with a four foot burden and four foot spacing. The number of blastholes that need to be drilled can be estimated by knowing the total cubic yard volume of the trench and determining the total volume of rock broken for each blasthole. Table 4.3 shows the number of blastholes for each trench segment and the total drill footage needed. It should be noted that the blastholes have two feet of subdrill below grade and that is added to the trench depth to determine the drill feet.

Table 4.3 Trench Location, Number of Blastholes and Drill Feet

Trench Location	Trench Volume (yd^3)	Average Volume per Hole (yd^3)	No. of Holes	Drill Feet
Unit 3 Trench	24,500	12.14	2019	42,399
Unit 2 Trench	70,100	12.14	5775	121,275
Total	94,600		7794	163,674

As discussed in Section 2.1, the 5-10 feet of Unit 2 pipe trench closest to the Riverfront would be limited by the OBE vertical acceleration. Additional measures would be implemented to meet the vertical acceleration limit, namely smaller diameter blast holes and additional deck loading. Another option for excavating this small area would be to extend the manual excavation in the Riverfront 5-10 feet. Due to the small fraction of the overall blasting project, the methods used to ensure that the vertical acceleration limit is not exceeded in this area would not be expected to significantly increase cost or duration of the project.

4.3 Presplit Blasting for Towers and Trenches

The presplit will be drilled with three inch diameter blastholes and spaced 2 feet apart, center to center along all perimeters. We would load each hole with 800 grains per foot detonating cord plus one 2 in by 8 in explosive cartridge in the blasthole bottom. A summary of the total presplit drill footage is shown in Table 4.4.

Table 4.4 Summary of Presplit Drilling for Trenches, Cooling Towers and Cooling Tower Bases

Location	Spacing (ft)	(yd^3) per foot of trench length	Length Both Sides (ft)	Face Area (ft^2)	Area per Hole (ft^2)	No. Of Holes	Total Drill Footage (ft)
Unit 3 Trench	2	11.66	4202	88,242	42	2101	44,121
Unit 2 Trench	2	11.66	12,024	252,504	42	6012	126,252
Tower Unit 3	2	20	--	110,000	40	2750	55,000
Tower 3 Base	2	10	1650	16,500	20	825	8,250
Tower Unit 2	2	20	--	65,973	40	1650	33,000
Tower 2 Base	2	10	1650	16,500	20	825	8,250
Total	--	--	--	549,719	--	14163	274,873

4.4 Blasting Operations

The duration of a blasting project is controlled by the maximum rate of blasthole drilling, because drilling of blastholes is more time consuming than loading the explosives and firing the blast. Therefore, the maximum number of drills that can be used efficiently will control the project duration. Three to five drills could efficiently be used in each cooling tower location, while two drills could be used in each trench location. The trench excavations are much smaller than the cooling tower excavations and the blasting project would be planned to utilize drills in the piping trenches during the short period of time that those drills cannot be efficiently used in the cooling tower excavations. A total of ten drills would therefore be in use at all times. While a blast is being drilled, another crew would load and prepare to fire the previously drilled blasting pattern.

The actual loss in drilling time as a result of firing the blasts would be no more than 15 minutes per day. All blasts at the different locations could be prepared, loaded and fired within a few minutes of one another at the end of the day. A reasonable drilling rate for blastholes in this rock type average 120 ft/ hr for production blastholes, and 60 ft/h for presplit blastholes.

4.5 Seismic Monitoring

Six seismographs would monitor each blast for vibration analysis. The seismic monitoring would be done by blast control experts VCE Inc. for the duration of the project. VCE Inc. uses seismographs manufactured by Physical Measurement Technologies, Inc. (PMT) with sampling rates of 20,000 samples per second. These are the most accurate blast seismographs available for high frequency blast vibration measurement.

5 Projected Duration and Cost for Both Units

5.1 Estimated Project Duration

The project duration is determined by the required drill time and the maximum possible drill rate, as discussed in Section 4.4. The total drill hours required for presplitting and the cooling tower and trench excavation are shown in Table 5.1. Allowing one hour each day for loading and firing the blasts, the maximum drilling hours allowed per day would be 10 hours, in compliance with the Code of the Village of Buchanan. However, when daylight hours are shorter in winter, total maximum drilling hours would not exceed 8 hours.

Table 5.1 Total Drill Days

Location	**Total Feet**	**Ft/hr**	**Ft/Drill/Day @ 10 hr Day**	**Drill Days**
Cooling Towers	1,778,172	120	1200	1482
Trenches	163,674	120	1200	137
Presplit	274,873	60	600	459
Total	**2,216,719**	--	--	**2078**

The preliminary blasting plan uses a total of ten hydraulic rock drills, as described in Section 4.4. The project would span 208 10-hour days for each of 10 drills at 100% efficiency. However, consistent with professional judgement, a typical equipment availability of 85% would be expected, which would increase the required drill days per drill from 208 to 245.

In accordance with the Code of the Village of Buchanan (Section 2.2), blasting operations would be allowed on 250 business days of each year, i.e., blasting is restricted on weekends and the twelve holidays observed by New York State. The hours of the blasting operations are restricted to 8 a.m. to 7 p.m. In addition, blasting would only be conducted during daylight hours, in accordance with industry standards. In Buchanan, NY, daylight spans the 11-hr allowed blasting period from mid-March to mid-September. There are approximately 135 allowed blasting days in this time period. Blasting would be restricted to shorter hours on the remaining 115 business days of the year. Construction in the New York area would also be subject to weather delays, especially in the winters. Finally, any delay associated with equipment availability, blasting, rock removal, pipe placement, etc. would extend the project duration. Considering these schedule factors, it is expected that drilling would occur on the equivalent of approximately 150 10-hour days per year (i.e., 1,500 drill hours per year).

Under typical commercial operating conditions and the 150-days-per-year estimate, the drilling and blasting project duration would be 1.6 years, regardless of how many work crews were available. However, blasting at an operating nuclear reactor would be limited by additional site-specific considerations which are expected to increase the schedule duration by a factor of 2.5, as estimated by Enercon. Therefore, the total blasting project duration is expected to extend approximately 4 years.

These time estimates assume efficient excavation of the broken rock. After each series of blasts at the end of a day, all broken rock would need to be removed before blasts at the end of the next day would be fired.

5.2 Estimated Project Cost

The estimated cost of drilling and blasting, a blasting consultant, and seismic monitoring for the project is $40,081,851, as shown in Table 5.2. This estimate does not include the cost of spoils removal or insurance for the blasting project.

Table 5.2 Estimated Project Cost for Conversion of Both Units 2 and 3

	Rate	**Quantity**	**Cost**
Cooling Towers Drilling and Blasting	$15/yd^3	1,794,300 yd^3	$ 26,914,500
Trench Rock Drilling and Blasting	$58/yd^3	94,600 yd^3	$ 5,486,800
Precision Presplitting	$85/yd^2	61,080 yd^2	$ 5,191,791
Blasting Consultant	$2,000/day	800 days	$ 1,600,000
Seismic Monitoring (6 seismographs)	$26,140/month	34 months	$ 888,760
		Total	**$ 40,081,851**

6 Project Duration and Cost for Each Unit

The project duration and costs were evaluated for Unit 2 and Unit 3 separately. Table 6.1 and Table 6.2 show the drill footage and drill days needed for both projects. The drilling time would be almost the same if the projects were done separately or at the same time. The drilling and blasting at two separate sites would not greatly impact one another whether done independently or at the same time.

Table 6.1 Unit 2 Cooling Tower Drill Footage and Drill Days

Description	Volume (yd^3)	Blast Holes	Drill Footage (ft)	Drill Days
Unit 2 Trench	70,100	5775	121,275	102
Unit 2 Tower	693,100	31,221	686,862	573
Unit 2 Tower Base	80,200	3613	79,486	67
Unit 2 Presplit	--	--	167,502	280
		Total	1,055,125	1022

Table 6.2 Unit 3 Cooling Tower Drill Footage and Drill Days

Description	Volume (yd^3)	Blast Holes	Drill Footage (ft)	Drill Days
Unit 3 Trench	24,500	2,019	42,399	36
Unit 3 Tower	940,800	42,379	932,338	777
Unit 3 Tower Base	80,200	3,613	79,486	67
Unit 3 Presplit	--	--	107,371	179
		Total	1,161,594	1060

6.1 Project Duration – Unit 2

The total project duration for construction of Unit 2 would be, in the best case, determined by the drilling. The plan would be to use two drills on the trench presplit and trench production hole drilling and three to five drills on the cooling tower, with a total of five drills at all times. It would take a total of 1022 drill days for five drills or a total of 204 days for each of five drills at 100 percent efficiency. The equipment availability would be expected to be no higher than 85%, increasing the drill days per drill from 204 to 240.

Any delay associated with equipment availability, blasting, rock removal, pipe placement, etc. would extend the project duration. In addition, construction in the New York area would be subject to weather shut downs and shorter drilling and blasting hours, 9 hours maximum, in the spring and fall. Considering these schedule factors, it is expected that blast operations would occur on the equivalent of approximately 150 10-hour days per year, as estimated in Section 5.1.

Under typical commercial operating conditions, the drilling and blasting project duration would be realistically about 1.6 years (19.2 months) regardless of how many work crews were available. However, blasting at an operating nuclear reactor would be limited by additional site-specific considerations which are expected to increase the schedule duration by a factor of 2.5, as estimated by Enercon. Therefore, the total blasting project duration is expected to extend approximately 4 years.

These time estimates assume100 percent efficiency on the excavation of the broken rock. After each blast at the end of a day, all broken rock would need to be removed before the blast at the end of the next day would be fired.

6.2 Project Duration – Unit 3

Like Unit 2, the total project duration for construction of Unit 3 would be, in the best case, determined by the drilling. The plan would be to use two drills on the trench presplit and trench production hole drilling and three to five drills on the cooling tower, with a total of five drills at all times. It would take a total of 1060 drill days for five drills or a total of 212 days for each of the five drills at 100 percent efficiency. The equipment availability would be expected to be no higher than 85%, increase the drill days per drill from 212 to 250.

Any delay associated with equipment availability, blasting, rock removal, pipe placement, etc. would extend the project duration. In addition, construction in the New York area would be subject to weather shut downs and shorter drilling and blasting hours, 9 hours maximum, in the spring and fall. Considering these schedule factors, it is expected that blast operations would occur on the equivalent of approximately 150 10-hour days per year, as estimated in Section 5.1.

Under typical commercial operating conditions, the drilling and blasting project duration would be about 1.67 years (20 months), regardless of how many work crews were available. However, blasting at an operating nuclear reactor would be limited by additional site-specific considerations, which are expected to increase the schedule duration by a factor of 2.5, as estimated by Enercon. Therefore, the total blasting project duration is expected to extend approximately 4.2 years.

These time estimates assume efficient excavation of the broken rock. After each blast at the end of a day, all broken rock would need to be removed before the blast at the end of the next day would be fired.

6.3 Estimated Project Cost – Unit 2

The estimated cost of drilling and blasting, a blasting consultant, and seismic monitoring for conversion of Unit 2 only is $18,069,460, as shown in Table 6.3. This estimate does not include the cost of spoils removal or insurance for the blasting project.

Table 6.3 Estimated Project Cost for Conversion of Unit 2

	Rate	**Quantity**	**Cost**
Cooling Towers Drilling and Blasting	$\$13/\text{yd}^3$	$773{,}300\ \text{yd}^3$	$ 10,052,900
Trench Rock Drilling and Blasting	$\$50/\text{yd}^3$	$70{,}100\ \text{yd}^3$	$ 3,505,000
Precision Presplitting	$\$85/\text{yd}^2$	$37{,}219.67\ \text{yd}^2$	$ 3,163,672
Blasting Consultant	$2,000/day	423 days	$ 846,000
Seismic Monitoring (6 seismographs)	$26,140/month	19.2 months	$ 501,888
		Total	**$ 18,069,460**

6.4 Estimated Project Cost – Unit 3

The estimated cost of drilling and blasting, a blasting consultant, and seismic monitoring for conversion of Unit 3 only is $23,278,919, as shown in Table 6.4. This estimate does not include the cost of spoils removal or insurance for the blasting project.

Table 6.4 Estimated Project Cost for Conversion of Units 3

	Rate	Quantity	Cost
Cooling Towers Drilling and Blasting	$18/yd^3	1,021,000 yd^3	$ 18,378,000
Trench Rock Drilling and Blasting	$60/yd^3	24,500 yd^3	$ 1,470,000
Precision Presplitting	$85/yd^2	23,860.22 yd^2	$ 2,028,119
Blasting Consultant	$2,000/day	440 days	$ 880,000
Seismic Monitoring (6 seismographs)	$26,140/month	20 months	$ 522,800
		Total	**$ 23,278,919**

7 Impact of Reactor Shutdown

This report assumes that continued operation of Units 2 and 3 during the 4 year blasting schedule is a goal. Shutting down the reactors during the project may reduce the cost of blasting by about 5% for the trench and tower excavation, but would not necessarily impact the number of blastholes, nor the presplitting costs. The only impact of a reactor outage concurrent with the project would be that deck loading would not be required if the reactor was offline, because the design basis earthquake is based on a higher horizontal ground acceleration than the operating basis earthquake, as discussed in Section 2.1. The potential 5% savings would correlate to the avoided cost of deck loading holes nearer than 650 ft to the containment buildings.

8 Execution of Project

The project would require the skills and prudence of an expert drilling and blasting contractor. The contractor should not be selected by lowest bid but based on reputation and past history of successfully completing delicate projects. In addition, the selected contractor must be required to hire a reputable blasting consultant who must be present during the project. The drilling and blasting costs used in this Report are based on the selection of an expert blasting contractor and experienced blasting consultant.

Core drilling must be done prior to any construction on the project. Rock Quality Designation (RQD) and percent recovery are critical site-specific variables which must be provided to the blasting consultant in advance of construction.

Test blasts, described in Section 3.4, would be conducted at the farthest distance (1660 feet) from the reactor using small charges to test the scaling factors and determine the site specific vibration decay factors. At least six seismographs would be strategically placed during the test blast phase of the project. At least four seismographs would be strategically placed and monitored during all production blasting.

9 Conclusions

It is feasible and safe to blast the rock for the cooling towers and trenches at Indian Point. For the purposes of developing the preliminary blasting plan described in this Report, it was assumed that blasting would be limited to the 0.1 g horizontal ground acceleration limit corresponding to the operating basis earthquake. The 0.1 g limit would translate to a blasting vibration limit of 0.1 in/s. Subject to these limits, a feasible blasting plan was developed for excavation related to cooling tower construction at IPEC. Cost estimates are provided for the drilling and blasting project. The effect of blasting vibrations on sensitive equipment throughout the facility would need to be carefully analyzed before a blasting limitation was finalized. Depending on the finalized limits, significant changes to the blasting plan may be necessary that would have corresponding effects on project duration and cost. However, no finalized limit is anticipated that would challenge the feasibility of the project.

The drilling and blasting project would require ten rock drills and the project duration, if limited only by drill rate, would be 1.6 years. However, blasting at an operating nuclear reactor would be limited by additional site-specific considerations which are expected to increase the schedule duration by a factor of 2.5, as estimated in the Enercon Report. Therefore, the total project duration is expected to be approximately 4 years. The estimated cost of drilling and blasting, a blasting consultant, and seismic monitoring for the project is $40,081,851, as detailed in Section 5.2. This estimate does not include the cost of spoils removal or insurance for the project (Enercon Report, Section 6; Enercon Report, Attachment 7, Section 3). As noted in Section 3 of this Attachment, obtaining insurance for the project is not assured.

10 Limitations

Enercon contracted Precision Blasting Services (PBS) of Montville, Ohio, to provide this report.

The professional judgments presented in this Blasting Feasibility Study for Conversion of Indian Points Units 2 and 3 to a Closed-Loop Cooling Water Configuration were conducted in a manner consistent with the standard of care ordinarily applied as the state of practice in the profession within the limits prescribed by our client. No other warranties, either expressed or implied, are included or intended in this Blasting Feasibility Study for Conversion of Indian Points Units 2 and 3 to a Closed-Loop Cooling Water Configuration.

The professional judgments presented in this report are based on excavation drawings and data supplied by Enercon in 2003 and 2009 to PBS. The subsurface conditions and excavation geometry have been assumed to not deviate significantly from those disclosed in the provided information.

11 References

11.1 Barlow, G. *Precision Blasting in Shadow of On-Line Plant.* Electrical World. February 1, 1979. pp. 43-45.

11.2 Crandell , F.J. *Ground Vibration Due to Blasting and Its Effect Upon Structures.* Journal of the Boston Society of Civil Engineers. 1949.

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11.4 Edwards and Northwood. *Experimental Blasting Studies on Structures.* National Research Council. Ottawa, Canada. 1959.

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11.6 Indian Point Energy Center. Indian Point 3 UFSAR. Rev. 2. 2007.

11.7 Indian Point Energy Center. Procedure 0-AOP-Seismic-1. Seismic Event. Rev. 0. 2007.

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11.9 Langefors, Westerberg and Kihlstrom. *Ground Vibration in Blasting.* Parts I-III, Water Power, 1958.

11.10 Nichols, Johnson and Duvall. *Blasting Vibration and Their Effects on Structures.* U. S. Department of the Interior, Bureau of Mines Bulletin 656. 1971.

11.11 Oriard, L.L. and Coulson, J.H. TVA Blast Vibration Criteria for Mass Concrete. Proceedings of the Conference of the ASCE, Portland, OR. 1980.

11.12 Siskind, D.E. et al. *Structure Response and Damage Produced by Ground Vibration from Surface-Mine Blasting.* U.S. Department of the Interior, Bureau of Mines RI 8507. 1980.

11.13 Stagg, M.S., and Engler, A.J. Measurement of Blast-Induced Ground Vibrations and Seismograph Calibration. U.S. Department of the Interior, Bureau of Mines RI 8506. 1980.

11.14 Thoenen and Windes. *Seismic Effects of Quarry Blasting.* U.S. Bureau of Mines Bulletin 442. 1942.

Attachment 7

Precision Blasting and Rock Removal

Section 2

Breaker Program Results

Prepared by Precision Blasting Services

Breaker, v. 8.0, Size Distribution Prediction Results

The Breaker, v. 8.0, program predicts the average fragmentation size and the fragmentation distribution of blasted rock. This software can predict and compare relative difference in fragmentation from one blast design to another. This software is based on calculations developed by authorities in the field. Size distribution results from this program have been validated; a fragmentation comparison is accurate when compared to actual sized materials from available sources, where all material was screened after the shot. Breaker can compare the changes in fragmentation as effected by many of the normal blasting variables, such as burden, spacing, bench height, and type of explosive used. The software will also work with two different explosives in the borehole. A scientific method to determine the effects of rock strength and geologic structure is also provided. Breaker will calculate the percentage, weight and volume of material produced in various size ranges, and display charts in the form of line and bar graphs. The software conforms to the worldwide standard for the blasting industry.

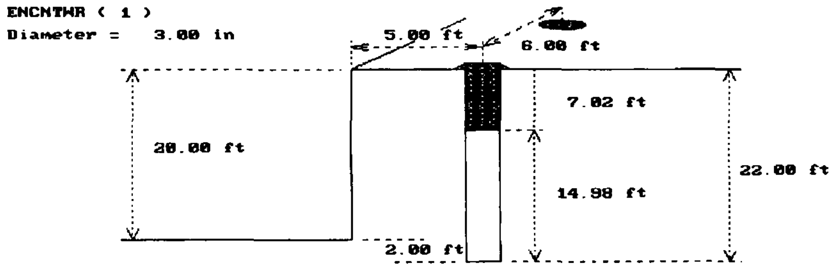
Two different rock strengths were used to estimate the fragmentation size and distribution of blasted rock that would be produced by excavation at the cooling tower and pipe trenching sites. The geologic structure affects fragmentation results; this is incorporated in the rock strength coefficients.

All blasted rock fragments larger than 1.5 inch size would need to be crushed. The expected percentage of blasted rock fragments that would be able to pass through a 1.5 inch screen is shown in the Passing column of the Breaker results. Approximately 65-77% of the rocks produced in the cooling tower site excavation would be larger than 1.5 inch pieces. The blasting in the piping trenches would produce smaller pieces of broken rock, with approximately 43-61% of the rocks larger than 1.5 inch pieces.

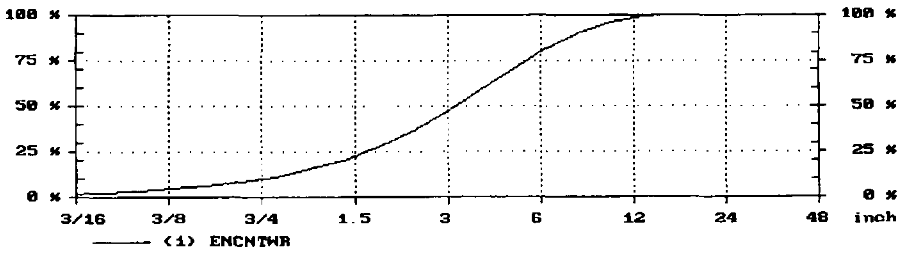
```
Precision Blasting              B R E A K E R                       V5.01
Services, Inc.                                          Date: 11-12-2009
--------------------------------------------------------------------------
Entry: 1                        ENERCON TOWERS              File: ENCNTWR

        ENTRY 1  Calculation based on Weight Strength, Square pattern

 Number of rows .......................       6
 Total number of holes ...............       60
 Diameter of blasthole ...............        3.00 in
 Burden ..............................        5.00 ft
 Spacing .............................        6.00 ft
 Stemming ............................        7.02 ft
 Bench height ........................       20.00 ft
 Subdrill ............................        2.00 ft
 Hole length .........................       22.00 ft
 Drilling angle from vertical ........        0.00 °

 Type of rock ........................    MARBLE/LIMES
 Specific gravity of rock ............        2.70 g/cm3
 Rock strength (weak=1, strong=10) ...        3.00

 Type (brand) of explosive ...........    EMULSION
 Specific gravity of explosive .......        1.20 g/cm3
 Explosive strength (ANFO=100) .......       97.00
 Diameter of explosive ...............        2.50 in
 Length of explosive charge ..........       14.98 ft
 Weight of explosive charge ..........       38.25 lb

 Total explosive weight ..............     2,295.00 lb

 Total blasted rock ..................     1,333.33 yd3
                                           3,034.02 ton

 Powder factor .......................        1.72 lb/yd3
                                              0.58 yd3/lb

 Powder factor .......................        0.76 lb/ton
                                              1.32 ton/lb
```

```
Precision Blasting              B R E A K E R                       V5.01
Services, Inc.                                                Date: 11-12-2009
------------------------------------------------------------------------------
Entry: 1                        ENERCON TOWERS                File: ENCNTWR

------------------------------------------------------------------------------
 SCREEN      +------ P A S S I N G ------+     +----- F R A C T I O N -----+
 SIZE        |                           |     |                           |
 inch Entry       yd3       ton        %         yd3        ton          %
------------------------------------------------------------------------------
 3/16   1          22        50     1.65
                                                  54        123       4.06
 3/8    1          54       123     4.06
                                                  77        174       5.74
 3/4    1         131       297     9.80
                                                 171        390      12.84
  1.5   1         302       687    22.64
                                                 328        745      24.57
  3     1         630     1,432    47.21
                                                 432        983      32.39
  6     1       1,061     2,415    79.60
                                                 246        561      18.48
 12     1       1,308     2,976    98.09
                                                  25         58       1.91
 24     1       1,333     3,034    99.99
                                                   0          0       0.01
 48     1       1,333     3,034   100.00
------------------------------------------------------------------------------
        1         Average size =   3.19 in   Fragmentation index =    1.315
```

```
Precision Blasting                B R E A K E R                                V5.01
Services, Inc.                                                       Date: 11-12-2009
---------------------------------------------------------------------------------------
Entry: 1                          ENERCON TOWERS                      File: ENCNTWR
```



PASSING



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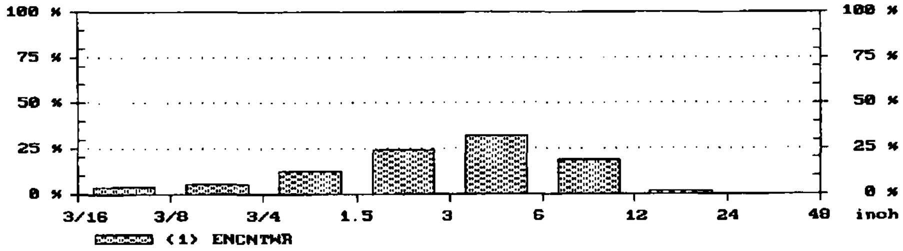
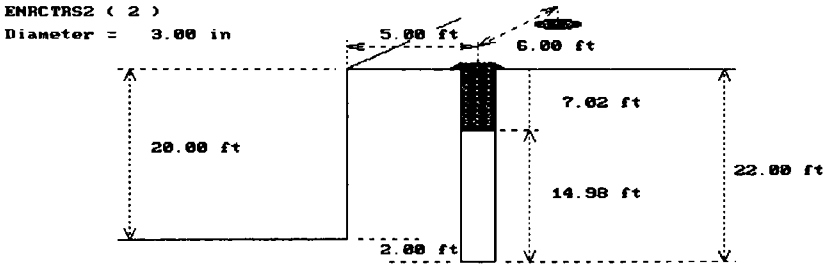
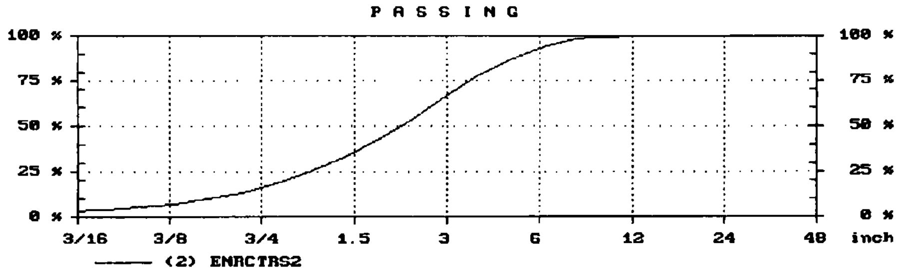


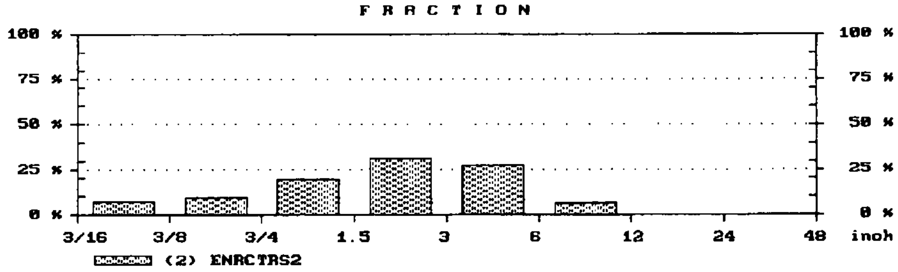
```
Precision Blasting               B R E A K E R                         V5.01
Services, Inc.                                              Date: 11-12-2009
--------------------------------------------------------------------------------
Entry: 2                        ENERCON TOWERS 2                File: ENRCTRS2

         ENTRY 2  Calculation based on Weight Strength, Square pattern

 Number of rows .......................         6
 Total number of holes ...............         60
 Diameter of blasthole ...............          3.00 in
 Burden ..............................          5.00 ft
 Spacing .............................          6.00 ft
 Stemming ............................          7.02 ft
 Bench height ........................         20.00 ft
 Subdrill ............................          2.00 ft
 Hole length .........................         22.00 ft
 Drilling angle from vertical ........          0.00 °

 Type of rock ........................     MARBLE/LIMES
 Specific gravity of rock ............          2.70 g/cm3
 Rock strength (weak=1, strong=10) ...          2.00

 Type (brand) of explosive ...........     EMULSION
 Specific gravity of explosive .......          1.20 g/cm3
 Explosive strength (ANFO=100) .......         97.00
 Diameter of explosive ...............          2.50 in
 Length of explosive charge ..........         14.98 ft
 Weight of explosive charge ..........         38.25 lb

 Total explosive weight ..............      2,295.00 lb

 Total blasted rock ..................      1,333.33 yd3
                                            3,034.02 ton

 Powder factor .......................          1.72 lb/yd3
                                                0.58 yd3/lb

 Powder factor .......................          0.76 lb/ton
                                                1.32 ton/lb
```

```
Precision Blasting              B R E A K E R                       V5.01
Services, Inc.                                               Date: 11-12-2009
-----------------------------------------------------------------------------
Entry: 2                       ENERCON TOWERS 2                File: ENRCTRS2

-----------------------------------------------------------------------------
 SCREEN      +------ P A S S I N G ------+     +----- F R A C T I O N -----+
 SIZE        |                           |     |                           |
 inch Entry        yd3         ton       %           yd3         ton       %
-----------------------------------------------------------------------------
 3/16   2           37          85    2.80
                                                      91         207    6.82
 3/8    2           91         207    6.82
                                                     124         282    9.30
 3/4    2          215         489   16.13
                                                     258         586   19.32
  1.5   2          473       1,075   35.44
                                                     412         938   30.90
  3     2          885       2,013   66.34
                                                     360         819   27.00
  6     2        1,245       2,832   93.35
                                                      87         198    6.54
 12     2        1,332       3,030   99.88
                                                       2           4    0.12
 24     2        1,333       3,034  100.00
                                                       0           0    0.00
 48     2        1,333       3,034  100.00
-----------------------------------------------------------------------------
        2         Average size =   2.13 in   Fragmentation index =   1.315
```

```
Precision Blasting              B R E A K E R                    V5.01
Services, Inc.                                           Date: 11-12-2009
---------------------------------------------------------------------------
Entry: 2                       ENERCON TOWERS 2            File: ENRCTRS2
```







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Precision Blasting                B R E A K E R                          V5.01
Services, Inc.                                                 Date: 11-12-2009
-------------------------------------------------------------------------------
Entry: 3                          ENERCON TRENCH                 File: ENCNTRNC

         ENTRY 3  Calculation based on Weight Strength, Square pattern

 Number of rows ......................         6
 Total number of holes ...............        60
 Diameter of blasthole ...............         3.00 in
 Burden ..............................         4.00 ft
 Spacing .............................         4.00 ft
 Stemming ............................         7.02 ft
 Bench height ........................        20.00 ft
 Subdrill ............................         2.00 ft
 Hole length .........................        22.00 ft
 Drilling angle from vertical ........         0.00 °

 Type of rock ........................    MARBLE/LIMES
 Specific gravity of rock ............         2.70 g/cm3
 Rock strength (weak=1, strong=10) ...         3.00

 Type (brand) of explosive ...........    EMULSION
 Specific gravity of explosive .......         1.20 g/cm3
 Explosive strength (ANFO=100) .......        97.00
 Diameter of explosive ...............         2.50 in
 Length of explosive charge ..........        14.98 ft
 Weight of explosive charge ..........        38.25 lb

 Total explosive weight ..............     2,295.00 lb

 Total blasted rock ..................       711.11 yd3
                                           1,618.14 ton

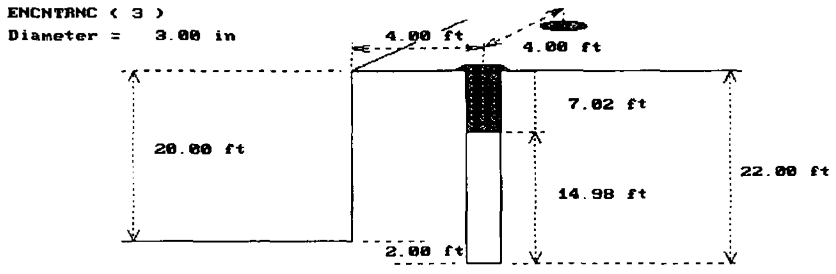
 Powder factor .......................         3.23 lb/yd3
                                               0.31 yd3/lb

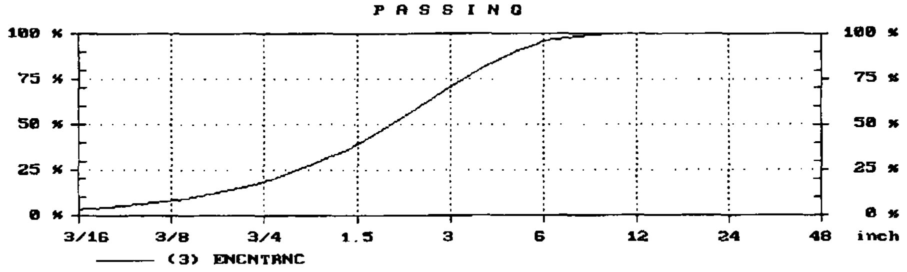
 Powder factor .......................         1.42 lb/ton
                                               0.71 ton/lb
```

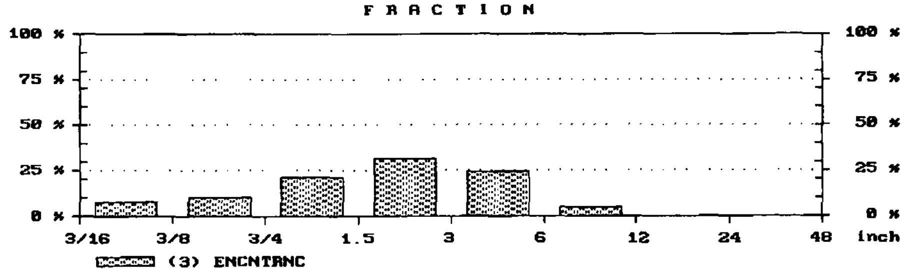
```
Precision Blasting              B R E A K E R                      V5.01
Services, Inc.                                          Date: 11-12-2009
------------------------------------------------------------------------
Entry: 3                        ENERCON TRENCH          File: ENCNTRNC

-----------------------------------------------------------------------
 SCREEN      +------ P A S S I N G ------+    +----- F R A C T I O N -----+
 SIZE        |                           |    |                           |
 inch Entry       yd3        ton        %         yd3        ton        %
-----------------------------------------------------------------------
 3/16    3         23         53     3.30
                                                   56        128     7.92
 3/8     3         56        128     7.92
                                                   74        169    10.45
 3/4     3        131        297    18.37
                                                  149        339    20.95
  1.5    3        280        636    39.31
                                                  224        509    31.43
  3      3        503      1,145    70.75
                                                  173        395    24.40
  6      3        677      1,540    95.14
                                                   34         78     4.80
 12      3        711      1,617    99.94
                                                    0          1     0.06
 24      3        711      1,618   100.00
                                                    0          0     0.00
 48      3        711      1,618   100.00
-----------------------------------------------------------------------
         3          Average size =    1.93 in   Fragmentation index =   1.299
```

```
Precision Blasting            B R E A K E R                 V5.01
Services, Inc.                                   Date: 11-12-2009
-----------------------------------------------------------------
Entry: 3                      ENERCON TRENCH     File: ENCNTRNC
```







```
Precision Blasting              B R E A K E R                      V5.01
Services, Inc.                                             Date: 11-12-2009
--------------------------------------------------------------------------
Entry: 4                      ENERCON TRENCH 2                File: ENRCTRN2

         ENTRY 4  Calculation based on Weight Strength, Square pattern

 Number of rows .....................         6
 Total number of holes ..............        60
 Diameter of blasthole ..............         3.00 in
 Burden .............................         4.00 ft
 Spacing ............................         4.00 ft
 Stemming ...........................         7.02 ft
 Bench height .......................        20.00 ft
 Subdrill ...........................         2.00 ft
 Hole length ........................        22.00 ft
 Drilling angle from vertical ........        0.00 °

 Type of rock .......................     MARBLE/LIMES
 Specific gravity of rock ...........         2.70 g/cm3
 Rock strength (weak=1, strong=10) ...        2.00

 Type (brand) of explosive ..........     EMULSION
 Specific gravity of explosive .......        1.20 g/cm3
 Explosive strength (ANFO=100) .......       97.00
 Diameter of explosive ..............         2.50 in
 Length of explosive charge .........        14.98 ft
 Weight of explosive charge .........        38.25 lb

 Total explosive weight .............     2,295.00 lb

 Total blasted rock .................       711.11 yd3
                                          1,618.14 ton

 Powder factor ......................         3.23 lb/yd3
                                              0.31 yd3/lb

 Powder factor ......................         1.42 lb/ton
                                              0.71 ton/lb
```

```
Precision Blasting                B R E A K E R                        V5.01
Services, Inc.                                                  Date: 11-12-2009
--------------------------------------------------------------------------------
Entry: 4                        ENERCON TRENCH 2                  File: ENRCTRN2

------------------------------------------------------------------------------
 SCREEN        +------ P A S S I N G ------+    +----- F R A C T I O N -----+
 SIZE          |                           |    |                           |
 inch Entry        yd3        ton        %          yd3        ton        %
------------------------------------------------------------------------------
 3/16    4          39         89     5.52
                                                     93        211    13.03
 3/8     4          93        211    13.03
                                                    114        260    16.05
 3/4     4         207        471    29.09
                                                    199        453    27.99
  1.5    4         406        924    57.08
                                                    217        493    30.45
  3      4         622      1,416    87.53
                                                     84        192    11.88
  6      4         707      1,608    99.40
                                                      4         10     0.60
 12      4         711      1,618   100.00
                                                      0          0     0.00
 24      4         711      1,618   100.00
                                                      0          0     0.00
 48      4         711      1,618   100.00
------------------------------------------------------------------------------
         4          Average size =    1.29 in   Fragmentation index =    1.299
```

```
Precision Blasting                B R E A K E R                       V5.01
Services, Inc.                                             Date: 11-12-2009
---------------------------------------------------------------------------
Entry: 4                        ENERCON TRENCH 2              File: ENRCTRN2
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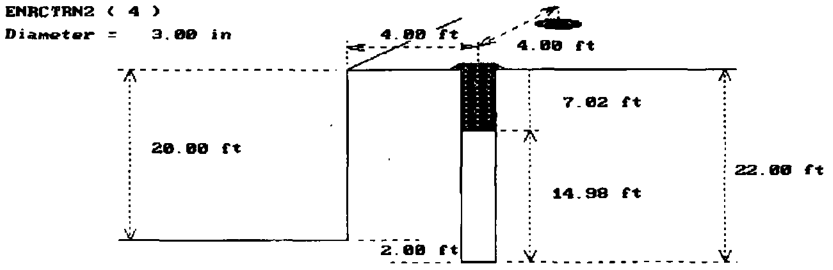
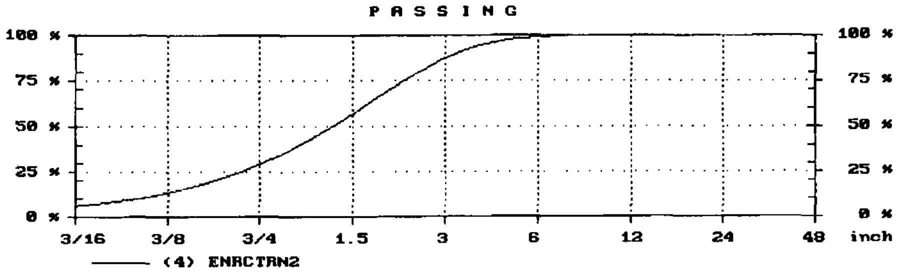
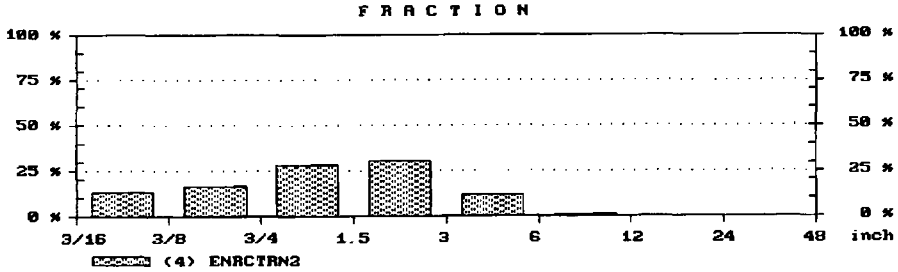






Attachment 7

Precision Blasting and Rock Removal

Section 3

Blasting Program Insurance

Correspondence with Wortham Insurance and Risk Management

Blasting Program Insurance

Entergy's counsel has advised that blasting insurance coverage would be required for the conversion of IPEC Units 2 and 3 to closed-loop cooling (Enercon Report, Section 5.1.3). The feasibility of obtaining insurance for the blasting project was evaluated by Fairmont Specialty and Wortham Insurance & Risk Management (Wortham). Fairmont Specialty has over twenty years of experience providing insurance for the commercial explosives and blasting industry and the company is an active member of the International Society of Explosives Engineers, participating in numerous association and industry workshops and trade shows promoting safety. Wortham has been conducting business since 1928 and is one of the top 25 insurance brokers nationwide.

Obtaining blasting insurance for the project is not assured. Wortham provided a cursory overview of a representative coverage plan in the Fairmont Specialty explosives program. The representative coverage plan does not provide coverage for business interruption. Notably, Fairmont Specialty indicated that nuclear incidents would not be covered. Entergy's counsel has advised that coverage for both business interruption and nuclear incidents would be required before undertaking a project like the conversion of Units 2 and 3 to closed-loop cooling. The finalized blasting plan would have to be reviewed by the underwriters before any commitment could be made to provide coverage for the project.

Ashlie Brown

From: Ralph Hamm
Sent: Friday, November 06, 2009 12:11 PM
To: Ashlie Brown
Subject: RE: Kesco - Entegy Project

Ashlie,
Following are our comments on your questions:

1. Does Fairmont Specialty have experience with blasting insurance for projects at or near nuclear facilities?

To my knowledge, Fairmont Specialty has not insured a blasting project on the premises of a nuclear facility. However, the company has been providing insurance for blasting contractors since 1988, many of whom are involved in sensitive close-in type projects.

2. What coverage would Fairmont Specialty propose for this project?

Fairmont offers the following coverage in their explosives program; however, the company has not reviewed appropriate underwriting information and therefore can not commit to providing this coverage at this time:

- General Liability - $1,000,000 per occurrence, $2,000,000 aggregate with limited Pollution Liability
- Excess Liability – up to $5,000,000 occurrence excess of the General Liability , Automobile liability, and Employer's Liability
- Workers' Compensation and Employers' Liability - $1,000,000
- Automobile Liability - $1,000,000 combined single limit

3. What limits of liability would apply to this policy? See above for program limits. Higher limits can be sought and obtained in the open insurance market

4. What would be the period of coverage? Policies are issued on an annual basis; updated underwriting information is required prior to renewal of program each year.

5. Would a holdback or retention be required? This is a negotiable issue.

6. Would this policy cover nuclear considerations (i.e. would a shutdown due to the perceived risk of a nuclear incident be covered)? Nuclear incidents would not be covered. We have had some discussions about shutdown of the plant as a result of the blasting that triggers the sensors which in turn shut down the plant. This is problematic and the underwriters require careful review of the blasting plan, etc before they can commit to providing coverage for this risk.

7. Would this policy include or exclude preexisting conditions? The policies will not cover damages that occur prior to inception of the blasting operation.

If you have any other questions, please let me know.

Ralph Hamm CPCU CRM CIC CLU
Texas AGA, Managing Director
Wortham Insurance & Risk Management

WORTHAM
Insurance & Risk Management

Please note coverage cannot be bound or altered without confirmation from an agency representative

Ashlie Brown

From:	Ralph Hamm
Sent:	Friday, November 06, 2009 4:05 PM
To:	Ashlie Brown
Subject:	RE: Kesco - Entegy Project

Ashlie,
Thanks for your call. I spoken to the lead underwriter on this case and they are simply unwilling to speculate about what might be an appropriate premium charge for the risk of this proposed operation. As more information becomes available, we can go back to the company and ask this question again.

If I was asked to make an educated ***guess***, I suppose that the project is looking at 1.0-1.5% of the gross blasting revenues on the project for a $5,000,000 limit of liability. This ***guess*** is based on a number of assumptions about the self-insured retention, risks assumed under the contract governing the project and exact coverage requirements for the project.

I look forward to hearing from you.

Ralph Hamm CPCU CRM CIC CLU
Texas AGA, Managing Director
Wortham Insurance & Risk Management

WORTHAM
Insurance & Risk Management

Attachment 8

Cultural / Historic Considerations for Cooling Tower Feasibility

Enercon Services, Inc.

MEMO TO:	Kelli Dowell Entergy Services, Inc.	cc:	Dara Gray Entergy Nuclear Indian Point Elise Zoli Goodwin Procter, LLP
FROM:	Tim Basham Enercon Services, Inc.		
DATE:	02/05/2010		

RE: Cultural / Historic Considerations for Cooling Tower Feasibility

Issue:

Under Section 106 of the National Historic Preservation Act federal actions (or actions subject to federal approval) are subject to review by the State Historic Preservation Office (SHPO) for their potential to impact sites listed, or eligible for listing, in the National Register of Historic Places. Installation of cooling towers at the Indian Point Energy Center (IPEC) would be subject to approval by the Nuclear Regulatory Commission (NRC). Therefore, SHPO review of potential impacts to cultural or historic properties is necessary.

Actions To-Date:

Phase I-A and Phase I-B studies of the Area of Potential Effect (APE) from cooling tower installation have been conducted. The Phase I studies identified evidence of both historic and pre-historic components in the APE. Reports documenting these findings were submitted to the New York SHPO, Ms. Cynthia Blakemore. Ms. Blakemore (NYSHPO) provided review comments in a December 8, 2009 letter. NYSHPO indicated that if a decision is made to install cooling towers, the APE should be reassessed, a geomorphological assessment should be conducted if warranted, and that a Phase II archaeological site examination should be conducted for the historic and prehistoric components identified in the Phase I studies. NYSHPO noted that such Phase II studies may require removal of asphalt paving in order to adequately address the potential for historic resources below.

In a follow-up phone conversation on 12/21/2009, NYSHPO also recommended initiating consultation with tribal organizations with potential interest in the APE. She identified these to be the Stockbridge-Munsee community of Mohicans and the Delaware Nation. She indicated that tribal organizations have records of historic/pre-historic occupations (including burial grounds) to which NYSHPO does not have access.

Considerations:

Pursuant to NYSHPO's comments, installation of cooling towers at IPEC must not proceed without extensive additional considerations of potential impacts to cultural / historic resources. These considerations must include:

- Correspondence with, and solicitation of comments from, affected tribal organizations. (Many tribes do not respond but are given a 30-day opportunity to do so.) Approximate duration – 60 days.
- Reassessment of the APE including all temporary construction work areas and relocation of utilities, parking lots, etc. (The APE also includes the visual impacts on historic properties in nearby areas and the NY natural area across the river). Approximate duration – 60 days.
- Design of a Phase II archaeological site examination that extends beneath such site facilities as parking lots, roadways and among buried utilities that may exist in the APE. Approximate duration – 45 days.
- Submittal of the reassessed APE and Phase II study design to NYSHPO and affected tribes for review and approval prior to execution. Approximate duration – 45 days.
- Execution of the Phase II study (with notice to tribes and invitation to send observers). Approximate duration (including report preparation) – 9 months.
- Submittal of the Phase II study results to NYSHPO and affected tribes for review and comment. Approximate duration - 60 days.
- Consideration of Phase II study results, NYSHPO and tribal review comments in project planning. Approximate duration – see discussion below.

Discussion

The duration needed to accomplish the above considerations cannot be known yet. The conduct of a Phase II study that encompasses the site-wide historic component and the pre-historic component in the south tower area might entail six months of field work and another three to six months of artifact curation and report preparation. Coupled with review periods required by the SHPO and the tribes, these considerations could take as long as 18 months. Costs cannot be determined at this point either, but would be substantial recognizing the disruption of existing facilities that would occur. Because of the concentration of buried utilities in the area of the south tower, Phase II investigations would potentially require temporary de-activation/relocation in order to accomplish excavations safely. Until a Phase II study design is approved, it is unknown the degree to which this would be necessary or to which this would disrupt normal plant operations.

The outcome of the additional considerations could be any of the following scenarios:

1. Finding, with SHPO and tribal concurrence, that indicates no sites listed or eligible for listing in the National Register of Historic Places will be adversely affected by the proposed action.
2. Finding that eligible properties are present, but effects are avoided, minimized or mitigated (Phase III) to ensure their protection to the satisfaction of the SHPO and tribes. (In many cases, data recovery that occurs as part of the Phase II investigation itself is sufficient to mitigate impacts.)
3. Finding that eligible properties are present for which no mitigation measure other than no-disturbance (project-cancellation) can ensure protection (human burial sites).

At this stage, any of the above scenarios is a possibility. However, the second is the most likely scenario. In that case, a wide variety of alternatives might need to be considered to avoid, minimize or mitigate impacts, including:

- alternative tower configurations
- alternative construction arrangements
- mitigation activities to recover historic/prehistoric data

It should be noted that, due to the necessary interactions involved in considerations of alternative project designs/mitigation measures and SHPO approval, the duration for the second scenario would be considerably longer than either of the other scenarios – and in addition to the approximately 18 month duration required to accomplish the Phase II itself.

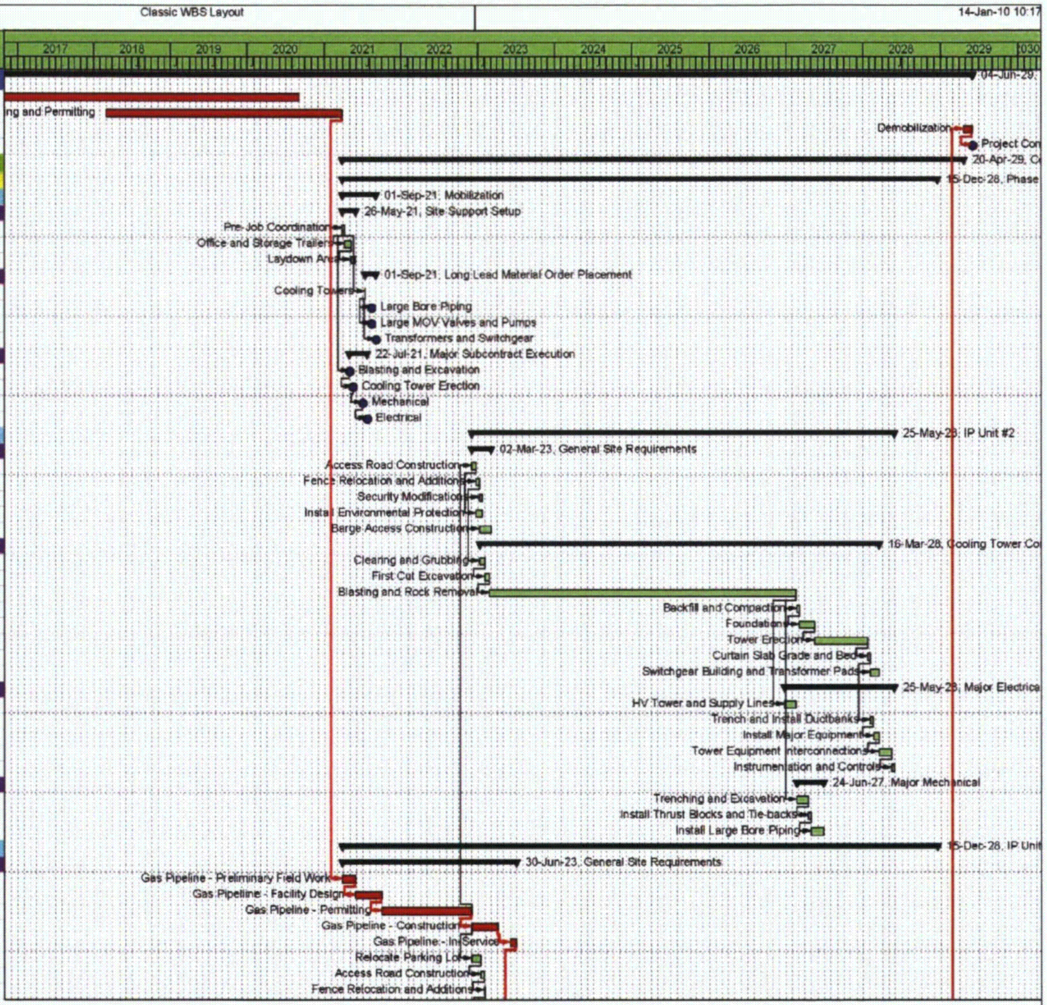
Attachment 9

Construction Schedule

Section 1:	**Conversion of Unit 2 and Unit 3**
Section 2:	**Conversion of Only Unit 2**
Section 3:	**Conversion of Only Unit 3**

IP Cooling Water Conversion Project | Classic WBS Layout | 14-Jan-10 10:17

Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
IP Cooling Water Conversion Project			3327	01-Sep-16	04-Jun-29
0001	Design Engineering and Mod Packages	0%	1043	01-Sep-16*	31-Aug-20
0002	Local Zoning and Permitting	0%	800	01-Mar-18*	24-Mar-21
120	Demobilization	0%	30	23-Apr-29	01-Jun-29
121	Project Completion	0%	0	04-Jun-29	
Cooling Tower Conversion Construction Schedule			2107	25-Mar-21	20-Apr-29
Phase I - Online (Pre-Outage)			2017	25-Mar-21	15-Dec-28
Mobilization			114	25-Mar-21	01-Sep-21
Site Support Setup			45	25-Mar-21	26-May-21
006	Pre-Job Coordination	0%	10	25-Mar-21	07-Apr-21
007	Office and Storage Trailers	0%	20	08-Apr-21	05-May-21
008	Laydown Area	0%	15	06-May-21	26-May-21
Long Lead Material Order Placement			35	14-Jul-21	01-Sep-21
009	Cooling Towers	0%	0	14-Jul-21	14-Jul-21
011	Large Bore Piping	0%	0	11-Aug-21	
012	Large MOV Valves and Pumps	0%	0	11-Aug-21	
013	Transformers and Switchgear	0%	0	01-Sep-21	
Major Subcontract Execution			61	28-Apr-21	22-Jul-21
014	Blasting and Excavation	0%	0	28-Apr-21	
015	Cooling Tower Erection	0%	0	13-May-21	
017	Mechanical	0%	0	01-Jul-21	
018	Electrical	0%	0	22-Jul-21	
IP Unit #2			1430	02-Dec-22	25-May-28
General Site Requirements			65	02-Dec-22	02-Mar-23
21	Access Road Construction	0%	15	02-Dec-22	22-Dec-22
22	Fence Relocation and Additions	0%	10	23-Dec-22	05-Jan-23
23	Security Modifications	0%	10	06-Jan-23	19-Jan-23
24	Install Environmental Protection	0%	20	23-Dec-22	19-Jan-23
25	Barge Access Construction	0%	40	06-Jan-23	02-Mar-23
Cooling Tower Construction			1355	06-Jan-23	16-Mar-28
27	Clearing and Grubbing	0%	20	06-Jan-23	02-Feb-23
28	First Cut Excavation	0%	15	03-Feb-23	23-Feb-23
29	Blasting and Rock Removal	0%	1040	24-Feb-23	18-Feb-27
30	Backfill and Compaction	0%	10	19-Feb-27	04-Mar-27
31	Foundations	0%	50	05-Mar-27	13-May-27
32	Tower Erection	0%	180	14-May-27	20-Jan-28
33	Curtain Slab Grade and Bed	0%	10	21-Jan-28	03-Feb-28
34	Switchgear Building and Transformer Pads	0%	30	04-Feb-28	16-Mar-28
Major Electrical			370	25-Dec-26	25-May-28
36	HV Tower and Supply Lines	0%	40	25-Dec-26	18-Feb-27
37	Trench and Install Ductbanks	0%	10	04-Feb-28	17-Feb-28
38	Install Major Equipment	0%	20	18-Feb-28	16-Mar-28
39	Tower Equipment Interconnections	0%	40	17-Mar-28	11-May-28
40	Instrumentation and Controls	0%	10	12-May-28	25-May-28
Major Mechanical			90	19-Feb-27	24-Jun-27
42	Trenching and Excavation	0%	40	19-Feb-27	15-Apr-27
43	Install Thrust Blocks and Tie-backs	0%	10	16-Apr-27	29-Apr-27
44	Install Large Bore Piping	0%	40	30-Apr-27	24-Jun-27
IP Unit #3			2017	25-Mar-21	15-Dec-28
General Site Requirements			592	25-Mar-21	30-Jun-23
46	Gas Pipeline - Preliminary Field Work	0%	46	25-Mar-21	27-May-21
47	Gas Pipeliine - Facility Design	0%	90	28-May-21	30-Sep-21
47A	Gas Pipeline - Permitting	0%	305	01-Oct-21	01-Dec-22
47B	Gas Pipeline - Construction	0%	90	02-Dec-22	06-Apr-23
47C	Gas Pipeline - In-Service	0%	21	02-Jun-23	30-Jun-23
48	Relocate Parking Lot	0%	30	02-Dec-22	12-Jan-23
49	Access Road Construction	0%	10	13-Jan-23	26-Jan-23
50	Fence Relocation and Additions	0%	5	27-Jan-23	02-Feb-23



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TASK filter: All Activities

IP Cooling Water Conversion Project

Classic WBS Layout

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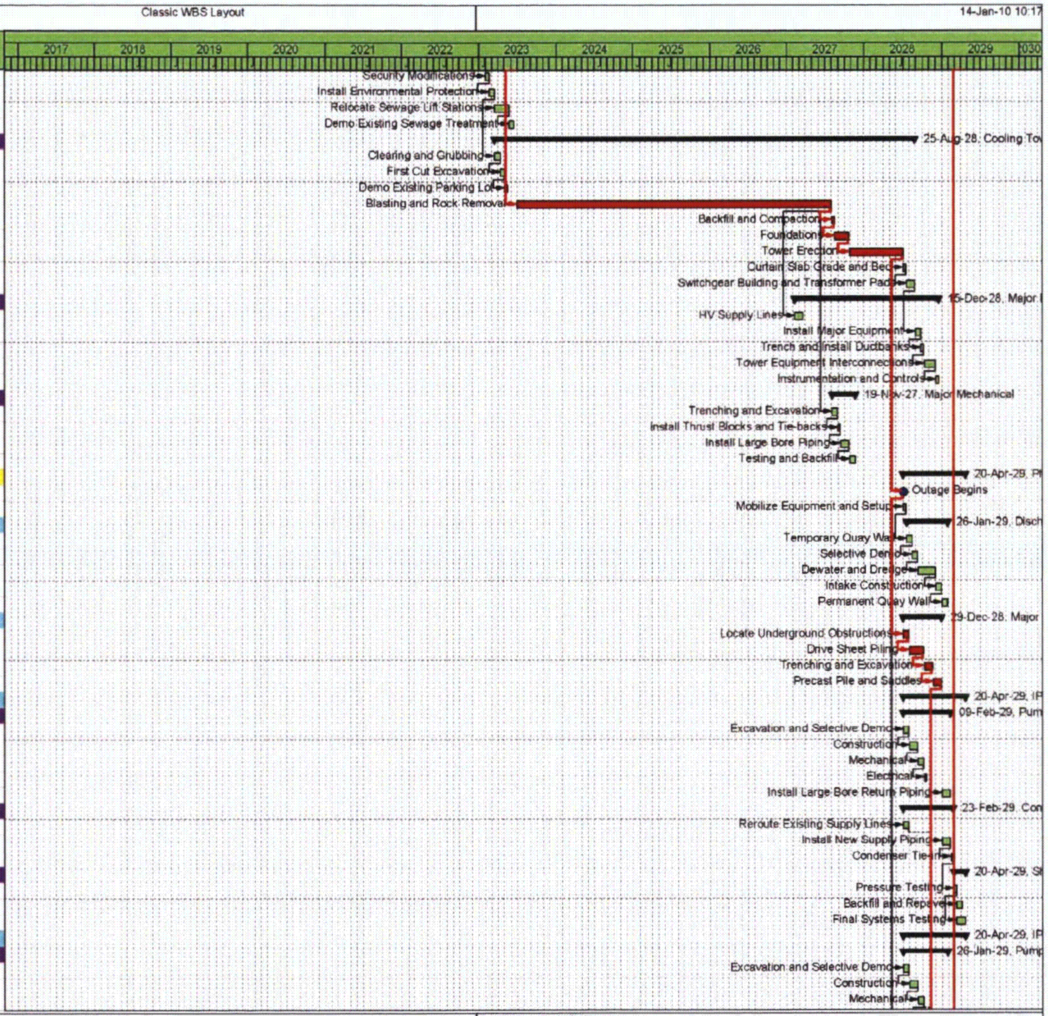
Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
51	Security Modifications	0%	10	03-Feb-23	16-Feb-23
52	Install Environmental Protection	0%	20	17-Feb-23	16-Mar-23
53	Relocate Sewage Lift Stations	0%	50	17-Mar-23	25-May-23
54	Demo Existing Sewage Treatment	0%	15	26-May-23	15-Jun-23
Cooling Tower Construction			1421	17-Mar-23	25-Aug-28
56	Clearing and Grubbing	0%	20	17-Mar-23	13-Apr-23
57	First Cut Excavation	0%	15	14-Apr-23	04-May-23
58	Demo Existing Parking Lot	0%	10	05-May-23	18-May-23
59	Blasting and Rock Removal	0%	1065	03-Jul-23	30-Jul-27
60	Backfill and Compaction	0%	10	02-Aug-27	13-Aug-27
61	Foundations	0%	50	16-Aug-27	22-Oct-27
62	Tower Erection	0%	180	25-Oct-27	30-Jun-28
63	Curtain Slab Grade and Bed	0%	10	03-Jul-28	14-Jul-28
64	Switchgear Building and Transformer Pads	0%	30	17-Jul-28	25-Aug-28
Major Electrical			485	08-Feb-27	15-Dec-28
66	HV Supply Lines	0%	30	08-Feb-27	19-Mar-27
67	Install Major Equipment	0%	20	28-Aug-28	22-Sep-28
68	Trench and Install Ductbanks	0%	10	25-Sep-28	06-Oct-28
69	Tower Equipment Interconnections	0%	40	09-Oct-28	01-Dec-28
70	Instrumentation and Controls	0%	10	04-Dec-28	15-Dec-28
Major Mechanical			80	02-Aug-27	19-Nov-27
72	Trenching and Excavation	0%	20	02-Aug-27	27-Aug-27
73	Install Thrust Blocks and Tie-backs	0%	10	30-Aug-27	10-Sep-27
74	Install Large Bore Piping	0%	30	13-Sep-27	22-Oct-27
75	Testing and Backfill	0%	20	25-Oct-27	19-Nov-27
Phase II (Outage Required)			210	03-Jul-28	20-Apr-29
77	Outage Begins	0%	0	03-Jul-28	
78	Mobilize Equipment and Setup	0%	10	03-Jul-28	14-Jul-28
Discharge Canal Modifications			140	17-Jul-28	26-Jan-29
80	Temporary Quay Wall	0%	20	17-Jul-28	11-Aug-28
81	Selective Demo	0%	20	14-Aug-28	08-Sep-28
82	Dewater and Dredge	0%	60	11-Sep-28	01-Dec-28
83	Intake Construction	0%	20	04-Dec-28	29-Dec-28
84	Permanent Quay Wall	0%	20	01-Jan-29	26-Jan-29
Major Excavation of Broadway Area			130	03-Jul-28	29-Dec-28
86	Locate Underground Obstructions	0%	20	03-Jul-28	28-Jul-28
87	Drive Sheet Piling	0%	50	31-Jul-28	06-Oct-28
88	Trenching and Excavation	0%	30	09-Oct-28	17-Nov-28
89	Precast Pile and Saddles	0%	30	20-Nov-28	29-Dec-28
IP Unit #2			210	03-Jul-28	20-Apr-29
Pump House			160	03-Jul-28	09-Feb-29
92	Excavation and Selective Demo	0%	20	03-Jul-28	28-Jul-28
93	Construction	0%	30	31-Jul-28	08-Sep-28
94	Mechanical	0%	20	11-Sep-28	06-Oct-28
95	Electrical	0%	10	09-Oct-28	20-Oct-28
96	Install Large Bore Return Piping	0%	30	01-Jan-29	09-Feb-29
Condenser Tie-in			170	03-Jul-28	23-Feb-29
098	Reroute Existing Supply Lines	0%	20	03-Jul-28	28-Jul-28
099	Install New Supply Piping	0%	30	01-Jan-29	09-Feb-29
100	Condenser Tie-in	0%	10	12-Feb-29	23-Feb-29
Shake out and Testing			40	26-Feb-29	20-Apr-29
102	Pressure Testing	0%	10	26-Feb-29	09-Mar-29
103	Backfill and Repave	0%	20	12-Mar-29	06-Apr-29
104	Final Systems Testing	0%	30	12-Mar-29	20-Apr-29
IP Unit #3			210	03-Jul-28	20-Apr-29
Pump House			150	03-Jul-28	26-Jan-29
107	Excavation and Selective Demo	0%	20	03-Jul-28	28-Jul-28
108	Construction	0%	30	31-Jul-28	08-Sep-28
109	Mechanical	0%	20	11-Sep-28	06-Oct-28



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TASK filter: All Activities

IP Cooling Water Conversion Project

Classic WBS Layout

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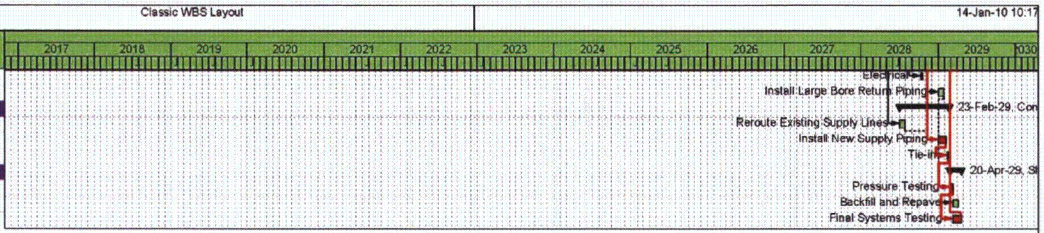
Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
110	Electrical	0%	10	09-Oct-28	20-Oct-28
111	Install Large Bore Return Piping	0%	20	01-Jan-29	26-Jan-29
Condenser Tie-in			170	03-Jul-28	23-Feb-29
113	Reroute Existing Supply Lines	0%	20	03-Jul-28	28-Jul-28
114	Install New Supply Piping	0%	30	01-Jan-29	09-Feb-29
115	Tie-in	0%	10	12-Feb-29	23-Feb-29
Shake out and Testing			40	26-Feb-29	20-Apr-29
117	Pressure Testing	0%	10	26-Feb-29	09-Mar-29
118	Backfill and Repave	0%	20	12-Mar-29	06-Apr-29
119	Final Systems Testing	0%	30	12-Mar-29	20-Apr-29



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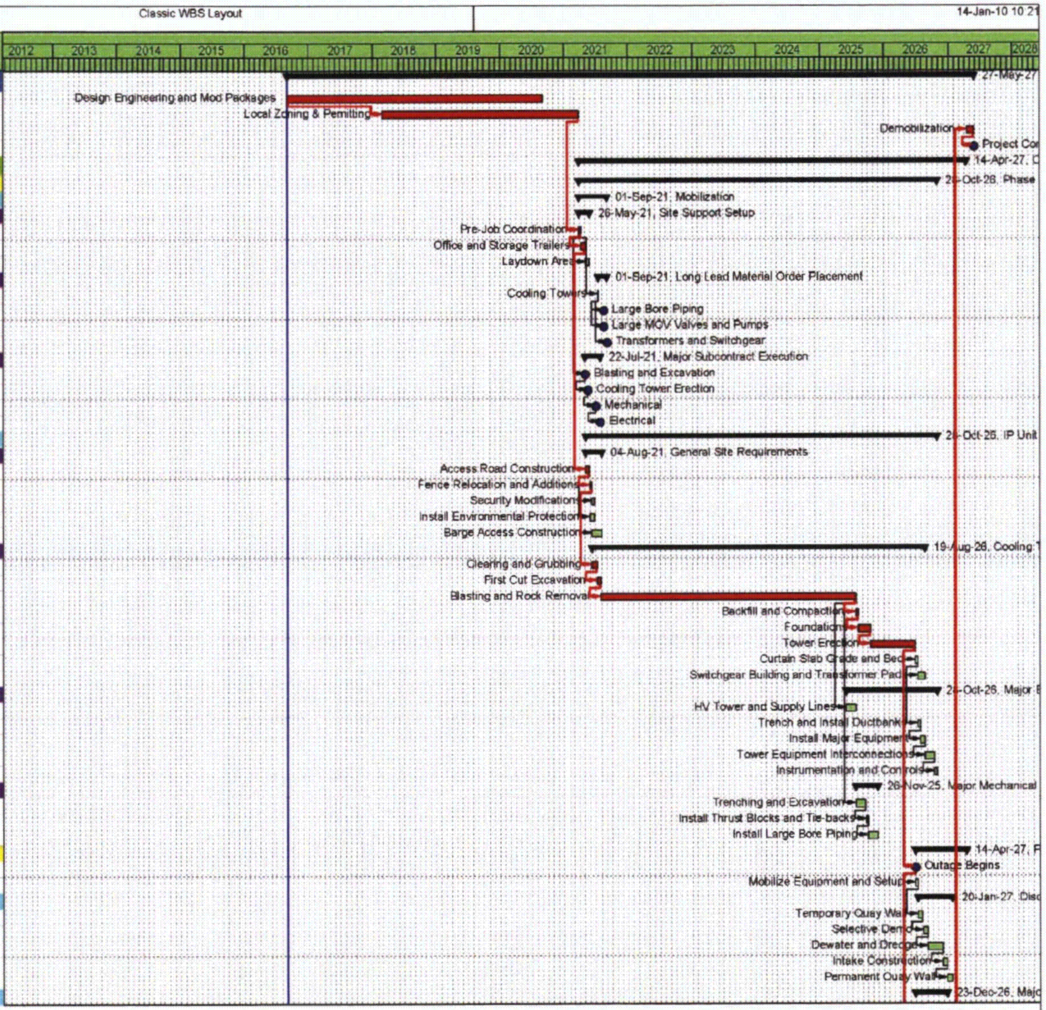
IP U2 Cooling Water Conversion Project

Classic WBS Layout

14-Jan-10 10:21

Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
IP U2 Cooling Water Conversion Project			2800	01-Sep-16	27-May-27
001	Design Engineering and Mod Packages	0%	1043	01-Sep-16*	31-Aug-20
002	Local Zoning & Permitting	0%	800	01-Mar-18*	24-Mar-21
120	Demobilization	0%	30	15-Apr-27	26-May-27
121	Project Completion	0%	0	27-May-27	
Cooling Tower Conversion Construction Schedule			1580	25-Mar-21	14-Apr-27
Phase I - Online (Pre-Outage)			1460	25-Mar-21	28-Oct-26
Mobilization			114	25-Mar-21	01-Sep-21
Site Support Setup			45	25-Mar-21	26-May-21
006	Pre-Job Coordination	0%	10	25-Mar-21	07-Apr-21
007	Office and Storage Trailers	0%	20	08-Apr-21	05-May-21
008	Laydown Area	0%	15	06-May-21	26-May-21
Long Lead Material Order Placement			35	14-Jul-21	01-Sep-21
009	Cooling Towers	0%	0	14-Jul-21	14-Jul-21
011	Large Bore Piping	0%	0	11-Aug-21	
012	Large MOV Valves and Pumps	0%	0	11-Aug-21	
013	Transformers and Switchgear	0%	0	01-Sep-21	
Major Subcontract Execution			61	28-Apr-21	22-Jul-21
014	Blasting and Excavation	0%	0	28-Apr-21	
015	Cooling Tower Erection	0%	0	13-May-21	
017	Mechanical	0%	0	01-Jul-21	
018	Electrical	0%	0	22-Jul-21	
IP Unit #2			1430	06-May-21	28-Oct-26
General Site Requirements			65	06-May-21	04-Aug-21
21	Access Road Construction	0%	15	06-May-21	26-May-21
22	Fence Relocation and Additions	0%	10	27-May-21	09-Jun-21
23	Security Modifications	0%	10	10-Jun-21	23-Jun-21
24	Install Environmental Protection	0%	20	27-May-21	23-Jun-21
25	Barge Access Construction	0%	40	10-Jun-21	04-Aug-21
Cooling Tower Construction			1355	10-Jun-21	19-Aug-26
27	Clearing and Grubbing	0%	20	10-Jun-21	07-Jul-21
28	First Cut Excavation	0%	15	08-Jul-21	28-Jul-21
29	Blasting and Rock Removal	0%	1040	29-Jul-21	23-Jul-25
30	Backfill and Compaction	0%	10	24-Jul-25	06-Aug-25
31	Foundations	0%	50	07-Aug-25	15-Oct-25
32	Tower Erection	0%	180	16-Oct-25	24-Jun-26
33	Curtain Slab Grade and Bed	0%	10	25-Jun-26	08-Jul-26
34	Switchgear Building and Transformer Pads	0%	30	09-Jul-26	19-Aug-26
Major Electrical			370	29-May-25	28-Oct-26
36	HV Tower and Supply Lines	0%	40	29-May-25	23-Jul-25
37	Trench and Install Ductbanks	0%	10	09-Jul-26	22-Jul-26
38	Install Major Equipment	0%	20	23-Jul-26	19-Aug-26
39	Tower Equipment Interconnections	0%	40	20-Aug-26	14-Oct-26
40	Instrumentation and Controls	0%	10	15-Oct-26	28-Oct-26
Major Mechanical			90	24-Jul-25	26-Nov-25
42	Trenching and Excavation	0%	40	24-Jul-25	17-Sep-25
43	Install Thrust Blocks and Tie-backs	0%	10	18-Sep-25	01-Oct-25
44	Install Large Bore Piping	0%	40	02-Oct-25	26-Nov-25
Phase II (Outage Required)			210	25-Jun-26	14-Apr-27
77	Outage Begins	0%	0	25-Jun-26	
78	Mobilize Equipment and Setup	0%	10	25-Jun-26	08-Jul-26
Discharge Canal Modifications			140	09-Jul-26	20-Jan-27
80	Temporary Quay Wall	0%	20	09-Jul-26	05-Aug-26
81	Selective Demo	0%	20	06-Aug-26	02-Sep-26
82	Dewater and Dredge	0%	60	03-Sep-26	25-Nov-26
83	Intake Construction	0%	20	26-Nov-26	23-Dec-26
84	Permanent Quay Wall	0%	20	24-Dec-26	20-Jan-27
Major Excavation of Broadway Area			130	25-Jun-26	23-Dec-26



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TASK filter: All Activities

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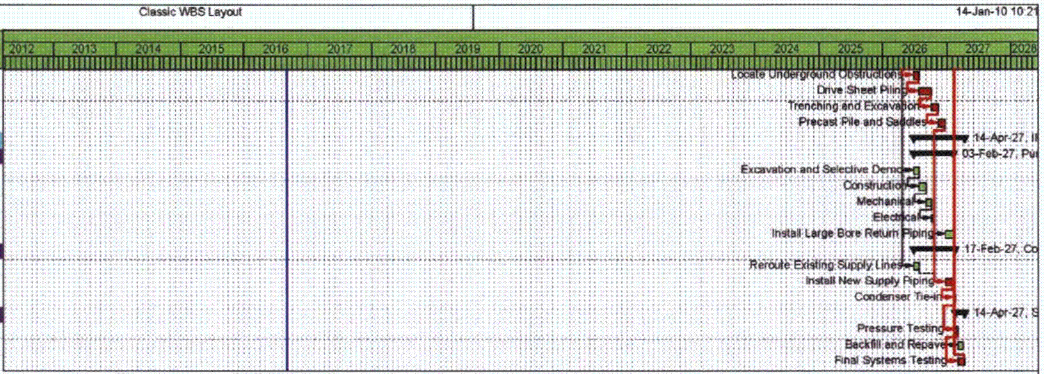
IP U2 Cooling Water Conversion Project

Classic WBS Layout

14-Jan-10 10:21

Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
86	Locate Underground Obstructions	0%	20	25-Jun-26	22-Jul-26
87	Drive Sheet Piling	0%	50	23-Jul-26	30-Sep-26
88	Trenching and Excavation	0%	30	01-Oct-26	11-Nov-26
89	Precast Pile and Saddles	0%	30	12-Nov-26	23-Dec-26
IP Unit #2			210	25-Jun-26	14-Apr-27
Pump House			160	25-Jun-26	03-Feb-27
92	Excavation and Selective Demo	0%	20	25-Jun-26	22-Jul-26
93	Construction	0%	30	23-Jul-26	02-Sep-26
94	Mechanical	0%	20	03-Sep-26	30-Sep-26
95	Electrical	0%	10	01-Oct-26	14-Oct-26
96	Install Large Bore Return Piping	0%	30	24-Dec-26	03-Feb-27
Condenser Tie-in			170	25-Jun-26	17-Feb-27
098	Reroute Existing Supply Lines	0%	20	25-Jun-26	22-Jul-26
099	Install New Supply Piping	0%	30	24-Dec-26	03-Feb-27
100	Condenser Tie-in	0%	10	04-Feb-27	17-Feb-27
Shake out and Testing			40	18-Feb-27	14-Apr-27
102	Pressure Testing	0%	10	18-Feb-27	03-Mar-27
103	Backfill and Repave	0%	20	04-Mar-27	31-Mar-27
104	Final Systems Testing	0%	30	04-Mar-27	14-Apr-27



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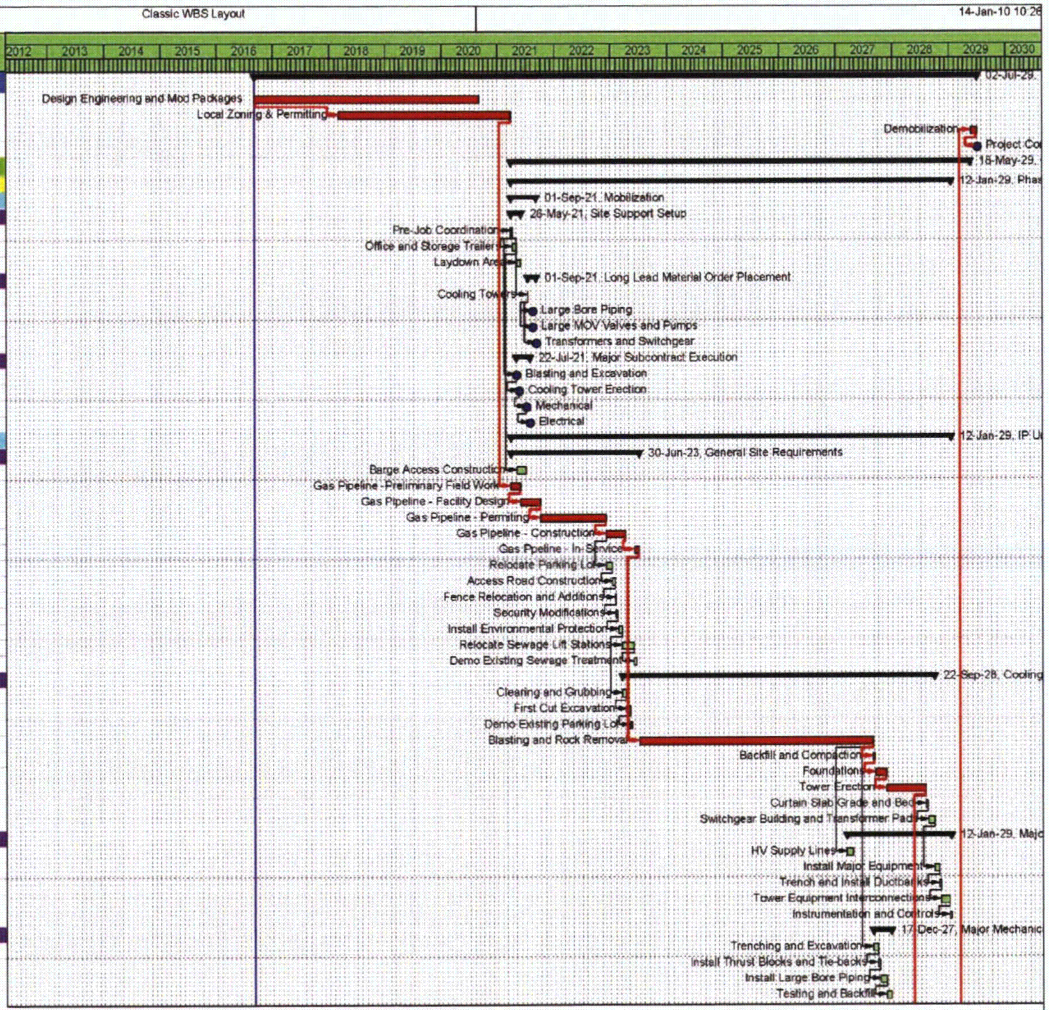
TASK filter: All Activities

IP U3 Cooling Water Conversion Project

Classic WBS Layout

14-Jan-10 10:26

Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
IP U3 Cooling Water Conversion Project			3347	01-Sep-16	02-Jul-29
001	Design Engineering and Mod Packages	0%	1043	01-Sep-16*	31-Aug-20
021	Local Zoning & Permitting	0%	800	01-Mar-18*	24-Mar-21
120	Demobilization	0%	30	21-May-29	29-Jun-29
121	Project Completion	0%	0	02-Jul-29	
Cooling Tower Conversion Construction Schedule			2127	25-Mar-21	18-May-29
Phase I - Online (Pre-Outage)			2037	25-Mar-21	12-Jan-29
Mobilization			114	25-Mar-21	01-Sep-21
Site Support Setup			45	25-Mar-21	26-May-21
006	Pre-Job Coordination	0%	10	25-Mar-21	07-Apr-21
007	Office and Storage Trailers	0%	20	08-Apr-21	05-May-21
008	Laydown Area	0%	15	06-May-21	26-May-21
Long Lead Material Order Placement			35	14-Jul-21	01-Sep-21
009	Cooling Towers	0%	0	14-Jul-21	14-Jul-21
011	Large Bore Piping	0%	0	11-Aug-21	
012	Large MOV Valves and Pumps	0%	0	11-Aug-21	
013	Transformers and Switchgear	0%	0	01-Sep-21	
Major Subcontract Execution			61	28-Apr-21	22-Jul-21
014	Blasting and Excavation	0%	0	28-Apr-21	
015	Cooling Tower Erection	0%	0	13-May-21	
017	Mechanical	0%	0	01-Jul-21	
018	Electrical	0%	0	22-Jul-21	
IP Unit #3			2037	25-Mar-21	12-Jan-29
General Site Requirements			592	25-Mar-21	30-Jun-23
25	Barge Access Construction	0%	40	06-May-21	30-Jun-21
27	Gas Pipeline -Preliminary Field Work	0%	46	25-Mar-21	27-May-21
28	Gas Pipeline - Facility Design	0%	90	28-May-21	30-Sep-21
29	Gas Pipeline - Permiting	0%	305	01-Oct-21	01-Dec-22
30	Gas Pipeline - Construction	0%	90	02-Dec-22	06-Apr-23
40	Gas Ppeline - In-Service	0%	21	02-Jun-23	30-Jun-23
48	Relocate Parking Lot	0%	30	02-Dec-22	12-Jan-23
49	Access Road Construction	0%	10	13-Jan-23	26-Jan-23
50	Fence Relocation and Additions	0%	5	27-Jan-23	02-Feb-23
51	Security Modifications	0%	10	03-Feb-23	16-Feb-23
52	Install Environmental Protection	0%	20	17-Feb-23	16-Mar-23
53	Relocate Sewage Lift Stations	0%	50	17-Mar-23	25-May-23
54	Demo Existing Sewage Treatment	0%	15	26-May-23	15-Jun-23
Cooling Tower Construction			1441	17-Mar-23	22-Sep-28
56	Clearing and Grubbing	0%	20	17-Mar-23	13-Apr-23
57	First Cut Excavation	0%	15	14-Apr-23	04-May-23
58	Demo Existing Parking Lot	0%	10	05-May-23	18-May-23
59	Blasting and Rock Removal	0%	1085	03-Jul-23	27-Aug-27
60	Backfill and Compaction	0%	10	30-Aug-27	10-Sep-27
61	Foundations	0%	50	13-Sep-27	19-Nov-27
62	Tower Erection	0%	180	22-Nov-27	28-Jul-28
63	Curtain Slab Grade and Bed	0%	10	31-Jul-28	11-Aug-28
64	Switchgear Building and Transformer Pads	0%	30	14-Aug-28	22-Sep-28
Major Electrical			485	08-Mar-27	12-Jan-29
66	HV Supply Lines	0%	30	08-Mar-27	16-Apr-27
67	Install Major Equipment	0%	20	25-Sep-28	20-Oct-28
68	Trench and Install Ductbanks	0%	10	23-Oct-28	03-Nov-28
69	Tower Equipment Interconnections	0%	40	06-Nov-28	29-Dec-28
70	Instrumentation and Controls	0%	10	01-Jan-29	12-Jan-29
Major Mechanical			80	30-Aug-27	17-Dec-27
72	Trenching and Excavation	0%	20	30-Aug-27	24-Sep-27
73	Install Thrust Blocks and Tie-backs	0%	10	27-Sep-27	08-Oct-27
74	Install Large Bore Piping	0%	30	11-Oct-27	19-Nov-27
75	Testing and Backfill	0%	20	22-Nov-27	17-Dec-27



- ▬ Actual Work
- 🟩 Remaining Work
- 🟥 Critical Remaining Work
- ● ● Milestone
- ▼▬▼ Summary

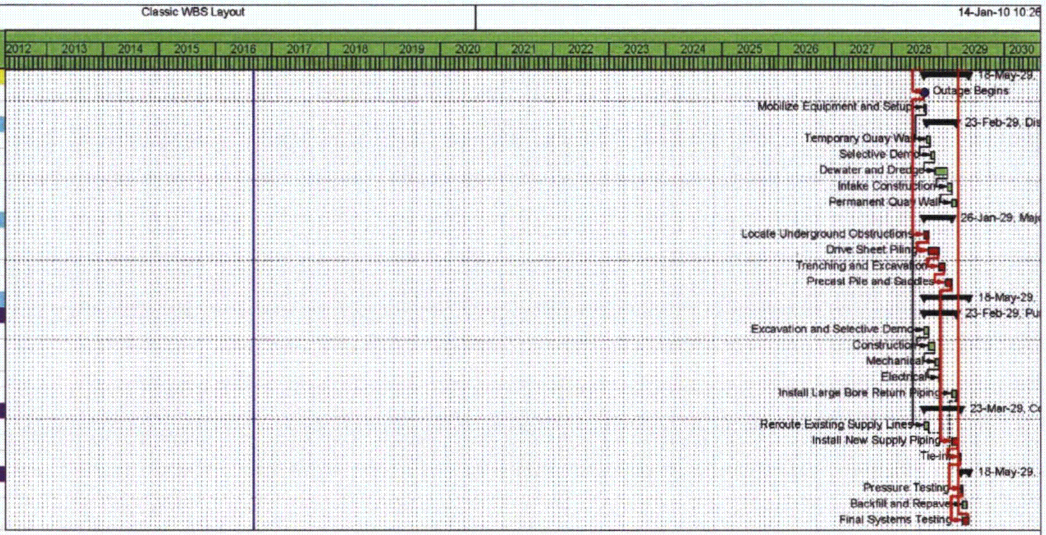
Page 1 of 2

TASK filter: All Activities

(c) Primavera Systems, Inc.

IP U3 Cooling Water Conversion Project | Classic WBS Layout | 14-Jan-10 10:26

Activity ID	Activity Name	Physical % Complete	aining ration	Start	Finish
Phase II (Outage Required)			210	31-Jul-28	18-May-29
77	Outage Begins	0%	0	31-Jul-28	
78	Mobilize Equipment and Setup	0%	10	31-Jul-28	11-Aug-28
Discharge Canal Modifications			140	14-Aug-28	23-Feb-29
80	Temporary Quay Wall	0%	20	14-Aug-28	08-Sep-28
81	Selective Demo	0%	20	11-Sep-28	06-Oct-28
82	Dewater and Dredge	0%	60	09-Oct-28	29-Dec-28
83	Intake Construction	0%	20	01-Jan-29	26-Jan-29
84	Permanent Quay Wall	0%	20	29-Jan-29	23-Feb-29
Major Excavation of Broadway Area			130	31-Jul-28	26-Jan-29
86	Locate Underground Obstructions	0%	20	31-Jul-28	25-Aug-28
87	Drive Sheet Piling	0%	50	28-Aug-28	03-Nov-28
88	Trenching and Excavation	0%	30	06-Nov-28	15-Dec-28
89	Precast Pile and Saddles	0%	30	18-Dec-28	26-Jan-29
IP Unit #3			210	31-Jul-28	18-May-29
Pump House			150	31-Jul-28	23-Feb-29
107	Excavation and Selective Demo	0%	20	31-Jul-28	25-Aug-28
108	Construction	0%	30	28-Aug-28	06-Oct-28
109	Mechanical	0%	20	09-Oct-28	03-Nov-28
110	Electrical	0%	10	06-Nov-28	17-Nov-28
111	Install Large Bore Return Piping	0%	20	29-Jan-29	23-Feb-29
Condenser Tie-in			170	31-Jul-28	23-Mar-29
113	Reroute Existing Supply Lines	0%	20	31-Jul-28	25-Aug-28
114	Install New Supply Piping	0%	30	29-Jan-29	09-Mar-29
115	Tie-in	0%	10	12-Mar-29	23-Mar-29
Shake out and Testing			40	26-Mar-29	18-May-29
117	Pressure Testing	0%	10	26-Mar-29	06-Apr-29
118	Backfill and Repave	0%	20	09-Apr-29	04-May-29
119	Final Systems Testing	0%	30	09-Apr-29	18-May-29



■ Actual Work	● ● Milestone	Page 2 of 2	TASK filter: All Activities
🟩 Remaining Work	▼▬▼ Summary		(c) Primavera Systems, Inc.
🟥 Critical Remaining Work			

Attachment 10

Capital Cost Evaluation

Cost Multipliers

Each cost estimate in this Attachment will have two cost multipliers:

- Recommended Minimum Contingency (30%)[1]
- Corporate Overheads and Work In Progress Cost (30%)[2]

The current stage of development of the various conceptual designs provides a sound basis for estimating the associated overall design, procurement, and construction costs. However, none of this captures the full scope of work, as would be possible if the final detailed design were completed, all associated bill of materials developed, and vendor quotes obtained for all materials. For this reason, a Recommended Minimum Contingency of 30% was added to all cost estimates.

Additionally, a cost multiplier of 30% was added to the design and installation costs to capture both corporate overhead and the cost of carrying the associated funding (i.e., a Corporate Overheads and Work In Progress Cost).

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[1] United States Department of Energy. Cost Estimating Guide. Publication No. DOE G 430.1-1. March 28, 1997.

[2] Entergy Nuclear Operations, Inc. Procedure EN-DC-114. Project Management. Rev. 10. June 12, 2009.

Basis of Cost Estimate

The initial capital costs to convert IPEC to closed-loop cooling include the cost of engineering design; the selection, procurement, and installation of major equipment (i.e., cooling towers, pumps, valves, etc.); and the costs of closed-loop construction, including the blasting required to excavate the cooling tower areas. Capital cost estimation was done in such a way as to minimize the necessary assumptions, and relied instead on well-developed, detailed conceptual designs to greatly increase the accuracy of the estimates. However, costs are likely to be understated due to the unprecedented nature of a conversion of an existing nuclear station to closed-loop cooling. The 2003 Report lists the components and construction activities necessary for closed-loop operation, providing a high level of detail to the conceptual design estimation (Attachment 1).

Three estimation techniques were used to determine the initial capital costs:

(1) Vendor provided budgetary estimates

Industry leading vendors were contacted for updated quotations on the major equipment and material components to allow for as accurate an estimation as possible, with the correspondence, reference material, and quotations provided in Section 4 of this Attachment.

(2) Third-party detailed construction estimates

Since blasting at each of the Unit cooling tower sites would require a unique engineering solution, a nationally recognized consultant was used to determine a conceptual design, cost, and schedule for blasting (Attachment 7).

(3) Computational estimation utilizing national production rates and cost factoring

Remaining cooling equipment and construction activities were estimated using 2009 RSMeans cost data software at MeansCostWorks.com. RSMeans is a construction cost estimating tool that provides detailed cost estimates for the construction industry including labor, piping, concrete, industrial equipment, electrical systems, and other heavy construction components.

Much of the cost information provided in this attachment consists of update information from the 2003 Report; such updated information is noted accordingly.

The following summarizes the engineering and construction capital cost estimate in 2009 dollars for the implementation of closed-loop cooling at IPEC Units 2 & 3.

Conversion of IPEC Units 2 and 3 to Closed-Loop Cooling		
Work Scope	**Estimated Cost**	**Notes:**
Design Engineering and Modification Packages	$ 25,526,000	15% of non-turn-key estimates[1]
Project Management and Support Labor	$ 44,598,000	Updated ENERCON Estimate
Turn-Key Estimates		
Blasting	$ 40,108,000	Attachment 7, Section 1
Unit 2		
Round Hybrid Cooling Tower	$ 205,000,000	Attachment 9, Section 4
Unit 3		
Round Hybrid Cooling Tower	$ 205,000,000	Attachment 9, Section 4
Relocation of Algonquin Pipeline	$ 13,800,000	Attachment 6, Section 1
Subtotal	$ 463,908,000	
Tasks for Closed-Loop Cooling Implementation		
Phase I - Online (Pre-Outage)		
Mobilization and Setup	$ 847,000	Updated ENERCON Estimate
General Site Modifications	$ 11,342,000	Updated ENERCON Estimate
Spoils Removal and Disposal	$ 55,620,000	ENERCON Estimate
Unit 2		
Pre-Outage Construction Activities (Cooling Tower Installation, Electrical, Mechanical, etc.)	$ 11,290,000	Updated ENERCON Estimate
Unit 3		
Pre-Outage Construction Activities (Cooling Tower Installation, Electrical, Mechanical, etc.)	$ 10,396,000	Updated ENERCON Estimate
Phase II - Offline (Outage Required)		
Common Construction Activities (Discharge Canal Modifications, Trenching and Excavation, etc.)	$ 23,515,000	Updated ENERCON Estimate
Unit 2		
Construction Activities Requiring an Outage (Pump House Construction, Large Bore Piping, Tie-In, etc.)	$ 28,465,000	Updated ENERCON Estimate
Unit 3		
Construction Activities Requiring an Outage (Pump House Construction, Large Bore Piping, Tie-In, etc.)	$ 27,250,000	Updated ENERCON Estimate
Testing and Commissioning	$ 825,000	Updated ENERCON Estimate
Demobilization	$ 617,000	Updated ENERCON Estimate
Subtotal	$ 170,167,000	
Total Work Scope		
Subtotal	$ 704,199,000	
Corporate Overheads and Work In Progress Cost (30%)	$ 211,260,000	
Recommended Minimum Contingency (30%)	$ 274,638,000	
Recommended Engineering and Construction Budget	**$ 1,190,097,000**	

1. United States Department of Energy. March 28, 1997. Cost Estimating Guide. Publication No. DOE G 430.1-1

The following summarizes the engineering and construction capital cost estimate in 2009 dollars for the implementation of closed-loop cooling at IPEC Unit 2.

Conversion of IPEC Unit 2 to Closed-Loop Cooling

Work Scope	Estimated Cost	Notes:
Design Engineering and Modification Packages	$ 15,388,000	15% of non-turn-key estimates[1]
Project Management and Support Labor	$ 31,219,000	Updated ENERCON Estimate
Unit 2		
Round Hybrid Cooling Tower	$ 205,000,000	Attachment 9, Section 4
Blasting	$ 18,070,000	Attachment 7, Section 1
Subtotal	$ 223,070,000	
Tasks for Closed-Loop Cooling Implementation		
Phase I - Online (Pre-Outage)		
Mobilization and Setup	$ 593,000	Updated ENERCON Estimate
General Site Modifications	$ 7,940,000	Updated ENERCON Estimate
Spoils Removal and Disposal	$ 29,770,000	ENERCON Estimate
Unit 2		
Pre-Outage Construction Activities (Cooling Tower Installation, Electrical, Mechanical, etc.)	$ 11,290,000	Updated ENERCON Estimate
Phase II - Offline (Outage Required)		
Common Construction Activities (Discharge Canal Modifications, Trenching and Excavation, etc.)	$ 23,515,000	Updated ENERCON Estimate
Unit 2		
Construction Activities Requiring an Outage (Pump House Construction, Large Bore Piping, Tie-In, etc.)	$ 28,465,000	Updated ENERCON Estimate
Testing and Commissioning	$ 578,000	Updated ENERCON Estimate
Demobilization	$ 432,000	Updated ENERCON Estimate
Subtotal	$ 102,583,000	
Total Work Scope		
Subtotal	$ 372,260,000	
Corporate Overheads and Work In Progress Cost (30%)	$ 111,678,000	
Recommended Minimum Contingency (30%)	$ 145,182,000	
Recommended Engineering and Construction Budget	**$ 629,120,000**	

1. United States Department of Energy. March 28, 1997. Cost Estimating Guide. Publication No. DOE G 430.1-1

The following summarizes the engineering and construction capital cost estimate in 2009 dollars for the implementation of closed-loop cooling at IPEC Unit 3.

Conversion of IPEC Unit 3 to Closed-Loop Cooling

Work Scope	Estimated Cost	Notes:
Design Engineering and Modification Packages	$ 14,441,000	15% of non-turn-key estimates[1]
Project Management and Support Labor	$ 31,219,000	Updated ENERCON Estimate
Turn-Key Estimates		
Unit 3		
Round Hybrid Cooling Tower	$ 205,000,000	Attachment 9, Section 4
Relocation of Algonquin Pipeline	$ 13,800,000	Attachment 6, Section 1
Blasting	$ 23,310,000	Attachment 7, Section 1
Subtotal	$ 242,110,000	
Tasks for Closed-Loop Cooling Implementation		
Phase I - Online (Pre-Outage)		
Mobilization and Setup	$ 593,000	Updated ENERCON Estimate
General Site Modifications	$ 7,940,000	Updated ENERCON Estimate
Spoils Removal and Disposal	$ 25,716,000	ENERCON Estimate
Unit 3		
Pre-Outage Construction Activities (Cooling Tower Installation, Electrical, Mechanical, etc.)	$ 10,396,000	Updated ENERCON Estimate
Phase II - Offline (Outage Required)		
Common Construction Activities (Discharge Canal Modifications, Trenching and Excavation, etc.)	$ 23,515,000	Updated ENERCON Estimate
Unit 3		
Construction Activities Requiring an Outage (Pump House Construction, Large Bore Piping, Tie-In, etc.)	$ 27,099,000	Updated ENERCON Estimate
Testing and Commissioning	$ 578,000	Updated ENERCON Estimate
Demobilization	$ 432,000	Updated ENERCON Estimate
Subtotal	$ 96,269,000	
Total Work Scope		
Subtotal	$ 384,039,000	
Corporate Overheads and Work In Progress Cost (30%)	$ 115,212,000	
Recommended Minimum Contingency (30%)	$ 149,776,000	
Recommended Engineering and Construction Budget	**$ 649,027,000**	

1. United States Department of Energy. March 28, 1997. Cost Estimating Guide. Publication No. DOE G 430.1-1

2010 Update to Cooling Tower Cost:

From: John.Arntson@ct.spx.com [mailto:John.Arntson@ct.spx.com]
Sent: Monday, September 28, 2009 9:59 AM
To: Jim Hubbard
Subject: Indian Point

Jim,
Based on fairly recent pricing for Calvert Cliffs (also salt/brackish water), the budgetary pricing for Indian Point would be approax. $ 205,000,000 per tower.

FYI,
John K Arntson
SPX Cooling Technologies, Inc.
7401W 129 th St.
Overland Park, KS
66213

E-mail: john.arntson@ct.spx.com

2010 Update to Circulating Water Pump Cost:

-----Original Message-----
From: Harrelson, Jerry [mailto:Jerry.Harrelson@sulzer.com]
Sent: Monday, September 14, 2009 9:44 AM
To: Richard Clubb
Cc: Jim Hubbard
Subject: RE: Pump Quote Update

Richard,
A budget price for the pumps already quoted should be increased by 5% to cover the cost of material increases.

Thanks,

Jerry Harrelson
Nuclear Account Manager
Sulzer Pumps (US) Inc.
4126 Caine Lane
Chattanooga, TN 37421

Internet www.sulzerpumps.com

-----Original Message-----
From: Richard Clubb [mailto:rclubb@enercon.com]
Sent: Wednesday, September 02, 2009 11:23 AM
To: Harrelson, Jerry
Cc: 'Jim Hubbard'
Subject: Pump Quote Update

Jerry,

Attached is a pump quotation that was provided to Jim Hubbard back in 2003. We are updating this project to current pricing and technology and were hoping you would be able to confirm that this product is still available and update the quotation to current pricing?

Thanks in advance for your assistance with both of these pump requests, and if you have any questions please feel free to contact either myself or Jim Hubbard.

Richard T. Clubb
Enercon Services, Inc.

COOLING TECHNOLOGY INSTITUTE

Legionellosis

Guideline: Best Practices for Control of Legionella

July 2008
CTI Guidelines WTB-148 (08)

Foreword

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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board

©

This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2013.

Approved by the
CTI Executive Board

Guideline: Best Practices for Control of Legionella

I. PURPOSE

The purpose of this guideline is to provide information and guidance in order to minimize Legionella in evaporative cooling water systems, specifically evaporative condensers, closed-circuit fluid coolers, and cooling towers.

II. SCOPE

This guideline provided specific environmental and operational guidelines that will contribute to the safe operation of cooling water systems to minimize the risk of occurrence of Legionellosis.

III. WHAT IS LEGIONNAIRES' DISEASE?

Following the 1976 American Legion Convention at the Bellevue Stratford Hotel in Philadelphia, 34 attendees died and 221 people became ill from pneumonia caused by the bacterium *Legionella pneumophila.* Although not recognized at the time, *Legionella* is not a new microorganism. It has since been found in many archived tissue samples at the US Centers for Disease Control and Prevention (CDC). These specimens were taken from persons with previously undiagnosed pneumonia-like illnesses.

This disease, now commonly known as Legionnaires' Disease, is a respiratory infection that strikes susceptible individuals exposed to *Legionella pneumophila.* Infection results from inhaling airborne water droplets or mist containing viable *Legionella pneumophila,* which are small enough to pass deep into the lungs and be deposited in the alveoli, the small pockets in the lungs. The dose of *Legionella pneumophila* required to infect humans is not definitively known. Ingesting *Legionella pneumophila* has not been shown to cause illness. Legionnaires' Disease can have an incubation period of two to ten days. Most reported cases have occurred in the 40- to 70-year old age group. Although healthy individuals may develop Legionnaires' Disease, people thought to be at increased risk of infection include smokers, patients with cancer, chronic respiratory diseases, kidney disease, and any immuno-suppressed condition. The fatality rate is estimated at 10 to 20% of those who contract the disease; but in immuno-suppressed persons or those with other underlying diseases, this figure can be much higher.

Legionella pneumophila is a ubiquitous organism. It appears in almost every ground and surface water. The organism survives typical chlorine disinfection for potable water and consequently can appear in finished water distributed to homes and industry. It is important to keep the incidence of Legionellosis in perspective. For example, in the United States, the Technical Manual published by OSHA (Occupational Safety and Health Administration) estimates over 25,000 cases of the illness occur each year. More than 4,000 deaths are believed to occur, but only about 1,000 are reported. However, the CDC usually investigates less than ten community outbreaks per year (in 1995 there were three). An outbreak is considered to occur when two or more cases of the disease can be attributed to a work site.

IV. SYMPTOMS OF LEGIONNAIRES DISEASE

Initial symptoms of Legionnaires' Disease include high fever, chills, headache and muscle pain. A dry cough soon develops and most patients suffer breathing difficulty. Some patients also develop diarrhea or vomiting and can become confused or delirious. Legionnaires' Disease may not always be severe; in community outbreaks, mild cases may be recognized that would probably have escaped detection except for the increased awareness of the disease.

A common but less serious infection caused by *Legionella pneumophila* is an illness known as "Pontiac Fever." The symptoms of Pontiac Fever are similar to those of moderate to severe influenza: headache, fatigue, fever, arthralgia (joint pain), myalgia (muscle pain) and, in a small proportion of cases, nausea, vomiting and coughing. The incubation period is one to two days and the illness passes in five to ten days. No deaths have been attributed to Pontiac Fever. Since this illness generally escapes detection, statistical information about its occurrence is sparse.

V. MICROBIOLOGY

Legionella is the name given to a genus of bacteria for which at least 37 different species have been identified. *Legionella pneumophila,* for which fourteen serogroups have been identified, is the species most commonly associated with disease outbreaks. Serogroups 1, 4, and 6 are most commonly associated with human illness. *Legionella pneumophila* are rod-shaped bacteria and are widespread in natural water sources. They have been found in rivers, lakes, and streams; mud and soil samples; water and sludge from cooling towers; and in other man-made water systems. They have been detected in many drinking water sources, including well water, resulting in the contamination of a variety of public and private systems using this water.

A cooling tower system can present an ideal environment for growth of *Legionella pneumophila.* Cooling tower drift in the form of aerosols can be easily inhaled. Showers, wash stands, sinks, air scrubbers and air washers / handlers can also provide a good growth environment and possible means of transmission of *Legionella pneumophila* bacteria.

VI. ECOLOGY

The ecology of *Legionella pneumophila* in water systems is not fully understood; however, the following conditions have been found to affect its growth rate:

- Sediment, sludge, scale and organic materials can harbor the bacterium and promote growth. The formation of a biofilm within a water system is thought to play an important role in harboring and providing favorable conditions in which *Legionella pneumophila* can grow. A biofilm is a layer of microorganisms contained in a matrix that may form a thin layer of slime on surfaces in contact with water. *Legionella pneumophila* grows within biofilms and within protozoa acting to shield *Legionella pneumophila* from concentrations of biocides that would otherwise kill or inhibit *Legionella pneumophila* when freely suspended in water.
- Water temperatures in the range of 68°F (20°C) to 113°F (45°C) favor growth. It is uncommon to find proliferation below 68°F (20°C), and it does not survive above 140°F (60°C). The optimum laboratory temperature for the growth of the bacterium is 99°F (37°C). Organisms may, however, remain viable and dormant in cool water, multiplying only when the temperature reaches a suitable level and when growth and reproduction are not inhibited by adequate bio-control.
- *Legionella pneumophila* have been shown to colonize certain types of water systems that may have stagnant areas, e.g., water heaters, tanks, reservoirs, and basins. Fittings, piping, and various gasket materials used in these systems can also be colonized. Stagnant conditions promote growth of *Legionella pneumophila* and make eradication difficult.
- Commonly encountered microorganisms (such as algae, amoebae and other bacteria) in untreated or ineffectively treated water may promote *Legionella pneumophila* growth. Some protozoa serve as hosts for *Legionella pneumophila*, which can enable rapid proliferation of *Legionella.*

VII. BEST PRACTICES AND RECOMMENDATIONS FOR MINIMIZATION OF RISKS ASSOCIATED WITH LEGIONELLA

The following best practices for microbiological control are recommended to promote and maintain clean heat transfer surfaces and a healthy work environment around open recirculating cooling systems. The practices outlined in this document are a description of the consensus of existing best practices as recommended by various authoritative bodies worldwide. Halogen oxidizers have been proven to control *Legionella* when applied properly. Evidence exists that other compounds, such as ozone, peroxides, and non-oxidizing biocides are effective against *Legionella* bacteria in limited circumstances. Treatment techniques such as ultraviolet light or ultrasonics have also shown the ability to kill *Legionella* bacteria in limited circumstances.

The CTI reviewed publications and interviewed representatives from authorities such as OSHA, CDC, ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), the UK HSE (United Kingdom Health and Safety Executive), the UK BACS (British Association of Chemical Specialties), and the health & safety agencies of Japan, Australia, Singapore, and Taiwan, among others. *In no way, however, should these recommendations be interpreted to guarantee the absence of Legionella bacteria or any other particular pathogen, and consequently that these measures will prevent illness (e.g. Legionellosis).*

Nevertheless, we believe these measures can be effective in fostering the safety of cooling systems. This is accomplished directly by destruction of planktonic (free-swimming) bacteria including *Legionella*, and indirectly by eliminating conditions that favor *Legionella* amplification (multiplication), i.e. the elimination of biofilms and amoebae and other protozoa that feed on biofilms and which serve as *Legionella* hosts. Research continues on effective means for control of protozoan cysts, which can also harbor and protect *Legionella* for extended periods.

These best practice recommendations focus on chemical control parameters. Halogens serve as the primary disinfectants in these recommendations. Sources of halogens include chlorine gas, hypochlorites, chlorine dioxide and stabilized halogen donors. It must be recognized, however, that chemical treatment is only one aspect of risk minimization. Design, operation, and maintenance practices are also crucial to reducing health risks associated with cooling systems.

Monitoring *Legionella* in Cooling Water Systems

Evaluate system cleanliness and the effectiveness of microbial control by visual inspection as well as through regular monitoring of bulk water (planktonic) and surface (sessile) microbial populations.

Check the cooling tower deck and tower fill for gross evidence of biofouling. When operations permit, the mist eliminator section of the cooling tower should also be inspected for biological deposits. Collect suspected biological deposits for microscopic examination to confirm biological content and the presence or absence of amoebae and ciliated protozoa. When performed by a trained microscopist, this approach can provide valuable, same-day information on system cleanliness and associated health risk since some protozoans can serve as host organisms for *Legionella* allowing amplification of *Legionella* to dangerous levels. High numbers of protozoa therefore represent an increased risk for multiplication of *Legionella* and consequent increase in the risk of Legionnaires' disease for susceptible individuals.

Use dipslides, PetriFilm™, or other culturing techniques to quantify total aerobic heterotrophic bacteria populations in bulk water and on sur-faces. Alternatively, ATP-based biomonitoring can be used. This technique has the advantage of eliminating the 2-day delay in results imposed by incubation requirements of culture-based methods.

Most professional and government agencies that have issued *Legionella* position statements and guidelines do not recommend testing for *Legionella* bacteria on a routine basis. These reasons derive from difficulties in interpreting *Legionella* test results and in using test results as a basis for control. Note the following aspects:

- An infectious dose level for *Legionella* has not been established and in any case, (given variations in strain virulence and wide differences in individual susceptibility) the concept of a fixed infectious dose level may be misleading. Since no fixed "danger" level can be assigned, it also follows that no specific level of the organism can be assigned as "safe."
- *Legionella* may be "non-detectable" in bulk water samples collected on one day but can repopulate and be found within a few days. *Legionella* can be released from biofilms or from host life forms associated with these films. *Legionella* are reported to be capable of rapid recolonization of previously cleaned systems, especially if conducive conditions are present.
- Simple detection of the organism in a cooling system does not necessarily mean there is a risk of disease, in part because not all *Legionella* serogroups are associated with Legionellosis.
- Culture-based techniques used by testing labs to quantify *Legionella* have a 10 to 14 day turnaround for results. This period is too long for *Legionella* monitoring to serve as an effective tool for treatment control.

Various studies have shown that some 40 to 60% of cooling towers tested contained *Legionella*. Therefore, it is best to assume that any given system can harbor the organism, and that routine, continuous microbiological control practices should be implemented to minimize the risk of *Legionella* amplification and associated disease.

Testing for *Legionella* is recommended in the event of an outbreak (to identify potential sources of the organism) and to evaluate the effectiveness of disinfection procedures. Testing is also recommended whenever process intrusions into the cooling water occur or other factors mitigate a loss of microbiological control for an extended period of time. There have been reports of vary rapid increases in *Legionella* concentrations in a short period of time under these circumstances.

If testing is required, contact a laboratory experienced in performing *Legionella* analyses on environmental samples. Also, concurrent sampling should be performed on the bulk water and surface deposits for microscopic detection of higher life forms, along with total aerobic heterotrophic counts. Collect bulk water samples from several locations within the system (e.g., makeup water, hot return water, basin water, and from sample taps on heat exchangers remote from the cooling tower if available). Where evident, collect deposit samples from the basin walls, tower fill, and distribution decks. The following three scenarios are possible:

- A low *Legionella* count with an undetectable or small population of amoebae/protozoa (higher life forms) and low biofilm counts (low sessile bacteria numbers) is a good indication of a clean, well-maintained system with low risk to health.
- A low bulk water *Legionella* count along with low numbers of higher life forms in deposits, but with high biofilm counts may indicate a low present health risk but suggests the potential for future problems if steps are not taken to reduce biofilm levels. Since protozoa that promote *Legionella* amplification graze on bacteria in biofilms, the presence of significant biofilm can promote the development of higher, and thus potentially more dangerous, levels of *Legionella*.

- A low bulk water *Legionella* count associated with a large number of higher life forms indicates a strong potential for amplification, and the low *Legionella* count cannot therefore be interpreted to indicate a system with a low health risk.

Recommended Target Values
Routine Treatment of Cooling Water Systems

Parameter	Dipslides	Agar Pour Plate or Petrifilm	Microscopic Exam
Planktonic Counts (Bulk Water)	<10,000 CFU/mL	<10,000 CFU/mL	No higher life forms
Sessile Counts (Surfaces)	<100,000 CFU/cm^2	<100,000 CFU/cm^2	No higher life forms
Deposits	NA	NA	No higher life forms

Note: Results from dipslides, agar pour plates, or Petrifilm are colony forming units (CFU per milliliter or per square centimeter) of total aerobic heterotrophic bacteria. Legionella bacteria are not detected by these conventional plate count media. Microscopic examination for the presence of higher life forms requires a trained microscopist and specialized microscopy equipment.

Routine Treatment
Continuous Application of Halogens

- For relatively clean systems or where clean potable water makeup is used, feed a source of halogen (chlorine or bromine) continuously and maintain a free residual. Continuous free residuals of 0.5 to 1.0 ppm (as Cl_2) in the cooling tower hot return water have been recommended by many agencies[1]. Periodic monitoring of the residual at sample points throughout the cooling water system is needed to insure adequate distribution. The effectiveness of either halogen decreases with increasing pH; bromine is relatively more effective at a higher pH (8.5 to 9.0).
- Stabilized halogen products should be added according to the label instructions, and sufficient to maintain a measurable halogen residual.
- Discharge of system water directly to surface water may require dehalogenation.
- A biodispersant/biodetergent may aid in the penetration, removal, and dispersion of biofilm and often increases the efficacy of the biocide.
- Continuous halogen programs may require periodic use of nonoxidizing biocides. These may be required to control biofilm and planktonic organisms in systems that use makeup water from other than potable water sources, and those with process leaks or contamination. The choice of nonoxidizing biocides should be based on the results of toxicant evaluations. Reapply as dictated by results of biomonitoring.

Intermittent Use of Halogens

Continuous halogenation is always preferred for *Legionella* risk minimization; however, if this is not possible, intermittent use of halogen is necessary.

- As a minimum control program for relatively clean systems or where clean, potable water is used for makeup, establish a free halogen residual of 1.0 up to 2.0 ppm (as Cl_2) and hold this residual for no less than one hour each day. Free residual must be monitored throughout the distribution system.
- Stabilized halogen products should be added according to the label instructions and to achieve a measurable halogen residual. This residual should be held for no less than one hour each day.
- Bulk water and sessile counts, along with microscopic examination of deposit samples, will be necessary to ensure that the concentration and duration of halogen residuals are adequate.
- A biodispersant may aid in penetrating the biofilm and may increase the efficacy of the biocide.
- Discharge of system water directly to surface water may require dehalogenation.
- Nonoxidizing biocides are critical to the cleanliness of systems treated intermittently with halogens and are recommended. The choice of nonoxidizing biocide should be based on the results of toxicant evaluations. Reapply as dictated by the results of biomonitoring.

Routine On-Line Disinfection
Hyperhalogenation

Hyperhalogenation as practiced is the maintenance of a minimum of 5 ppm free halogen residual for at least 6 hours. Periodic on-line disinfection may be necessary for systems:

- That have process leaks
- That have heavy biofouling
- That use reclaimed wastewater as makeup
- That have been stagnant for a long time
- When the total aerobic bacteria counts regularly exceed 100,000 CFU/ml
- When *Legionella* test results show greater than 100 CFU/ml

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[1] UK Publication "The Control of Legionella in Water Systems" Approved Code of Practice & Guidance.
Third Edition

Periodic hyperhalogenation will discourage development of large populations of *Legionella* and their host organisms. Consequently, periodic hyperhalogenation may eliminate the need for conducting more complicated and higher risk off-line emergency disinfection procedures.

Other Treatment Approaches:

Because of the interest incontrolling Legionella, a number of products have been promoted as a control of Legionellosis in Cooling Systems. Some of them are electronic water treatment devices, material coatings and bio-static components. At the date of this publication, there is little application data to support these approaches. While these technologies may have some benefit, they should not distract your attention from the key issues of:

- Eliminating stagnant water areas
- Eliminating controllable sources of nutrient to the Cooling Water system.
- Maintain overall system cleanliness and provide good biological control.
- Use the best technology in Drift Eliminiation (lowest drift rate).

Emergency Disinfection

The following emergency disinfection procedure is based on OSHA and other governmental recommendations. This procedure may require modification based on system volume, water availability and wastewater treatment capabilities.

Conduct emergency disinfection:

- When very high *Legionella* counts exist (i.e., >1000 CFU/ml).
- In cases where Legionnaires disease are known or suspected and may be associated with the cooling tower.
- When very high total microbial counts (>100,000 CFU/mL) reappear within 24 hours of a routine disinfection (hyperhalogenation).

Emergency Disinfection Procedure

1. Remove heat load from the cooling system, if possible.
2. Shut off fans associated with the cooling equipment.
3. Shut off the system blowdown. Keep makeup water valves open and operating.
4. Close building air intake vents in the vicinity of the cooling tower (especially those downwind) until after the cleaning procedure is complete.
5. Continue to operate the recirculating water pumps.
6. Add a biocide sufficient to achieve 25 to 50 ppm of free residual halogen.
7. Add an appropriate biodispersant (and antifoam if needed).
8. Maintain 10 ppm free residual halogen for 24 hours. Add more biocide as needed to maintain the 10 ppm residual.
9. Monitor the system pH. Since the rate of halogen disinfection slows at higher pH values, acid may be added, and/or cycles reduced in order to achieve and maintain a pH of less than 8.0 (for chlorine-based biocides) or 8.5 (for bromine-based biocides).
10. Drain the system to a sanitary sewer. If the unit discharges to a surface water under a permit, dehalogenation will be needed.
11. Refill the system and repeat steps #1 through 10.
12. Inspect after the second drain-off. If a biofilm is evident, repeat the procedure.
13. When no biofilm is obvious, mechanically clean the tower fill, tower supports, cell partitions, and sump. Workers engaged in tower cleaning should wear (as a minimum) eye protection and a ½ face respirator with High Efficiency Particulate (HEPA) filters, or other filter capable of removing >1 micron particles.
14. Refill and recharge the system to achieve a 10 ppm free halogen residual. Hold this residual for one hour and then drain the system until free of turbidity.
15. Refill the system and charge with appropriate corrosion and deposit control chemicals, re-establish normal biocontrol residuals and put the cooling tower back into service.

VIII. RECORDKEEPING

To ensure that adequate information is available to describe tower operations, records should be kept of precautionary measures and treatments, monitoring results and remedial work. Some government agencies specify the type and level of detail for these records. In any case, sufficient information should be recorded to show the particular measures taken, including but not limited to: instances of mechanical cooling tower cleaning, the frequency and amount of biocide addition, halogen residual levels, results of biomonitoring, and other significant aspects of the tower operation.

If there are any complaints or safety, helath or environmental audit findings regarding tower operations, they should be documented, as should any corrective actions taken.

A records retention policy should be developed and adhered to, and should be in reasonable conformance to any general records retention policy at the facility, utility or corporation. Records retention should not be any shorter than any minimum regulatory requirement that may have been established.

IX. MECHANICAL DESIGN CONSIDERATIONS FOR MINIMIZING LEGIONNAIRE'S DISEASE

Any new or retrofit tower or component design should include consideration of the issues discussed below.

Drift Eliminators (DE)

- State-of-the-art high-efficiency nesting type eliminators, if not already present to minimize drift mass flow, are suggested [reference CTI ATC-140].
- Tower designers should use these eliminators within their design air velocity requirements as set and tested by the manufacturer. Drift eliminators are intended to prevent escape of entrained water droplets that might contain LD bacteria from the tower.

Plenum

- Tower designers should avoid locally elevated exit air velocities at the eliminators, designing the plenum to maintain airflow within the tolerances of design throughout, particularly at the center of the eliminator bank in counterflow towers and at the upper portions of the eliminator bank in crossflow towers.
- Tower designers should supply effective eliminator air seals, covering all open area beyond the eliminators themselves. Small gaps allow elevated local velocities and can lead to substantial water droplet formation and leakage.
- Proper installation of the eliminators and air seals is critical to minimize the drift rate.

Water Distribution, Falling Water, and Fill

- Tower designers should provide distribution components to minimize the creation of very small droplets which are more likely to escape through the drift eliminators.
- Tower designers should provide distribution components to minimize masses of water at louver or eliminator locations that might by-pass air-seals allowing circulating water to enter the exit airstream.
- Tower designers should provide tower air inlet and rain zones that minimize splash-out and aerosol droplet creation.
- Tower designers should select the fill for proper air and water management to control the drift rate and splash-out.
- Fill selection should be based on expected water quality and treatment, to minimize fouling and poor water distribution of water that might encourage Legionella propagation.

Fan and Fan Cylinder

- Tower designers should provide fan cylinder seal integrity such that no extraneous water can make its way to the fan even if the hot water basin (HWB) overflows (crossflow towers).

Siting and Flow

- System design engineers should place cooling towers away from building air intakes in such a manner that cooling tower drift or splash-out is not fed into the building air supply system.
- The tower should be designed to provide good continuous water flow through and out of the tower to move water effectively. There should be no dead flow locations in the basins.
- System design engineers should provide discharge piping and equalizers to move water effectively with no dead flow locations. Special attention should be paid to equalizer piping to ensure these areas are not stagnant.

Side Stream Filtration

- When suspended solids in the cooling tower water are excessive, side stream filtration may be considered for reduction of these solids. Side stream filtration has been shown to control suspended solids in cooling tower circulating water. Particulate solids are suitable surfaces for the growth of bacterial films that provide a safe haven for *Legionella* bacteria. The exact design of this equipment is site specific; it will consider makeup water quality, design of tower fill, recirculation rate, and total system volume.

X. COOLING TOWER INSPECTIONS AND PHYSICAL MAINTENANCE

It is important to visually inspect the cooling tower frequently to maintain the tower and its components in good working order. During maintenance and inspection operations, plant safety procedures must always be followed. Organic fouling, dirt or debris must be removed. Defects in the components or their installation, which may lead to emission of excessive drift or spray, should be corrected.

Inspection should also be performed on the outside of the unit for general cleanliness, leaks, or any evidence of biomass. Pools of water or small droplets emanating from the tower may be a sign of excessive drift. The appearance of heavy deposits on the outside of the unit may be an indication of excessive water loss due to windage or other factors. During maintenance and inspection operations appropriate plant safety procedures should always be followed.

Water Treatment System

Inspect the water treatment system for proper operation of all components.

Louvers

Inspect louvers and surrounding area for biomass and scale. Louvers should be undamaged and positioned as designed to prevent spray from splashing or blowing out of the tower. Missing or damaged louvers should be replaced. Out of position louvers should be properly placed back in position, making sure retaining hardware is also correctly placed.

Piping dead legs

Inspect circulating water piping system for deadlegs. Any deadlegs which cannot be removed or replaced with a circulating line should be bled frequently. Bleed equalizer piping between adjacent cooling tower cells frequently.

Cold water basins

Inspect the cold water basin for build-up of organic matter, dirt, and debris. If any significant accumulation of debris or sludge is found, the accumulation should be removed.

If the tower is taken out of service, the basin should be cleaned.

Crossflow hot water basin

Leaks from the hot water basin that might lead to droplets becoming entrained in the air-stream should be repaired. Missing or broken nozzles should be replaced. Basin covers that may be missing or broken should be replaced or repaired. Water overflowing the basin should be corrected.

Counterflow spray system

The spray system should be properly positioned and free of fouling. Missing nozzles should be replaced. Misaligned nozzles may spray water up into the eliminators and should be correctly re-positioned. Leaks at piping joints or nozzles that spray water into the eliminators should be repaired.

Eliminators

The eliminator system is critical for controlling the water droplets leaving the cooling tower. Drift eliminators should be inspected for build-up of organic and inorganic material and for deterioration or damage. Eliminators should be cleaned as needed.

Missing or damaged eliminators should be replaced. Any gaps in or between eliminators or between eliminators and casing, structural elements, air seals, or plenum framework should be corrected.

Fill

Fill air entrance and exit surfaces should be thoroughly inspected. Evidence of fouling should lead to a more extensive inspection and review of water treatment and maintenance procedures. Damaged or deteriorated fill should be replaced.

XI. SUMMARY

To minimize the proliferation of *Legionella pneumophila* and the associated risk of Legionnaires' disease, the consensus recommendations are:

- Minimize water stagnation
- Minimize process leaks into the cooling system that provide nutrients for bacteria
- Maintain overall system cleanliness. This will minimize the buildup of sediments that can harbor or provide nutrients for bacteria and other organisms.
- Apply scale and corrosion inhibitors as appropriate.
- Use high-efficiency mist eliminators on cooling towers.
- Control the overall microbiological population.

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COOLING TECHNOLOGY INSTITUTE

COOLING TOWER EMISSIONS QUANTIFICATION USING THE COOLING TECHNOLOGY INSTITUTE TEST CODE ATC-140

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Cooling Tower Emissions Testing Using the Cooling Technology Institute Test Code – CTI ATC-140

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INTRODUCTION

This paper illustrates the methodology for calculating particulate emissions from a cooling tower drift rate test and discusses the conservatism applied when considering all particulate to be PM_{10}. The special characteristics of cooling tower emissions are discussed. The technology used for controlling cooling tower emissions is explained. The methodology used in Cooling Technology Institute's (CTI), (formerly Cooling Tower Institute). CTI ATC-140[1] is described and the assumptions and procedures used in the calculation of the drift rate and particulate emission rate are detailed. Recent test data are presented in order to illustrate the repeatability of the method.

Evaporative cooling towers are by far the most common form of heat rejection for power plants utilizing a steam turbine cycle. Cooling towers emit large volumes of low concentration particulate from multiple stacks that in aggregate are often significant mass emission sources. The amount of these emissions are often site specific even when the cooling towers use the same components. The variability in the emission rates is primarily due to variability in the quality of the drift eliminator installation and the condition of the drift eliminators themselves.

When evaluated using emission factors from the EPA's guideline AP-42[2], calculated cooling tower particulate emissions may be equivalent to the particulate performance standard for a coal fired power plant. Some air permitting agencies, particularly in areas with degraded air quality, consider cooling towers as point emission sources and require quantification of both particulate matter and constituent cooling tower emissions. The dissolved and suspended materials in the cooling water are the source of the emissions. The cooling tower exhaust air is typically saturated with water vapor. Condensed water vapor, which is essentially pure water, is not considered an emission.

The lowest liquid emission rate guarantees – also known as drift rate guarantees - currently offered by cooling tower manufacturers on new installations are a factor of 40 less than the estimates from AP-42. There is currently no EPA method suitable for determining cooling tower particulate emissions because the traditional EPA Method 5[3] test for particulate is poorly suited for this application given the proximity of the sampling plane to the fans, the size of the fan stacks, and the sampling duration dictated by the Method 5 gravimetric analysis. There is, however, an isokinetic method, CTI ATC-140, used by the cooling tower industry to assess compliance with the cooling tower manufacturers' guarantees. Various regulatory authorities have adopted this method to quantify the particulate emissions from cooling towers.

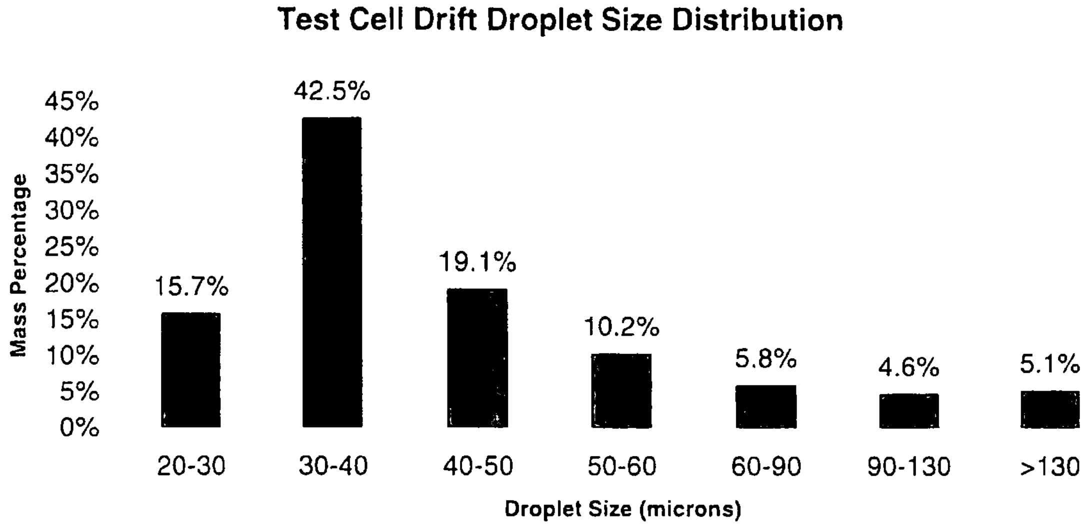
Generation of Air-borne Emissions from Cooling Towers

In an evaporative cooling tower, the circulating water is pumped to the top of the unit where the water is distributed through nozzles and allowed to fall over heat transfer media that either sheets the water into numerous small films or breaks the water into small droplets. The large surface area facilitates the evaporation and cooling of the remaining circulating water. In the majority of systems, a fan on the top of the tower is used to induce an air stream against the water droplets. As the air is drawn through the tower, a small fraction of the water droplets are entrained in the airstream. Baffles, called drift eliminators, are placed between the nozzles and the fans to minimize (through inertial impaction) the amount of entrained water droplets that leave the cooling tower and are discharged into the atmosphere. The escaping droplets are called drift. An important distinction between drift and the normally visible condensing plume is that the drift contains the same chemicals and solids present in the circulating water, whereas, the condensation is pure water vapor. Cooling tower emission rates are usually presented as a drift fraction which is defined as the ratio of the water exiting the tower as drift divided by the circulating water flow rate.

Special Characteristics of Cooling Tower Emissions

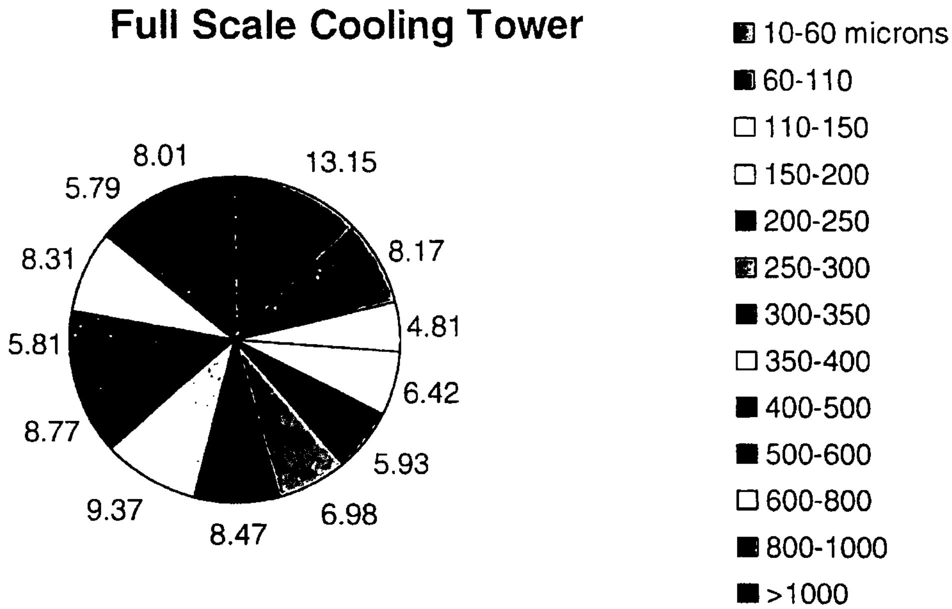
Cooling tower drift has several special characteristics. The size of the drift droplet is usually very large with a typical mass mean diameter of 100-300 microns[4]. A droplet size spectrum as determined from a sensitive paper test of a high efficiency drift eliminator which was tested in a laboratory test cell is shown in Figure 1.

Figure 1: Test Cell Droplet Size Distribution (% Mass Basis)



The most significant factor in the size distribution and amount of emitted drift droplets is the quality of the drift eliminator installation. The drift eliminators must be installed around structural members, standpipes, and other penetrations in the drift eliminator plane. Small gaps around these penetrations or between drift eliminator panels act as essentially uncontrolled emission sources. Another source of large diameter droplets is the collection and re-entrainment of drift by structural members, the fan stack and even the fan blades. The circulating water can also be re-entrained from the trailing edge of the drift eliminators if the drift eliminators are overloaded. Overloading occurs when the drift incident on the drift eliminators exceeds their drainage capacity. This can happen when the drift eliminators are installed too close to the water distribution system or when there are broken nozzles or leaks in the hot water distribution system. A droplet size distribution from a full scale cooling tower test is presented in Figure 2. Prior to the conduct of the test, the tower manufacturer verified that the tower was ready for testing and the tower did pass its drift guarantee. Additional information regarding sensitive paper drift tests and droplet distributions are found in references 4 and 5.

Figure 2: Droplet Size Spectrum For Full Scale Cooling Tower (% Mass Basis)



While care in drift eliminator installation can minimize the drift rate, some gaps are unavoidable in the installation. For this reason, cooling tower manufacturers' guaranteed drift rates of field erected equipment are typically higher than drift rates determined from tests conducted in test cells. Because the quality of the field installation varies from cooling tower to cooling tower, the amount of drift emitted from various towers will vary greatly even with the same drift eliminators installed. The drift rate will also tend to increase over the lifetime of the tower as the drift eliminators deteriorate due to aging, ice damage, hydraulic excursions, physical abuse and fouling.

Calculation of Particulate Emissions from Drift Rate

Current designs for new cooling towers specify drift rates of 0.0005 to 0.002 percent of the circulating water flow. A typical design for a 250 MW combined cycle power plant would be an 8 cell cooling tower with 10 meter (33 ft) diameter fans and a water flow rate of 820 kg/s (13,000 gpm) per cell. At drift rate of 0.001 percent of the circulating water flow, such a cooling tower would emit

$$\dot{m}_w = \frac{0.001}{100} * 820 \frac{kg}{s\ cell} 8\,cells * 1000 \frac{g}{kg} = 65.6\ g/s \qquad (Eq.1)$$

of liquid water. At a total solids concentration of 5000 ppm in the circulating water, the total particulate emission rate would be

$$\dot{m}_{pm} = 5000x10^{-6}\ 65.6\ g/s = 0.327\ g/s = 11.4\ \ ton/yr \qquad (Eq.2)$$

AP-42 specifies that particulate emissions be calculated based on an emission factor equivalent to a drift rate of 0.02 percent of the circulating water flow. Using this emission factor, the cooling tower described above would have a PM_{10} emission rate of 4.58 g/s (159 ton/yr), a factor of 20 higher than the cooling tower previously described.

The diameter of the airborne particle produced by the evaporation of the liquid water from a drift droplet can be calculated by manipulation of the following relationship:

$$m_{salt} = \rho_w C_{TS} \frac{\pi}{6} d_d^3 = \rho_{salt} \frac{\pi}{6} d_p^3 \qquad (Eq.3)$$

from which d_d can be determined:

$$d_d = d_p \sqrt[3]{\frac{\rho_{salt}}{\rho_w C_{TS}}} \qquad (Eq.4)$$

where

m_{salt} = mass of salt particle, g
ρ_{salt} = density of particle, g/cm^3
ρ_w = density of drift droplet, g/cm^3
C_{TS} = concentration of solids in circulating water, ppm
d_p = diameter of solid particle, microns
d_d = diameter of drift droplet, microns

For a circulating water concentration of 5000 ppm and assuming a particle density of 2.5 g/cm^3, the maximum diameter of the drift droplet that would produce a dry salt particle of 10 microns would be:

$$d_d = 10\left(\frac{2.5}{1.0*5000*10^{-6}}\right)^{1/3} = 79\,microns \qquad (Eq.5)$$

For the unique drift droplet size distribution in Figure 2, over 78 percent of the particulate emission would be greater the 10 microns.

Overview of Cooling Tower Emission Testing

The measurement of drift leaving a cooling tower fan stack is problematic. The stack itself may be very large; some stacks are 40 feet in diameter. The most accessible location for drift measurement is at the stack exit plane. The distance between the exit plane and the rotating fan is usually less than ½ of the fan stack diameter. The proximity of the fan creates swirling, non-parallel streamline vectors of varying pitch across the stack exit plane. Near the middle of the stack there is usually a significant area with airflow coming back into the measurement plane. The total tower elevation at the fan stack exit plane may be 50-60 feet above grade and subject to elevated winds due to the influence of the tower itself. The effect of the wind is to skew the velocity profile and thus skew the distribution of emissions within the stack to the downwind side. Furthermore, because the fan blade pitch determines the amount of airflow through the tower, and because the amount of water delivered to the tower can impact the quality of the water distribution, these operating parameters can also influence the amount of drift emitted from a tower.

Initial cooling tower emission tests were performed as particulate matter emission tests according to the general guidelines of EPA Method 5. Typically, a total of 24 points, 6 per radii, were sampled in order to obtain a composite sample of the particulate exiting the fan stack. The EPA Method 5 test utilizes an isokinetic approach where the sampled air is collected through a probe that is oriented into the air stream at the sampling location. The air is drawn through the probe at the same velocity (speed and direction), as the exiting air stream, thus the test is called isokinetic (IK). A vacuum pump is used to draw the air sample through the sampling train and flow measurement system. The sampling train consists of the sample probe, heated liner, heated filter box and filter, a series of impingers and a dry gas meter. Particulate drawn through the sampling train is deposited on the pre-weighed filter which is conditioned and reweighed at the conclusion of the test. Particulate that is deposited within the probe and on the sides of the tubing leading to the filter box is recovered through washing. In the laboratory, the wash samples are placed in a pre-weighed crucible which is heated to evaporate the water thus leaving the washed particulate mass as residue. Knowing the total collected mass, the sampled air volume and the total sampling time permitted the calculation of the mass flux. The fractional solids emissions rate was then calculated by dividing the mass flux by the product of the water flow rate and the concentration of total solids in the circulating water. The implementation problems with the EPA Method 5 approach included – difficulty in rotating the sampling train at each measurement point; difficulty in managing long sampling lines containing moisture laden air; and the difficulties associated with having to sample for an extremely long time to collect enough sample for gravimetric analysis.

In the 1980's, the Cooling Tower Institute (CTI) began to codify a sampling technique that utilized isokinetic sampling to quantify the mass emission rate from cooling towers. In 1990, the CTI published the drift emission code ATC-140. This test code was developed by a cross section of cooling tower manufacturers, owner/operators, and suppliers that were familiar with both the difficulties inherent in cooling tower emissions tests and the influence of ambient and operating factors on the amount of the drift.

CTI Drift Test Code Overview and Test Instruments

Isokinetic drift testing is the process of collecting "drift emissions by drawing a portion of the cooling tower exit airstream into a collection apparatus at the same speed and direction (isokinetically) as the local velocity in the cooling tower". Instead of collecting particulate mass, the CTI test code ATC-140 is based on the isokinetic collection of composite mass sample of a tracer element (e.g., sodium, calcium or magnesium) leaving the tower. Most tests are conducted at the fan stack exit plane where the cross-sectional area is divided into 12 concentric rings of equal area. The midpoint of each of the 12 rings is sampled with apparatus suspended from ropes above the fan stack. After one diameter is sampled, the ropes and suspended equipment are rotated 90 degrees and a perpendicular diameter is sampled to obtain an integrated sample from the 24 locations. The primary collection apparatus in the CTI system is a cylindrical tube containing tightly packed glass beads. The outside of the tube is heated with high wattage band heaters that heat the outside of the tube and in turn heat the glass beads. As water droplet laden air is drawn through the bead pack, the droplets strike the beads and evaporate depositing salts from the droplets onto the beads. The amount of salt deposited on the beads is a function of the amount of drift leaving the tower. A "back-up" filter is placed immediately behind the glass bead pack to capture salts that escape the beads. The sampled air exits the filter holder via a vacuum hose connected to a flow section containing a calibrated orifice and a large capacity vacuum pump. The collection apparatus is suspended from ropes over the fan stack. Lanyards tied to the sides of the collection assembly are used to rotate the assembly into the flow at each sampling point and to move the assembly from sampling point to sampling point. The sampling assembly contains a calibrated resistance protractor that measures the angle of rotation at each sampling station. The cosine of the measured angle is used to correct the sampling time at each point in order to maintain the sample proportionality. Adjusting the time is more convenient and is mathematically equivalent to adjusting the area for the sampled component that is normal to the fan stack. Because of the proximity of the fan to the fan stack exit plane, the angle of the airflow at the sampling location often approaches 30-40 degrees from vertical.

The collection assembly also contains a calibrated propeller anemometer to measure the air speed and a temperature probe to measure the stack temperature at the sampling location. The differential pressure across the calibrated orifice, the static pressure, and the temperature at the orifice are used to calculate the flow through the sampling system. The flow control valve is adjusted to match the sampling probe inlet velocity to the local air velocity in the stack measured with the propeller anemometer. Barometric pressure is also measured to correct for the density difference between the air at the inlet to the sampling probe and the air flowing through the orifice.

The solids collected on the glass beads and the filter are recovered by acid wash and repeated rinses with ultra-pure (metals analysis grade) water. The quantities of the tracer collected are generally so small that only constituents present in concentrations above 100mg/l are acceptable trace elements. Sodium, magnesium, and calcium are the most commonly used tracer elements. Sample analyses are made by flame atomic adsorption (AA) or inductively coupled plasma techniques (ICP).

Another difference between the EPA Method 5 and the CTI Heated Glass Bead Isokinetic (HGBIK) sampling equipment is in the size of the sampling probes and pumps. In order to reach the typical fan exit velocity of 2500 fpm, the nozzle associated with the typical Method 5 pump would be about 0.25 inches in diameter, whereas, the HGBIK system can reach isokinetic velocities with sample probe inlet diameters that range from 0.8 to 1 inch. The larger area of the HGBIK nozzle means that a much larger sample is collected in a given amount of time, which reduces the overall duration of the test.

Drift Rate Calculation

The test apparatus collects an integrated sample of the exiting tracer mass from 24 equal area locations across the stack. The exiting mass consists of the total tracer mass collected in the appartatus, corrected for the tracer mass found in a clean glass bead pack or filter (blanks). This mass may mathematically expressed :

$$\mathrm{M} = \left(\mathrm{M}_{\mathrm{GB}} - \mathrm{M}_{\mathrm{GB}_{\mathrm{B}}}\right) + \left(\mathrm{M}_{\mathrm{F}} - \mathrm{M}_{\mathrm{F}_{\mathrm{B}}}\right) \qquad (\mathrm{Eq}.6)$$

Where:

M = the net mass recovered from the glass bead pack and the back-up filter for the selected tracer element, (e.g. µg calcium);

M_{GB} = mass recovered from the glass bead pack for the selected tracer element, (e.g. µg calcium);

M_{GBB} = mass recovered from the glass bead field blank for the selected tracer element, (e.g. µg calcium);

M_{F} = mass recovered from the back-up filter for the selected tracer element, (e.g. µg calcium); and

M_{FB} = mass recovered from the back-up filter field blank for the selected tracer element, (e.g. µg calcium).

The liquid (circulating water) emission of drift may be expressed as:

$$q_e = \frac{M}{t * C_{CW}} \frac{A_S}{A_N} \qquad (Eq.7)$$

Where:

q_e = mass emission rate of circulating water(m^3/hr)

t = the total sampling duration (hours);

A_N = the area of the sampling nozzle. (e.g. m^2)

A_S = the area of the stack. (e.g. m^2)

C_{CW} = the average concentration of the selected tracer element in the circulating water during the drift test, (e.g. µg calcium/m^3);

Finally, the total drift rate from the stack may be expressed as:

$$D\% = \frac{q_e}{Q} * 100 \qquad \text{(Eq.8)}$$

Where:

Q = the circulating water flow rate, (m^3/hr).

D% = the drift rate (%).

In most cases, drift rates are calculated based on multiple tracer elements. This is an important quality assurance check, since this will reveal the presence of gross contamination on the filters and HGBIK tubes.

The amount of each trace element collected in the sampling train is proportional to the concentration of the element in the circulating water and thus for elements with similar detection limits, the duration of the test is a function of the concentration of the element in the circulating water. In most cooling towers, the elements sodium, calcium, and magnesium are present in the highest concentration and thus are used for analysis. The sampling times are chosen such that collected mass of at least one of the tracer elements, at the anticipated drift rate, will be at least 10 times the analytical detection limit for the tracer. Sampling times vary from 4 to 16 hours, depending on the expected drift rate and the tracer concentration.

In some situations where the circulating water is exceptionally clean or where the ambient concentrations in the air are unusually high, the circulating water may be spiked with a target analyte. Because of economic consideration, spiking the circulating water is often only practical for small systems.

Test Influences and Repeatability

Although the primary contributor to the amount of drift that is emitted from the tower is the quality of the installation of the drift eliminators, the type of drift eliminator, water distribution, water quality, airflow rate, and the air distribution all contribute to the amount of drift. Calm winds also facilitate more even velocity distributions at the fan stack exit plane and repeatable distribution of drift at the sampling locations. Tower with small localized gaps in the drift eliminators, may have large amounts of drift coming from a very small area. Gusty or variable winds shift the localized drift within the sampling plane leading to scatter in the calculated drift emission rate between repeat tests of the same stack. Since the drift rate is highly dependent on the quality of the drift eliminator installation and this may vary from cell to cell, it is not unusual for the drift rate to vary by up to 50 percent from cell to cell on the same cooling tower. This occurs even when repeated cell tests yield consistent results.

Although the test code requires the sampling of the ambient air to determine the concentration of the tracer element(s) in the ambient air, no correction is applied for the ambient concentration because the scrubbing efficiency of the tower is unknown. This leads to the potential for positively biased test results as ambient concentrations are drawn through the tower air inlets and exhausted through the tower stack and into the sample train. The ambient concentration of the tracer elements at some locations is a function of wind blown dust and thus more repeatable tests may be performed during days with relatively calm winds.

The following table presents a typical test summary.

TABLE 1: ISOKINETIC TEST SUMMARY

Drift Rate as a Percentage of Test Water Flow Rate

Test Number	Calcium %	Magnesium %	Sodium %	Average %
1 West Cell	0.0020	0.0017	0.0013	0.0017
2 West Cell	0.0015	0.0019	0.0018	0.0017
Avg. West Cell	0.0018	0.0018	0.0016	**0.0017**
1 East Cell	0.0011	0.0009	0.0006	0.0009
2 East Cell	0.0011	0.0010	0.0007	0.0009
Avg. East Cell	0.0011	0.0010	0.0007	**0.0009**
Overall Average				**0.0013**

On this test the repeat runs on the same cell yielded identical drift rates, but the drift rate for the two cells differed by almost a factor of 2. The agreement between drift rates calculated based on the different tracers and the repeatability of the test runs indicates that contamination was not a problem.

Summary of Recent Test Results

A summary of selected HGBIK test results performed by the authors is presented in Table 2.

TABLE 2: SUMMARY of TEST RESULTS

Cooling Tower	Test Type	DE Type	Tested Drift Rate %Flow	Guaranteed Drift Rate %Flow
A	Status	ME	0.008	
B	Status	HE	0.004	
C1	Acceptance	HE	0.0009	0.002
C2	Acceptance	HE	0.0013	0.002
D	Acceptance	HE	0.0006	0.002
E1	Status	ME	0.025	
E2	Acceptance	HE	0.0007	0.001
F1	Acceptance	HE	0.007	0.002
F2	Acceptance	HE	0.007	0.002
G	Status	LE	0.019	
H	Status	LE	0.009	
I	Status	LE	0.008	
J	Acceptance	HE	0.001	0.002
K	Acceptance	HE	0.0002	0.001
L	Acceptance	HE	0.0004	0.0005
M	Acceptance	HE	0.0007	0.002
N	Acceptance	HE	0.0008	0.005
O1	Acceptance	HE	0.0006	0.0005
O2	Acceptance	HE	0.0005	0.0005
P1	Acceptance	HE	0.0036	0.002
P2	Acceptance	HE	0.0052	0.002
Number of Tests			21	
Average Drift Rate			0.005	
Maximum Drift Rate			0.025	
Minimum Drift Rate			0.0002	

*LE = low efficiency drift eliminators; wood lathe
*ME = medium efficiency drift eliminators; chevron type
*HE = high efficiency drift eliminators; wave form

Status tests are done at the request of the owner usually based on a perceived problem. These problems are usually manifested by excessive salt deposition around the cooling tower. Cooling towers G, H, and I are different designs of 40 year old wooden cooling towers with wood lathe drift eliminators. They are in reasonably good condition considering their age. Note that the drift rates from these older towers are lower than for cooling tower E1.

The difference in drift rate that can be achieved by rebuilding an existing cooling tower is illustrated by cooling towers E1 and E2. Cooling tower E1 had chevron type drift eliminators that had been seriously damaged by icing. Cooling tower E2 is the same cooling tower after the internal components, including the drift eliminators, had been replaced.

Cooling tower A was in good repair but had serious water chemistry problems. Foam covered the cold water basin as well as the drift eliminators. Large pieces of this foam were continuously being emitted. Since the drift eliminators cannot function properly in the presence of foam, foam control is required to minimize the amount of emissions. Excessive foam can usually be controlled through pH control.

Of all the cooling towers tested, only E1 exceeded the 0.02% drift rate specified by AP-42. The maximum and minimum drift rate for cooling towers tested differed by a factor of 167. Considering only the acceptance tests (for which the cooling towers were new or recently rebuilt), the difference between the high and low drift rates was a factor of 47. With this degree of variability, the concept of an average drift rate of all cooling towers seems to have little meaning. Testing of the specific cooling tower in question is necessary in order to quantify the specific emissions from that tower. When tested, all of the new cooling towers tested had emissions levels much lower than that specified by AP-42.

CONCLUSIONS

The assumption that all cooling tower drift is PM_{10} overstates the amount of drift in this fraction. Although the amount of drift emitted from a cooling tower is always site-specific, the amount of emitted drift is nearly always significantly less than presented in the EPA emissions guideline AP-42. The Cooling Technologies Institute ATC-140 provides the best means currently available for the quantification of cooling tower drift emissions.

References

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CATEGORY: CORROSION

COOLING TECHNOLOGY INSTITUTE

A Synergistic Combination of Advanced Separation and Chemical Scale Inhibitor Technologies for Efficient Use of Impaired Water in Cooling Towers

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ABSTRACT

Water is essential to thermoelectric power plants, used primarily for cooling. Using impaired water in place of fresh water is a potentially attractive solution to the problems of water scarcity and competing demands. Nalco was awarded DOE grant to develop a cost effective integrated solution (chemical and physical) for the use of impaired water and maximize the cycles of concentration. Argon National Laboratories under CRADA demonstrated the use of ED/RWEDI while Nalco developed scale inhibitors for the integrated solution.

Introduction

As the population increases, good fresh quality water is much more needed for human use including growing food. Tertiary sewage treated water and sea water (1) has been successfully used in many industrial applications. The use of impaired water is currently not very practical and cost effective, as the inferior water quality results in additional treatment requirements to address the high propensities of scaling, corrosion, and biofouling and to avoid adverse impacts to the environment.

Depending on the impairment the treatment cost is prohibitively high because 1) the current separation technologies are inefficient, and 2) the scaling potential of the impaired waters is generally high and severely limits the number of cycles that can be achieved with current scale control technologies. Scale inhibitors alone can only control deposit up to certain number of cycles of concentration; beyond their maximum limit it does not matter how much inhibitor is added. In these situations the only way to improve water reuse is remove impairment either completely or partially (Figure1). Operating at low cycles reduces water utilization efficiency and greatly increases the volume of blowdown wastewater, resulting in unacceptable high costs and a significant environmental impact. In this figure, the yellow line represents the scale inhibitors only using existing commercial scale inhibitors while the green line represents the target for new scale inhibitor. The dark blue line represents model water as is while the magenta color represents with at least 50% calcium hardness removed.

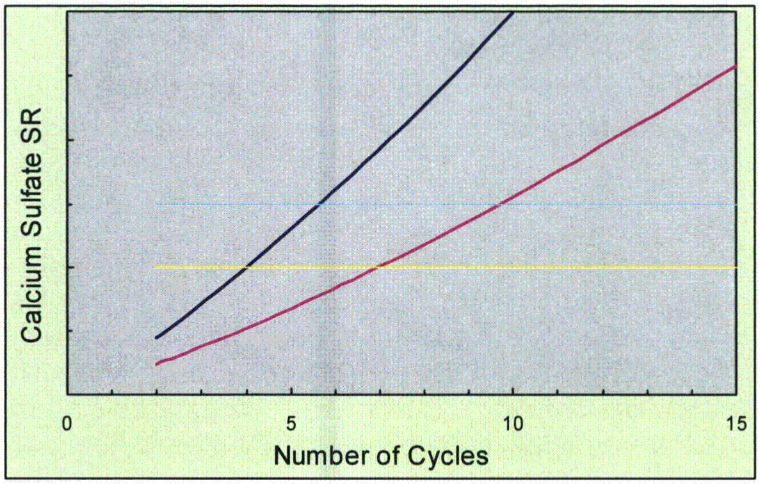

Figure1. Synergy of Ion Separations and Scale Inhibitor

Nalco Company by partnering with Argonne National Laboratory (ANL) in this project has developed advanced scale control technologies that will provide cost-effective solutions for recirculating cooling water systems to operate at high cycles using impaired waters. This will reduce the amount of make-up water required and the volume of blowdown generated, resulting in lower treatment cost and less environmental impact. The overall approach is to use synergistic combinations of physical and chemical technologies. More specifically, the paper reports the use of novel membrane separations and scale inhibitor technologies that work synergistically; membrane separations reduces the scaling potential of the cooling water and the scale inhibitors extending the safe operating range of the cooling water system. This approach has not been possible to date because the technical risks involved in integrating these technologies have not been addressed. The new scale inhibitor chemistries developed in this work can handle the higher stress scaling conditions as well as new types of scales from impaired water.

Results and Discussion

Identify Limiting Factors for High Cycles and Quantify Technical Targets:

Potential sources of impaired waters were identified based on literature and industry information provided by Nalco's Power business unit. As the first step to determine the cycle-limiting factors of the impaired waters, the characteristics of various impaired waters were collected and evaluated. There are several sources of water that are used for cooling water application

- Ground water
- Surface water
- Tertiary sewage treated water (municipal waste water)
- Produced water

- Sea water/brackish water

General impairment with ground water in addition to hardness, alkalinity, and silica is the presence of iron and manganese. Surface water contains high suspended solids and many times colloidal silica in addition to dissolved silica and other ions mentioned in the ground water. Surface water, however, very rarely contain iron and manganese. The challenges with municipal treated waters (sewage treated water) are the presence of variable phosphate, ammonia and biological material. Produced water is not used very commonly for cooling tower. There has been a recent trend in the use of sea or brackish water being used in power plants in coastal areas (1). The impairment of these waters is due to the corrosive nature, which is overcome by using corrosive resistant metallurgy. Cooling towers using brackish or sea water are generally run at lower cycles due to abundance resource and easy discharge without impacting the environment. In this study we focused on high hardness, high alkalinity, and high silica waters and in general high total dissolved solids (TDS).

Table 1 shows that produced water characteristics can vary significantly from site to site, with respect to the total dissolved solids and the ion profile. Two common potential cycle-limiting minerals are calcium carbonate and calcium sulfate. These waters often contain very high levels of bicarbonate (HCO_3^-) ions and present unique challenges in calcium carbonate scale control.

Table 1.Characteristcs of produced water

Reference	Tsai (1995)		Nalco	EPRI & CEC (2003)	EPRI (2004)	
Location	Site B	Site C	Gillette, WY	Central Valley, CA	McGrath , NM	Fairway, NM
Type		CBM	CBM	Oil Well	Mixed	CBM
pH	7.6	7.2	8.1	7.9	7.1	8.0
TDS, mg/L	8,000	14,700	4,000	3,879	12,714	12,236
Na, mg/L	2,640	6,200	870	982	4,149	3,620
Ca, mg/L	18.9	22.1	44	40	143	31.0
Ba, mg/L	10.1	27.2	1.5		3.1	25.1
Fe, mg/L	3.87	3.16	0.6		41	4.87
Cl, mg/L	18.9	1,920	25	920	6,298	2,018
SO4, mg/L	6.9	10.6	0	110	544	4.3
HCO3, mg/L	1,976	11,700	2,684	1,100	765	6,381
SiO2, mg/L			15	120	18.5	21.4

Compared with produced waters, characteristics of reclaimed municipal wastewater effluents, as shown in Table 2, are more uniform from various sites. The total dissolved solids level varies from 500 to slightly over 1000 mg/L. Again, calcium

Table 2.Charactersitics of Typical Municipal Effluent Treated Water

Reference	This Work			2
Location	OCWD, CA	DDSD, CA	Naperville, IL	Bay Area, CA
Total Dissolved Solids, mg/L	940	1190	555	869
Conductivity, mS/cm	2.2	1.8	0.9	
Total Organic Carbons, mg/L	10			
BOD 5-day, mg/L	19		3	8
pH	7.8	8.0	7.9	7.0
Sodium, mg/L as Na	230	248.3	88.0	76
Potassium, mg/L as K	19	16	12	5
Calcium, mg/L as Ca	82.0	52.1	64.0	76
Magnesium, mg/L as Mg	23.0	26.7	28.0	43
Barium, mg/L as Ba	< 0.1	< 0.1	< 0.1	
Strontium, mg/L as Sr	0.62	0.36	0.2	
Iron, mg/L as Fe	0.55	0.19	0.08	
Aluminum, mg/L as Al		0.4		
Chloride, mg/L as Cl		290.5	120	102
Sulfate, mg/L as SO_4		220.8	60	68
Bicarbonate, mg/L as HCO_3		305	171	396
Phosphate, mg/L as PO_4	2.5	0.6	2.0	6.0
Silica, mg/L as SiO_2	26.0	23.0	8.3	17.0

OCWD: Orange County Water District
DDSD: Delta Diablo Sanitation District

carbonate is a common potential cycle-limiting factor, and silica/silicate is an issue for the western region. The concentration of phosphate in some reclaimed municipal effluents is high enough to potentially cause calcium phosphate scaling, and this can be a challenging issue, especially if silica is also present at high concentrations. The presence of iron and aluminum, due to their uses as treatment additives in upstream treatment processes, also present potential iron and aluminum fouling issues. However, the extent of potential iron and aluminum fouling appears to be controllable with current cooling water treatment technologies.

Development of High Stress Calcite and Silica Scale Control Chemistries:

Scale formation in cooling water systems occurs when mineral salts precipitate from the water phase because the solubility of the particular mineral has been exceeded (i.e., the water is supersaturated with the mineral). Supersaturation of any mineral is defined by the following relations,

$$\text{Supersaturation} = \text{Activity product of scale forming ions}/\ Ks_p$$

Where, Ks_p is the thermodynamic equilibrium solubility constant of the mineral.

The process of scale formation from a supersaturated solution involves a series of steps, including nucleation, crystal growth and deposition on the heat exchangers. Chemical scale inhibitors (also known as antiscalants) control scale formation by a variety of mechanisms: threshold inhibition, crystal modification, sequestration, or dispersion. In terms of their chemical nature, scale inhibitors include inorganic polyphosphates (e.g., hexametaphosphate), organophosphonates (e.g., 1-hydroxyethylidene-1, 1-diphosphonic acid) and polymers (e.g., polyacrylate).

Antiscalants for calcite (calcium carbonate) and silica/silicate scale control are currently available. However, for high stress conditions (at high supersaturation ratios) these antiscalants are either ineffective or uneconomical. Scale inhibitor chemistries (including new molecules, polymers, and formulations) were evaluated under high stress chemistry to develop new antiscalants that will be superior to the existing antiscalants in terms of cost and performance. The evaluations were performed initially in bench tests and, subsequently, in the pilot cooling towers.

The term silica is often used loosely to include both silica and silicates, which are, in fact, two distinct families of silicon-containing compounds. Silica refers to SiO_2, including the crystalline quartz and the non-crystalline amorphous silica, resulting from polymerization of silicic acid, H_2SiO_3. Silicates refer to the compounds formed by reacting ionized silicic acid with metals, such as calcium (Ca), magnesium (Mg), aluminum (Al), iron (Fe), zinc (Zn), etc. It is also very common for silica/silicates to coprecipitate on suspended solids or other precipitating minerals. The solubility of silica is approximately constant in the pH range of 6 to 8 and increases at pH >8.5. The solubility of silicates follows the opposite trend, and silicate precipitation generally occurs only at pH > 8.5. Silica/silicate control using chemical inhibitors include inhibition of silicic acid polymerization and dispersion of silica/silicate crystals. Amorphous silica solubility increases with increasing temperature while the solubility of silicates decreases with increasing temperature. Most of the time in cooling towers amorphous silica is deposited on the high efficiency fill and silicates are found on the heat exchangers surface in systems with moderately low silica levels. On the carbon steel heat exchanger surface due to the presence of hydroxyl groups, silica can directly deposit as silicates or even monomeric silica.

Calcium carbonate precipitation is directly a function of hardness, carbonate alkalinity, temperature, TDS and pH. Most of the time calcium carbonate precipitation is controlled by adjusting the pH of the recirculating water. There are several draw back to control calcium carbonate precipitation by acid feed. Reduction in carbonate alkalinity by addition of sulfuric acid is also responsible for adding to the greenhouse gasses by emitting 0.73 ton of carbon dioxide for every ton of carbonate alkalinity reduced with sulfuric acid.

- Corrosion.
- Other potential scales such as calcium and barium sulfate (if sulfuric acid is used for pH control).
- CO2 emission as a result of carbonate alkalinity neutralization.

- Cost.
- Safety due to acid handing risk.

Solubility of calcium carbonate is inversely proportional to temperature and thus is a very common scale on the heat exchangers. Scale inhibitors have been used but largely in conjunction with pH adjustment for high cycles of concentration or high alkalinity waters.

Calcium Carbonate Scale inhibitor:

For an initial quick screening of different molecules at various concentrations a stagnant flask test was developed. The simple impaired is prepared using calcium chloride and a mixture of sodium carbonate and sodium bicarbonate. An 80/20 mixture of sodium bicarbonate/sodium carbonate in addition to providing the required alkalinity provides a buffer at pH 9.0. These flasks are dosed with different amounts of different inhibitor and are incubated for 24 hours in a water bath at 55 °C. At the end of the incubation time, each test solution is filtered through 0.22 μm membrane filter, while the solution is still hot. The filtrate is analyzed for calcium concentration using Atomic absorption spectrophotometer and complexometric titration to determine the %age inhibition using the following equation.

$$\% \text{ Inhibition} = \frac{V_E - V_o}{V_T - V_o} \text{ X } 100$$

Where: V_E = Total Calcium as mg/L for treated test sample
V_o = Total calcium as mg/L for untreated (blank) test sample
V_T = Total calcium as mg/L for calcium reference (initial s

The flask, which contains no inhibitor gives V_o, is considered at no inhibition (0%) and if V_E (treated with inhibitor) is equal to V_T, it will give complete inhibition (100%). V_T is determined from a flask, which contains only calcium and no alkalinity (or theoretical initial amount of calcium added to each flask. Initially to create conditions of calcite saturation of 250X, the following composition of the water was synthesized:

150 mg/L Ca^{++}, 600 mg/L Alkalinity as $CaCO_3$ (80/20 $NaHCO_3/Na_2CO_3$), 266 mg/L Chloride, and 276 mg/L sodium.

The results of this study are shown in table 3.

Table 3. Results of calcium carbonate inhibition with different inhibitors

Inhibitor	Concentration mg/L	% Calcite Inhibition
L99BO	10	45.6
L99BO	20	100
L99BO	50	100
5636-130	20	44
5636-130	50	65
5636-130	100	62
5636-130	130	77
5636-130B	10	28
5636-130B	25	42
5636-130B	130	60

L99BO is a known phosphonate, which is effective in the test conditions; however this inhibitor can undergo degradation to orthophosphate under high bleach use, however, it has shown good stability with stabilized/unstabilized hypobromous acid oxidative environment. In the cooling towers, oxidizing biocides are often used to control microbes in the water biofouling. New compounds, 5636-130 and 5636-130B, were synthesized and evaluated. These new compounds are deemed more stable in an oxidizing environment than LLB90 but the performance was not up to the level of LLB90.

Table 4. Silica testing with laboratory prepared inhibitor sample

Testing Time	Blk	6107-79-5ppm	6107-79-10ppm	6107-79-20ppm
Initial	302.61	297.07	317.99	301.55
~1.5hrs	313.88	310.71	306.45	307.17
~2.5hrs	298.05	282.64	308.79	317.50
~3.5hrs	280.79	295.11	308.55	309.07
~4.5hrs	284.92	291.82	311.38	324.29
24hrs	156.68	234.80	291.59	300.24

These results in table 4 shows that the silica inhibitor is capable of handling silica as SiO_2 at up to 300 PPM. In subsequent field trials the results were even more encouraging.

Ion Removal:

One of the membrane systems being tested by Argonne for the removal of scaling components is resin wafer electrodeionization (RW-EDI). EDI is an industrial process that incorporates ion-exchange (IX) resin beads into an electrodialysis (ED) stack. ED is an electrically-driven membrane-based separations process. Commercial EDI systems are constructed by filling the diluate channel in an ED stack with loose ion exchange resin beads. Argonne has immobilized the loose IX resin beads with polyethylene resins to form a porous resin wafer (RW) material. A typical EDI system schematic is shown in Figure 2.

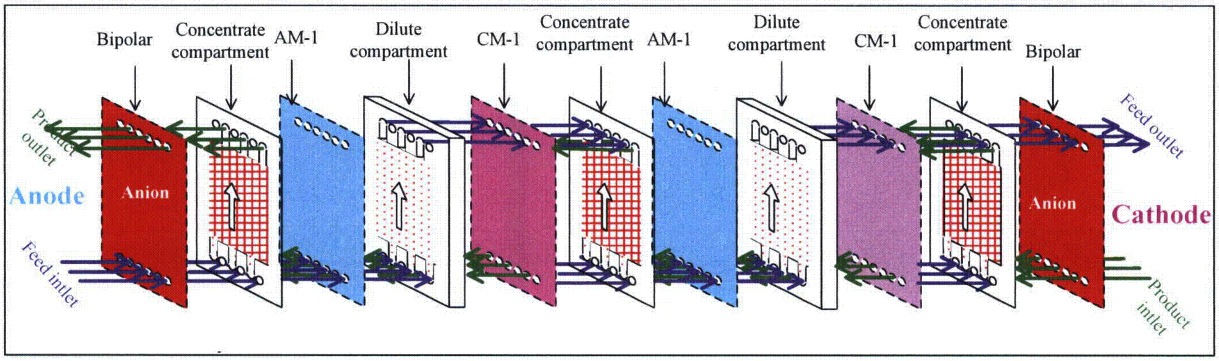

Figure 2: Schematic of the EDI system used for scaling ions removal

The RW-EDI platform enables in-situ pH control by using the water splitting reaction which eliminates or minimizes the need for acid or base additives. The RW-EDI platform provides flexibility in terms of membranes used and their configuration. Additionally, the wafer resin composition can be varied (anion excess, cation excess or equal amounts of anions and cations) to facilitate the removal of scaling components.

Electrodialysis (ED) System:
Two different systems were tested. While investigating hardness removal in simulated make-up water, a four-cell pair stack comprised of Ameridia's CMX-s and AHA-1 ion exchange membranes was used. Hardness removal from simulated 10-cycled power plant cooling water was done with a 6-cell pair ED stack using Ameridia's AM-1 and CM-1 ion exchange membranes.

Electrodeionization (EDI) System:

The Argonne EDI resin wafers were fabricated from commercial grade gel-type strong acid cation and strong base anion exchange resins. The resin wafers with different ratios of cation/anion exchange resins were fabricated using Argonne's patented process (Patents 6797140, 7306934, and 7452920). Commercial polymeric ion-exchange membranes were used to assemble the RW-EDI stack. Different membrane configurations were tested during process development. A commercial ED stack was used as the base template to assemble the EDI stack. Two different EDI stack sizes were employed which had a cross-section membrane area size of either 14 cm^2 or 195 cm^2. Argonne's in-house gasket material was used to seal the resin wafers in the stack.

The feasibility of using ED to reduce the hardness and hence the scaling potential of power plant recirculated cooling water and make up water was tested at the bench-scale. Ten liters of simulated make up water, which contained 995 mg/L of NaCl equivalent, was tested in a four-cell pair ED stack which used Ameridia's CMX-s and AHA-1 ion exchange membranes. The results showed a 99+% removal of salts from the simulated solution with low power consumption. Simulated 10 cycled cooling water containing 8500 mg/L of NaCl equivalent and 1.3 meq hardness was tested in a six-cell pair ED stack built with Ameridia's AM-1 and CM-1 ion exchange membranes. This test showed a 99+% removal of salts from the simulated solution with very low power consumption. The divalent cations were removed preferentially over the monovalent cations. These results suggest that it is technically and economically feasible to use ED for the separation of scaling species from reused water.

Feasibility of using EDI to reduce alkalinity in simulated recirculated cooling water and make up water was also studied. Reducing alkalinity could potentially increase the number of cycles of concentration. Bench-scale EDI stacks were assembled using Ameridia's CMX-s and AHA-1 ion exchange membranes and porous ion-exchange resin wafers. Initial screening runs were done with a four–cell pair mini-stack (14 cm^2 membrane area/cell pair) while subsequent runs were done with a larger six cell-pair stack (195 cm^2 membrane area/cell pair). Two different simulated waters were used – one with 2500 ppm of NaCl equivalent and 2700 ppm of alkalinity and the other with 3500 ppm of NaCl equivalent and a similar 2700 ppm of alkalinity. For these tests, the power required to remove high levels of alkalinity from the simulated water was around 2 – 3 kWh/100 gal of water. Although the EDI system could remove the alkalinity, it was not preferentially removed compared to the other salts because the pH of the processed effluent was not low enough.

The EDI system's selectivity was improved by changing the ratio of cation and anion ion-exchange resin beads in the wafers. Three different wafers were tested: an anion-excess resin wafer, a cation-excess resin wafer and a wafer made with equal amounts of cation and anion resins. Of these three, it was found that the wafer made with an excess of cation resin gave the best separation efficiency.

An EDI stack with these optimized resin wafers was then tested. Two different simulated waters were used – one with 9600 ppm of NaCl equivalent and 4600 ppm of alkalinity and the other with 3500 ppm of NaCl equivalent and 6400 ppm of alkalinity. The results showed low power consumption and over 98% removal of the alkalinity from the simulated waters.

In addition to the removal of hardness and alkalinity, the removal of silica was also studied with bench-scale ED and EDI. These technologies were tested using a simulated impaired water solution which contained 200 ppm of silica. Both ED and EDI demonstrated the ability to remove silica from the simulated water. The power consumption for EDI was approximately 25 – 30% less than the power consumption observed for ED. These results are shown in tables 6 through 8.

Table 6. Comparison of Alkalinity removal using EDI with different resin wafers

Resin Wafer Composition	Processing Flux ($gal/m^2/hr$)	Power consumption (kWh/100 gal)
Excess Cation	11.5	2.8
Excess Anion	2.0	19.8
Excess Cation (weak acid)	2.8	38.0

A series of tests were done to determine the effect of stack configuration and the type of ion exchange membranes on the EDI system's alkalinity removal efficiency. Table 6 shows the optimized performance while Table 7 shows the estimated capital cost based on the process performance as shown in Table 8.

Table 7. Optimized Process Performance

Process Salt content		Processing Flux ($gal/m^2/hr$)	Power consumption (kWh/100 gal)
Initial (ppm)	Final (ppm)		
5000	500	5.9	3.7
500	50	19.5	0.68

Table 8. Estimated Processing Cost Based on Performance

Impaired Water flow rate (gal/day)	100,000	100,000
Alkalinity Concentration (ppm)	5000 - 500	500 - 50
Processing flux (gal/hour/m2)	5.9	19.2
Power consumption (kWh/100 gal)	3.7	0.5
Capital cost Range (High - Low)	\$1,000,000 - \$1,400,000	\$325,000 - \$433,333
Power Cost \$/day at 5c/kwh	\$187	\$27
Power Cost '\$/year	\$68,103	\$9,793

The optimized EDI system was able to increase the processing flux fourfold. It also reduced the power consumption by 20% compared to what had been previously reported. The fourfold increase in processing flux provides significant savings (75%) in the capital equipment cost.

In order to reduce membrane fouling and lengthen the time between device cleaning cycle, we further optimized the EDI desalination process by modifying membrane configuration and operating conditions. An anti-fouling chemical developed by was also tested but the precipitation that was causing the membrane fouling did not decrease. In the enhanced process, the removal efficiencies of hardness, alkalinity and total salt removal were improved, as shown in Table 9. The cost of water desalination using EDI was estimated to be approximately $0.05/barrel of water

Table 9. Desalting Performance of Revised EDI System

Process Range Salt content	Processing Flux ($gal/m^2/hr$)	Power consumption (kWh/100 gal)	Salt Removal	Hardness Removal	Alkalinity Removal
500 to 50 ppm	19.5	0.57	87.0%	83.2%	86.0%
500 to 50 ppm	19.2	0.54	95.1%	88.8%	99.5%

Pilot study with PCT (EDI and Scale Inhibitor):

Finally after all the optimization studies the integrated program was evaluated using the PCT. The economics of water desalination using EDI was estimated to be around $0.05/barrel water (table 8); that figure includes both capital and operating costs.

A synthetic impaired water is brought into the EDI unit and the soften water (with impaired ions removed) is used as a makeup water to the Pilot Cooling Tower. The unit was properly sized to meet the makeup requirements for the PCT. Several runs were planned to evaluate the efficacy of the concept in terms of maximizing the cycles, economics of >95% ion removal (power consumption), partial removal of impaired ions and combination with inhibitors, and Ion removal from the makeup water as well blowdown water.

We conducted this study by approaching from two different scenarios:

1. Removing the impaired ions using EDI upfront from the makeup water
2. Removing the impaired ions using EDI from the blowdown of the cooling tower

Both approaches provided excellent results indicating the possibility of operating cooling tower using water with impaired ions close to zero liquid discharge. In this system the small wastage of the water came from blowing down the concentrate (about 23 liters) twice per week and another small volume (about 20 liters per week) for cleaning in place (CIP) and the rinse. The results of these studies showed approximately 90% reduction in the water wastage. The concentrate tank (i.e., waste water recycled tank) conductivity is increased from 350 $\mu S/cm^2$ to >30,000 $\mu S/cm^2$, although some of the conductivity in the concentration tank comes from sodium chloride added as a means of conducting solution. In a zero liquid discharge system, removal of TDS from the blowdown stream is more cost effective than removal of TDS from makeup water, due to processing of less volume through

EDI, even though former requires higher power consumption than the latter. A long-term integrated evaluation (550 hours) of the optimized EDI system and the inhibitor resulted in 90% decrease in water wastage.

Conclusions

In the final analysis for any size cooling tower the water consumption is through evaporation, blowdown and some leaks. The evaporation rate depends on the recirculating rate and delta temperature; it remains constant at any cycles of concentration. Increasing cycles of concentration from 5 cycles to 10 cycles reduces blowdown by 55% and the blowdown rate is 25% of the evaporation rate, which means 75% water consumption is due to evaporation. By further increasing cycles of concentration from 10 to 15 cycles, there is further reduction of 15% in blowdown rate; however 93% water consumption comes from evaporation. Thus there is a much more water savings from 5 cycles to 10 cycles than going from 10 cycles to 15 cycles of concentration. Beyond15 cycles of concentration, there is practically very little water savings. Process was optimized by reducing the impairment ion by 50% and then maintaining zero liquid discharge by using a low level of scale inhibitors and oxidizing biocide.

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PAPER NO: **TP10-10**

CATEGORY: **COOLING TOWER WATER TREATMENT PROGRAMS**

COOLING TECHNOLOGY INSTITUTE

WHAT IS THE BEST WATER TREATMENT PROGRAM FOR MY TOWER

ROBERT J. CUNNINGHAM

ARTHUR FREEDMAN AND ASSOCIATES

Presented at the 2010 Cooling Technology Institute Annual Conference

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ABSTRACT:

One of the most frequently asked questions received by the CTI "Ask the Expert" department is "What is the best cooling water program for my cooling tower?" This question comes up so often that CTI has decided to dedicate a panel discussion to the subject, as well as to solicit papers on the topic.

The best answer to this question is "it depends". Many factors should be considered in the decision regarding the proper treatment for any open recirculating cooling tower system. The relative severity of each factor must be considered in order to arrive at the optimum solution for each case. There is no "one best fits all" when selecting the optimum treatment, and there is no substitute for a thorough understanding of all of the factors that surround this selection process. Ignore this maxim at your peril!

BACKGROUND:

Cooling towers are employed to reject heat to the atmosphere from one or more processes. While the cooling tower itself is a very important component of an integrated cooling system, it is just one component. In addition to the tower itself, there is the process(s) that provides the unwanted excess thermal energy, or heat, and there is the associated infrastructure, including the associated pumps, valves, and recirculating water piping. Frequently a cooling tower is rejecting heat from multiple processes, each with its own associated equipment, and its peculiar set of pre-ordained considerations, including heat transfer design considerations, metallurgy, etc.

Cooling towers, evaporative condensers, or closed circuit coolers accomplish almost all of the desired cooling effect by evaporating a portion of the recirculating cooling water. This requires a continuing source of supply, or "make-up" water to replace that lost to "evaporation". When evaporation occurs, pure water vapor is lost from the system. This evaporation causes the dissolved solids that were originally present in the make-up, or source water, to concentrate in the remaining system "recirculating water". If this process of concentration is not interrupted or limited, the solubility of a range of dissolved sparingly soluble compounds will be exceeded, and precipitation will result in sludge formation and probably lead to scale formation. We limit the concentration process by "blowing down", "bleeding off", or removing a portion of the concentrated cooling water. This requires more make-up water.

In addition, a variable amount of the recirculating water is lost from the system due to "windage" or "drift" loss due to carryover of entrained water droplets in the mass flow of exit air. This amount will vary greatly due to environmental conditions, tower maintenance, treatment chemical selection, and the efforts of each manufacturer to minimize "drift" by providing "drift elimination". In addition, in real world systems there is always some amount of water loss due to "leakage", or unintentional water loss due to miscellaneous leaks of water from the system piping and equipment. In some plants cooling water is intentionally used for various plant "wash down" purposes.

In order to provide the make-up water required to replace that lost due to evaporation, blow-down, drift, and leaks, these systems also, by extension, incorporate a make-up water supply system of varying complexity, and a blow-down treatment/disposal system that will again vary in design and operating complexity. Because the cooling tower depends on evaporation to accomplish the cooling duty, and requires intimate contact of the water with copious quantities of air, there is also ambient air quantity and quality that must be considered.

Depending on where the cooling tower is installed, and on the availability of one or more sources of make-up water, as well as on prevailing climatic conditions, make-up water quantity and quality may vary over time, and blow-down discharge restrictions may also vary from location to location, as well as over time.

From a chemical treatment point of view, the ideal cooling tower water system would incorporate equipment of relatively simple construction, with all materials selected to exhibit minimal deterioration in the system operating environment. Heat transfer surfaces would employ very conservative design flows with lots of surface area, in order to minimize unit heat flux and exchange surface skin temperatures. Such an ideal system would employ high quality stable make-up water, and low cycles of concentration. In addition, the system would be equipped with generously sized side stream filtration to minimize suspended solids loading in the recirculating water, due to suspended matter present in the make-up, or carried to the tower by the ambient air, or by process streams.

Metallurgy would be selected to minimize corrosion. Sacrificial or impressed current anodes might also be installed. Cooling tower components would be selected to minimize deterioration, and tower fill would employ open splash bar construction resistant to fouling. The recirculating system would be equipped with a very reliable pH, cycle of concentration, and oxidant control system. All chemicals would be fed based on make-up flow and trimmed based on a specific ion control program. On-line analyzers would analyze continuously for all critical parameters, not for convenient but possibly misleading proxies, and control results would be entered onto a web based data base in real time, so that operators and management would be able to insure convenient and continuous long term real time, stable and reliable operation that is continuously within optimum control limits to achieve efficient operation with minimal heat transfer losses, minimum maintenance expense, and maximum reliability.

Such a system would be close to ideal from a chemical treatment point of view, possibly not requiring any corrosion inhibitor, instead receiving an appropriate oxidant for microbial control, along with a reversion resistant scale control agent(s), possibly some surfactant to aid in microbial control, some antifoam to minimize windage, and if necessary, some organic copper corrosion inhibitor to control background corrosion of copper bearing alloys, if present.

While such a system would be very easy to treat from a chemical point of view, and it would require very little operator attention, it would bear very little resemblance to the real world, as we find it today.

In today's economic and competitive environment, the players within our industry (designers, manufacturers, component suppliers, regulators, and bean counters) have been very busy creating the perfect storm! We are now living in an environment where we have optimized heat transfer surface efficiency, minimized footprint, minimized drift, optimized fill efficiency, and reduced operating budgets to the point where the unsuspecting owner/operator may find himself operating a system designed with no room for error, with a maintenance and operating budget that is inadequate to insure long term reliable operation. At the same time we are pushing plants harder and longer, and running for extended time periods with process leaks, and without adequate time to schedule routine maintenance and system turn-around inspections.

FACTORS AFFECTING SYSTEM PERFORMANCE:

Against this background, our question, "what is the best treatment?" takes on special meaning, as we may well be facing the more appropriate question of "under what circumstances can my system be successfully treated?", or what must I do to be able to treat the system successfully over the long haul?" Let's start by asking ourselves "what information do I need in order to determine if the system can be successfully treated?" In order to make this process relatively easy, let's look at the system, component by component, to see what information is available, and what more we need to know. Let's conduct a thorough system survey. Unless the process heat transfer equipment has been properly designed, we have very little chance of successfully treating the system over the long haul. For this reason, let's start our survey with the process heat transfer equipment.

PROCESS HEAT TRANSFER EQUIPMENT:

The inventory of process heat transfer equipment is very broad indeed. Depending on the industry in question, the heat transfer equipment can vary greatly with respect to the type of and variability in installed equipment, specific design considerations, complexity, metallurgy, water flow rates, turbulence, and linear flow velocity, heat flux, exit water temperature, equipment skin temperature on the heat transfer surface, etc. We have to ask ourselves what industry (HVAC, power production, petro- chemical, refining, oil production, food processing, iron and steel production, etc.) we are dealing with.

Within each industry we need to find out which processes are involved? For example, within the iron and steel industry, are we talking about blast furnace cooling, continuous caster cooling, scarfing, quenching, surface condenser cooling, etc? To further define what specific conditions we might expect, we need to further define each unit process, for example within the blast furnace area, are we talking about tuyere cooling, furnace door cooling, etc? Each different type of specialty cooling device or sub-process will have inherent design, metallurgy, flow, and temperature considerations that must be well known and well understood by the person who is selecting the cooling water treatment program. Tuyere cooling refers to the water cooling of hollow copper distribution tubes supplied at regular intervals within the blast furnace for the purpose of distributing the "blast" within the furnace.

The refining and petrochemical industries frequently employ "shell side" heat exchangers, with the cooling water flowing through the exchanger shell, and the process fluid flowing through the tubes. Unless these exchangers are very well designed, with proper baffling and fluid flows and process temperatures carefully controlled to achieve the conditions for which the exchanger was designed, low velocity regions on the shell side can result in severe scaling and/or corrosion. It is also quite common for changes in operating conditions, such as process side flow changes to achieve changing or up-dated process temperature requirements dictated by process economics, to result in insufficient or in excessive flows on the process side, which can result again in problems on the cooling water side. Other industries employ specialized heat exchanger designs, such as vertical heat exchangers, which can result in solids accumulation due to the orientation and operating conditions of the exchanger. Each industry presents unique applications that must be fully understood to avoid common pitfalls.

All of this information bears directly on which specific problems, with what specific severity, must be solved. Some aspect of the chemical selection, dosage determination, and control determination process may well need to be "tweaked" in order to achieve good over-all results. In addition, all of this information will guide us in the selection of monitoring processes, locations, and frequency, and in the design of the data management system.

Exchanger Design:

Are the exchangers designed so that the water and process side heat transfer surfaces are easily inspected? Can the process and water side of the exchangers be easily cleaned and inspected after cleaning to verify results? Are exchanger process and water side flow rates sufficient to provide for turbulent flow and sufficient linear velocity at all points along the heat transfer surface to minimize fouling and deposition due to settling of particulate solids and deposition of scale (5 ft/sec, with 3 ft/ sec as a minimum possible flow rate in the case of water side)? Have provisions been made for reverse flow flushing or air/inert gas bumping? Is cooling water mass flow rate sufficient to provide enough flow to insure turbulent flow conditions at the exchange surface and to carry away enough heat to limit exchanger exit skin temperature to a level that can be treated successfully for scale and corrosion control given the discharge limits in play? Is this true for all of the various parallel and series installed equipment?

Metallurgy:

What specific alloys are contacted by cooling water and/or process side products? What alloys are galvanically coupled? Are the metals and alloys present properly selected for both the cooling water and the process side environments? If dissimilar metals have been used, are they properly electrically insulated, or close enough on the electromotive series that significant galvanic attack will not occur? Has any high voltage equipment been improperly grounded on this equipment? Does any of the equipment that is being cooled operate with high voltage equipment, requiring special attention to water chemistry, or special attention to conductance of cooling water piping materials and cooling conduit hose lengths in order to prevent stray current grounding through the cooling water column and conduits?

Heat Transfer Surface Skin Temperatures:

Most detrimental reactions (corrosion, scaling, fouling, microbial growth) are exacerbated due to increasing temperature. As cooling water side skin temperatures rise, the driving force behind most of these reactions increases, requiring progressively better chemical treatment and control. In general the rate of many of these reactions will double for every twenty degrees C that the temperature increases. As skin temperatures start to exceed 120 degrees F, many inhibitors begin to show marked reductions in efficiency. Above 140 degrees F, even the best corrosion inhibitors become highly strained, and dramatic failures may result. Are all exchangers equipped with a means of measuring inlet and outlet fluid flows and temperatures? If critical exchangers are present, are provisions made to measure cooling water maximum skin temperature? On the other hand, are flows so high that failures from erosion and/or vibration induced cracking must be anticipated?

Cooling Water/Process Fluid Flow Considerations:

The system should have originally been designed with particular cooling water, process flow, and air flow conditions provided. These flows should be periodically checked to insure that none of these flows have changed due to factors such as abraded or corroded pump impellers, blocked or partially blocked valves and piping, construction that blocks air flow to and from the cooling tower, the addition to the system of new or re-designed heat transfer devices, or intentional bypassing of either cooling water or process fluid around an exchange(s). On many process cooling systems, recirculating water pumps have been so closely sized that even the installation of a corrosion coupon bypass on the return water to the tower or condenser can result in too little cooling water flow, and can result in improper water distribution through the cooling unit. Don't forget to look for improperly wired recirculating pumps. Some pumps will run in reverse if improperly wired, and this will cause large flow disruptions.

COOLING TOWER DESIGN:

There are many aspects of cooling tower design that can affect the ability of the tower to reject the necessary system heat load. Many other aspects affect the degree of maintenance required, as well as the frequency of maintenance. In order for the system to function effectively, the recirculating cooling water and the inlet cold air supply must achieve intimate contact in order to effect maximum evaporation.

This is normally achieved by providing for an excess of air flow by means of either density difference (hyperbolic towers), or by means of installed fans to either blow air through the tower (forced draft), or suck air through the tower (induced draft). Hot return cooling water is then sprayed over the tower fill, or cascaded over the fill, counter current to the cold air supply. In order to achieve maximum cooling efficiency, both the air flow and the water flow should be relatively uniform across the tower. This is accomplished by means of the water distribution system, and by the spacing achieved across the fill to allow uniform air flow. In general, the less efficient this process is, the more cross sectional area is required in order to accomplish the same cooling load. Towers accomplish this task by providing for water distribution by means of distribution basins on the top deck of the tower. These basins are designed to provide sufficient depth in the distribution basin to provide sufficient head to efficiently operate the distribution nozzles installed in the bottom of the distribution basins. Alternatively many towers depend on a header and lateral system with spray nozzles installed above the fill. In a specialized design, a heat exchanger is installed in the tower itself, where the fill would go in a conventional tower, and the tube bundle replaces the fill, with the tubes acting like splash bars in a conventional fill arrangement. This modification is called an evaporative condenser or closed circuit cooler.

Fill:

In recent years, the splash bar type fill has in many cases been replaced with "film pack" fill, which consists of sheets of corrugated rigid plastic that are layered upon one another. The geometry of the extruded plastic sheets affects both air and water flow, and exposes maximum water surface area to the air flow. While this type of fill can be very efficient, there are many fine passages involved in the design, and if too little water flow is provided in one or more areas of the fill, evaporation results in over-concentration of the cooling water, causing solubility products to become exceeded, and scaling and fouling to result. This can result in deposition on and plugging of the fill. This process of fouling and eventual "blinding" over the fill open space is called "bridging".

Once the surface of the fill is roughened by scale formation and/or microbial accumulation, then the degraded fill surface texture becomes a site for rapid accumulation of suspended solids, as well as more scale formation. The resultant mass of accumulation can not only block airflow from portions of the fill, but it can also result in complete collapse of the fill, due to the weight of the accumulated solids. While film pack fill is relatively inexpensive and very efficient, it is easily fouled, and once fouled, very difficult to clean. For this reason, the presence of such fill places special limitations on the water treatment program, and unless the supply water is of very high quality, and the ambient air is very clean, its presence will dictate the use of bypass filtration to remove all suspended particulate matter. It may also dictate operation of the water treatment at a lower pH than would be the case with splash bar type fill.

Each installation should be evaluated first for the presence of suspended solids in the air supply (dirt, dust, sand, plant fibers) as well as in the water supply (mud, silt, and other particulate materials). If these materials are present, they must either be removed by means of filters, or film pack fill might not be the best choice. In addition, if the tower will be subject to high cycle operation due to water shortage or to environmental restrictions on blow down, then film pack fill selection must again be questioned. I believe that any system equipped with film pack fill is a candidate for a good multi-media bypass filter. Sizing, materials selection, and operation of bypass filters is a topic best left for another time, but in general, I recommend a bypass filter capable of handling a minimum of 2%to 5% of the recirculating water. If film pack fill is used, then special attention must also be paid to microbial control, and the fill should be inspected and cultured periodically for signs of bio-accumulation.

In areas of the country that are subject to periodic high velocity catabatic wind storms, such as the famous Santa Ana winds of Southern California, consideration should be given to sizing side stream filters to handle sufficient flow to rapidly remove sudden heavy loads of suspended matter, including course dense sand.

Tower Basin:

The design of the tower basin governs how much excess water the system is capable of holding. At times plants will select deep basin towers, primarily to allow for additional fire fighting water in an emergency. All tower basins are more or less subject to accumulating suspended solids and microbial growth. As deeper basins are selected, all else being equal, the system volume and holding time index goes up. This means that the water will be in the system longer, and it means that the chemicals chosen to treat the system must be more reversion resistant, and the film formed must be more tenacious. In other words, the chemicals have to last longer in the desired form, and be less resistant to degradation due to time, temperature, and the influence of oxidizing microbicides and process contaminants.

In my opinion, deep basin, high holding time index systems are all candidates for side stream filtration, and they should all be equipped with a reliable system for adding oxidizing microbicide into the bottom of the basin. In addition, if such a system experiences a process leak, it should be immediately repaired, or the system must be carefully inspected and treated to insure freedom from accumulation of process contaminant degradation products and microbial growth, especially in the basins. I also believe that all such systems should be equipped with a system of headers and laterals to inject water containing oxidizing, as well as non-oxidizing microbicides, and possibly surfactants, uniformly across the back of the basin, so that the chemical sweeps across the basin at the bottom on its way to the recirculating pumps. Any plant with a deep basin tower system should be subjected to periodic basin inspection and if necessary, the basin should be either cleared of suspended material mechanically during shut-down, or it should be cleaned on line using vacuum systems, possibly employed by divers equipped with SCUBA gear.

Recirculating Pumps:

And now a word about recirculating pumps! Many such pumps are subjected to incorrectly fed and diluted acid and oxidant, present at excess concentration at the pump itself. These pumps also frequently have brass or bronze impellers, and they are subject to corrosion, as well as to mechanical erosion, due to suspended solids. Such pumps should be equipped with flow measuring devices, and they should be inspected at least every turn around or earlier if flow concerns arise. Without adequate water flow, critical exchangers are frequently doomed to rapid fouling with scale, suspended solids, microbial growth, and corrosion products. Under such conditions, the corrosion inhibitor program will most likely fail as well. While our modern "green" treatment products have many good features, it is important to remember that they have some real water chemistry related limitations, and they may not be as effective, corrosion wise, as the older products that we relied on for many years.

Tower Fans:

Design of tower fans is outside the scope of this paper, but it must be remembered that the fans are the primary drivers for air flow. Anything that affects the efficiency of the fans is likely to reduce air flow. Without good air flow, the tower performance, and hence the efficiency of the entire heat rejection system, will suffer. Tower air flow measurement should be periodically checked to insure proper performance. Also consider existing or new construction in the vicinity of the tower. It is not at all uncommon for a large new structure in the vicinity of the tower to block air flow.

Air Quality:

The ambient air quality over time can have a significant impact on the entire system. Is the system subject to continuous or periodic air contamination? (Consider sand storms, catabolic winds, contamination from a neighboring stack or process air emission). I have seen Santa Ana winds in Southern CA completely load up a very large, very critical cooling tower system with dirt, dust, and with loads of sand and plant fibers. The system is located in a large coastal refinery within the confines of a large city. I have also seen a rooftop package tower that was being quickly stripped of its protective coatings due to the proximity of an exhaust stack from paint spray booths where MEK solvent was in use. In addition, I have seen pH control programs completely overwhelmed by the presence of acid gasses from a neighboring combustion exhaust stack, with pH levels dropping to close to 4.0.

Tower Support Members:

At one time, most cooling towers were constructed of heart redwood. As this high quality wood became more costly and scarce, less desirable types and grades of wood were used. Today there is a great deal of metal, plastic, and ceramic used in the construction of towers. All materials have advantages and disadvantages. Wood construction makes the tower vulnerable to microbial attack of various kinds. Metal towers are subject to corrosion. Ceramic towers tend to be quite costly, and the use of ceramic materials places design limitations on construction. If wood is used in a given tower, the inspection program must incorporate periodic inspection by a qualified person to look for the various types of deterioration that can occur, and the water treatment program must incorporate specific control for such organisms. If metal is used, the inspection program must look for corrosion, and the corrosion control portion of the water treatment program must incorporate specific treatment to protect the tower metal, as well as the exchangers and system piping.

MAKE-UP WATER QUALITY:

Now let's take a look at the impact of available make-up water on the performance of the system. The composition of the make-up and our responses to it in terms of program selection and control responses will have a great deal of influence over the success that we achieve.

Many areas of the world are cursed with rapidly varying make-up water quality. Systems receiving make-up water directly from surface streams and lakes are subject to large variations in suspended solids, as well as to variations over time in water chemistry. Systems receiving well water supply usually do not have a big suspended solids problem due to solid material entrained in the supply water, but they are frequently limited by water that is very high in hardness, sulfate, chloride, and alkalinity. In addition, well waters in many areas contain high and variable levels of silica, manganese, and iron. Well supplies are usually quite constant in composition, but many locations must pull their water from a large number of low volume wells, with each well exhibiting markedly different composition. Such is often the case in areas that are relatively geologically active, or that have been in the recent geological past, with attendant fracturing and faulting. A third rapidly growing source of make-up water is the use of reclaimed industrial process or municipal waste water. Reclaimed waste water is frequently contaminated with process and metabolic constituents. The consistency of this third source will depend on the type of process(s) that is generating the reclaimed water.

Each source of make-up should be carefully studied, paying particular attention to variability in chemical composition and contamination over time. Changes in composition and contaminants over time must be carefully addressed by the control and treatment chemistry, and may require supplemental pre-treatment of the make-up source to mitigate the variability and contamination to prevent operating problems that might arise due to these causes.

Systems that receive water that is high in suspended solids should be equipped with good side-stream filtration systems, and deep basin tower construction should be discouraged, unless the system is equipped with highly efficient filters to deal with suspended solids build-up. In addition to the accumulation of suspended solids, the user must consider the influence of suspended solids on the proliferation of micro-organisms. In addition to suspended solids, process leaks and airborne contaminants can greatly influence the rate of microbial proliferation.

Many plants employ clarification practices to clean up the water and remove the suspended material prior to use. On the other hand, some plants are specifically designed to perform with high solids surface water. They do this with well designed exchangers that incorporate good metallurgy that is relatively resistant to corrosion and erosion, high flow rates, and easily cleaned bundles, such as straight tube shell and tube designs with removable heads on both ends to facilitate mechanical and/or chemical cleaning and inspection. Some facilities that receive high solids surface water are equipped with systems such as Amertap, an on-line mechanical cleaning system incorporating recirculating sponge balls that have been surfaced with various abrasive materials, depending on the nature of the foulant.

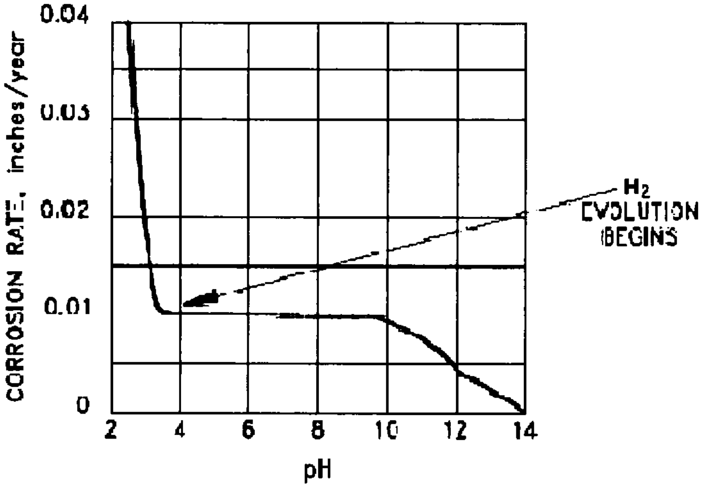
Plants that receive water with rapidly varying chemistry can sometimes benefit from make-up pretreatment, such as partial softening, partial RO treatment, supplemental mineral feed, and make-up pH control. Especially in plants with rapidly varying make-up quality, the available water should be modeled using one of the advanced solubility predictive programs, such as Water Cycle, to predict the impact of the make-up variations on the performance of the system as make-up varies. In this way a chemical treatment protocol or possibly multiple protocols can be developed to deal with the make-up variation. Very small systems will usually find that by setting the blow-down at a rate that will accommodate worst case conditions, and then designing the treatment program around this set of conditions, that good results can be obtained with minimal automatic controls, and acceptable over-all cost. If the systems are large enough for the blow-down heat, water, and chemical savings to justify the extra cost, then advanced controllers, using PLCs and appropriate control algorithms, can be programmed to automatically change control ranges and chemical feed rates as make-up water quality changes.

SYSTEM WATER CHEMISTRY CONTROL PARAMETERS:

As mentioned earlier, in order to limit the build-up of dissolved solids in the system recirculating water, a method of controlling this process must be provided. In addition to the build-up of dissolved solids, other factors, such as pH and oxidant control will probably be required.

PH Control:

The selection of pH control range is, in my opinion, possibly the most important control factor, and one of the least clearly understood and misapplied areas of cooling water chemistry today. There is a misconception that the corrosion rate of mild steel is reduced in open aerated cooling water systems by increasing the pH control range in the cooling water. While this is certainly true at pH values below 5.0, and above 9.5, the range in between is where we usually operate, and therefore where the problem lies. The idea that corrosion rate is reduced as pH is increased within this range is potentially a dangerous one, responsible directly and indirectly for many program failures. A graph of pH value versus corrosion rate for mild steel at constant temperature and constant flow rate in the presence of excess oxygen demonstrates this clearly.



EFFECT OF pH ON THE CORROSION OF IRON
EXPOSED TO AERATED WATER AT ROOM TEMPERATURE

Fig 1: Effect of pH on Iron Corrosion rate in water

Within this range the rate of corrosion of mild steel is relatively unaffected by pH. The type of corrosion that occurs instead changes in response to increasing pH, while the rate is largely unaffected. Within the range in question, reducing the pH tends to promote more even general attack, with less deposition in place of corrosion products, while raising the pH within this range promotes deposition of corrosion products in place, with attendant pitting under deposits. This tends to fix anodic areas of the metal in place, and to reduce the relative size of the anodic surface, while the corrosion potential remains unchanged. This mechanism tends to increase the pitting tendency. In addition to in-place deposition of corrosion products, higher pH values often contribute to greater potential for scale formation in the case of many sparingly soluble salts. It is this tendency that I believe is responsible for the assumption that changes in pH within this range directly reduces corrosion rates.

Three factors have combined to promote this misconception, the first being the relatively weak corrosion inhibiting properties of the modern "green" inhibitors, the second being a desire to eliminate the use of acid, especially in smaller systems, due to safety considerations and to concerns over control variability, and the third being a trend toward neutral to above neutral discharge limits with respect to pH. The implementation of higher pH limits than were used in the past has been made possible by the development of more effective deposit control programs employing the organo-phosphates, organic copper corrosion inhibitors, surfactants, and by the introduction of increasingly specialized and more effective low molecular weight dispersant polymers.

While depending on increased pH to help control corrosion may work in small, very low temperature, low heat flux systems, where cycles of concentration are not maximized, and where metallurgy is confined to more corrosion resistant alloys, it is easy to delude yourself into thinking that you have provided good corrosion and deposition control, and then find that the hotter surfaces are suffering deposition, while the cooler areas are experiencing higher corrosion rates, or more pitting than expected. Where the problem becomes severe is in larger, higher temperature, lower flow, and higher skin temperature process systems, as well as when someone decides to tighten things up and to minimize water consumption, maximize cycles of concentration, and minimize inhibitor discharge at the same time.

This becomes especially acute when combined with "enhanced" heat transfer devices that employ thinner heat transfer surfaces, especially those designed with fins and grooves, which make great places for deposition of alluvial materials, such as corrosion products, airborne suspended solids, high make-up suspended solids, precipitates of scale forming minerals in the bulk water, and suspended materials leaked from process. Microbial sessile and planktonic contributions to deposition further exacerbate the process. The thinner heat transfer surfaces often mean higher skin temperatures at the same time. We see this situation potentially developing now with the introduction of some of the "enhanced" chillers being offered in the HVAC industry.

In addition another misconception has been propagated throughout the industry. That is the idea that the older expectations for corrosion rates were too restrictive. I frequently see performance specifications that call for over-all corrosion rates of 2 mpy, or higher on mild steel. While this is fine so long as there is no pitting, such is not usually the case, especially at lower water velocities and at higher temperatures and pH values. To add insult to injury, I see many applications where these compromises are implemented in systems where high suspended solids make-up is employed, especially in the presence of exchanger designs that promote deposition, such as plate and frame exchangers or low velocity shell and tube exchangers with the open cooling water on the shell side, without adequate provisions for mechanical cleaning of the exchangers.

In addition to promoting general corrosion as opposed to pitting, the lower pH control limits will generally minimize deposition by minimizing scale formation, with calcium sulfate being a notable exception. The inclusion of zinc in the inhibitor formulation will further help to reduce overall corrosion rates and to minimize pitting. Some of the organic inhibitor ingredients actually partially sequester zinc, subsequently widening its application as an inhibitor ingredient, and stabilizing it in the presence of higher pH values, as well as process leaks that may tend to promote the deposition of zinc, such as "sour" sulfur bearing process materials. While the impact of zinc on the environment must be considered, many systems discharge their blow-down into municipal and/or industrial waste water treatment systems that are operated to dilute and/or to remove such contaminants down to a level that is safe for discharge to a receiving stream. Zinc is in fact a component of many municipal potable water corrosion control programs.

Virtually all of the phosphate and organo-phosphorous bearing inhibitors will provide lower and more *uniform corrosion at lower pH, rather than higher, within the range normally encountered in open* recirculating systems. Another benefit to pH control in the lower end of the recirculating cooling water system range is that the less expensive chlorine bearing oxidants work better, and frequently this precludes the need for the more expensive bromine, ozone, and chlorine dioxide chemistries that tend to work better than chlorine based materials at the higher end of the pH range.

Most of the "all organic" formulations actually provide relatively poor actual corrosion inhibition and protection in a classical sense at any point within the normal pH range, so many practitioners recommend elevated pH to try to overcome corrosion of mild steel by precipitating a very thin layer of calcium carbonate on the steel surfaces. While this can be made to work relatively well in high velocity, low heat flux, low temperature systems, especially in those with copper or copper alloy heat transfer surfaces, it leaves much to be desired in hotter systems, where temperature differences force un-even scale deposition, resulting in either excessive scale on the hot surfaces, or excessive corrosion on the cold end.

In my opinion, a better approach in the more severe systems is probably the use of metaphosphate at relatively high levels, with zinc if possible, combined with lower pH control ranges, sufficient organic copper inhibitor to largely overcome any tendency toward copper alloy corrosion, and the use of specific low molecular weight dispersants that work well on stabilizing calcium phosphate and any other sparingly soluble salt present in concentrations high enough to exacerbate their tendency to precipitate under the prevailing physical and chemical conditions present. Depending on the rate of reversion of the metaphosphate, some orthophosphate addition may be desirable, as well, especially in the less challenging lower heat flux segment of the process cooling water market.

If this approach is used, the operator should use oxidants on a low level continuous basis carefully to control microbial growth without degrading the inhibitor ingredients (phosphonates, organic copper inhibitors, and phosphates) due to excessive oxidant feed. If necessary, the oxidants can be supplemented with periodic slug addition of higher levels of specific non-oxidizing microbicides.

Cycles of Concentration:

The second most critical control parameter in most open cooling systems is the control of the degree of concentration of dissolved solids permitted as a consequence of system blow-down or bleed-off rate. The cooling tower cools primarily due to evaporation of a portion of the recirculating water. Because the water that is evaporated leaves the system primarily as pure water vapor and the dissolved and suspended solids that the water originally contained are left in the remaining system water, this water becomes progressively more concentrated with respect to its original dissolved and suspended constituents. If this process is left un-controlled the build-up of solids will eventually cause one or more sparingly soluble salts to exceed their individual solubility product s and to precipitate. When this occurs, these precipitated solids tend to form on either the hottest or the coldest system surfaces, depending on how temperature affects the solubility of the specific salt. While most limited solubility compounds exhibit inversely proportional solubility with respect to temperature (higher temperature decreases solubility), a few exhibit direct solubility (lower temperature decreases solubility). Some silica deposits are examples of direct solubility. These specific materials will be found typically on cooling tower fill.

For this reason, the gradual concentration of solids by evaporation is at some point limited and controlled by removing a pre-determined amount of the concentrated cooling water by blow down, and by replacing its contribution to system volume with fresh make-up water. The blow-down rate is then varied to achieve a constant level of the most critical dissolved solids as thermal load and make-up water composition vary. The rate of blow down is controlled manually, based on operator control testing, or automatically, based on control valve response to either continuous conductivity level, or to the results of automatic analysis of another appropriate system control parameter, such as iron, silica, and/or calcium of magnesium.

The degree of desired system water concentration, or "cycles of concentration" is selected by comparing the most critical parameter with respect to precipitation of its most insoluble salt. This process can be conducted empirically, based on the operator's knowledge of the most critical parameter given the make-up water chemistry and the system operating characteristics. Alternatively, if multiple control parameters are likely to limit solubility as operating conditions and water chemistry changes over time, then the availability of very easy-to-use soft ware permits the use of a computer to make this selection based on solubility predictions generated by the soft ware. Of the available alternatives, Water Cycle is the best known and the most widely used program, and the developer of this software is speaking during this same meeting that we are currently attending.

The determination of the desired "cycles" is further refined based on the cost and availability of make-up water, the treatment chemistry being employed, local regulations governing discharge, energy cost, the time-stability of make-up water chemistry, the criticality of system operating conditions, the cost of suffering poor control, the availability of advanced pretreatment equipment to provide optimum make-up water chemistry, and the amount of operator time, or the availability and sophistication of automatic control system equipment to be devoted to system chemistry monitoring and control testing.

We should remember that while it is technically possible to achieve very high cycles of concentration in many systems under very specific circumstances, there is a point of diminishing returns from the stand point of water, chemical, and energy savings, as cycles are pushed progressively higher. While these savings are a linear function of blow down volume reduction, the reduction in blow down volume itself is a logarithmic function of recirculation rate. In most systems, there is little point in driving cycles higher than about 10, as the blow down savings diminishes very rapidly beyond this point. The savings due to blow down reduction can be greatly exceeded by the costs of suffering poor control if unexpected changes in system chemistry result from changes in make-up composition, process temperatures or flow rates, pH control swings due to control system malfunction, or sudden changes in blow down rate due to cycle control deviation or failure. This is especially true in smaller systems, where control sophistication and operator attention may be minimized due to first cost or to labor cost considerations. In addition, the system holding time index increases very rapidly as cycles increase, greatly exacerbating fouling problems due to suspended solids accumulation and to degradation of treatment chemicals and subsequent deposition of the degradation products.

The purpose of this paper is not to answer all of the questions that will arise as a result of the discussion, but rather it is to provoke thought and discussion, and to help the reader to understand the complexity of the process of selecting, applying, and optimizing a control chemistry program for each cooling tower system, based on a knowledge of the factors that must be considered in order to arrive at the best answer. Unless plant personnel are well versed in this process, it is very important that they choose a water treatment professional that has this experience, and also has the time available to assist the plant in the development, proper application, and on-going control of the program.

The object of chemical treatment is:

- To minimize corrosion of common system metals.
- To reduce the tendency for scale to form.
- To control the proliferation of deleterious micro-organisms to an acceptable level.
- To minimize the accumulation of mud, silt, sludge, and soft deposits in the system.

Corrosion Control:

Corrosion control is normally accomplished by optimizing those non-chemical factors (flow, temperature, metallurgy, etc.) that influence the reaction, and by controlling the pH and dissolved solids concentration and the oxidation potential in the cooling water to the proper range, and by the addition of specific chemical corrosion inhibitors. The chemical corrosion inhibitors consist of soluble compounds that are added to minimize the corrosion reaction. They do this by acting at either the anode, the cathode, or at both the anode and cathode. Inhibitors are thus broadly classified as anodic, cathodic, or mixed anodic and cathodic inhibitors.

Anodic inhibitors function by decreasing the rate of transference of metal ions into solution. They generally tend to decrease the area of the anodic surface. While this mechanism results in a reduction of the over-all rate of reaction, any remaining attack is concentrated over the remaining anodic surface.

For this reason, the anodic inhibitors result in an increase in the intensity of attack, or the tendency to result in severe pitting, unless the over-all corrosion process is completely stifled.

Cathodic inhibitors reduce corrosion by interfering with any of the steps of the oxygen reduction reaction, which is the primary process occurring at the cathode. Cathodic inhibitors do not affect the relative size of the cathode or anode, and thus decrease both the rate and the intensity of the corrosion reaction. Because of these differences in mechanism of corrosion control anodic inhibitors are sometimes referred to as "dangerous inhibitors", while cathodic inhibitors are referred to as "safe inhibitors". In other words, an under-feed of anodic inhibitor can result in progressively more severe pitting, while an under-feed of cathodic inhibitor does not increase pitting.

In practice, both types of inhibitors are normally combined into the inhibitor program to provide corrosion control at both the anode and the cathode.

Scale Control:

Scale control resulting from the feed of scale inhibitors is accomplished by one of three primary mechanisms:

- "Solubility Product Modification", where the scale forming species is maintained in a completely soluble state as it passes through the system.
- "Threshold Stabilization", where the inhibitor restricts the physical growth in the size of the precipitate crystal at the "threshold of precipitation".
- Crystal Distortion", where the inhibitor interferes with the orderly growth of the precipitate crystal, and thereby prevents its deposition in a solid scale crystal matrix

All three processes are time dependent, and the relative success will depend on not only the concentration of each species entering into the precipitation reaction, but also on the amount of time that the reactants are subject to the conditions which force the reaction (temperature, flow rate, and concentration).

Microbial Control:

Control of the growth of undesirable micro-organisms is typically accomplished through the addition of microbicides, or chemicals that retard or prevent the growth of the organisms. These products are classified into two different groups, designated as "oxidizing microbicides" and "non-oxidizing microbicides". The oxidizing materials consist of oxidizing agents such as chlorine. These products function by "burning" the organisms, or causing the rupturing of the cell wall and lysing (the death of a cell by breaking of the cellular membrane, causing the contents to spill out) of its contents. The non-oxidizing products contain specific agents that are toxic to the organism, and which retard its growth and reproduction.

The oxidants typically work well at very low concentrations. They must be carefully controlled because they are non-selective, and they will oxidize beneficial chemicals in the system water, as well as system materials of construction. For these reasons, oxidants are typically fed to achieve and maintain a continuous low level of active ingredient sufficient to retard the organisms, but at concentrations low enough to avoid deterioration of beneficial chemicals as well as system components. Typically organisms do not develop any resistance to oxidants, so it is not necessary to alternate oxidants. Some organisms can combat the action of the oxidants by generating slime masses, or accumulations of metabolic products that provide a physical barrier to the oxidants. In order to prevent this, the oxidant can be periodically slug fed at a higher temporary use rate, or the use of the oxidant can be combined with periodic non-oxidizer slug based use, with or without bio-dispersants, to defeat these mechanisms.

Each oxidant shows relative benefits over the others, depending on the system operation and chemistry. In some cases more than one specific oxidant is fed at the same time. Many of the oxidants are available as inorganic as well as organic products. The choice of specific chemistry, as well as the physical form and concentration is made based on cost, effectiveness, method of application selected, and safety considerations. In general, the oxidants can be fed continuously or as slug or shock fed materials. The susceptibility of many of the organic inhibitor ingredients to destruction by oxidants generally limits their application to continuous addition, under carefully controlled conditions, where the level of oxidant present, as well as other chemistry parameters is carefully controlled to prevent destruction or deactivation of these key ingredients.

The non-oxidizing products are generally very specific organic toxicants that function by interfering with cell function by permeating across the cell wall and interfering with the cell's metabolic processes without oxidizing the cell directly. These compounds usually require a much higher level of active ingredient for optimum function, and they are generally less deleterious to both inhibitor components as well as system materials of construction, so they are periodically slug or shock fed on some predetermined frequency, under specific system chemistry requirements.

The treatment is typically repeated at a frequency that will prevent excessive growth of the organism between treatments. Because non-oxidizers are typically fed at levels that do not result in a complete kill of all organisms, the organisms can gradually acclimate to the presence of the toxicant, and they can develop resistance to it. For this reason, more than one oxidant is normally fed on a rotating slug basis, if only non-oxidizers are being used.

In most systems specific chemicals are fed to control the proliferation of deleterious micro-organisms, including bacterial, algae, fungi, slime forming organisms, and molds. These organisms exist as stationary as well as free floating populations. In addition to plugging and deposition in the system due to accumulation of the organisms, some species can directly exacerbate corrosion of most common metals due to secretion of acidic materials, including some sulfur bearing metabolic products. Other species can attack and metabolize components of wood used in construction of tower components. Still other organisms are capable of directly metabolizing and deactivating treatment chemical components including the phosphates, organo-phosphates, copper inhibitors, and microbicides.

In addition to direct chemical action on the system components, a host of organisms are capable of entering into the formation of deposits, which accumulate on the surface of system metals and other components, and aggravate the corrosion and deterioration mechanisms by reducing water flow, increasing temperature by retarding heat transfer, and by reducing the oxygen concentration at the metal surface, causing the formation of anodic areas with respect to the bulk of the metal surface.

Because of cost, toxicity, and system component deterioration considerations, microbicides, oxidizing, or non-oxidizing, are usually fed based on the results of specific chemical, and/or physical tests, as well as based on system volume, make-up water rate, and system holding time index.

Regardless of which materials are selected, they are generally applied based on their biological control performance. This is typically measured by collecting samples of system water, and samples of any materials accumulating on system surfaces, and by measuring the concentration of organisms present using serial dilution and specific plate count methods. In addition direct visual examination of equipment, as well as heat transfer measurements are normally used to confirm performance. The use of corrosion coupons and heat transfer test devices often provides additional data related to the performance of microbicides with respect to their impact on these aspects of the program.

Because the ingredients of these products are toxic, their use is strictly regulated by various agencies such as state and federal environmental protection agencies, various local agencies, the USDA, the FDA, and by other agencies depending on industry and location. Before permitting the presence of these materials on sites under their supervision, the operator should insure that all products brought in by the vendor, or purchased from the vendor, comply with all appropriate regulations regarding registration, labeling, storage, handling, and application. The vendor should provide appropriate handling, application, and safety training for all chemicals involved in the treatment program. In some states, personnel who actually apply the biocides must be licensed by the state, and they must receive specific application, safety, and environmental training before they are allowed to use these products. California is an example of such state regulation.

One specific organism, legionella sp., is capable of causing human respiratory disease. While it is unusual to find this organism in concentrations high enough to cause disease in most cooling tower systems, the disease can be devastating in susceptible individuals, or in individuals who do not receive proper diagnosis and treatment. For this reason it is good policy to implement a routine testing program to insure that legionella does not become a problem in your plant. The presence of this organism, in concentrations high enough to be troublesome, is generally the result of improper system water treatment combined with inadequate equipment maintenance and cleaning.

This organism is not limited to cooling towers, but can be present in all kinds of water handling systems, such as cooling ponds, evaporative condensers, decorative pools and fountains, domestic potable water systems, humidifiers, etc. Any system where the water is broken up into droplets small enough to be suspended in the ambient air and inhaled by people is a concern, and a proper program should be implemented. There are many good papers on the subject, and there are proven treatment and maintenance programs that, combined with a proper testing protocol, can protect personnel subject to exposure. This is a relatively inexpensive and straight forward control program that provides a lot of peace of mind for management, personnel, and the public.

Sludge and Silt Control:

Materials from many different sources (scrubbed from the air, present as suspended solids in the make-up, or contributed from process contamination, or as the result of the growth of micro-organisms) can accumulate in the system into masses of soft deposits. These materials tend to settle out in low velocity regions of the circulating system. Aggravated corrosion and microbial growth can occur under these deposits, and they can interfere with heat transfer. In addition proper equipment design criteria and to the use of mechanical means to minimize the accumulation of these deposits, specific deposit inhibitors can be fed. These are typically large polymeric organic molecules, or combinations of such materials, that can behave as either dispersants or as flocculants. Such properties are modified by selection of specific molecular weight materials, as well as by selection and incorporation of various functional groups. The dispersants function by causing the suspended solids to form very small particles with specific surface electrical charges that result in suspension of the particles back into the bulk water, where they can be carried out of the system. The flocculants have the opposite effect. They cause the suspended solids to accumulate into larger particles with lower over-all particle density that are more readily moved out of undesirable locations by the force of the flowing recirculating water.

In addition to the dispersants and the flocculants, surfactants are sometimes used in cooling water systems to aid in the break-up and penetration of slime masses generated by organisms, and organic deposits due to process leaks. The surfactants also function as "oil dispersants", and help remove oils from system surfaces and cause it to disperse in the cooling water until it can be removed by blow-down or by mechanical means within the system (filters, floatation units, etc.). Surfactants are typically used at very low treatment levels, and they are typically slug fed as needed. In some cases they are fed continuously along with the other inhibitor ingredients.

Foam Control:

Cooling water systems frequently are prone to the generation of unacceptable foaming, caused by process contamination, contamination from the ambient air, and foam due to the oxidation of organics by oxidizing microbicides, or foam generated due to over-feed of surfactants and some microbicides. Excessive foam blanketing can interfere with heat transfer, and foam discharged from the system by the tower fans can cause contamination of items within the drift range of the tower. Such airborne foam can result in problems such as paint spotting, etc. Classes of chemicals known as antifoams are sometimes used to control foaming tendency. These chemicals are typically chosen from certain oils, and water soluble organic silicone compounds. Antifoams are typically slug fed at very low doses as needed to control foaming.

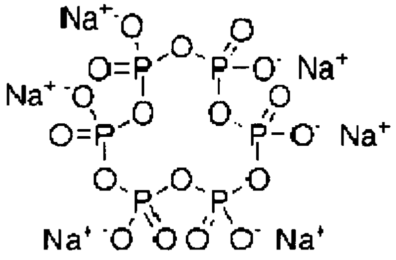
TREATMENT CHEMISTRY SELECTION:

There are many alternative treatment chemistries available. The choice of which program to use, and how best to apply it, is based on many factors. A brief discussion of the most commonly employed inhibitor ingredients is now in order. Again, my purpose is not to provide exhaustive details in this paper, but to help guide interested individuals in determining what questions to ask to begin the process of selecting the best program for their individual circumstances.

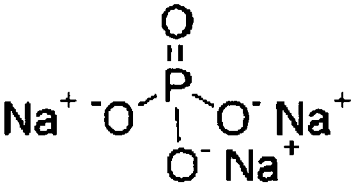
Phosphates:

Specific inorganic phosphorous compounds exhibit desirable scale inhibition, as well as corrosion inhibition properties. They provide corrosion inhibition on a variety of metals, including mild steel. Of these inorganic phosphorus bearing compounds, orthophosphate and meta-phosphate enjoy the widest applicability.

These two compounds are polymeric oxides of phosphate with different oxidation states, different molecular weights, and differing oxygen to phosphorous ratios. Ortho phosphate functions as a corrosion inhibitor primarily by functioning at the anode. Metaphosphate, or polyphosphate, works at the cathode.



SODIUM HEXAMETAPHOSPHATE



TRISODIUM PHOSPHATE

For this reason, orthophosphate is classified as an anodic inhibitor, while metaphosphate is classified as a cathodic inhibitor. Metaphosphate functions as both a corrosion and as a "threshold stabilization" type scale inhibitor, while orthophosphate does not inhibit scale formation. Orthophosphate, in fact, can combine with calcium, iron, and certain other cations to form scales which exacerbate the problem. This tendency, combined with the pronounced tendency of metaphosphate to revert to orthophosphate, proved to be the primary limitation on the usefulness of the phosphates in large, high volume, low flow, high temperature, industrial cooling systems prior to the development of the organo-phosphates and the modern dispersants.

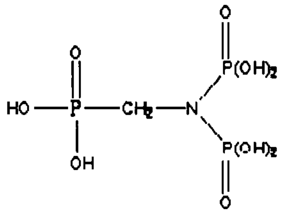
The performance of phosphate based inhibitors can be enhanced by the addition of other ingredients, such as chromate, zinc, silicate, molybdate, and one or more of the organo-phosphates. When copper alloys are present, the usefulness of the phosphates can be extended, and the useful pH range broadened, by the addition of one of the available organic copper inhibitors.

Modern polyphosphate based programs, supplemented with organo-phosphates, specific dispersant polymers, and organic copper corrosion inhibitors, enjoy wide acceptance and perform very well in refinery open recirculating cooling water systems, as well as in other very critical high temperature, low flow, high holding time index systems in other industries.

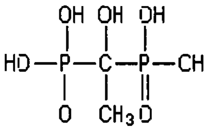
Organo-phosphates:

Many different organic molecules containing phosphorous are of significant benefit as scale and corrosion inhibitors. Of these, the most widely employed in water treatment are ATMP (amino trimethylene phosphonate), HEDP (hydroxyethylene diphosphonate), and PBTC (phosphonobutane tricarboxycilic acid).

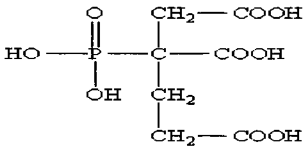
ATMP



HEDP



PBTCA



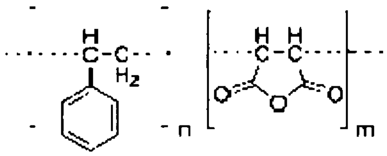
Many other organic phosphorus compounds have been used for scale and corrosion control, but the three mentioned previously enjoy the bulk of this market, and have so far proved to be the most cost effective of the many compounds available. Significant benefits of some of the organo-phosphates over the inorganic phosphates include greater resistance to reversion, and the ability to sequester, or to partially sequester certain inorganic ingredients, such as zinc. Because the organo-phosphates are generally more resistant to reversion and oxidation, they can be employed under more severe operating conditions than the inorganic phosphates, and they often exhibit greater time stability, making their use beneficial in high volume, high holding time index systems.

Dispersants:

Specific low molecular weight organic polymers can be added to water to alter the surface charges of finely divided suspended solids particles and cause them to repel each other, or to disperse themselves and to re-suspend into the system water. This approach can be used to help remove finely divided solids that have settled out of suspension and contributed to the formation of soft sludge in the system. It can also be used to disperse particles as they precipitate out of solution, and to keep them suspended until they are removed from the system by blow-down. This class of compounds also has the ability to interfere with orderly crystal growth, and to minimize deposit formation by a process known as "crystal modification". Some of these polymers can limit crystal growth to a size where inter-particle charge density and repulsive forces prevent precipitation, a process known as "threshold stabilization".

The development of very specific dispersant products, capable of selectively dispersing specific precipitants, has greatly expanded the role of cooling water treatment in recent years, and allows us to safely exceed solubility products that were inviolate just a few years ago. This is the technology that I mentioned earlier that allows the use of higher pH limits in open cooling water systems than were previously employed.

The end results of this technology can be dramatic and quite beneficial, but its use must be carefully controlled using proper chemistry selection, close observation, and proper control limits. Improperly selected and applied dispersants can result in dramatic scale formation very quickly.



STYRENE MALEIC ANHYDRIDE COPOLYMERS

The sulfonated styrene maleic anhydride polymers are very good general dispersants, and they are especially effective for dispersing iron precipitants and corrosion products. They are in wide use in both boiler and cooling water formulations.

Flocculants:

Specific high molecular weight organic polymers, such as the polyacrylamides, cause suspended solids, oils, and grease present in a given water to "flocculate", or to agglomerate into larger particles of lower density and altered surface charge than the original suspended material. These larger particles, having a much greater individual particle surface area combined with a lower particle density, can frequently be subsequently removed from the system after such treatment, by the force of any water flow present. This technology has been used for many years to successfully remove mud and silt from tankage, from the bilges of vessels, and from system piping and heat transfer equipment, and it can be considered anywhere that there is enough water flow to suspend the particles so formed and sweep them from the system. This same sort of agglomeration is also used in waste water treatment to remove suspended solids, oil, and grease, using clarifiers and or floatation units.

Molybdenum:

Molybdenum is often used supplementally as an additional ingredient in corrosion inhibitor formulations. I have worked with a wide range of open and closed cooling water systems using molybdenum, and I am sorry to report that I have not seen some of the very good results reported by others. When you consider that molybdenum is a strongly anodic inhibitor, similar in function, but less effective and more expensive than chromium, it is not too hard to see why molybdenum has not lived up to the early promises reported in the literature. In order for molybdenum to function effectively it must be used at high concentrations. Because of its expense, precluding its use at high levels, it is rapidly being relegated to the role of an analytical tracer. Despite these comments, molybdate is currently being widely used, especially in the HVAC industry, where it can be effective in combination with zinc, phosphates, and other ingredients in these smaller systems with relatively mild operating conditions, relatively high water velocity and more corrosion resistant alloys, minimal water volume and holding times, and no process contamination. Molybdenum may also have some benefit in the control of pitting, but this is questionable in light of relatively poor performance in a growing number of systems.

I much prefer to see the active ingredients of the inhibitor being used for control testing, rather than a tracer with no other function, as I have seen many programs fail because the tracer, for one reason or another, did not accurately measure the level of the actual ingredients doing the work.

Zinc:

Zinc is a very beneficial cathodic corrosion inhibitor. It can be incorporated into a finished product with a variety of inorganic and organic compounds to form very effective mixed cathodic/anodic corrosion inhibitors.

Specific Organic Copper Corrosion Inhibitors:

Another area of cooling water chemistry that is frequently misapplied is the use of specific organic copper corrosion inhibitors. These organic inhibitors (benzotriazole, mercaptobenzothiazole, and tolyltriazole, or their close cousins) are required any time that the organo-phosphorous or phosphorous based inhibitors are being applied, especially without zinc, to mild steel systems containing copper alloy components in the cooling water loop. The organo-phosphorous compounds are not copper or copper alloy corrosion inhibitors. In fact, they can be corrosion accelerators of these metals, and can result in high steel corrosion rates by increasing the background levels of soluble copper with resultant plating of copper onto steel surfaces, with attendant pitting of the steel. Several of these compounds are employed in bottle washing and other chemical cleaning applications as copper sequesterants. These materials should be continuously fed to achieve control ranges of 2 to 8 ppm of the active organic inhibitor salt in open recirculating systems in order to minimize copper alloy corrosion, and the attendant plating of copper on mild steel surfaces, which will aggravate pitting of the steel.

These products are typically under-fed due to cost and solubility issues. The amount of copper inhibitor used should be verified with frequent analysis of available inhibitor and feed rate correlation, and the results should be confirmed with both copper, copper alloy, and mild steel corrosion coupons to verify performance and to adjust inhibitor feed and control. The feed of organic copper inhibitors should be carefully controlled and the results should be verified with coupon and analytical testing, especially where oxidizing biocides, such as chlorine or bromine are being fed. These oxidants, if not carefully fed and controlled, will oxidize and destroy the copper inhibitors, and they can promote chlorine addition to some of the organic molecules, which can result in reduced corrosion inhibition efficacy and in odor complaints because of the odor associated with the chlorinated molecule.

Microbicides:

As discussed earlier, a variety of different oxidants are used in cooling water systems to control objectionable organisms. Typically used materials include chlorine, bromine, hydrogen peroxide, peracetic acid, persulfates, perborates, ozone, and chlorine dioxide. Non-oxidizing products include materials such as the quaternary amines, glutaraldehyde, dibromonitrilopropionamide, isothiazolin, methylene bisthiocyanate, 2 hydroxypropyl methanethiolsulfonate, dimethyldithio carbamate, oxydiethylene (alkyl dimethyl ammonium chloride), Surfactants:

A variety of specific organic surface active molecules are frequently applied to cooling tower systems to disperse oils and biological slime masses, and to enhance the penetration of microbicides and inhibitors into deposit accumulations, allowing the needed ingredients of the treatment chemicals to reach all areas of accumulated deposits , as well as the surfaces of system components. These materials differ with respect to charge, and foaming tendency, as well as in their relative penetrating power. Selection of the proper surfactant and optimization of its feed can reduce over-all treatment costs, and improve performance of both microbicides and inhibitors. Surfactants such as the non-ionic octylphenol ethoxylates should be strongly considered any time the presence of oils in the cooling water, due to either process leaks or transference from ambient air is complicating program performance. Biodispersants such as the anionic lignosulfonates and the newer, more effective ethylene oxide/propylene oxide copolymers can very effectively be used to disperse slime masses, allowing the microbicides to achieve more effective and less costly kills.

Antifoams:

These organic materials are frequently applied to reduce foaming tendency in cooling systems. Foaming can be exacerbated due to process leaks, airborne contaminants, and due to the over-feed of surfactants as part of the treatment program. Several different types of materials, including some oils, can function as antifoams. Of these, the organic silicones are among the most effective, frequently providing good foam control at doses as low as 1 ppm based on system volume.

General comments about system chemistry components:

Many of the treatment chemicals available contain ingredients that carry electrically charged molecules. These ingredients may exhibit strongly anionic or cationic charge. Depending on the nature of such charges, and on the reaction with other soluble and insoluble materials present in the system water, a pronounced tendency to promote precipitation and deposit formation may exist. For this reason, these materials should be selected and their dosage proposed by individuals knowledgeable in the formulation and application of the products in order to minimize the tendency for deposit accumulation.

Conclusion:

This purpose of this paper is to help interested parties fully appreciate the complexity of the technology behind the implementation and maintenance of an operation, treatment, testing, monitoring, and data management program that will result in long term, trouble free, economical operation of their cooling systems, without suffering damage due to the common problems encountered due to water treatment and control problems. I hope that it will serve as the basis of further discussion and investigation, and that it will convince all interested parties that there is no one best treatment program for all cooling tower systems.

PAPER NO: TP12-23
CATEGORY: FILL

COOLING TECHNOLOGY INSTITUTE

FILM FILL FOULING: UPDATED METHODS, RESULTS AND PREDICTIONS

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Contents

I. History

Problem Description – Film filled counterflow cooling towers, whether natural or mechanical draft, are the product of choice in power and industrial markets today. In a number of cases, older crossflow splash tower installations have been converted to counterflow film. Fill fouling, discussed in this paper, is the single largest cause of PVC film fill failure in cooling applications. It is important for cooling tower owner, operators, manufacturers, and water treaters to understand the impact of film fill selection, maintenance, and fouling's progression on tower longevity.

Counterflow Film Fill Fouling - Fouling is the process of deposition of foreign matter, including bio-growth, on the evaporative heat exchange surface—in this case the plastic film water flow area. In many circulating waters at operating chemistries and with treatment systems in place, this process is controlled so that it does not measurably inhibit the cooling process or allow excessive weight to build up in the cooling tower fill or on structure. In some circumstances, however, fouling is not well controlled and can result in a reduction in the overall cooling efficiency - a manifestation of foulant interfering with air and/or water flow through the film media.

In TP94-05, "Film Fill Fouling in Counterflow Cooling Towers: Mechanism and Design"[1], Mortensen and Conley presented strong evidence that the primary cause of film fill fouling was biological growth, with weight gain being accelerated by the capture of suspended solids in the circulating water. Laboratory fouling testing, along with water and deposit analysis supported this conclusion. TP94-05 Figure 4 is given below.

Analysis at that time, identified water borne bacteria producing sticky binder in the biofilm, as Extra Cellular Polysaccharide Producers (ECPS), with "the microbial mass cementing or sticking together general debris."[2] These organisms are foulants in a number of industrial processes and tend to thrive in the aerobic (O2 saturated), temperate (80- 120degF), and nutrient rich environment such as the one provided in film fill. Figure 1: TP94-05 Fig. 4 [1], documents the laboratory weight gain of High Efficiency Fill [HE], defined as cross-corrugated 30 degree angle ¾" spaced film fill, in Silt-Only [Silt, S], High Bio-growth[Silt + Biological, SB], and Moderate Bio-Growth [Limited Carbon, LC] exposure. Weight gain without biological growth is minimal and not catastrophic to the HE film fill pack.

[1] Mortensen,K.P., and Conley S.N., Marley Cooling Tower Company, "Film Fill Fouling in Counterflow Cooling Towers: Mechanism and Design", presented at the 1994 Cooling Tower Institute Annual Meeting, Houston, Texas, February 13-16, 1994.

[2]McCarthy, R.E., and Ritter, J.G., Nalco Chemical Company, Case Histories of Cooling Tower Fill Fouling in the Electric Utility Industry. Presented at the 55th Annual American Power Conference, Chicago, Illinois, April13-15,1993.

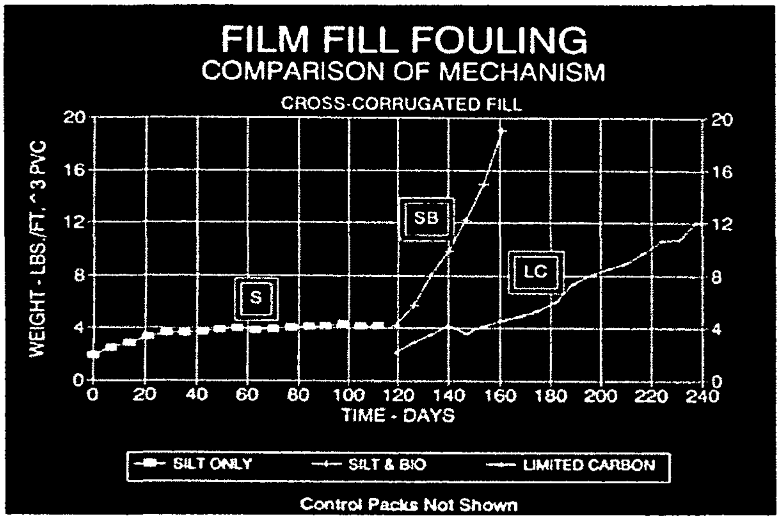


Figure 1: TP94-05 Figure 4 [1]

Solids analysis from these recent inspections supports this same conclusion, characterizing foulant solids as organic binder with 90% inorganic material including aluminum, calcium, iron, and silica. The aluminum, iron, and silica materials indicate soils.

The predominant cause of film fill fouling is biological growth creating substantial detrimental blockage. Silt exposure alone is not the cause. The combination of silt and biological growth can create rapid and catastrophic fouling.

Today much more research and experience can be used to guide cooling tower owners, operators, manufacturers, and water treaters in the proper application of film fill. That experience in applying low-clog fills for many years, under varying water conditions is the subject of this paper.

For purposes of this paper, the following definitions will be used:

High Efficiency Film Fill [HE], is cross-corrugated, 30 degree angle, opposite hand, ¾" spaced film fill and is the control for comparing other fill geometries fouling characteristics.

"Low-Clog" (LC) film fill is packing adding 2X + operating life to that of estimated HE Control film fill.

"Ultra-Low-Clog" (ULC) film fill is packing adding 4X+ life to that of estimated HE Control film fill.

II. Evaluation Techniques

A. Laboratory Methods

Past - Laboratory studies of the fouling mechanism, and cooling tower film fill characteristics were first undertaken in the 1990's to evaluate and optimize cooling tower response to this serious problem. Several fouling mechanisms were considered for investigation—the base condition chosen was a 100% bio-growth sequence, with comparisons in 100% silt, and a very severe combined silt and bio mechanism.

Dedicated test cells were built to accommodate a test fill cube, see Figure 2. These test units featured a miniature counterflow spray system but did not include fan or eliminators. Oxygen saturation of the water stream was accomplished here by using a venturi to entrain air via vacuum. Temperature, nutrient and suspended solids levels were controlled.

Analysis of a plug sample from a lab unit revealed that bacteria potentials are very high at 1.15 x 10^9 organisms/ml in the solid Further analysis identified water borne organisms which produce sticky biofilm material as Extra Cellular Polysaccharide Producers (ECPS) with "the microbial mass cementing or sticking together general debris."[2]

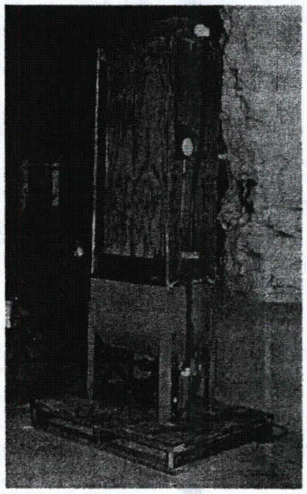


Figure 2: Original Fouling Cell, source ANDTP94-05 [1]

Current - In recent years, a multi-bay fouling test chamber was designed and built, see figure 3 and 4. It features the ability to expose larger packs of multiple fills to fouling with a single control pack. This chamber provides electronic data-logging of both "operating" and "drip dry" weights. This chamber provides increased testing capability, while retaining proper cooling tower exposure: temperature, oxygenation, water loading, and allows methodical nutrient additions for growth promotion. Testing in this newly designed fouling chamber is detailed in the "Results Section" of this paper.

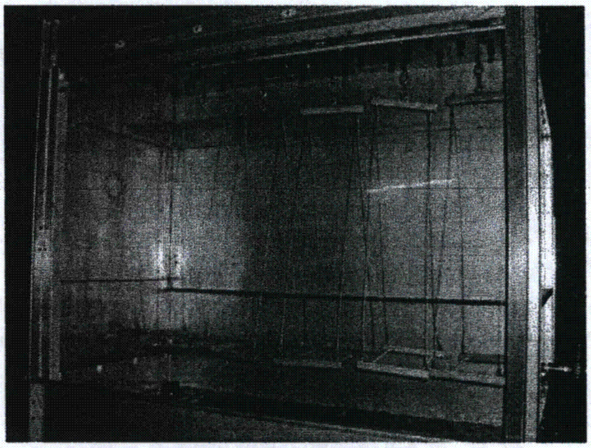


Figure 3: New Fouling Test Cell

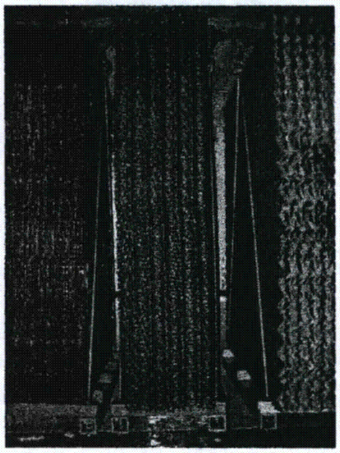


Figure 4: Packs in Fouling Test

Current Results - The new test unit produces simultaneous results for all test packs and the control as weight-gain versus time. As with previous laboratory fouling testing, the fouling process in an individual pack is greatly accelerated. This testing presents a severe screen for any fouling reduction design. This unit allows rapid evaluations of many possible designs with the comparison being under identical conditions. An example of the output curve is presented in

Figure 5. The unit produces continuous operating- weight versus time curve and "drip-dry" points are gathered on a timed basis. These "drip dry" points correlate with all the previously generated single unit tests, while the operating weight points can be correlated with field weigh rack data.

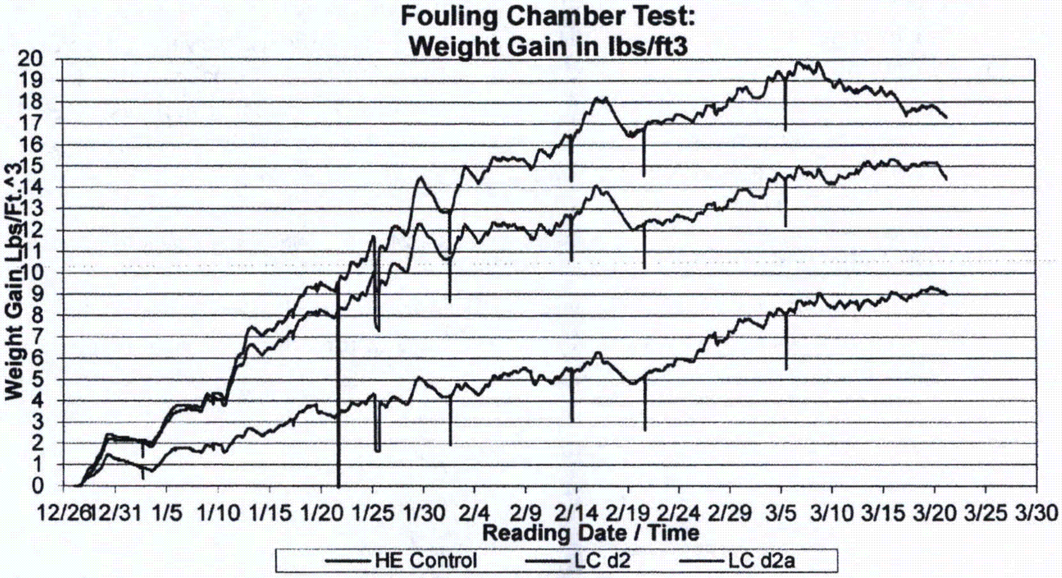


Figure 5

Current laboratory methods are more consistent and accurate than at any time in the past. Current laboratory data is reliable as one piece in film fill evaluation for suitability of application. In the "Conclusions" section of this paper, Fouling Performance Modeling [FPM] using available data and site information is discussed as a technique for making fill recommendations.

B. Field Methods – Removal Weighing

Past - In the late 1980's and early 1990's, cooling tower customers and manufacturers began recognizing problems with the application of HE film fills under some water conditions. New fill geometries were being identified and evaluated.

Monitoring these new fill shapes has been an important activity in the evaporative cooling industry since that time. Film fill shapes applied in the field in varying and severe water conditions have been monitored primarily by weighing and visual examinations. Tests were done as direct weight gain comparisons of a "low-clog" film fill vs. "HE" Control pack at the same site. These tests supported the broad conclusions that larger openings, lower angles, fewer layers and reduced texture seem "to be essential to achieve antifouling characteristics"[3].

---

[3] Mirsky, G.R., Monjoie, M., and Noble, R. Research of Fouling Film Fill. Paper presented at the Cooling Tower Institute Annual Meeting, New Orleans, Louisiana, February 17-19, 1993.

The weight gain improvements however resulted in some reduction in thermal performance of the evaporative cooling tower installations. Below are pictures from field examinations, Figure 6, 7, and 8:

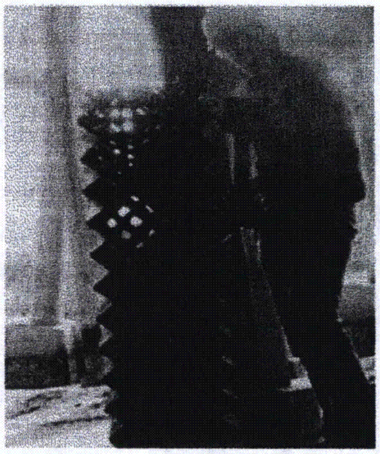


Figure 6

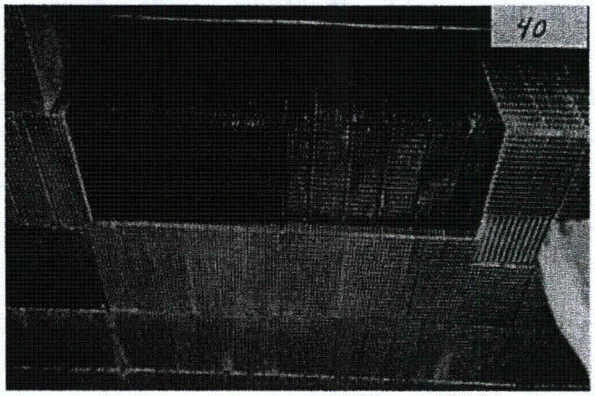


Figure 7

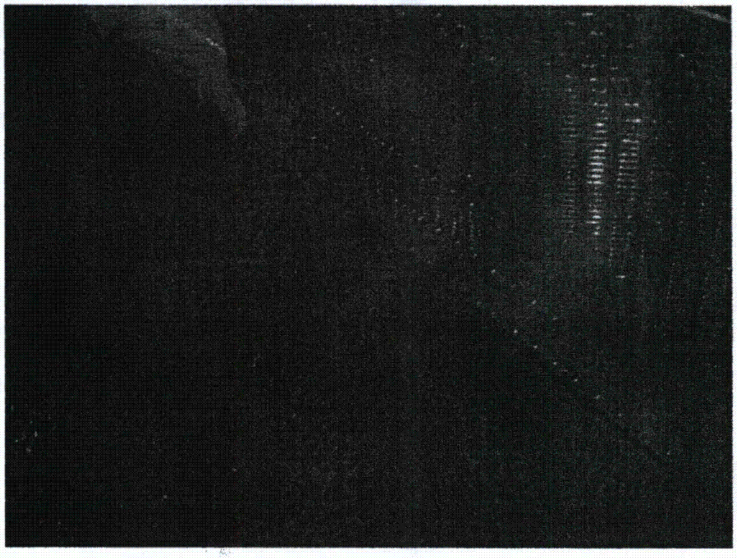


Figure 8: Field Fill Examinations and Weighings

Weighing results of these early samplings resulted in widely spaced data points or single data points at an outage examination opportunity. Figure 9 is an example of early control versus low-clog design results are given below.

Fill	Site, 5 Year Data, lb/ft3	20 Year Projection	Lab %, (calc)
HEControl	8.12	24.36	100
LC A	3.17	9.51	20, (1.64)
ULC 1	1.08	3.24	28, (2.27)
ULC 2	0.19	0.57	25, (2.03)

Figure 9

Field testing was intended to "close the loop" on laboratory predicted film fill fouling performance. It has some inherent problems, including season-to-season, site-to-site, water chemistry, water treatment variations, long timeframe, and customer tower risk tolerance. Other logistical problems include: time/cost/travel and lack of the necessary control to verify data. It is not a complete design tool. Field testing should be used to confirm, but not to design a product.

C. Field Methods: In-Situ Weighing

Past – Operating field towers have been fitted at an outage with a load cell on support hangers that supports a section of fill. This load cell records fill weight. The fill media is then weighed prior to start up and the dry load recorded. The fill media is again weighed at 1) "start-up" with water load and 2) at the six to eight week "seasoned" condition to establish the base line weights for comparison. The fill media is periodically weighed with water load to record any increase in weight that will indicate bio growth or other fouling. These systems consist of conventionally available load gauges with recording capability and have functioned in a cooling tower environment for varying periods, generally one to three years. They have not proved to be robust and durable enough to monitor the problem for the life of the tower.

New Design with Data Logging – Improved load gauges with recording capabilities have been identified and are being used on new installations. Materials and seals are superior to previous designs. Durability of this improved equipment will be judged over the next several years.

Description of New Data Logger Output - This test produces continuous operating weight versus time curves compared to a control pack and can provide "drip-dry" points at the plant shutdowns. "Drip-dry" points correlate with previously generated test information, while operating weight points can be correlated with current lab weight data. As with previous field fouling testing, the fouling process is specific to individual location conditions. Figure 10, below, is an output curve. The test period here is 6 Months.

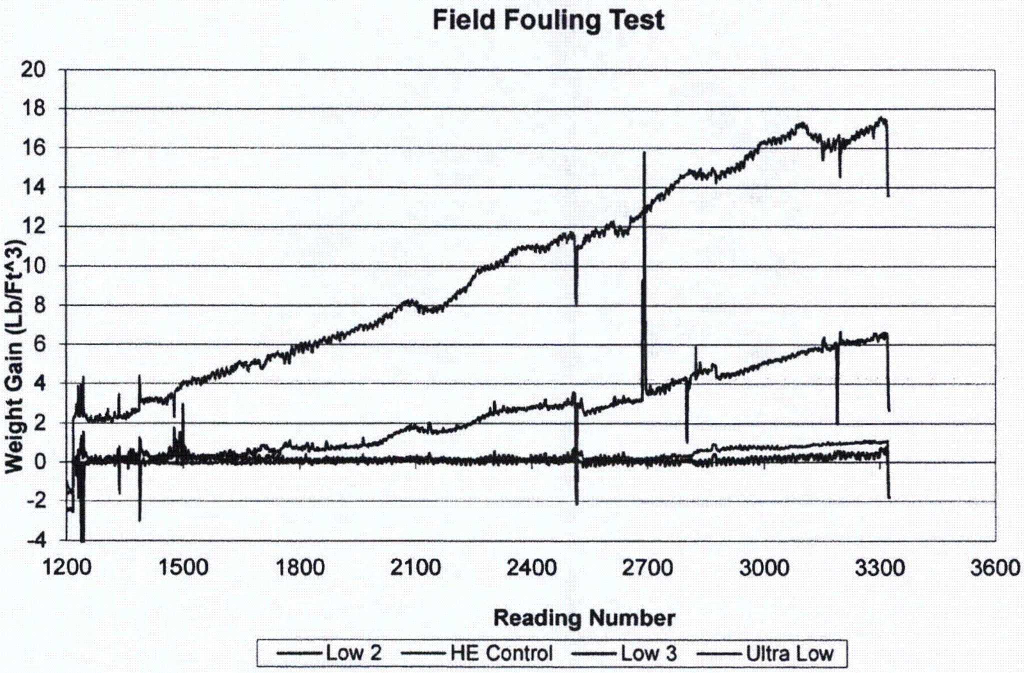


Figure 10

Combining lab and field methods then gives an indication of the fills capability generally and field examination gives specific film fill performance under a site specific set of circumstances. In the "Conclusions" section of this paper, Fouling Performance Modeling [FPM] using available data and site information is discussed as a technique for making fill recommendations.

D. Probing: Developing a New Field Method for Monitoring Film Fill

Method description – With multiple visits to tower sites, the limited ability to observe fouling from above or below film fill without dismantling whole sections of the tower becomes apparent. There is a limited ability to see into film fill, particularly with layering. Several years ago while examining fill, the author added a step to the evaluation process by inserting a probe into long narrow straight passages of that particular fill pack. In that first instance and subsequent checks, a narrow width tape measure was used as the probe, see picture below. The tape was extended up into the film fill. Assessing the difficulty of moving the tape through and examining the material output became indicators of the condition of that fill.

This technique works best on straight passages, whether angular or vertical, in deep packs, with no change of direction or interface type blockages. This method is simple, inexpensive, and immediate.

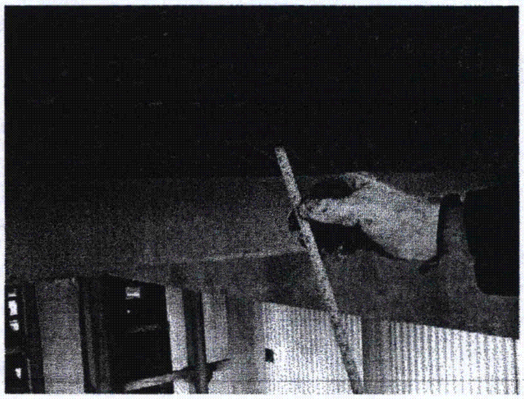


Figure 11

Inspection Results – Multiple tower examinations have been undertaken by the author in recent years. Descriptions from some of those examinations are given below:

> Eastern Power Plant A – Fill looks good in the tower interior. A very thin TSS film is on the base level packs, estimated at less than 5 mils thick. The estimated weight is less than 0.5lb/ft3.

Figure 12: Tower A in 2009

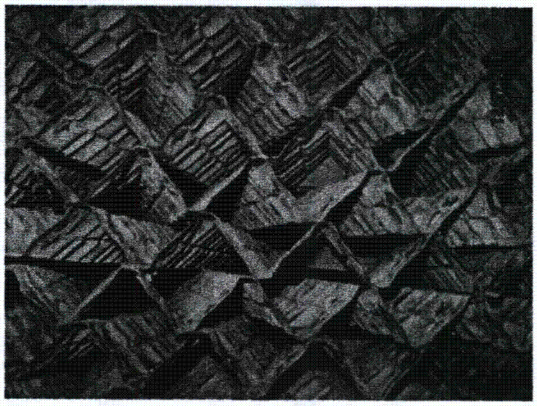


Figure 13: Tower A Fill in 2010

Eastern Power Plant B – Film fill looks acceptable in Tower. An accumulation of soils is noticeable, estimated at between 5 and 10 mils thick with an estimated weight less than 1.0 lb. /ft3. Solids analysis indicates 5 to 6 % loss on ignition and 6 to 7% organic matter, usually indicative of the biological portion of a fouling solid.

Chlorine additions are currently 2X/day. Plant reports indicate in March, 2011 the TSS #'s were very high, ranging from 370 to 912 ppm.

Customer discussion included the following observations, "There is a difference (greater amount) in deposition of silt on the fill in the Plant B Cooling Tower inspected a few weeks ago than on the Plant A Cooling Tower fill we inspected in December, 2010. Both towers have the same fouling resistant fill."

"The analysis of the Plant A Cooling Tower fill deposit indicates presence of some organic compounds which acts as a binder for clumping the silt together and adhering it to the PVC Fill sheets. The records indicate that river turbidity of the river at Site B is consistently much higher in magnitude than on the river at Site A."

"The slight build-up of silt on the Site B fill is not a serious problem but without taking some measures now to limit bio activity in the circulating water can cause significant issues down the road..."

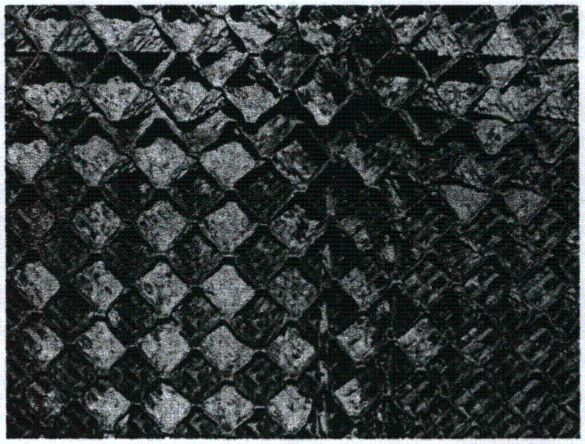


Figure 14: Tower B Fill in 2011

Eastern Plant C - Film Fill looks acceptable in Plant C. An accumulation of soils in some of the flutes was noticeable, estimated weight of 1.0 to 2.0 lb./ft3. Generally the fill was quite clean with only a thin veneer of silt. Non-oxidizing biocide additions, currently 1X/week, and hypochlorite 1X/mo. are maintaining the fill in good condition. TSS condition is modest to low at 25 ppm average, with occasional spikes to 200ppm at this site. Continuing the current biocide treatment in this moderate TSS environment is recommended to maintain the long-term condition of the film fill.

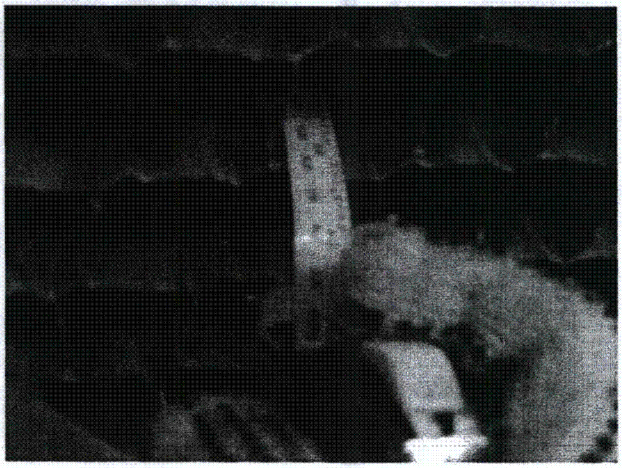


Figure 15: Tower C Fill in 2011

Plant D - Inspection of a low-clog fill with HE overlay revealed significant mud accumulation in areas by probing from underneath. From the top side of the fill was quite clean. Center estimated at drip dry weight of 5 lb./ft3, 1 bay from shell estimated drip dry weight 10-20 lb./ft., At shell estimated at drip dry weight of 5 lb./ft3.

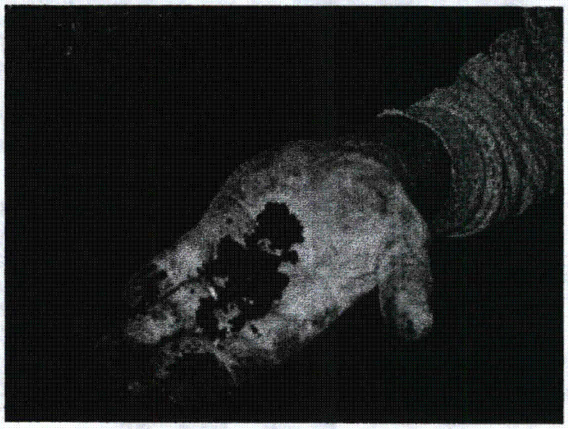
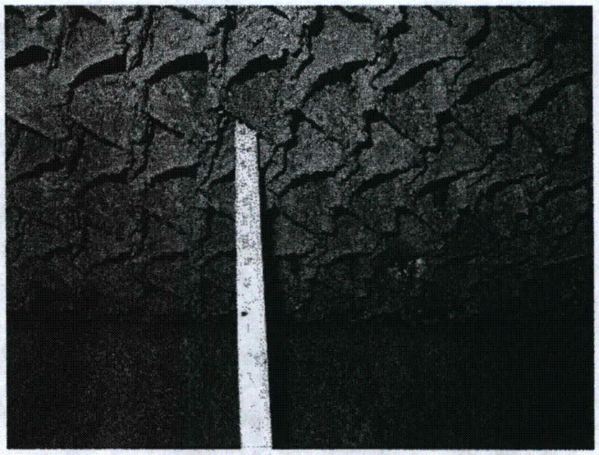
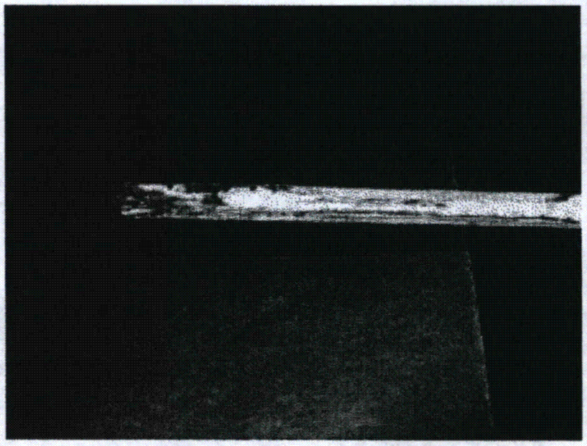
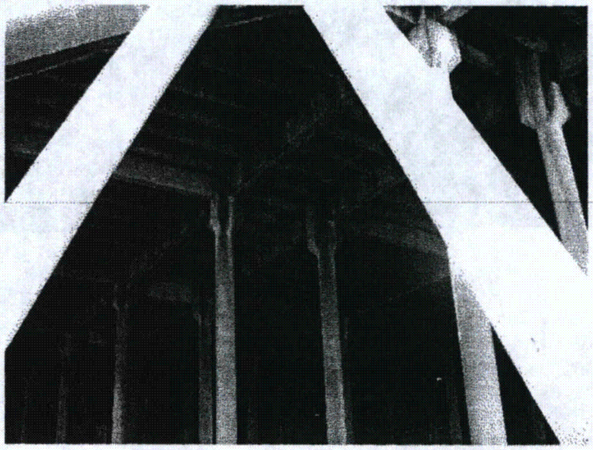


Figure 16: Plant D

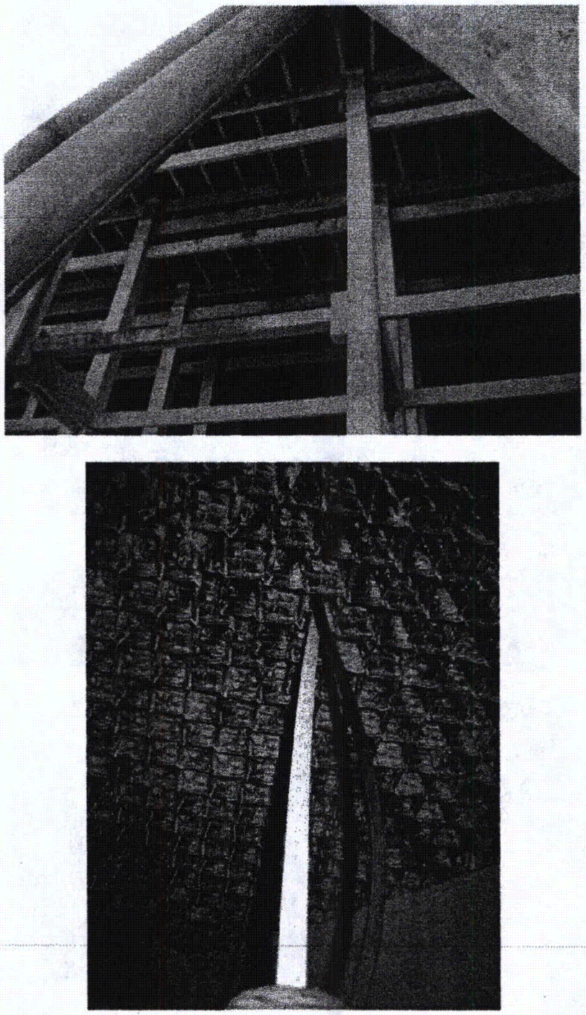




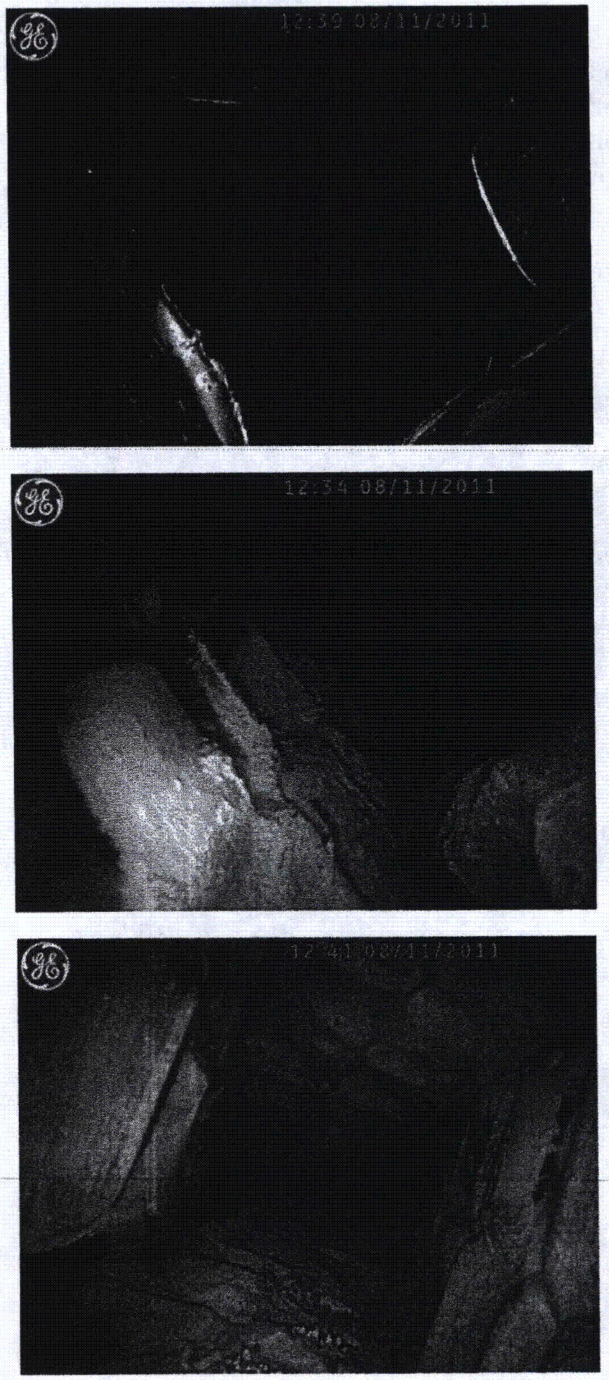


Figures 17, 18 and 19: Plant D in 2009

Internal Examination of Film Fill, an extension of the probing method: In one recent examination a boroscope was provided by the site water treatment vendor at the customer's request. It was used to examine fill flutes of fill from 0" up to 72" into the pack. This technique shows promise by allowing more complete fill condition assessment in-situ. Results are shown below.



Figures 20 and 21



Figures 22, 23, and 24: Plant A in 2011

Conclusion – The simple probing examination method described here has been effective in evaluating film fill use in field application. It is recommended for towers without operable weigh rack systems and gives insight into both fill selection and water treatment effectiveness at a specific condition. In order to be effective fill probing must be done diligently and consistently. Internal boroscope examination provides a promising technique for more in-depth in-situ examination.

III. Results - Fill Capability Assessment

A. Combined Assessment of Results for Fill Longevity

This paper describes laboratory methods for fouling assessment of fill designs and several methods for fouling assessment of installed fills. These methods are best used in combination to arrive at the best fill selection and longevity for the customer.

A concept called Fouling Prediction Modeling [FPM] can be envisioned that blends lab fouling data, field fouling data, fill geometry/characteristics, and site data, into a predicted fill life at an installation location. The site data would include tower design conditions with water quality/treatment information. FPM would combine this in formation and experience with the chosen film fill geometry to derive its expected longevity at site-specific thermal, water quality, and treatment conditions. A fill recommendation would be relative to a judgment standard and might express a confidence level for the prediction. Fouling loads that cause thermal degradation are typically 15-20 lb./ft^3 average measured drip-dry after exposure for film fills.

B. Tower Application of Film Fills: What Did Work

Low-Clog film fill application began in the 1990's in North America. There are a number of early power industry installations from the 1990-1995 time-period operating effectively today. Updated LC film fill designs from the 2000's combine improved thermal performance with fouling protection. The growing pool of film filled towers provides operating history.

As a result of an accumulation of data from laboratory, field application, and field monitoring, the use of LC and ULC film fills with specific water quality for each selection have been successful. There are a number of examples of long-term installations that are cooling efficiently with little biological and/or solids material accumulating in the film fill. Several are described below:

1. Power Plant A – Re-pack with LC has been monitored and found effective. This plant applies Chlorine 3 times/day. See Field Notes in Section D for more detail.

2. Power Plant B - Re-pack with LC has been monitored and found to be effective. This plant applies Chlorine 2 times/day. See Field Notes in Section D for more detail.

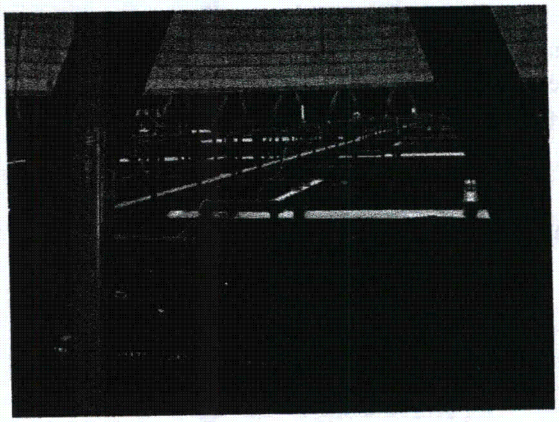
3. Power Plant C - Re-pack with LC has been monitored and found effective. This plant applies Non-Oxidizing Biocide 1 times/week and Chorine 1 time/Month. See Field Notes in Section D for more detail.

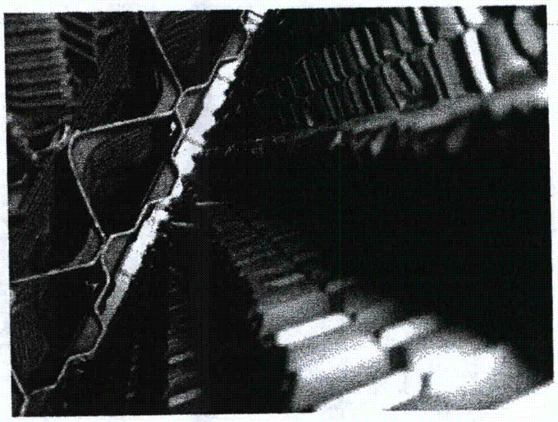
4. Power Plant D – After re-pack with ULC with 1' High Efficiency overlay operating successfully. Water Treatment is chlorine 3 times/ day. See Field Notes in Section D for evaluation of the fill that was replaced.

5. Power Plant E –Plant application of HE from the 1980's, with specifically designed application of biocide and dispersant during operation and high rate application with closed blowdown at outages has been successful after initial issues with fouling in the 1990's. The circulating water quality in operation has been 2500 ppm TDS and 30 ppm TSS.

6. Power Plant F – This plant runs HE film fill from the 1980's and 1990's using highly treated sewage effluent as make-up and a designed water treatment system. Operation is successful and fill is clean. The circulating water quality in operation has been 2000 ppm TDS.

7. Power Plant G – Re-pack with LC using river water at 25ppm+ TSS, 4 Cycles. This plant applies chlorine 1time/week.





Figures 25 and 26: Plant G tower and fill

8. Power Plant H –Re-pack with ULC and restored thermal performance from a drastic reduction due to fouling. This plant applies chlorine gas to packing and continuous make-up disinfection. The plant runs at 1.5 cycles with a TDS of 20,000-40,000ppm.

C. Tower Application of Film Fills: What Did Not Work

In general, HE film fills in power plants using river water make-up without strict water quality and treatment guidelines eventually failed.

1. Power Plant A – Originally packed with HE film fill fouled in 10 years, see "What Did Work" above for repack success.

2. Power Plant H – Originally packed with HE film fill fouled at 5 years. Top 1' layer looks clean, varying fouling at interfaces. The plant applies Chlorine 1 time/day and is at or near the ability to discharge from the plant. See "What Did Work" above for repack success

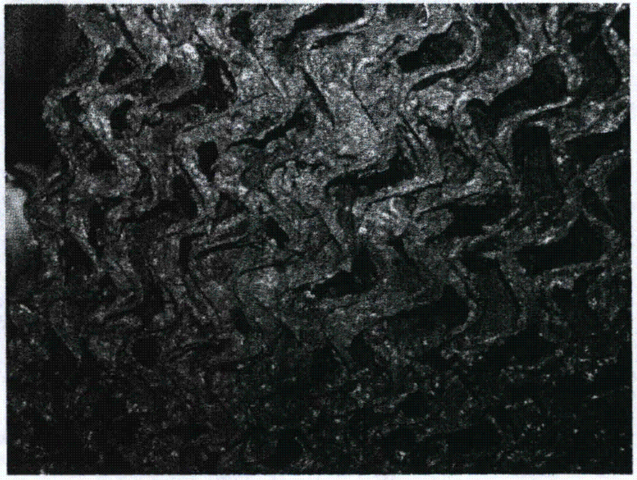


Figure 27: Plant H prior to re-pack

3. Power Plant I - Originally packed with HE film fill fouled in 5 years. Plant used river water make-up, TSS 160ppm.

4. Power Plant J – Initially packed with HE fill, this tower was re-packed with ULC.

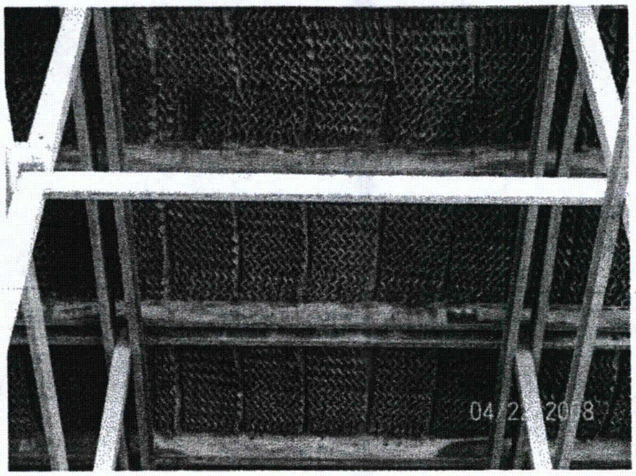


Figure 28: Plant J before Repack

Conclusions –

1. Film fill fouling remains an industry focus.
2. Owner/Operators consistently indicate they want maximum thermal performance with assurance of film fill fouling protection.
3. Better evaluation tools, techniques, and information are available now than at any time in the past.
4. By using this information improved fill longevity is being achieved.
5. Low-Clog Fill designs vary and owner/operators should seek fills with proven fill track record on thermal and fouling resistance from suppliers who collect this information.

MEMORANDUM

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TO: Paul Shriner and Jan Matuszko, USEPA
FROM: John Sunda, SAIC and Kelly Meadows
DATE: June 11, 2010

SUBJECT: Cooling Tower Noise, Plume and Drift Abatement Costs

EPA tasked SAIC and Tetra Tech with evaluating how costs for noise, plume and drift abatement technologies may be developed for a universe of facilities potentially subject to closed-cycle cooling under the proposed existing facility rulemaking. This memo presents a brief overview of abatement technologies and associated costs and presents possible approaches for incorporating these costs into the proposed rule.

Noise Abatement

Background

When installing cooling towers at power plants close to residential and commercial areas, consideration must be given to noise impacts. For plants close to residential areas, local noise ordinances may be as low as 50 dBA, especially at night.[1] For a conventional mechanical draft cooling tower, sound levels of about 60 dBA can be expected at a distance of 500 ft (SPX 2010a). Distance to the nearest receptor is an important factor, as the noise dissipates as the distance increases. The general rule-of-thumb is that at distances of less than half the length of the tower, the noise level will dissipate roughly 3 dBA for each doubling of the distance, and at distances greater than half the tower length, the noise level will dissipate roughly 6 dBA for each doubling of the distance. Based on this rule-of-thumb, the nearest receptor would need to be at least 1,600 ft from the

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[1] As an example, a study conducted for the Manchester Street Station (CH2MHill 2009) indicated that the noise regulations in Sections 16-91 through 16-109 of the City of Providence, Rhode Island Municipal Code required the following:

- In the absence of specific maximum noise levels, a noise level that exceeds the ambient noise by 5 dBA or more at the nearest property line or a noise audible at 200 feet is defined as unnecessary, excessive, or offensive noise.
- It is unlawful to operate equipment in any residential neighborhood that would exceed 50 dBA between 8 p.m. and 7 a.m. or exceed 55 dBA between 7 a.m. and 8 p.m.

unmodified conventional tower described above (60 dBA at 500 ft) to meet a noise limit of 50 dBA.

Cooling tower noise consists of two components: one is the sound of the fans and fan drives, and the other is the sound of the water splashing down through the tower. Noise abatement technologies used primarily for reducing fan noise may include:

- Low noise fans and gear boxes
- Fan deck barriers
- Inlet and outlet attenuation
- Building a larger tower to allow use of smaller Hp fans and/or reduced fan tip speed[2]
- Cooling tower designs that do not use fans (e.g., natural draft towers).

Noise abatement technologies used primarily for reducing water splashing noise include:

- Sound walls
- Splash attenuation
- Inlet attenuation.

Various combinations of these technologies may be selected, depending on the site conditions, equipment design, noise reduction requirements, and economic considerations.

Table 1 presents estimates using the rule-of-thumb for distances of 150, 350, and 500 ft, and 1,000 ft for a conventional mechanical draft cooling tower, a moderate reduction design (-10 dBA) and an aggressive noise abatement design (-16 dBA).

Table 1. Rough Estimate of Noise Levels at Varying Distances For Cooling Towers With and Without Noise Abatement Technology

Receptor Distance	Conventional Design	Moderate Noise Abatement (- 10 dBA)	Aggressive Noise Abatement Design (–16 dBA)
Ft	dBA	dBA	dBA
1,600 [a]	50	40	34
1,000 [a]	54	44	38
500	60	50	44
350 [a]	65	55	49
150 [a]	71	61	55

[a] Estimated values based on rule-of-thumb.

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[2] Reducing the fan tip speed is a simple way to reduce fan noise. Fan tip speeds "over 61m/s are considered high by most people. 51-61 is considered typical and expected. 41-51 would be considered low noise. Below 41 is difficult to hear above the water noise." (Marley 2010)

The data in Table 1 estimating the noise reduction attainable and distances are intended for illustrative purposes only. The determination of the degree of noise reduction required, if any, must be based on site-specific data and may vary greatly from site to site. In practice, noise abatement requires a sophisticated analysis by a specialist. A more detailed analysis using the octave band analysis and the proposed tower design, location, noise receptor locations, and consideration of nearby buildings and topography would need to be performed to obtain a more definitive answer regarding necessary tower design requirements.

Estimated Costs

EPRI's cost estimation tool for cooling towers does not include costs for noise abatement. An example design provided by a cooling tower vendor indicated that reducing the noise level by 10 dBA from 60 to 50 dBA at 500 ft could increase the tower costs by approximately 60% (SPX 2010b). In this case, the design included a reduction in the fan speed requiring a physically larger tower, an added fan deck, perimeter barrier walls, and splash attenuation. If greater reduction is required, the cooling tower vendor cited a design that reduced noise by 16.3 dBA at a distance of 500 ft that would increase costs of the cooling tower by nearly 100% (SPX 2010a).

By comparison, the 2001 316(b) Phase I technical documentation ("Economic and Engineering Analyses of the Proposed §316(b) New Facility Rule" Table A-4) provided relative cost factors for various cooling tower types and indicated that the addition of 10 dBA noise abatement should increase cooling tower capital costs by a factor of 30% and O&M costs by a factor of 7% when compared to a standard mechanical draft cooling tower. Using these data points as bounding estimates, the noise abatement tower capital cost factors can range from 30% to 60% to 100% represent a range of noise reduction and abatement technology combinations.

The amount of noise abatement required is a function of both the local community noise code and the distance from the tower to the nearest sound receptor that must meet the specified noise code. Noise abatement costs will be highest if a tower must be located near areas with highly restrictive noise codes, such as residential areas. The location and orientation of the receptors surrounding the tower are also important, as some noise abatement technology components may be needed only on one side of the tower, which can help reduce costs.

As noted above, noise abatement costs may range from 30-100% of cooling tower capital costs. The median tower component cost (including the basins) of a closed-cycle system retrofit is estimated by EPA to be approximately $80/gpm of recirculating cooling water flow (SAIC 2010). Based on the 30% and 60% factors, the added costs for a 10 dBA noise abatement design can range from $24/gpm to $48/gpm. These differences represent different noise abatement strategies, with the higher cost example relying on larger towers and lower fan speeds, which should reduce the operating costs when compared to the lower cost approach which cited a 7% increase in O&M including the fan energy component. Since these costs are based on well-known design principles, the higher capital, lower O&M cost example has been selected as the best choice for estimating noise abatement costs in the proposed approach outlined below. While the larger tower may require a minor increase in the cost of materials maintenance, the reduced air velocities and reduce fan tip speed in the larger tower should reduce fan energy and fan maintenance requirements. Thus, the net effect of this noise abatement technology design on cooling tower O&M costs is expected to be minimal.

Plume Abatement

Background

Cooling towers dissipate heat via evaporation, resulting in warm, humid air being discharged from the towers. Under certain conditions, the plume is visible and may persist for some time or distance. In some cases, this may be a concern for visibility on roads or at airports, icing of roadways or other structures (as the plume condenses), or for aesthetics.

Plume abatement can be accomplished by various means and is often accomplished using a hybrid wet/dry cooling tower that combines air from both dry cooling and wet cooling to produce a less saturated tower exhaust air stream.

Estimated Costs

EPRI's cost estimation tool for cooling towers does not include costs for plume abatement. For plume abatement technology, the total cost of the tower component is estimated to increase by a factor of 2.0-3.5.[3] For this discussion of proposed changes to the cost methodology, a factor of 2.5 was selected for estimating the cost of conventional cooling towers with plume abatement, resulting in an additional cost of 1.5 times $80/gpm which is equal to $120/gpm.

Hybrid cooling towers will have higher O&M costs for the energy requirements and equipment maintenance compared to conventional mechanical draft cooling towers. A cooling tower vendor estimated that the pumping head would increases by 8 ft and the fan energy requirement would increase by 10% (SPX 2010a). This results in an increase in the EPA estimate for cooling tower energy requirement of 0.0000031 MW/gpm. It was also estimated that the non-energy O&M cost would increase by 50% to 100% due to the larger tower and maintenance of coils and dampers (SPX 2010a). A factor of 80%, which is close to the midpoint of the range cited and equal to an increase of $1.00/gpm, was assumed for the increase in non-energy O&M for plume abatement towers.

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[3] A cooling tower vendor cited 2.5 to 3.5 (SPX 2010a) as cost factors. The 316(b) Phase I support document (Table A-4) indicates that typical hybrid towers have capital cost factors of 2.5 to 3.0 when compared to standard cooling towers made of Douglas fir. Similarly, the EPRI Cooing Tower Calculation documentation states that plume abatement capital costs will be 2 to 3 times those of conventional mechanical draft towers.

Space Requirements

Conventional mechanical draft hybrid wet/dry plume abatement towers must be configured in an in-line configuration. For large volumes of cooling water, this requires a series of long towers that require an area that is long enough for the towers and wide enough to allow for spacing if two towers are set side by side. If the towers are placed too close together, plume recirculation can occur and significantly reduce tower performance. Potential solutions include a new design by SPX called ClearSky Air2Air, which provides plume abatement and can be configured in the back-to-back configuration, and round towers which are described in more detail below.

In a recent cooling tower retrofit study for Units 2 and 3 at the Indian Point Nuclear Power Plant, a more compact round tower configuration was the selected technology. The tower design included a round counterflow forced draft configuration, hybrid wet/dry plume abatement with low noise fans, and sound attenuation baffles. These more expensive round hybrid towers were selected over conventional mechanical draft towers due to space limitations at the site which required a more compact design. The vendor's design-and-construct estimate[4] for these round hybrid cooling towers was $205 Million (2009 dollars) for a 702,000 gpm tower (Enercon 2010). This is equal to a tower unit cost of $292/gpm or roughly 3.65 times the estimated conventional tower cost of $80/gpm. These higher cost towers are representative of the cost of plume abatement, noise abatement, and compact size requirements combined, and are within the range cited above for plume abated towers considering they include noise abatement as well.

Application to Proposed Rule Costing Methodology

Table 2 provides a summary of the increase in cooling tower costs for the options described above and the estimated total costs when they are applied to the "average" retrofit cost estimation factors used by EPA for conventional mechanical draft cooling towers. The "difficult" retrofit costs are also shown for comparison. EPA has selected the "average" difficulty retrofit cost factors as ones that take into consideration the range of variations in site-specific conditions that affect the degree of difficulty in retrofitting to closed-cycle cooling. Some facility retrofits will cost more and some less, but on a national basis these costs should balance out.

The EPRI costs are based on a cooling tower retrofit cost analysis prepared by Maulbetsch Consulting for approximately 50 facilities, which categorized cooling tower retrofits into "easy," "average," and "difficult" cost categories. Data presented by Maulbetsch indicates that noise and plume abatement technologies are used for some of the plant costs (Maulbetsch 2003, Maulbetsch 2008). Thus, it is reasonable to assume that some noise and plume abatement technologies may be included as part of the technology mix associated with the Maulbetsch cost estimates used to derive these costs, particularly those that fall toward the "difficult" end of the range of costs. However, if requirements for cooling tower retrofits are more widely and strictly applied (i.e., noise or

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[4] Enercon's analysis is based on a recent estimate for the Calvert Cliffs Nuclear Plant, which also uses brackish water

plume abatement is more prevalent), particularly in high density population areas, the proportion of retrofits near the "difficult" end of the cost range may be greater than the mix in the Maulbetsch study cost database.

Table 2. Summary of EPA Cooling Tower Costs Plus the Added Costs of Noise and Plume Abatement

	Capital Cost (2009 Dollars)	**Fixed O&M (2009 Dollars)**	**Variable O&M – Chemicals[1] (2009 Dollars)**	**Variable O&M - Pump & Fan Power**
	Dollars/gpm (% Increase[2])	**Dollars/gpm**	**Dollars/gpm**	**MW/gpm**
Average Retrofit[3]	**$263 (0%)**	**$1.265**	**$1.25**	**0.0000237**
Difficult Retrofit[3]	**$411 (56%)**	**$1.265**	**$1.25**	**0.0000237**
Add for Noise Abatement	$48	$0	0.0	0.0
Add for Plume Abatement	$120	$1.0	0.0	0.0000031
Add for Round Plume and Noise Abatement[4]	$212	$1.0	0.0	0.0000031
Average with Noise Abatement	**$311 (18%)**	**$1.265**	**$1.25**	**0.0000237**
Average with Plume Abatement	**$383 (47%)**	**$2.265**	**$1.25**	**0.0000268**
Average with Both Plume and Noise Abatement	**$431 (64%)**	**$2.265**	**$1.25**	**0.0000268**
Average with Plume and Noise Abatement with Space Limitations – Round[4]	**$475 (81%)**	**$2.265**	**$1.25**	**0.0000268**

[1] Non-power variable O&M costs are for additional treatment chemical for optimized tower operation at higher cycles of concentration.

[2] Percent increase compared to "average" difficulty retrofit.

[3] Values shown are same as used in previous cost estimates except that the previous fixed O&M total is now split into variable O&M for Chemicals and Fixed O&M.

[4] Based on round tower with plume and noise abatement.

Noise abatement may be necessary at locations near residential, urban, or other areas. However, it is difficult to determine (on a national scale) which facilities would incur noise abatement costs using the current set of information. Noise ordinances are typically administered at the state or even local level and would require a site-specific analysis to determine if they would be applicable at a given facility.

Plume abatement will primarily be a concern in locations where the plume may create safety problems such as reduced visibility on nearby roadways or icing on roads and bridges. Thus, facilities located near major roadways and bridges will be candidates for this requirement. As with noise abatement, it is difficult to determine (on a national scale) which facilities meet this criterion using the current set of information.

The availability of space and whether conventional or round towers would be feasible will be very site-specific and must take into consideration property size, shape, adjacent development, and topography. Requirements for the demolition and/or moving of existing structures and infrastructure may be more likely to be a requirement at sites with space constraints. Facilities that are located close to areas of higher population density are more likely to have limitations on availability of space, since available space not currently used by the plant and adjacent property will tend to be developed.

A detailed evaluation of each site would be required to determine which requirements would apply to that site. One possible source of data that may be used to identify facilities that may be candidates for some combination of these requirements would be to use census data to identify facilities that are located within areas of higher population density.

As can be seen in Table 2, the selected retrofits for noise abatement, plume abatement, and both noise and plume abatement increase the estimated costs of an "average" retrofit by 18%, 46%, and 64%, respectively. If space constraints require a round tower that includes plume and noise abatement, the increase may be up to 81% using the assumptions in this analysis. By comparison, the "difficult" retrofit represents an increase of 56% and falls in the middle of this range of options.

There are two basic approaches that could be used to identify facilities that would be assigned higher costs for the proposed rulemaking, using surrogate data or using an alternative wet cooling tower design; these are described below.

Using Surrogate Data

Facility data necessary to determine specific tower requirements is not readily available and it may not be practical to apply the noise abatement, plume abatement, or round tower costs shown in Table 2 to plants individually. A simpler solution would be to identify candidate facilities that may be more likely to require some mix of these technology modifications using a surrogate measure such as local population density data.[5] Aggregate cost factors representing one or combinations of these requirements could then be applied.

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[5] The U.S. Census Bureau defines an urban area as: "Core census block groups or blocks that have a population density of at least 1,000 people per square mile (386 per square kilometer or 1.6 per acre) and surrounding census blocks that have an overall density of at least 500 people per square mile (193 per square kilometer or 0.8 per acre)" (US Census Bureau 2000). A review of the population density and aerial views of several sample facilities may help in establishing reasonable threshold values for high and low density areas.

One approach would be to assume that the "difficult" retrofit capital costs ($411/gpm) or the combined plume/noise abatement costs ($431/gpm) would be representative of the costs of requiring some combination of noise and plume abatement at facilities that would otherwise require an "average" difficulty retrofit. For all of these facilities, the increased O&M costs associated with plume abatement in Table 2 should also apply.

Alternative Wet Cooling Tower Design

A second approach would be to assume that facilities would install an alternative wet cooling tower design. The model wet cooling tower technology that forms the basis for the EPA compliance technology is the rectangular mechanical draft cooling tower configured either in an in-line or back-to-back configuration. For these types of cooling towers, the most common type of plume abatement technology involves use of separate dry (coils) and wet cooling sections with the exhaust of each being mixed prior to discharge.

Back-to-back configuration is not advised due to poor mixing that occurs because the dry section air is introduced on only one side. This limits the use of this technology to locations where the available space is compatible with in-line mechanical draft towers. Other wet cooling tower technologies that provide plume abatement but have different space requirements are described below.

SPX ClearSky

A new design by SPX called ClearSky Air2Air provides plume abatement and can be configured in the back-to-back configuration. This design places the dry cooling component directly above the wet component of the tower rather than along the side, thus allowing for a back-to-back configuration. This technology re-condenses a portion of the evaporated water and was designed to provide for water conservation, but was found to reduce plume visibility as well. It is a promising technology, especially with respect to reducing water consumption. The technology has only been demonstrated on a full-scale basis at a single location in New Mexico and remains a somewhat unproven technology and may require time to develop acceptance within the industry.

Natural Draft Cooling Towers

Natural draft cooling towers (NDCTs) have higher capital costs and lower O&M costs than conventional mechanical draft towers. The lower O&M costs are due to the elimination of fan energy costs. At locations where there are no noise or plume abatement requirements, NDCTs are more economical than conventional mechanical draft cooling towers only for large base-load plants with a service life of 40 or more years (SPX 2010b).

NDCTs are suitable alternatives for plume abatement because the high air outlet location and large size of the plume reduces the possibility that the plume will approach the ground or be recirculated. When equipped with sound barrier walls, NDCTs also serve as an effective noise abatement technology option. At locations where both plume and noise abatement is required, the economic benefits of NDCTs become more favorable—even more so if the cost of constructing a new flue gas stack associated with new air pollution control equipment is avoided by disposing treated flue gas through the tower.[6] However, as noted above, noise and plume abatement requirements are often the result of proximity to urban or residential areas where there may be building height restrictions and/or substantial public resistance to the installation of such large structures, potentially limiting the applicability of this technology.

Hybrid Round Forced Draft Cooling Towers

Round mechanical draft cooling towers function in a similar way to conventional towers, with the air entering radially from all sides. Fans may be clustered around the center point of the tower (induced draft) or at the perimeter openings (forced draft). The latter is commonly used for hybrid round plume abatement towers. These towers have the following advantages:

- Useful where available space is compact and site does not allow for the long narrow configuration of mechanical draft towers.
- While the air outlet is closer to the ground than natural draft towers, the large diameter and compact nature of the combined plume increases plume height over conventional mechanical draft towers, reducing plume recirculation and eliminating spacing concerns associated with conventional towers.
- Increased plume height improves the distribution of drift, making this technology useful where better dispersion of saltwater drift is desired.

In one example cited above, the estimated cost of round plume and noise abatement towers was about $44/gpm higher than the estimated cost for combined plume and noise abatement rectangular mechanical draft towers.

Fan Assisted Natural Draft Cooling Towers

Fan assisted natural draft cooling towers are a hybrid of mechanical draft and natural draft towers and are similar in design to NDCTs but have a much lower height and use fans during periods when conditions require them. These towers have the following advantages:

- Useful where space requirement is compact and site does not allow for the long narrow configuration of mechanical draft towers.
- Tower height is limited.
- Lower fan energy requirement than mechanical draft towers.

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[6] See detailed discussion in DCN 10-6681.

- Suitable for locations where climatic conditions would result in insufficient buoyant forces in an NDCT, requiring fan assist to provide sufficient airflow. In this case, the cost of the added height of NDCT is not justified.

These towers do not provide for plume abatement, but like NDCTs, they have a higher discharge location and the plume is larger and more buoyant, making it less prone to approach the ground or recirculate compared to conventional mechanical draft towers.

Drift Abatement

Background

The cooling tower engineering cost estimates use the EPRI cost spreadsheet methodology for the capital costs for "average" or "difficult" installation. The Spreadsheet Instructions accompanying the EPRI Tower Calculation Worksheet state: "Most modern cooling towers are equipped with drift eliminators which are specified to limit drift to 0.0005% of the circulating water flow." Since the EPRI costs are for modern cooling towers and the default drift rate in the spreadsheet is 0.0005%, EPA can reasonably assume that the compliance cost estimates include costs for drift eliminators.

For comparison, cooling towers that do not employ drift eliminators emit significantly more water droplets. Table 3 below illustrates typical drift rates for towers with and without drift abatement.

Table 3. Cooling Tower Drift Factors

Tower Type	Drift Estimation Factor*
Natural Draft	0.3 to 1.0%
Mechanical Draft	0.1 to 0.3%
Tower with Drift Eliminator	0.005%
Tower with High Efficiency Drift Eliminator	0.0005%

* Drift (gpm) = Recirculation (gpm) x Drift Estimation Factor / 100

Note that while the EPRI methodology assumes high efficiency drift eliminators, no data has been collected on the prevalence of standard drift eliminators versus high efficiency drift eliminators in use at existing facilities or at recently constructed towers. However, in addition to the EPRI documentation, BPJ suggests that new towers would likely use the high efficiency eliminators, as the additional costs of installing and operating them can be included in the initial cooling system design and the incremental costs over standard efficiency would be small. Additionally, air quality requirements at a given site may require high efficiency eliminators as part of Best Available Technology.

Estimated Costs

As noted above, costs for high-efficiency drift abatement are already included in the costs calculated by the EPRI cost tool. No further action is required.

Conclusion

Noise, plume and drift abatement technologies can add significant costs to a cooling tower retrofit design. A number of site-specific factors come into play to determine the selection of technology, but appropriate assumptions for estimating national-level compliance costs can be made regarding the impacts of these abatement technologies to the overall cost of the retrofit.

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BACKGROUND

Tetra Tech was asked by the New York State Department of Environmental Conservation (NYSDEC) to conduct a technical review and evaluate the feasibility of technical options at the Glenwood Main Power Station (Glenwood) fossil fuel steam electric facility to meet the requirements of CWA 316(a) & (b). In the draft SPDES permit for the Glenwood facility, the NYSDEC has determined that the "Best Technology Available" for Glenwood is not closed-cycle cooling and has identified alternative technologies and operational measures to minimize impingement mortality and entrainment. Comments have been received on the draft SPDES permit for the Glenwood facility stating that closed-cycle cooling is technically feasible and available as BTA. Tetra Tech was tasked with conducting a technical review of the documents and information supplied by NYSDEC as they relate to the feasibility of retrofitting the facility to a closed-cycle cooling system. Tetra Tech has also conducted a technical review of the claims of members of the public that a closed-cycle cooling system is feasible for Glenwood.

Tetra Tech based its review on prior experience supporting BTA determinations for steam electric power facilities and on the documentation supplied by the NYSDEC. The documentation included, by was not limited to, the following:

- *Design and Construction Technology Review for the Glenwood Generating Station*, KeySpan Corporation (National Grid), February 2007.
- *Draft Procedures for Determining BTA*, NYSDEC, undated.
- *Comments on Glenwood Generating Station SPDES Renewal and Modification*, Super Law Group, LLC., on behalf of Citizens Campaign for the Environment (CCE) and the Network for New Energy Choices (NNEC), October 7, 2009.
- Correspondence between NYSDEC staff and National Grid pertaining to the Glenwood BTA process.

Tetra Tech did not review these documents on issues unrelated to the closed-cycle cooling analysis, such as alternative impingement/entrainment reduction technologies or biological impacts.

General Summary

Tetra Tech agrees with NYSDEC's contention that cooling towers, while potentially technically feasible at the Glenwood facility, present difficulties that could reasonably be encountered resulting in increased costs. A final determination can only be made when site-specific concerns are addressed, such as the low utilization of the facility, the ability to secure the necessary permits from local authorities and potential local opposition to noise and visual impacts is mitigated by proper design and siting.

National Grid Documentation

A 2008 response to NYSDEC by National Grid, the owner of the Glenwood facility, on cooling tower feasibility was prepared to address wet cooling tower feasibility at that location. National

Grid claims the installation of closed cycle cooling at the facility is infeasible due to a number of considerations, including the location of the cooling towers, the capital costs associated with designing and constructing the towers, and the long-term economic considerations for the facility itself.

Tetra Tech Review

Summary

Type of Cooling Tower and Footprint

In general, Tetra Tech agrees that the available documentation supports National Grid's initial assertion that retrofitting the existing once-through cooling system with wet cooling towers is complex and potentially difficult at the Glenwood facility, with several unknown factors still to be addressed. Tetra Tech notes, however, that National Grid's claim of infeasibility is largely based on cost and long-term economic considerations rather than the basic technical and logistical feasibility of the project itself. Tetra Tech believes a retrofit project is *technically* feasible, although significant additional costs may be incurred to compensate for site-specific obstacles. Major points of National Grid's claims are discussed below.

For power plants that have limited available undeveloped space such as Glenwood, the availability of suitable locations for cooling towers is an important issue. A review of the plant site indicates that the only potentially viable locations are: 1) the site of the Station 2 turbine building and old boiler building; and 2) the parking lot across the street.

Give the proximity to residential areas, Tt assumes that any tower design will incorporate plume abatement. In order to meet any plume abatement requirements, the most applicable technology is mechanical draft cooling towers using an inline configuration. The smallest configuration that would serve both generating units would be two 4-cell inline towers, each 50-60 ft wide by 208 ft long. It would be difficult to place two such towers at the Station 2 site with sufficient spacing between them to prevent recirculation of airflow. In order to retrofit both generating units with cooling towers, a second tower would need to be located at another site. The only other potentially viable site is the parking lot across the street, which is closer to the adjacent resident areas. This site appears to be large enough to accommodate a single tower sized to serve only one generating unit. In summary, retrofitting to a closed-cycle system would require the installation of plume abated towers on both of the potential sites at Glenwood, leaving the facility with minimal remaining available space.[?is that correct?]

Noise

When installing cooling towers at power plants close to residential and commercial areas, consideration must be given to noise impacts. National Grid states that the Town of North Hampton noise code would prohibit noise levels above a range of 45 to 50 dba. They state that one tower manufacturer cited a noise level of 65dba at a 150 ft distance for plume abatement towers with upgraded noise attenuation. For a conventional mechanical draft cooling tower, sound levels of 60 dba can be expected at a distance of 500 ft. There are measures that can be taken to reduce noise levels to as low as 47 dba at 500 ft, but they may increase costs of the cooling tower component as much as 100%. Noise abatement technologies may include low noise fans and gear boxes, sound walls, fan deck barriers, splash baffles, and inlet and outlet attenuation, and/or building a larger tower to allow use of smaller Hp fans.

It is typically found that at distances of less than half the length of the tower, the noise level will dissipate roughly 3 dba for each doubling of the distance. At distances greater than half the tower length, the noise level will dissipate roughly 6 dba for each doubling of the distance. Table 1 presents estimates for distances of 150, 350, and 500 ft, so that the noise levels cited above can be compared. Table 1 indicates that it is possible to design a cooling tower capable of reducing noise to levels below those cited by National Grid, but that it may still be difficult to meet the Town of North Hampton noise code.

Table 1
Estimate of Noise Levels at Varying Distances
for Cooling Towers With and Without Noise Abatement Technology

Receptor Distance	Conventional Design (dba)	Aggressive Noise Abatement Design (dba)	National Grid Design (dba)
500 ft	60	47	55[a]
350 ft	65[a]	50[a]	58[a]
150 ft	71[a]	58[a]	65

[a] Estimated values based.

Based on the rough calculations in Table 1, if the actual location of the nearest receptor point where the noise code would need to be met is less than approximately 350 ft, then it may be difficult or at least very costly to meet the noise code. The Station 2 location appears to be farther from potential noise receptors and thus would more likely be able to meet the noise code than would the parking lot location, which is closer to residential areas.

The Table 1 estimates are intended for scoping purposes only. In practice, noise abatement requires a sophisticated analysis by a specialist. A more detailed analysis using the octave band limits and the proposed tower design, location, noise receptor locations, and consideration of nearby buildings and topography would need to be performed to obtain a more definitive answer.

Cooling Tower Costs

National Grid bases its cost estimate on the engineering and cost assessments done for the E.F. Barrett facility and estimates an approximate cost of $60 million in capital costs to install cooling towers at the Glenwood facility. Tt has utilized a 2002 EPRI cost model in conducting an evaluation of the costs. As part of supporting the revised 316(b) Phase II rule, Tt and SAIC have identified and used this costing model developed by EPRI (a leading electric industry research group) that generates approximate costs for retrofitting mechanical draft cooling towers. The EPRI model offers an approach by which a facility can develop reasonable initial capital cost estimates without the expense of preparing a detailed engineering and cost analysis. There is a certain degree of subjectivity in applying the EPRI cost factors, such as assigning the retrofit at a particular facility to the easy, average, or difficult categories (depending on complicating factors such as existing infrastructure, geology, etc.), but subsequent independent cost analyses have found that the approach is more or less accurate considering the level of detail typically provided during an initial inquiry.

Tetra Tech agrees that the initial capital cost estimate of $60 million is reasonable and may, in fact, be low considering some of the potential costs associated with issues described above. It is not clear from the information provided whether National Grid considered the cost premium associated with salt/brackish water applications developed by a later study prepared for the California Energy Commission (*Performance, Cost, and Environmental Effects of Salt Water Cooling Towers*, CEC, June 2007). The CEC analysis concluded that salt water cooling towers typically incur an additional cost of 7 percent due to the larger size and more expensive materials that must typically be used.

Public Comments (Super Law Group)

Comments submitted on behalf of CCE and NNEC by the Super Law Group (SLG) contend that the Glenwood facility can be retrofitted with closed cycle cooling in a relatively short timeframe and at considerably less cost than cited by National Grid and NYSDEC. A significant portion of the comments discuss the biological impact from the existing once-through cooled system and the substantial environmental benefits, in terms of number of fish saved, that would be achieved through conversion.

Tetra Tech Review

Summary

Cooling towers *may* be technically feasible at Glenwood, but many of the arguments made by SLG do not support this claim. The discussion presented in the comment letter contains several significant flaws, notably an inaccurate cooling tower size estimate that understates the number of cells by approximately 25 to 50 percent. This, in turn, leads to inaccurate available space estimates and unsupportable claims as to the cost of a retrofit project at Glenwood. Likewise, the numerous obstacles and considerations cited by National Grid, such as aesthetic concerns, are discussed only in a broad sense with SLG claiming they can be easily addressed with providing specific detail. In short, SLG's claims must be viewed as incomplete and inadequately supported by the information provided.

Tetra Tech limited its review of comments submitted by SLG to technical aspects of a wet cooling tower conversion and did not analyze the various claims of biological performance. Likewise, costs were reviewed for reasonableness, but Tetra Tech did not reach any conclusion as to whether those costs support any determination of cost-effective.

Type of Cooling Tower and Footprint

Comments submitted on behalf of CCE and NNEC SLG contend that the Glenwood facility can be retrofitted with closed cycle cooling in a relatively short timeframe and at considerably less cost than cited by National Grid and NYSDEC. A significant portion of the comments discuss the biological impact from the existing once-through cooled system and the substantial environmental benefits, in terms of number of fish saved, that would be achieved through conversion.

Power Engineering, the technical consultant for Super Law (see Exhibit E), proposed a back-to-back configuration for the towers. We agree that the site would be suitable for a single 4- to 6-cell tower capable of handling the cooling water flow from one generating unit only, or an 8- to 12-cell back-to-back cooling tower serving both generating units. However, the following should be noted about the Powers Engineering design:

- Conventional hybrid wet-dry plume abatement towers do not perform well if configured in a back-to-back configuration because the design results in uneven air mixing between the wet and dry components. The proposed Powers Engineering solution attempts to resolve this problem by specifying the use of the SPX Clear Skies Air2Air cooling tower design. This design places the dry cooling component directly above wet component of the tower, thus allowing for a back-to-back configuration. This technology re-condenses a portion of the evaporated water and was designed to provide for water conservation, but was found to reduce plume visibility as well. It is a promising technology, especially with respect to reducing water consumption, but that is not a concern at this site. The technology has only been demonstrated on a full-scale basis at a single location in New Mexico and remains an unproven technology for applications such as this.
- The proposed tower in the diagram from Powers appears to have only six cells total. This results in a per-cell water loading of about 20,000 gpm which is much higher than the 10,000 to 15,000 gpm/cell that is recommended from SPX. A properly sized tower would require 8 to 12 cells.

In order to meet any plume abatement requirements, the most appropriate technology is mechanical draft cooling towers using an inline configuration. The smallest configuration that would serve both generating units would be two 4-cell inline towers, each 50-60 ft wide by 208 ft long. As noted above, it would be difficult to place two such towers at the Station 2 site with sufficient spacing between them to prevent recirculation of airflow. In order to retrofit both generating units with cooling towers, a second tower would need to be located at another site. The only other potentially viable site is the parking lot across the street, which is closer to the adjacent resident areas.

Noise

SLG states that closed cycle cooling will comply with the local noise ordinances. The abatement technology noise levels in Table 1 (above) are consistent with the noise reduction example provided by Howden Cooling Fan in Exhibit D of the Super Law submission. In Exhibit D, a case study is presented for noise reduction fan retrofits at an Austrian refinery. A table is presented indicating that the noise level at the nearest residential area to the refinery cooling towers dropped from 49.1 to 39.2 dba after fan noise reduction technology was installed. Ultra low noise fans are able to meet fairly stringent noise limits but SLG does not discuss the noise that would be created by falling water within the tower and whether that would have to be addressed by other measures. A review via Google Earth indicated that the residential area was approximately 1,000 ft away from the refinery cooling tower. Using the typical results mentioned above, the comparable after-abatement noise level at a 500 ft distance should be about 45.2 dba, which is slightly below the 47 dba value cited in Table 1 for an aggressive noise abatement tower design. The 39.2 dba value, however, is a field measured value; since there are some large tanks located between the cooling towers and the point of measurement, the measured value is probably somewhat lower than would occur if the sound path had been unobstructed.

Costs

Tetra Tech believes the costs presented by the SLG are flawed for multiple reasons. First, SLG appears to have underestimated the number of cells required for each unit by 25 to 50 percent, leading to a much smaller tower than National Grid has proposed. SLG does not explain why fewer cells would be needed or how they would achieve the same cooling demand and at what cost. This error would have had a cascading effect through the SLG cost estimate as all design considerations would be based on the smaller tower (e.g., pump and pipe capacity, size of cooling tower basin, additional materials, excavation and grading, etc.), raising questions as to the estimate's accuracy. In the Powers Engineering costing, demolition is included for Station 2, as this is the most suitable location for a tower. However, the Powers Engineering estimate is more consistent with the cost of conventional cooling towers without plume or noise abatement technology.

References

EPRI. Tower Calculation Worksheet. 2007

SPX Cooling Technologies Inc. Marsten, Kent. Chief Technical Advisor - Evaporative Cooling. Personal communication with John Sunda, SAIC. January 15, 2010.

Super Law Group. Comments on Port Jefferson Station SPDES Permit Renewal and Modification (October 7, 2009) and Comments on Glenwood Power Station. SPDES Permit Renewal and Modification (September 25, 2009).

TETRA TECH

TO: Chuck Nieder (NYSDEC) and Jamie Hurley (USEPA OWM)
FROM: John Sunda, Steve Geil and Kelly Meadows (Tt)
DATE: October 5, 2011

RE: **Huntley Closed-Cycle Cooling System Evaluation**

EPA tasked Tetra Tech with conducting a technical review of several documents used by the New York State Department of Environmental Conservation (NYSDEC) in evaluating the Best Technology Available (BTA) for Huntley Generating Station, with particular attention on the feasibility of retrofitting a closed-cycle cooling system.

A report evaluating closed-cycle cooling and other cooling system intake technologies at Huntley Generating Station was provided by NRG in the "Cooling Water Intake Structure Design & Construction Technology Plan" (Shaw Environmental 2007) (hereafter the "DCTP"). In a subsequent, more detailed evaluation of closed-cycle cooling at Huntley, the "Cooling Tower Feasibility Study" (NRG 2008) (hereafter, the "Feasibility Study") two cooling tower systems are proposed. One is a recirculating cooling system using in-line hybrid wet/dry mechanical draft cooling towers designed to recycle a large portion of the condenser cooling water for both units 67 and 68. The other is a recirculating cooling system using a single tower of a similar design that would recycle a large portion of the condenser cooling water for unit 68 only. This evaluation will primarily focus on the two tower design serving units 67 and 68 except where noted.

From a purely technical perspective, closed-cycle cooling for both units 67 and 68 is feasible at Huntley Generating Station. The technical issues raised can be resolved through engineering solutions but in some instances may result in additional costs. At the same time, some of the NRG cost components in the Feasibility Study may be overstated. However, certain cost estimates may increase if the two-unit design were increased in size to enable the greater tower flow associated with higher intake flow reductions and cycles of concentration. As the analysis below discusses, there are a number of technically challenging issues that remain unresolved; it is unlikely that additional information on any of these issues would affect the overall feasibility, but resolution of these issues prior to making a BTA determination would be preferable.

The discussion below begins with a summary of the proposed system, which is an irregular design compared to many cooling tower retrofit applications due to the configuration of Huntley's cooling system. The analysis includes potential (but surmountable) technical challenges and areas for improved design, as well as an assessment of the assumptions used by NRG in their studies.

Proposed System Configuration and Flow Reduction

Ideally, a closed-cycle cooling system is designed such that there is a single set of pumps that operate in one of two configurations: 1) water is pumped to the cooling towers where it then flows by gravity from the tower basins, through the condensers, and back to the source; or 2) water is pumped through the condensers and then through the towers where it then flows by gravity back to the source. Option 1 requires that the towers be sufficiently elevated to allow gravity flow through the condensers and the ability to route the cold water pipes from the tower basins to a location where they can tie into the condenser inlet piping. Option 2 requires that the existing condensers and piping be capable of handling the increased hydraulic pressure associated with the additional pumping head and the ability to tie the condenser outlet piping into the hot water piping to the towers. Both configurations require pumps capable of producing the combined pumping head equal to the friction losses and elevation rise of both the condenser and cooling tower systems and need only one basin to pump water from.

Cooling tower cycles of concentration can be regulated by controlling the volume of make-up water pumped into the system or blowdown volume discharged out of the system. At Huntley Station, the intake water and condenser discharge water is conveyed into and out of the station house through a tunnel system rather than pipes. This configuration can make it difficult to tie cooling tower piping into the system without considerable construction that would likely require a fairly long downtime. Option 2 would likely require a costly condenser upgrade as well.

The alternative to the single set of pumps configuration is to create cold and hot water "basins" at the intake and discharge sides of the existing once-through cooling system. In such a configuration, the existing cooling water system continues to operate as before and new pumps are installed at the hot water basin to pump water through the towers, where it then flows by gravity to the cold water basin. One disadvantage of this system compared to the single pump configuration is that it requires that the pumping rates of the two systems be balanced. This is typically accomplished through the use of variable speed pumps (VSPs). VSPs can be used to pump water through the towers and possibly through the condenser system as well, but it is not necessary to have both. There must also be a sufficient amount of storage capacity in each basin to accommodate short term imbalances in the flow rates of each pumping system that may occur during start-up, shutdown, and changes in operating conditions. The storage capacity is a function of the open surface area of the basin and the depth to the minimum water level under which the pumps can be safely operated without damage due to cavitation and air entrainment. For the existing condenser pumps, this minimum level has already been established. For the cooling tower pumps, this minimum level can be set deeper by design if necessary. In closed-cycle systems where the intake basin is closed off, a small intake system with low head pumps may be needed to provide make-up water.

Although the Feasibility Study provides little detail regarding the design of the intake basin side of the proposed system, it appears to deal with potential imbalances by using a cooling tower pump flow rate that is markedly lower than the condenser and service water flow rates and by keeping the intake basin side open. By keeping the intake open, the flow volume associated with cooling tower evaporative losses and the excess once-through flow volume simply flow in from the river as needed to balance out the system flow. The intake area however, would need to be partially closed off to ensure the cooling tower return flow is drawn into the intake system and does not mix with river water flowing downstream. In order to achieve flow reductions commensurate with closed-cycle cooling, the cooling tower flow rate will need to be nearly equal to the plant cooling water flow rate.[1] The closer the cooling tower flow rate is to the power plant cooling water flow rate, the more important it is to limit the size of the opening.

The area in front of the intake forebay can at least be partially closed off (e.g., using sheet pile walls or similar structures) to form the cold water basin (the volume of which would include the screen channels). One important design consideration with closing off the intake area is the need for sufficient storage capacity and/or inflow capacity from the river to prevent rapid shut down of the condenser pumps and generating units should the cooling tower pumps cease operating. A possibility would be to extend this enclosure along the shore in the upstream (southward) direction which would both increase the basin volume and shorten the distance necessary for return flow piping/channel from cooling towers located in the vicinity of the coal pile.[2] At a minimum, an opening large enough to allow for the necessary make-up volume to enter is needed. Additional gated openings could be installed to allow for continued generating unit operation in the once-through or partial once-through mode when flow through the cooling towers ceases or is reduced.

Another design possibility would be for the discharge tunnel to be partially closed off with a weir as well to form a part of the discharge basin. In this scenario, additional storage capacity would be needed for periods when flow imbalances occur. The Feasibility Study addresses this issue by adding enough storage capacity in the new pump bay for the cooling tower pumps such that the system would supply five minutes of cooling tower pump flow if the condenser pumps were to shut down. The weir system could be designed to accommodate once-through flow operation. The DCTP proposes a system closed at both ends but provides no detail on how the flow will be balanced or how make-up and blowdown rates would be controlled. The DCTP proposed a flow reduction of 97% which is consistent with a balanced closed-cycle system using an operating cycle of concentration of approximately 1.5.

For the two tower system, the Feasibility Study appears to propose an open ended system (at least for the two tower system) where neither the cold water nor the hot water basins are closed off. This is essentially a combination once-through/recirculating cooling system. The result is a significant lowering of the flow reduction compared to what would occur in a more balanced closed-cycle cooling system operating at more flow efficient cycles of concentration (e.g., 1.5). The estimated percent reduction of 91.2% shown in Table 7 of the Feasibility Study appears to be based on a balanced system and an

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[1] If the blowdown is discharged from the discharge tunnel then the cooling tower flow volume will be equal to the plant cooling flow minus the blowdown.

[2] Insufficient information is available regarding whether placement of a sheet pile wall a short distance offshore south of the current intake house would interfere with existing structures, utilities, navigation, etc.

assumed cycle of concentration but fails to take into consideration the imbalance between the power plant cooling water and cooling tower pumps.

As proposed in the Feasibility Study, the cooling tower pumps will only withdraw 218,200 gpm and will return to the intake only 215,918 gpm (Tower Pump Flow – Evaporation – Drift). The cooling tower flow value appears to be consistent with a ratio of 10/11 of the condenser pump flow rate.[3] The Station 1 condenser and/or service water combined flow is 255,600 gpm (4 condenser pumps at 58,900 gpm and 20,000 gpm service water). As shown below, the resulting flow reduction for the proposed two tower configuration is 84.5% rather than the 91% claimed.

Percent Reduction = 1 – (New Intake Flow[4] / Current Intake Flow)

= 1 – ((255,600-215,918)/255,600) = 0.845

The estimated corresponding cycle of concentration of the proposed configuration is 1.06 and not 1.1 as suggested in the Feasibility Study.[5] In order to operate at a cycles of concentration of 1.5 and 2.0 the combined tower pumping rate should be approximately 250,000 and 253,000 gpm, respectively.

In a configuration where the intake basin area and discharge tunnel would not be blocked off, river water is capable of flowing into or out of each end of the system at flow rates that would be dependent on the flow balance of the two systems. In an open system, the make-up or blowdown flow rates cannot be measured and the accurate measurement of the condenser and cooling tower flow rates that would be needed to operate at higher cycles in an open system is impractical. Therefore, an open system will have limitations with regard to process control and would be difficult to achieve higher cycles of concentration and associated flow reduction. Operating at higher cycles of concentration would be easier to maintain in a closed system where the tower and cooling system flow rates can be controlled using level sensors in the basins. Cycles of concentration could be controlled by monitoring the increase in conductance of the tower basin discharge compared to the source water and then controlling either the make-up or blowdown flow rates accordingly.

Single Unit Option

The proposed configuration for a single unit tower includes dividing walls; one in the forebay (Wall A); one in the intake tunnel (Wall B); and one in the discharge channel (Wall C). It appears that the reason unit 67 was chosen was because the discharge into the tunnel is adjacent to the location selected for the

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[3] The Feasibility Study states on page 12 that the cooling flow rate was reduced by 1/11 in order to match the flow capability of two 5-cell towers instead of one 11-cell tower.

[4] The new intake flow is the current intake volume 255,200 gpm minus the flow returned from the tower basins which is the tower pumping rate minus evaporation and drift (218,200 – 2,280 – 2 = 215,918).

[5] The Emissions section of the Feasibility Study based estimates on a COC of 1.1 and is the only place in the document where cycles of concentration are discussed. However, calculations using the system flow balance numbers in Figure 5 are consistent with a design cycle of concentration of 1.13, suggesting the intended design value is approximately 1.1.

cooling tower pumps. However, it appears that the proposed configuration does not need to separate the cooling water for the two generating units at either the intake or the discharge as long as the generating units do not need to be modified for the closed-cycle system. In fact, it does not matter which of the two units cooling system the tower outlet (cold) water goes to or the tower inlet (hot) water comes from. Leaving the walls out, particularly on the discharge tunnel side would allow for the cooling tower to service either of the two units when one is not operating. This would further increase the potential for flow reduction compared to a tower dedicated to a single unit. The only design consideration is that the return cold water piping from the tower basin and the intake structure be configured such that the water could be directed to the intake forebay of either generating unit.

Cooling Tower Cycles of Concentration

The cooling tower performance data presented Figure 5 of the Feasibility Study indicate the following for the two-unit option:

Recirculating Flow = 218,200 gpm

Make-up Flow = 19,680 gpm

Blowdown Flow = 17,400 gpm

Evaporation = 2,280 gpm

Drift = 2.2 gpm (From "Emissions" section)

Cycle of Concentration = 1 + (Evaporation/(Blowdown + Drift))

These values are consistent with an operating cycle of concentration of approximately 1.13 and correspond with the cycles of concentration of 1.1 reported as typical operating conditions in the "Emissions" section of the Feasibility Study. These values also are consistent with the estimated percent flow reduction of 91% for a closed-cycle system; however, as discussed above, the proposed system is not a fully closed system.

Table 1 below presents estimated percent intake flow reduction and flow rates for make-up, blowdown, and drift for different cycles of concentration based on a closed-cycle system. Cooling tower pumping rates shown are those necessary for the selected cycles of concentration. These calculations are based on the equivalent evaporation rates for the different flow rates which are consistent with expected values based on general engineering estimates.

Table 1. Estimated Cooling Tower Flow Rates and Percent Intake Flow Reduction for Different Cycles of Concentration

Cycles of Conc.	Plant Cooling Water[A]	Tower Pumping Rate	Make-up Water	Blow-down	Evapora-tion	Drift	Percent Reduction in Recirculating Water[B]	Percent Reduction From Current Intake Flow
	gpm	gpm	gpm	gpm	gpm	gpm		
1.06	255,600	218,200	39,670	37,390	2,280	2.2	81.8%	84.5%
1.13	255,600	236,800	21,510	19,040	2,480	2.4	90.9%	91.6%
1.50	255,600	250,200	7,850	5,230	2,620	2.5	96.9%	96.9%
2.00	255,600	253,000	5,290	2,640	2,640	2.5	97.9%	97.9%
3.00	255,600	254,000	3,980	1,320	2,650	2.5	98.4%	98.4%

[A] Based on combined Station 1 condenser and service water pumping rates

[B] Indicates percent reduction for closed-cycle system where tower pumping rate is equal to the plant cooling water intake rate.

The first row represents the corresponding values if excess once-through flow volume associated with the proposed system are included as part of the closed-cycle system analysis. The second row represents a rough equivalent of system flow values using the apparent cycle of concentration used to derive flow values presented in Figure 5 of the Feasibility Study. The remaining rows show the corresponding expected system performance for closed-cycle operation at cycles of concentration of 1.5, 2.0, and 3.0.

The third column shows the corresponding tower pumping rate needed for each cycle of concentration. The percent reduction in recirculating water shows the percent reductions that would occur if the blowdown was discharged from the tower basins instead of the discharge tunnel and the plant pumping cooling water rate was equal to the tower pumping rate.[6] As can be seen from the table, in order to achieve a percent reduction discussed in the Feasibility Study, cooling tower pumping flow would need to be increased by about 18,000 gpm. This volume is approximate to the volume reduction in the Feasibility Study design flow to accommodate one less tower cell. If the system were designed with sufficient cooling tower pumping flow capacity necessary to operate at a COC of 1.5 or higher, a flow reduction of 97% or more is achievable.

Cooling Tower Type and Design

The Feasibility Study initially considered a mechanical draft cooling tower design consisting of fourteen 50-foot wide cells for the two-unit option. Initially, a doubled-up configuration was suggested for locations 6 and 7 to handle the combined cooling flow of both units in a single tower. Doubled-up towers are also referred to as back-to-back configurations and are generally not compatible with hybrid

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[6] This appears to be the assumption used in the flow reduction cited in the Feasibility Study.

wet/dry plume abatement cooling towers. However, this issue resolved itself by splitting the tower in half and placing each in separate locations. To accommodate tower length constraints, particularly with respect to use of a single tower for both units, a design using wider mechanical draft towers with eleven 60-foot wide cells was also considered. This design was then divided in half to allow for two separate towers. It is not clear why, when choosing to divide the 11-cell tower in half, that the number wasn't rounded up 12 resulting in two towers of 6 cells each. While this would result in towers that are 20% longer than those proposed it would eliminate the need to reduce cooling tower rates and the potential impacts on the achievable flow reduction.

Although not evaluated in the analysis, alternative tower designs such as round forced draft cooling towers could also be considered. The elevated discharge location and the natural buoyancy of the more compact tower discharge would eliminate concerns regarding plume recirculation and further reduce icing/fogging concerns. The potential higher capital cost of such towers is offset by lower energy requirements since the natural draft effect would supplement the fan energy requirement. These savings are more likely to be realized at base load facilities with a longer expected remaining plant life and thus would most likely only be chosen if a major repowering or plant upgrade were planned. Such a design may be suitable if for Location 1 and the area between the coal pile and the ponds (Locations 6 and 7).

Tower Location

The primary focus of the Feasibility Study was the evaluation of potential cooling tower site locations. The issue of tower location does not appear to be one of sufficient land availability, but rather which location(s) would result in the best balance of performance, cost, and operational impact concerns. It should be noted that even the plan for the IGCC,[7] which has been abandoned for now, was able to identify a location for a 14-cell cooling tower along the northern edge of the site. The new unit was to occupy a major portion of the northern half of the site including the area currently occupied by Station 2. Thus, the demolition of Station 2 is a possible consideration and may occur if future expansion or repowering occurs at the plant.

The Feasibility Study concluded that Locations 3a and 7 were the only possible locations for cooling towers. It does appear that these general locations may represent the best balance between costs and performance concerns. However, none of the locations considered relocating the coal pile slurry wall as a possible solution. The Feasibility Study eliminated Location 4 (west of wastewater basins adjacent to the river) as infeasible because of interference with wastewater basins but if the coal pile slurry wall were relocated northward,[8] the freed up space converts Location 4 (hereafter "4a") into a more favorable option. Based on the information provided, this location does not appear more problematic than Location 7 and has the benefit of minimizing the impact on coal pile operations.

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[7] At one time, Huntley was being considered as a site to construct an Integrated Gasification Combined Cycle (IGCC) plant, a clean coal technology.

[8] Recent aerial views of the coal pile indicate that this portion of the pile receives less use and thus relocation of the wall northward should result in minimal impact on the storage capacity or the operation of the coal pile.

It is also noted that some of the concerns regarding other locations in the vicinity of Station 2 (e.g., Location 1) are related to interferences for air flow. This is due to the height of station 2 or concerns in routing the piping through station 2 and the intake structures. No discussion was presented regarding the possibility of demolishing Station 2. Since this option was part of the plan for the proposed IGCC generating unit, it is likely that any future expansion or repowering at this facility will involve demolishing Station 2.

One reason cited for locating towers at Location 3a rather than 3 was the desire to retain the capability of transporting and offloading coal via barge. A June 3, 2010 local newspaper article (Snyder 2010) discussed a lawsuit NRG brought against their rail coal supplier (CSX) concerning excessive rail shipping rates for the Powder River Coal; NRG was quoted as saying "there is no effective competition from non-rail modes of transportation, such as shipping or trucking, to either plant (Huntley or Dunkirk)." Thus, NRG has already concluded that barge shipment does not appear to be a viable alternative. Thus, Location 3 (both towers) or 3a using a longer 6-cell towers may be viable options. A 6-cell tower at Location 3a may be a viable option regardless since it appears possible to place the sixth cell in the location of the tractor garage (see discussion below) if there is no room on the south end of the proposed tower.

Engineering Issues

Wall in Discharge Tunnel

The one tower configuration description in the Feasibility Study expressed concern regarding whether the installation of "wall C" in the discharge tunnel would leave an adequate cross-sectional area in the discharge tunnel. As noted above, this wall does not appear to be necessary.

Tower Return Piping Through Intake Structure

In the Feasibility Study, concern was expressed as to whether the return pipe from the cooling tower can be routed and supported within the intake structure in a one tower configuration. It is reasonable to assume that this concern may also be pertinent to the two tower option as well. Insufficient information is available to ascertain the validity of this concern. However, since the water is being returned to the intake and forebay area, there should be various engineering options available, including enclosing the intake area using sheet pile walls or similar structures to extend the intake basin southward along the shore. Another possible solution may be to route the piping in front of the Screen House.

Additional concerns are expressed regarding the cooling tower piping to and from Locations 3, 4, 6, and 7. Many of the concerns regarding the feasibility of Locations 3a, 7, and 4a are similar and are discussed below.

Long Pipe Cooling Water Run and Extensive Support Structures for 7 ft. Diameter Pipe

Piping distances are approximately 1500 feet to Locations 7 and 4a and approximately 750 feet to Location 3. These distances and the need for support structures for the large pipes are technically feasible and simply result in additional costs. It appears that such costs have already been incorporated into the cost estimate presented.

Need to Route Cooling Water Piping Under the Main Road and Utility Interference

Interference and rerouting of some utilities is to be expected in the retrofitting of existing facilities. This should not pose any insurmountable problems but does not appear to have been included in the cost estimate and may result in some additional costs.

Possible Need to Demolish and Relocate the Transfer House and/or Tractor Garage

The Transfer House does not appear to be in a location that would interfere with route of the cooling water piping while the Tractor Garage would likely need to be moved. There appear to be several other possible locations adjacent to the coal pile that would be suitable for placement of a new Tractor Garage. This is a minor cost item.

Restricted Area for Construction

Several of the areas under consideration are next to the river and the coal pile. While these areas are somewhat restricted regarding placement of equipment and laydown, the option of supplementing construction area requirements using barges to facilitate construction is available if necessary.

Issues Regarding Boat Dock Foundation for Location 3

Concerns that the boat dock foundation will be unable to support the cooling tower or that they will interfere with the tower foundation can be resolved through engineering solutions. Existing foundation structures can be removed and additional foundation structures can be installed as needed.

Costs

The capital cost scope is based on 5-cell towers, so it can be assumed that the corresponding flow rate is 109,100 gpm per tower. The capital costs are equal to a unit cost of $424/gpm[9] indicating that the costs are within the expected range for retrofitting plume abated cooling towers at a facility when various difficulties may be encountered.

The O&M cost including chemical costs is equal to a unit cost of $2.16/gpm. In developing the proposed Existing Facility rule, EPA estimated that for plume abated towers, the total may be as high as $3.5/gpm indicating that the Feasibility Study costs may be somewhat underestimated. However, EPA used some

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[9] This figure excludes the Allowance for Funds Used During Construction (AFUDC), which was not clearly explained.

conservative assumptions in deriving the unit cost value including chemical treatment necessary to operate at higher cycles of concentration of 3.0.

Downtime

There is insufficient information provided regarding the estimated tie-in time of 16 weeks to determine whether this estimate is reasonably accurate. However, assuming it is accurate, the cost estimate does not account for the likely possibility that the tie-in could be timed to coincide with the scheduled maintenance downtime for one or both units. EPA has estimated that such downtime periods last about 4 weeks on average. This alone could reduce estimated downtime costs by up to 25%. Even if a different system configuration (such as a more enclosed intake area) were incorporated, construction can be planned and scheduled such that plant operation continues until only the last portion of the enclosure needs to be set in place during the planned downtime.

Energy Penalty (Heat Rate Penalty)

The heat rate penalty (expressed in terms of added fuel costs) appears to be approximately 2.2%. This value is on the high side but within the expected range. Since the plant is capable of adjusting steam conditions to maintain output, the costs are expressed as the increase in fuel used rather than lost revenue. This is a reasonable method to estimate the heat rate penalty.

Energy Penalty (Lost Generation)

The estimated cooling tower system energy consumption at full load is valid for the proposed design. The lost energy estimate assumes the two units will operate at the equivalent of 80% of the year at 100% load. However, the fan component, which comprises approximately 41% of the total cooling tower energy requirements, will operate at reduced energy during the winter months.

During the winter months the plant recirculates a portion of the condenser effluent through three flumes into the intake forebays to maintain a temperature of 40 °F. According to Figure 3 of the DCTP, the source water temperature in 2005 dropped below 40 °F from mid-December through mid-April and was within 2 °F of freezing during two of those four months. Assuming an average operating temperature increase across the condensers of 18 °F,[10] and an equivalent of three months of near freezing river temperatures, approximately 1/4 of the cooling flow would need to be recirculated back to the intake during this period to maintain a condenser inlet temperature of 40 °F. The implications of this is that during the winter months, the flow through the cooling towers and number of cells in use will likely be reduced and/or water may simply be diverted directly into the tower basins in order to prevent freezing and maintain warmer conditions. The result is a reduction in pump energy consumption in addition to the expected reduction in fan energy consumption.

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[10] Table 17 of the DCTP shows a maximum temperature increase across the condensers of 21 °F

Plant Age

An important aspect of the cooling tower cost estimation is the period over which the up-front costs such as capital construction costs may be amortized. In general, the shorter the period, the higher the corresponding annual cost will be. The BTA determination assumes that the cooling tower costs will be amortized over a 20 year period. Units 67 and 68 came online in 1957 and 1958, respectively, and thus are 54 and 53 years old. Many components of these units are approaching the end of their service life. Without the implementation of a major upgrade to the boilers and turbines and/or repowering, the units may be retired sooner than 20 years. However, this facility appears to be an ideal candidate for repowering with the addition of new units. Repowering the Huntley Generating Station has numerous advantages over building a greenfield facility to fulfill a need to add capacity and/or replace the capacity of inefficient or retired existing generating units. Repowering at Huntley would have the following advantages:

- Avoid the difficulty and public resistance to the siting of new transmission lines associated with new facilities
- Avoid the difficulties and public resistance to the siting of new plant facilities
- Avoid the difficulties of obtaining environmental permits for new facilities
- Can reduce investment costs by utilizing existing equipment, structures, and land
- Can utilize existing transmission and steam distribution equipment
- Can utilize existing utility connections and fuel delivery systems
- Can utilize existing highway, rail, and barge access
- Can utilize existing trained staff
- Can utilize existing cooling water intake and discharge equipment, structures, and permitted water withdrawal capacity.

The fact that NRG was considering adding IGCC unit at the plant confirms that there is an interest in maintaining this facility well into the future. Figure 7 indicates that the planned IGCC facility would have been in the area currently occupied by Station 2, the switch yard and remaining areas on the northern half of the site. Station 1 would remain in-place. Also, NRG has been has been investing in various air pollution control strategies for Station 1 such as converting to low sulfur Powder River Coal, adding a baghouse to the electrostatic precipitator, and improving boiler operation and control to fine tune system operation to reduce NOX and improve system efficiency. Thus, there are indications that power generation at this site using new or repowered/upgraded equipment will persist for some time into the future and even if Units 67 and 68 were to be retired. Any cooling towers built to service the units could continue to function and be incorporated into any new system design, allowing for the use of an amortization period equivalent to the expected life of the towers rather than the existing generating units. It is likely that such considerations would be incorporated into the design and economic planning for any cooling towers built at this site.

Air Emissions

The Feasibility Study estimates that particulate emissions (PM10 and PM2.5) from evaporation of drift would be 2.2 lbs./hr. or 7.7 tons/yr. (assuming 80% capacity). This is based on an assumed cycle of concentration of 1.1 and a drift rate of 0.001% cited by SPX. If the towers were to operate at a higher cycle of concentration of 2 or more, the emission could be almost twice as high. High efficiency drift eliminators are available that are capable of drift rates of 0.0005%. SPX has indicated that their high efficiency drift eliminators are capable of a rate of 0.0005% but generally only guarantee a rate of 0.001%. Thus, the cooling towers with high efficiency drift eliminators should be capable of limiting air emissions to <10 tons/yr. and should be well within de minimis levels for this pollutant.

Coal Pile Dust

The plant recently converted from using high sulfur eastern bituminous coal to low sulfur Powder River Basin (PRB) coal to help reduce air emissions. This has increased the potential for generation of coal dust as this type of coal produces more fine dust. The fact that the proposed locations that are near the coal pile (3, 4a, and 7) are in an upwind direction with respect to prevailing wind direction will help minimize this problem. While it is likely that some coal pile fines would become entrained in the recirculating water of nearby cooling towers, this would not necessarily create an operational problem for the cooling system, especially if the system was to operate at lower cycles of concentration. Only if the system is operated at fairly high cycles of concentration (e.g., 3.0 or above) would there likely be any concern for the build-up of coal fines and other solids such as airborne solids or suspended solids in the intake water. If a build-up of fine coal solids in the recirculating water were to occur, the effects can be adequately controlled through the use of solids dispersion treatment chemicals which are commonly used in closed-cycle cooling systems. In fact, the proposed system included equipment and O&M costs associated with treatment using a solids dispersion agent. Potential contamination of the water associated with operating at higher COCs can be controlled though pH adjustment. Treatment of the blowdown is not practical in the proposed configuration where blowdown is discharged as overflow from the discharge tunnel.

A review of a worst-case example shows that operational problems can be overcome with treatment if necessary. A report describing innovative cooling tower treatment applications (Tylec et. al) at a nearby smaller coal fired plant with a two-cell cooling tower about 70 ft. located east of the facility coal pile (downwind), states that a high level of suspended solids contamination was a regular occurrence. The suspended solids were primarily airborne coal fines from the adjacent active coal storage pile. The cooling water appeared black and saturated with coal dust, particularly on very windy days. The report notes that the treatment program was able to prevent any sort of performance interference from the coal fines. This cooling system represents extreme worst-case conditions as the report describes implementation of an improved treatment scheme allowing the cooling tower to increase the cycles of concentration from 10 to 18. It demonstrates that coal dust entrainment can be dealt with through the use of chemical treatment if necessary. The expected cycles of concentration at the Huntley plant will be much lower, in the range of 1.5 to 3 or less. It is assumed that the blowdown in the referenced facility is treated prior to discharge. This is not practical for the proposed Huntley system and thus concern over the concentration of coal dust in the discharge may dictate operation at lower cycles of concentration during episodes of higher coal dust entrainment in order to maintain acceptable levels in the recirculating water and discharge.

Noise and Plume

The facility is located in an industrial area with the closest public roadway being approximately 1,000 feet from the proposed tower sites. The nearest residential areas are approximately 3,000 feet across the river to the northwest and approximately one mile away the southeast and northeast. There is a public marina at the north border of the site which is approximately 2,000 feet from Location 3. Interstate 190 is located about 1,800 feet from Location 7. Though no formal noise assessment has been performed, based on previous work with cooling towers, there do not appear to be any public receptors within these distances that would warrant concern regarding noise from the towers. The inclusion of plume abatement technology in the proposed system and distances from the public roadways should eliminate any concern regarding aesthetics, fogging, and icing.

Conclusion

From a purely technical perspective, closed-cycle cooling for both units 67 and 68 is feasible at Huntley Generating Station. The technical issues raised can be resolved through engineering solutions but in some instances may result in additional costs. At the same time, some of the NRG cost components in the Feasibility Study may be overstated. However, certain cost estimates may increase if the two-unit design were increased in size to enable the greater tower flow associated with higher intake flow reductions and cycles of concentration. Based on this review, a number of unresolved issues remain; as stated above, resolution of these issues or the submittal of additional information by NRG is not likely to affect the overall conclusion that a retrofit to close-cycle cooling is feasible, but these are engineering challenges that should be addressed before proceeding with a detailed engineering design.

1. The degree of flow reduction to be required. NRG has essentially proposed two partial closed-cycle systems. The two-unit cooling tower system proposed in the Feasibility Study produces a flow reduction of about 84.5% and not the 91% cited in the document. The proposed design flow of the two tower system is limited to 93% of the combined condenser flow of units 67 and 68; the result is a flow reduction of around 84.5%. However, reductions as high as 97% of greater can be achieved in a properly designed system. NRG does not explain why only 5-cell (60 ft. wide) towers were selected resulting in a two-unit cooling system that would operate at a very low effective cycle of concentration (about 1.06). There is no discussion regarding the feasibility of using 6-cell towers. A closed-cycle system capable of recirculating a larger portion of the entire plants cooling water flow at higher cycles of concentration is feasible and should be evaluated. Project costs would need to be revised accordingly.
2. The documentation does not consider the inclusion of the portion of service water that is used for equipment cooling. In addition to 20,000 gpm service water for Station 1, the DCTP states that the 22,000 gpm of service water previously pumped from Screen House 2 will be rerouted

to screen house #1 during 2008. It is not clear if this entire volume is still being used and how much is used as cooling water and returned to the discharge tunnel. Any service water returned to the tunnel could be included in the design flow of a closed-cycle system. It is also not apparent from the diagrams whether it may be possible to isolate the service water screens and pumps at the intake such that the service water pumps continue to withdraw from the river. This would allow the service water that is returned to the discharge canal to serve as a source of make-up water. Table 1 indicates that only 8,000 gpm of service water would be needed to operate at a cycle of concentration of 1.5.

3. The design of the intake for the proposed configurations is unclear. More details are needed regarding the method to be used for returning the cooling tower discharge to the intake system and how the return flow will be prevented from mixing with river water. A system designed to operate at higher cycles of concentration would require a more enclosed intake and possible consideration of a make-up flow intake system.
4. Whether an intake enclosure could be built so that it extended southward along the shore towards tower location 3a, increasing storage volume in the intake "basin" and reducing return piping distances from locations 3a, 4a, and 7.
5. Whether retaining the option of coal delivery via barge and the associated space limitations is necessary.
6. Whether the coal pile slurry wall in the southern corner could be relocated to make room for a 6-cell tower located outside the coal pile slurry wall between the coal pile, the wastewater ponds and the river.
7. Whether operating in the once-through mode should remain an option if closed-cycle is selected as BTA. The proposed configuration in the Feasibility Study appears to retain this option.
8. To what degree cooling tower fan and pumping energy requirements would be reduced during the colder months of the year.
9. Whether removal of Station 2 is a viable option for consideration in deciding the location for cooling towers. Demolition of Station 2 is a likely component of any future expansion or repowering at Huntley Station but other considerations may still favor selecting tower locations to the south of Station 1 as proposed.

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