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RS-14-193

10 CFR 50.90

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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Subject: Request for a License Amendment to Braidwood Station, Units 1 and 2, Technical Specification 3.7.9, "Ultimate Heat Sink"

Reference: Letter from Daniel J. Enright (EGC) to U.S. Nuclear Regulatory Commission, "Request for Enforcement Discretion for Technical Specification 3.7.9 'Ultimate Heat Sink,'" dated July 10, 2012

In accordance with 10 CFR 50.90, "Application for amendment of license, construction permit, or early site permit," Exelon Generation Company, LLC (EGC), is submitting a request for amendment to Facility Operating License Nos. NPF-72 and NPF-77 for Braidwood Station, Units 1 and 2. Currently, Technical Specification (TS) Surveillance Requirement (SR) 3.7.9.2 states: "Verify average water temperature of UHS is ≤ 100°F." If the Ultimate Heat Sink (UHS) temperature is > 100°F, Technical Specification (TS) 3.7.9 Required Actions A.1 and A.2 would be entered concurrently, requiring both Braidwood Station Units 1 and 2 to be placed in Mode 3 within 6 hours and Mode 5 within 36 hours.

Recent meteorological conditions have resulted in the TS UHS temperature being challenged. These conditions include elevated air temperatures, high humidity, and low wind speed. Specifically, July 4 through July 6, 2012 brought unprecedented hot weather and drought conditions to the northern Illinois area resulting in sustained elevated UHS temperatures. On July 7, 2012, the Braidwood Station average discharge temperature of the running essential service water pumps, used to monitor compliance with TS SR 3.7.9.2, exceeded 100°F. As a result, Braidwood Station verbally requested and received Enforcement Discretion to avoid an unnecessary plant shutdown and associated transient as a result of compliance with TS 3.7.9, Condition A. Although the Request for Enforcement Discretion (Reference) indicated that a License Amendment Request was not necessary at the time since the conditions requiring the requested Enforcement Discretion were atypical, in order to address future meteorological conditions that may continue to challenge the current UHS TS temperature limit of ≤100°F, this License Amendment Request (LAR) is being sought to increase the TS SR 3.7.9.2 allowable temperature to ≤102°F.

As described in Regulatory Guide (RG) 1.27 Revision 2, "Ultimate Heat Sink for Nuclear Power Plants," the predicted response of the UHS temperature to the design basis event is a function of the historical weather including the diurnal variations. This LAR is consistent with Braidwood Station's licensing basis (i.e., RG 1.27 Revision 2). The purpose of the UHS TS temperature limit is to restrict the initial UHS temperature such that the maximum UHS temperature (i.e., the temperature of the cooling water supplied to the plant safety systems from the UHS) experienced during the UHS design basis event would not exceed the design limit of the plant equipment cooled by the UHS. If the temperature of the cooling water supplied to the plant from the UHS exceeds the proposed TS limit, the existing Required Actions in the current TS would apply: Required Actions A.1 and A.2 would be entered concurrently, requiring both Braidwood Station Units 1 and 2 to be placed in Mode 3 within 6 hours and Mode 5 within 36 hours.

The attached amendment request is subdivided as follows:

- Attachment 1 provides an evaluation of the proposed changes.
- Attachment 2 provides the current TS pages with the proposed changes indicated with markups.
- Attachment 3 provides the current TS Bases pages with the proposed changes indicated with markups. The TS bases pages are provided for information only and do not require NRC approval.
- Attachment 4 includes a summary of the regulatory commitments made in this request.
- Attachment 5 provides Braidwood Station Analysis, "Thermal Performance of Ultimate Heat Sink (UHS) During Postulated Loss of Coolant Accident" (ATD-0109 Revision 4).
- Attachment 6 provides the vendor data sheet for the Emergency Diesel Generator (EDG) Jacket Water Coolers.
- Attachment 7 provides the vendor data sheet for the Main Control Room Chiller Condenser.

In accordance with 10 CFR 50.91, "Notice for public comment; State consultation," paragraph (b), EGC is notifying the State of Illinois of this application for license amendment by transmitting a copy of this letter and its attachments to the designated State Official.

EGC requests approval of the proposed license amendment by August 19, 2015. Should the need for this amendment become urgent, EGC will request that the NRC reviews and processes this amendment on an expedited basis. Once approved, the amendment will be implemented within 30 days.

The proposed amendment has been reviewed by the Braidwood Station Plant Operations Review Committee and approved by the Nuclear Safety Review Board in accordance with the requirements of the EGC Quality Assurance Program.

There are two regulatory commitments contained in this letter. These are described in Attachment 4.

Should you have any questions concerning this letter, please contact Jessica Krejcie at (630) 657-2816.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 19th day of August 2014.

Respectfully,

David M. Gullott
Manager – Licensing
Exelon Generation Company, LLC

Attachments:

1. Evaluation of Proposed Changes
2. Mark-up of Proposed Technical Specification Page Change
3. Mark-up of Proposed Technical Specification Bases Pages Changes – For Information Only
4. Summary of the regulatory commitments made in this request
5. Braidwood Station Analysis, "Thermal Performance of Ultimate Heat Sink (UHS) During Postulated Loss of Coolant Accident" (ATD-0109 Revision 4)
6. Vendor Data Sheet for the Emergency Diesel Generator (EDG) Jacket Water Coolers
7. Vendor Data Sheet for the Main Control Room Chiller Condenser

cc: Illinois Emergency Management Agency – Division of Nuclear Safety
NRC Regional Administrator – Region III
NRC Senior Resident Inspector – Braidwood Station

Attachment 1
Evaluation of Proposed Change

Subject: Request for a License Amendment to Technical Specification 3.7.9, "Ultimate Heat Sink"

1.0 SUMMARY DESCRIPTION

In accordance with 10 CFR 50.90, "Application for amendment of license, construction permit, or early site permit" Exelon Generation Company, LLC (EGC) is requesting a change to the Technical Specifications (TS) of Facility Operating License Nos. NPF-72 and NPF-77 for Braidwood Station, Units 1 and 2 for the Ultimate Heat Sink (UHS). Currently, TS Surveillance Requirement (SR) 3.7.9.2 states: "Verify average water temperature of UHS is ≤ 100°F." If the UHS indicated temperature is > 100°F, TS 3.7.9 Required Actions A.1 and A.2 would be entered concurrently, requiring both Braidwood Station Units 1 and 2 to be placed in Mode 3 within 6 hours and Mode 5 within 36 hours.

Recent summer meteorological conditions have resulted in the TS UHS temperature limit being challenged. These conditions include elevated air temperatures, high humidity, and low wind speed. Specifically, July 4 through July 6, 2012 brought unprecedented hot weather and drought conditions to the northern Illinois area resulting in sustained elevated UHS temperatures. Previous revisions of the UHS design analysis utilized weather data from 1948 to 1976. This UHS design analysis has been updated to include weather data through December 31, 2012, which includes the period when the maximum indicated cooling water temperature supplied to the plant from the cooling lake was observed (i.e., July 7, 2012). Additionally, the analysis has been updated to include the latest revision of the UHS Heat Load analysis which incorporates the post-Measurement Uncertainty Recapture (MUR) power level. The UHS design analysis methodology is based on Regulatory Guide (RG) 1.27, Revision 2, "Ultimate Heat Sink for Nuclear Power Plants," and NUREG-0693, "Analysis of Ultimate Heat Sink Cooling Ponds," dated November 1980.

This license amendment is being sought to allow the TS temperature limit of the cooling water supplied to the plant from the UHS to increase from ≤ 100°F to ≤ 102°F. The impact of the maximum UHS temperature experienced during a Design Basis Accident (DBA) event has been evaluated consistent with the Braidwood Station current licensing basis. This includes Regulatory Position C.1.b of RG 1.27, Revision 2 which states that the UHS temperature transient analysis should include diurnal variations for the total of the critical time period, based on examination of regional climatological measurements that are demonstrated to be representative of the site. While the analysis has been performed to analyze the diurnal variations, the proposed TS limit for the UHS temperature is proposed to increase from ≤ 100°F to ≤ 102°F, independent of time of day. This is consistent with the existing TS.

The evaluations and analyses performed to support the proposed license amendment demonstrate that the plant's safety related equipment will maintain its design function at the higher UHS temperature. Therefore, the proposed change has no adverse impact on Braidwood Station plant safety.

2.0 DETAILED DESCRIPTION

2.1 Proposed Changes

The proposed changes to TS 3.7.9 are shown in Attachment 2 and are as follows:

The current TS SR 3.7.9.2 states:

Verify average water temperature of UHS is ≤ 100°F.

The proposed TS SR 3.7.9.2 states:

Verify average water temperature of UHS is ≤ 102°F.

There are no proposed changes to the TS Required Actions, Completion Times, Frequency of SR performance, or any other portions of TS 3.7.9.

2.2 Background

The UHS consists of an excavated essential cooling pond integral with the main cooling pond. The volume of the UHS is sized to permit the safe shutdown and cooldown of both Braidwood Station units for a minimum 30-day period during a DBA with no additional makeup water source. The UHS is designed to withstand the separate occurrence of either the safe shutdown earthquake or the probable maximum flood on the cooling pond. The UHS provides a heat sink for process and operating heat from safety related components during a transient or accident, as well as during normal operation. The UHS dissipates residual heat after reactor shutdown and after an accident through the cooling components of the Essential Service Water (SX) System and the Component Cooling Water (CC) system, which are the principal systems at Braidwood Station that utilize the UHS to dissipate residual heat. The UHS also provides a source of emergency makeup water for the spent fuel pool and can provide water for fire protection equipment. Non-Essential Service Water (WS) pumps and Circulating Water (CW) pumps also take suction from the UHS during normal operation, however, operation for post-accident conditions is not considered since the WS and CW pumps are shut down before the UHS level reaches the minimum required water level for plant operation at 590 feet (Reference TS 3.7.9 and Reference 4).

The SX system takes suction from intake lines running from Safety Category I essential cooling pond to the auxiliary building where four SX pumps (two per unit) supply safety-related loads and components essential to safe shutdown. These include cubicle coolers, pump coolers, diesel engine coolers, CC heat exchangers, Reactor Containment Fan Coolers (RCFC) and chiller condensers. The CC system provides cooling water to the residual heat removal system, chemical and volume control system, reactor coolant system and process sampling system. Updated Final Safety Analysis Report (UFSAR) Figure 2.4-47, "Essential Cooling Pond," shows the layout of the SX supply and discharge piping along with the Circulating Water supply and discharge piping. Relevant elevations for the cooling pond are also included in this figure.

The Braidwood Station limiting UHS DBA (i.e., that event that results in the maximum heat load on the UHS) is one unit undergoing post-Loss of Coolant Accident (LOCA) cooldown concurrent with a Loss of Offsite Power (LOOP), in conjunction with the other unaffected unit undergoing a safe non-accident shutdown. This scenario assumes the worst case single failure of the manmade structure (i.e., the Category II retaining dikes) that encloses the main cooling pond. This limiting DBA includes three sources of heat energy to be transferred by the SX system after a LOCA: containment heat removal via the RCFCs, containment heat and reactor residual heat removal via the containment sumps, and Engineered Safety Features (ESF) equipment heat loads (e.g., ESF equipment coolers and room coolers).

The thermal performance of the Braidwood Station UHS was originally developed based on the initial UHS temperature of 98°F and meteorological conditions from the summer of 1955 for

highest temperature and summer of 1971 for highest evaporation. On June 13, 2000, the U.S. NRC issued an amendment to increase the allowable UHS temperature from 98°F to 100°F. The recent changes in meteorological conditions have resulted in the TS UHS temperature limit being challenged. Because of the recent change in meteorological conditions, such as increased temperature, the UHS DBA has been reassessed for an increase in initial temperature from 100°F to 102°F.

The analysis of the Braidwood Station UHS to determine the proposed TS limit and the associated post-DBA UHS temperature was a multi-step process. The steps included determining the critical time periods unique to the Braidwood Station UHS, gathering updated meteorological data, and screening the meteorological data to determine the most limiting sets of data. This information was used in the UHS analysis to determine UHS temperature and evaporation response by analyzing the combined effects of the most limiting sets of meteorological data with the DBA heat loads. Once the limiting post-DBA UHS temperature responses were determined, they were used (1) as input into the safety analysis to ensure responses remained within analyzed limits and (2) to evaluate performance margins of equipment cooled by the SX and CC systems. The evaporation response was assessed against the existing design analysis to ensure response remained within limits.

3.0 <u>TECHNICAL EVALUATION</u>

3.1 CRITICAL TIME PERIODS

Consistent with RG 1.27, Revision 2, the UHS analysis considered the controlling parameters and critical time periods unique to the Braidwood Station specific UHS design. Critical time periods are those time periods in which the maximum lake temperature coincides with the most severe combination of controlling meteorological parameters. The design of the Braidwood Station UHS is a closed loop, where the SX cooling water exiting the plant combines with the UHS volume and traverses through the UHS while being cooled by the environment, prior to returning to the SX system suction. The key parameter of this design is the length of time the water remains in the UHS to dissipate heat to the environment; which is a function of the time it takes the water to transit the UHS before returning to the plant. The number of SX pumps in operation determines the transit time. Due to the different flow rates associated with the number of pumps in operation, the transit time differs. The transit time calculation takes into account effective lake volume which is the same regardless of number of SX pumps in operation.

The Braidwood Station SX system design allows up to four SX pumps to be operating at the same time. Each single SX pump services a full capacity essential service water loop capable of supplying all safety-related heat transfer equipment associated with that Unit. The normal SX system line up consists of one pump operating on each Unit. An ESF signal due to an accident on one Unit will result in one additional SX pump automatically starting on the accident Unit, therefore, the maximum number of SX pumps that are expected to be in operation at the start of the UHS DBA is three.

A fourth SX pump would be in operation if started manually by the operators later in the event, if needed for the Unit undergoing a normal shutdown. Although the critical time period for four SX pumps in operation was determined and evaluated as an input in the downstream UHS analysis, actual plant operation with four SX pumps in operation occurs infrequently and is

limited. This is discussed further in section 3.7. Based on the effective volume and flow rates, the critical time periods were determined and set to be 24 hours for four SX pumps in operation, 36 hours for three SX pumps in operation and 48 hours for two SX pumps in operation.

3.2 UPDATED METEOROLOGICAL DATA

The present UHS analysis of record utilizes meteorological data from 1948 to 1976, obtained from the National Weather Service (NWS) in Peoria, IL or Springfield, IL. To support this LAR, updated meteorological data was obtained spanning the period from 1976 through December 31, 2012.[1] From January 1, 1990 through December 31, 2012, the meteorological data was a combination of data from the Peoria NWS and an onsite multi-level instrumented tower at Braidwood Station. All the meteorological data parameters collected were taken at one hour intervals from 1948 to 2012. This set of data was screened to identify and systematically correct any out of range or missing parameters.

3.3 METEOROLOGICAL DATA SCREENING TO DETERMINE LIMITING WEATHER PROFILES

RG 1.27, Revision 2 describes a method for considering meteorological conditions in the design of the UHS. A synthetic weather file may be created using weather data from the critical time period based on the design of the UHS, the worst 24 hours, and the worst 30 days, combined in this order.

In the Braidwood Station analysis, 64-years of meteorological data was analyzed in three-hour increments with a standard lake model, at the same initial conditions, to determine the set of data that resulted in the highest UHS water temperature (i.e., the set of hourly meteorological data that provided the most limiting conditions for the UHS to dissipate heat). This analysis was performed for each of the critical time periods identified as well as those required by RG 1.27 Revision 2 (i.e., 24 hours, 36 hours, 48 hours, and 30 days) and for the eight daily starting times (i.e., 12AM, 3 AM, 6 AM, 9AM, 12PM, 3 PM, 6 PM, 9 PM) used to model the diurnal lake behavior. A similar approach was used to determine the limiting set of data that resulted in the 30-day limiting evaporation.

The Braidwood Station UHS analysis created a series of synthetic weather files for use in the lake model. These files were created by combining the limiting meteorological data from each of the limiting critical times, with the worst 24 hour period followed by the worst 30 day period. The different synthetic weather files were input to the UHS analysis and represent the worst meteorological conditions for the UHS to dissipate heat under each SX pump operating scenario and associated daily start time. More details on the meteorological screening of data performed are included in Attachment 5, Section 2.0.

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[1] Meteorological data through December 2012 was used as this data was the latest available full set of parameters at the time of analysis performed in early 2014. The UHS temperature is an indication of environmental impacts on the UHS because the lake responds to environmental inputs. The UHS temperature did not exceed the TS limit during the summer of 2013 as it had during the summer of 2012, therefore, it is concluded that the data utilized through December 2012 is more severe and bounds the data from the summer of 2013.

3.4 UHS ANALYSIS

The purpose of this calculation is to determine the thermal response of the UHS to a DBA event under worst case meteorological conditions. In accordance with the Braidwood Station Design Basis, one unit is postulated to have a LOCA with LOOP, and the other unit is postulated to undergo normal shutdown. The dike of the Braidwood Station Lake is also assumed to have been breached leaving only the UHS available to support operation of the necessary equipment. The LAKET-PC computer program was used to determine the maximum UHS temperature and the maximum UHS inventory loss following a DBA using the proposed TS value of 102°F as an initial input. As specified in Regulatory Position 1 of RG 1.27, Revision 2, the diurnal variations of the UHS are accounted for in the temperature and evaporation response by varying the DBA start time.

The analysis modeled the heat dissipated by the UHS based on the synthetic weather file, specific to the accident starting time and number of SX pumps in operation, with the heat added due to one unit experiencing a DBA LOCA with LOOP and the other unit performing a simultaneous, safe non-accident shutdown. This same analysis was performed for a DBA starting at each of the eight daily starting times for two, three, and four SX pump operation.

The analysis determines the following parameters:

- Maximum UHS temperature versus DBA start time
- Maximum UHS inventory loss or drawdown

3.4.1 Computer Model

The computer program used to model the Braidwood Station UHS during the design basis event is LAKET-PC developed by Sargent and Lundy in 1976 as a one-dimensional thermal prediction model for bodies of water. The LAKET-PC computer program is utilized to determine the combined impact of decay heat, SX flowrate, initial UHS temperature, and meteorological conditions on the UHS response. The model assumes that the lake temperature is constant at any point along the plane perpendicular to the direction of the flow. The one dimensional model assumptions coerce the water body into an idealized rectangular channel. The movement of fluid through the one-dimensional channel is envisioned as a series of individual, distinct fluid segments. Each segment has an individual length and temperature, while the width and depth remain constant for all. The channel thus forms a queue of fluid segments, where additions are made at the inlet, and deletions are made at the outlet. Any segment that enters the channel will cause an equal amount to be expelled at the outlet. The program assumes that each segment is uniform in temperature, and each segment is allowed to react independently with the environment. The horizontal heat conduction for each segment is assumed to be negligible with respect to the heat rejection at the air-water interface and is ignored. Similarly, conductive heat loss at the water channel interface is conservatively ignored.

The methodology used in LAKET-PC is consistent with the thermal model presented in NUREG-0693 and the wind speed functions presented in Massachusetts Institute of Technology Report No. 161, "An Analytical and Experimental Study of Transient Cooling Ponds Behavior," dated January 1973, which is also referenced and cited in NUREG-0693.

Consistent with NUREG-0693, the LAKET-PC contributing components for the net heat transfer to the UHS are:

$Q = Q_{SN} + Q_{AN} - Q_{BR} - Q_E - Q_C + Q_{RJ}$

Where:
Q_{SN} = net incident short wave solar radiation
Q_{AN} = net incident long wave atmospheric radiation
Q_{BR} = net rate of long wave back radiation from the lake surface
Q_E = net rate of heat loss due to evaporation
Q_C = net rate of heat loss due to conduction and convection
Q_{RJ} = net rate of heat rejected to the lake by the plant

A comparison of the NUREG-0693 to LAKET-PC input parameters and equations is provided in Table 1.

Table 1: Comparison of Heat Load Equations

	NUREG- 0693	**LAKET-PC**
Q_{SN}	Measured value	Calculated outside of LAKET-PC (documented in Attachment 5)
Q_{AN}	$1.2x10^{-13}(T_A+460)^6(1+0.17C^2)$	Calculated outside of LAKET-PC (documented in Attachment 5)
Q_{BR}	$4.026x10^{-8}(460+T_S)^4$	$4x10^{-8}(460+T_S)^4$
Q_E	$(e_S – e_A)$ F(w) approximated as: $\beta(T_S-T_D)F(w)$	$(e_S – e_A)$ F(w)
Q_C	$0.26(T_S-T_A)F(w)$	$0.255(T_S-T_A)F(w)$
Q_{RJ}	Plant heat load input	Plant heat load input

Where:
C = fraction of sky covered by clouds (0.0-1.0)
T_A = dry bulb air temperature (°F)
T_S = water surface temperature (°F)
e_S = saturated vapor pressure at T_S (mmHg)
e_A = vapor pressure at T_A and relative humidity (mmHg)

$$\beta = 0.255 - 0.0085\left(\frac{T_S + T_D}{2}\right) + 0.000204\left(\frac{T_S + T_D}{2}\right)^2 \text{ (mmHg/°F)}$$

F(w) = wind function (LAKET-PC uses the Ryan wind function. The Ryan wind function is specifically formulated for lakes with heat load input from the plant. The use of the Ryan wind function is supported in NUREG-0693.)

The differences in the equations for Q_{BR} and Q_C are small. The terms Q_{BR} and Q_c represent energy losses from the lake. Since the constants are smaller in LAKET-PC, the LAKET-PC is slightly conservative relative to the NUREG-0693 values (heat losses from the lake are modeled as slightly less in LAKET-PC).

The table below provides details of the LAKET-PC modeling of the UHS with the size of the segments for each of the pumps running cases used in the analysis.

Table 2: LAKET-PC Model Details			
	2 Pumps	**3 Pumps**	**4 Pumps**
Total # of Segments	17	13	9
UHS Length (ft)	3,076	3,076	3,076
Segment Length (ft)	178	238	357
Eff. Area @ 590 ft (acre)	78.7	78.7	78.7
Conversion (ft^2/acre)	43560	43560	43560
Area (ft^2)	3,428,172	3,428,172	3,428,172
Segment Area @ 590 ft (ft^2)	198,728	264,970	397,456
Segment Width (ft)	1,114	1,114	1,114
Segment Depth (ft)	5.8	5.8	5.8

3.4.2 Wind Gradients

LAKET-PC models wind gradients (as a function of the elevation above ground level) per the following equation:

$$WNDCOR = 1.15\left[\frac{mph}{knots}\right]\cdot\left(6.56 / WINDZ\right)^{0.3}$$

Where:
WNDCOR = wind correction factor to 2m above ground level
WINDZ = measurement elevation above ground level [ft]
1.15 = conversion factor from knots to mph

The wind speed extrapolation is a power law equation correcting the wind speed to an elevation of 2 meters (6.56 ft) above the ground level (the reference wind speed elevation used for wind functions in MIT Report No. 161). There are a variety of exponential factors that have been used over the years in the power law equation; LAKET-PC uses a conservatively bounding value of 0.3 for the exponent.

3.4.3 Ultimate Heat Sink Temperature Profile

To account for the time of day at which the UHS DBA may start, eight cases on a 3-hour interval frequency at successive starting times were run for scenarios with two, three and four SX pumps running. The SX system at Braidwood Station is comprised of two trains, train A and train B, for each Unit. Each train includes one SX pump. The normal system line up consists of one pump operating on each Unit. An ESF signal due to an accident on one Unit will result in one additional SX pump automatically starting on the accident Unit, therefore, the maximum number of SX pumps that are expected to be in operation at the start of the UHS DBA is three.

Due to system operating alignments, the four SX pumps case is not representative of normal operation or post-accident plant operations. During normal operation, an additional SX pump may be started in support of surveillance testing or pump start-up/shutdown operations for a short period of time, as required in support of plant activities. For post-accident conditions, a fourth SX pump would be in operation if started manually by the operators later in the event, if needed for the Unit undergoing a normal shutdown. Additionally, with four SX pumps in operation, the actual flow through the SX system will be limited by the hydraulic resistance of the SX system and be less than that analyzed in the calculation of transit time for the four SX pump case (i.e., the transit time calculated for the four SX pump case is conservative relative to the actual flow expected through the SX system due to hydraulic resistance). See Regulatory Commitment #2 which discusses the required changes to operating procedures to ensure SX operation with four pumps is limited.

The two and three-SX pumps cases were reviewed and the three SX pump case with the 3 AM starting time results in the limiting UHS temperature of 105.2°F. The profile for this limiting case is shown in Figure 1 and Figure 2. Based on the UHS temperature profile in Figure 1, the following temperatures were selected as values for the accident analysis and equipment evaluation:

- 104°F was used to determine the heat removal performance for the RCFCs. This is an input to the accident analyses that use the RCFCs for heat removal
- All equipment cooled by the UHS is evaluated for the limiting UHS temperature of 105.2°F.

The use of 104°F in the accident analyses is conservative because:

- The UHS temperature remains below 104°F for the first 36 hours into the event.
- The UHS temperature exceeds 104°F to a maximum of 105.2°F for a period less than 6 hours (hours 36-42)
- From hour 42 onward, the UHS temperature remains below 104°F
- Except for the long term containment analyses, other accident analyses are evaluated for a time period less than 36 hours

The long term containment analysis was re-performed (see section 3.6.1) and it was demonstrated that the containment pressures and temperatures have been significantly reduced from the calculated peak value at 36 hours after the event. At 36 hours the containment pressure is approximately 30 psi lower than the calculated peak and the containment atmosphere temperature is approximately 80°F lower than the calculated peak. Therefore, the increase in the UHS temperature above 104°F post 36 hours will not result in exceeding any design criteria related to post-LOCA containment requirements.

The UHS analysis also calculated the maximum drawdown for the UHS at the end of the 30-day period. The maximum calculated drawdown of 1.78 ft is lower than the maximum estimated drawdown (2.10 ft) evaluated in existing design analyses and is therefore acceptable.

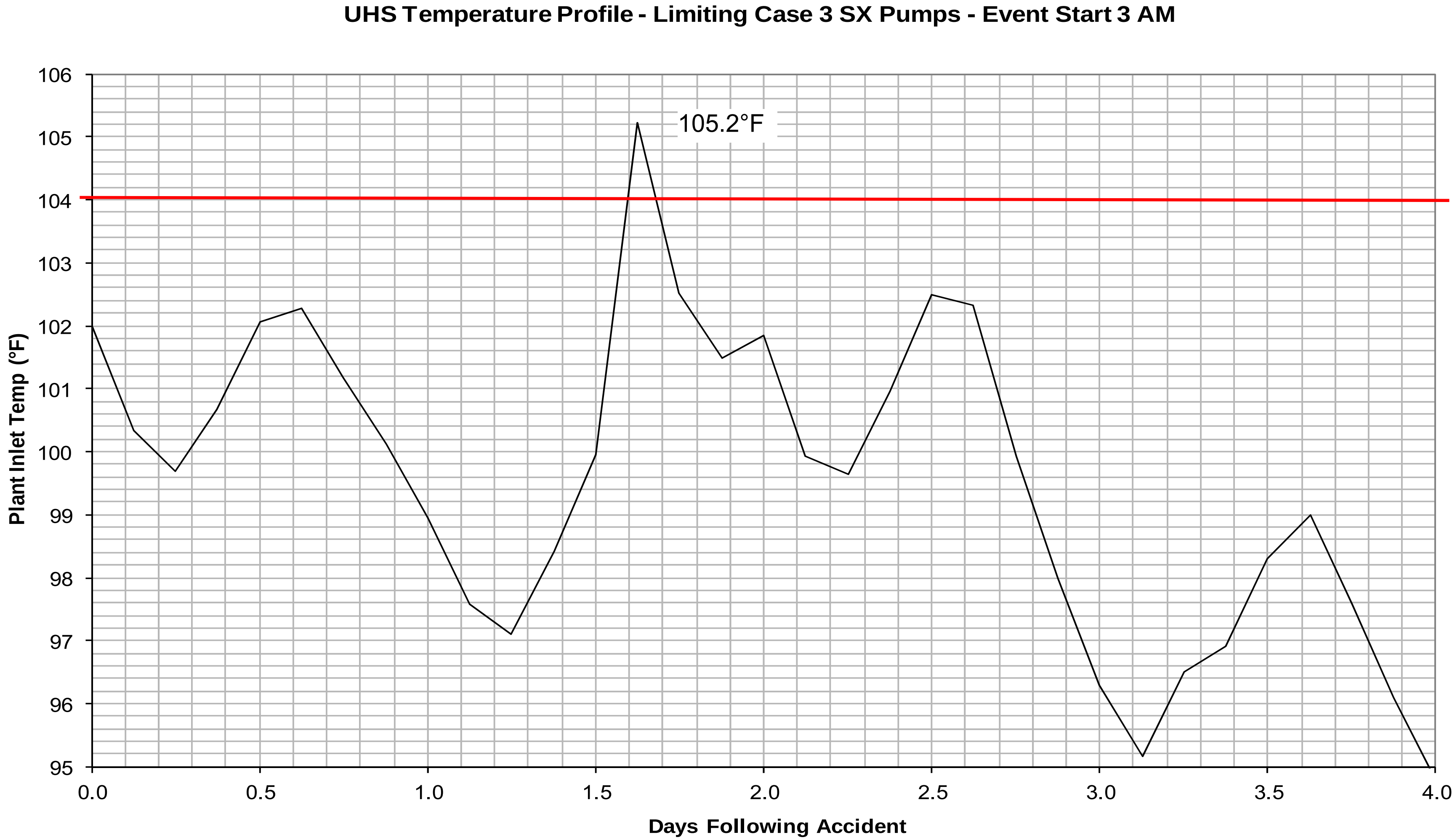

UHS Temperature Profile - Limiting Case 3 SX Pumps - Event Start 3 AM
105.2°F
106
105
104
103
102
101
100
99
98
97
96
95
Plant Inlet Temp (°F)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Days Following Accident

Figure 1

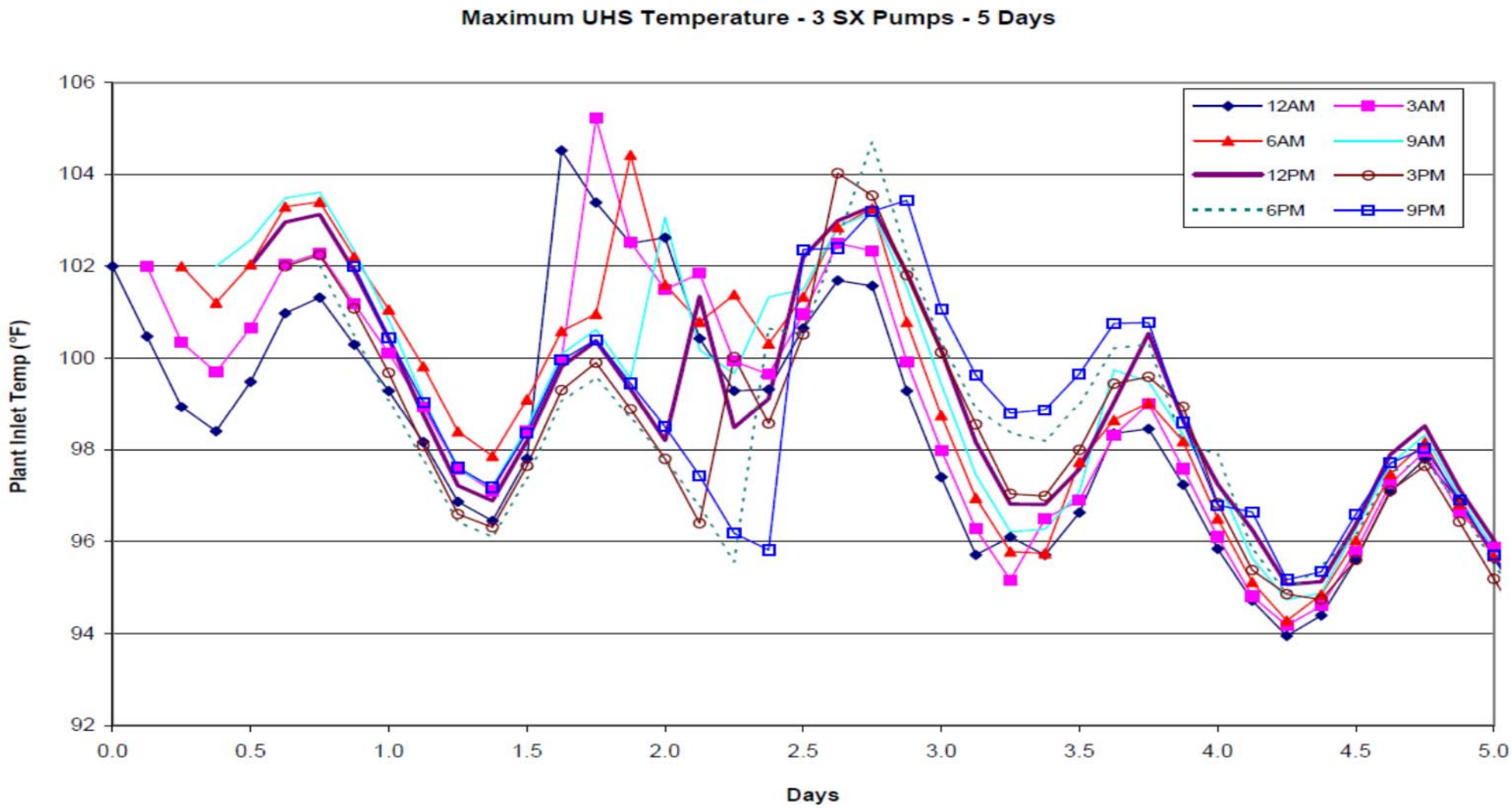

Maximum UHS Temperature - 3 SX Pumps - 5 Days
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM

Figure 2

3.5 EVALUATION OF EQUIPMENT

A formal engineering evaluation has been completed to review the impact of the increase in the UHS TS maximum temperature of 102°F and the increase in the maximum post-accident SX inlet temperature to 105.2°F. This was completed by reviewing the evaluations and design calculations for equipment cooled by the SX and CC systems and developing simplified models which were validated against the results of the existing calculations. The models replicated the analyses contained in the existing evaluations and design calculations with the increased SX temperature. Resulting margins were reviewed and it was determined that equipment cooled by the SX and CC systems have adequate margin at the elevated UHS temperature without physical plant modifications. The specific component analyses impacted by this evaluation have been identified and will be updated in accordance with the existing Engineering Change processes and as outlined in Regulatory Commitment #1.

The heat load on the UHS is determined based on one unit undergoing a LOCA with a LOOP and the other unit going through a normal shutdown from maximum power. Heat loads for the UHS DBA event are shown in UFSAR Table 9.2-1 and were evaluated for the components listed in sections 3.5.1 through 3.5.5 with the exception of the Positive Displacement (PD) Charging Pump Cubicle Cooler since the PD Charging pumps are not operated at Braidwood Station. While SX flow to the PD Charging Pump Room Cubicle Cooler is not isolated, the heat load in the room is insignificant with the pump idle. Note, the heat load for the Spent Fuel Pit Heat Exchanger includes the Spent Fuel Pool background heat load due to Spent Fuel Assemblies that are stored in the pool.

Note, all equipment that is cooled by the SX system is within the scope of the Generic Letter (GL) 89-13, "Service Water System Problems Affecting Safety-Related Equipment" program. The information below describes the formal engineering evaluations performed to ensure that required plant equipment can continue to perform their design function at the elevated UHS temperature.

3.5.1 Pump Room Cubicle Coolers

Pump room cubicle coolers are required to remove equipment heat from rooms with operating pumps. The formal engineering evaluation demonstrated that all cubicle coolers cooled by SX as listed below have margin of approximately 10% to 50% between the heat removed and the design heat load at design values for the SX cooling flow rates:

- SX Pump Cubicle Coolers
- Residual Heat Removal (RHR) Pump Cubicle Coolers
- Safety Injection (SI) Pump Cubicle Coolers
- Charging (CV) Pump Cubicle Coolers
- Spent Fuel Pit Pump Room Cubicle Coolers
- Diesel Driven Auxiliary Feedwater (AF) Pump Room Cubicle Coolers
- Containment Spray (CS) Pump Room Cubicle Coolers

These margins were evaluated under design conditions at the maximum post-accident SX inlet temperature to 105.2°F. To ensure margin, for the CS Pump Room Cubicle Cooler and the CV Pump Cubicle Coolers, a reduction in the Braidwood Station controlled tube plugging limits will be implemented. These changes will be implemented as part of Regulatory Commitment #1. In

addition to the margin described above, the pump room cubicle cooler evaluations conservatively apply a fouling factor for the water side of the cooler of 0.0025. This is conservative relative to the existing design fouling factor of 0.0015.

3.5.2 Oil Coolers

The SX system provides cooling water to oil coolers for safety related pumps. The lube oil coolers for safety related pumps are small heat exchangers that are periodically cleaned and inspected in accordance with GL 89-13. As described above, (section 3.5) a simplified evaluation of the oil coolers was performed to review and identify margin with the maximum post-accident SX inlet temperature to 105.2°F. This evaluation concluded that approximately 10°F margin exists between the highest expected oil temperature and the limiting oil temperature for all oil coolers cooled by the SX system as listed below.

- SX Pump Oil Coolers
- SI Pump Oil Coolers
- Diesel Driven AF Pump Gear Oil Cooler
- CV Centrifugal Pump Gear Oil Coolers
- Motor and Diesel Driven AF Pump Oil Coolers
- Diesel Driven AF Pump Right Angle Gear Lube Oil Cooler
- CV Centrifugal Pump Oil Coolers

For the SX Pump Oil Coolers evaluation, a conservative condition with no SX cooling flow was assumed. Therefore, greater margin exists than that determined in this evaluation. All other Oil Coolers evaluations performed used design heat loads and the design SX cooling flow rates.

3.5.3 Engine Coolers

The SX system provides cooling water to diesel engine cooling systems. Using the maximum post-accident SX inlet temperature to 105.2°F, engineering evaluations have been performed to confirm the cooling systems' capability to remove the design heat load. All engine coolers cooled by the SX system have been evaluated and demonstrated margin at the increased SX temperature. Evaluations of both the engine coolers identified below determined > 5°F margin available to their respective high jacket water temperature alarm setpoints.

- Diesel Driven AF Pump Engine Closed Cycle Heat Exchanger
- Emergency Diesel Generator (EDG) Jacket Water Coolers

The EDG Jacket Water Coolers evaluation was performed at the design SX cooling flow rate. For the Diesel Driven AF pump engine closed cycle heat exchanger, the UHS temperature increase was evaluated crediting a higher SX cooling flow rate of 350 gpm in place of the design flow rate of 250 gpm and current tube plugging values. The design analysis for the current SX system flow model was reviewed and demonstrates a flow rate in excess of 500 gpm for the Diesel Driven AF pump engine closed cycle heat exchanger. The 350 gpm flow rate credited in the evaluation and required reduced tube plugging will become part of the new design analysis as part of Regulatory Commitment #1.

3.5.4 Main Control Room Chiller Condenser

The SX system provides cooling water to the Main Control Room (MCR) chiller condensers, which remove sensible and latent heat from the control room to ensure equipment operability and personnel occupancy. An engineering evaluation was performed for the increased UHS temperature of 105.2°F using design heat loads, design SX cooling flow rates and existing tube plugging values. The evaluation also used reduced fouling factor based on the as-found fouling factors of other heat exchangers in the NRC GL 89-13 program. The results show that the MCR chiller condenser is able to remove the heat load with over 25% margin at the maximum post-accident SX inlet temperature to 105.2°F. The existing design analysis of the MCR chiller condensers will be updated as part of Regulatory Commitment #1.

3.5.5 CC Heat Exchangers

The CC system rejects heat to the UHS during normal plant operation and during accident conditions. Five different operating scenarios were evaluated to model the different plant configurations where the CC system is designed to operate (e.g., two units operating at power, one unit operating at power with the other unit shutdown, normal unit shutdown with other unit experiencing a LOCA). The CC heat exchangers were evaluated for increased normal operating UHS temperature of 102°F and increased post-DBA UHS temperature of 105.2°F using existing tube plugging values. The design basis scenario for the UHS DBA results in margin in excess of 50% for the CC heat exchangers.

Of the five operating scenarios evaluated, the two units operating at power and one unit operating at power with the other unit shutdown are numerically identical. These normal operating scenarios are more limiting than the design basis scenario described above and are the limiting configurations with respect to CC heat exchanger performance since the allowed maximum CC temperature for normal operations is 105°F which is lower than the allowed maximum CC temperature of 128°F for post-LOCA operations. These scenarios have greater than 30% margin. The existing design analysis of the CC Heat Exchangers will be updated as part of Regulatory Commitment #1.

The engineering evaluation of margin was performed using calculated fouling factors based on recent test data from the Unit 0 and Unit 2 CC heat exchangers. The recent test data measured temperature and flow through the heat exchangers using improved methods that allowed for a reduction in measurement uncertainty. While the Unit 1 CC heat exchanger has not yet been tested using the improved test method, the performance of the Unit 1 CC heat exchanger is expected to match or be bounded by the Unit 0 heat exchanger. This conclusion is based on the Unit 1 CC heat exchanger having fewer tubes plugged, being cleaned in February 2014, and having the same design as Unit 0.

3.5.6 Net Positive Suction Head (NPSH) Evaluations

The NPSH for all safety related pumps which take suction from the UHS has been evaluated and found to remain acceptable for the higher UHS temperature. Sections 3.5.6.1 through 3.5.6.3 describe the evaluations of NPSH that were performed. Existing design analyses will be updated in accordance with Regulatory Commitment #1.

3.5.6.1 SX Pump

The existing SX pump analysis calculates a limiting (minimum) NPSH Available (NPSHA) at 100°F SX water temperature of 43.27 feet. For the maximum post-accident SX inlet temperature to 105.2°F, the vapor pressure will increase slightly resulting in a decrease of 0.38 feet in NPSHA. The new NPSHA will be 42.89 feet which still has significant margin above the NPSH Required (NPSHR) value of 36 feet at 28,000 gpm per pump.

3.5.6.2 SX Booster Pumps

The SX booster pumps provide flow to various coolers associated with the diesel driven AF pumps. Normally, suction for the pumps is supplied by the SX pumps. The existing SX booster pump analysis calculates a limiting NPSHA of 26.62 feet. For the maximum post-accident SX inlet temperature to 105.2°F, a reduction in NPSHA of up to 0.38 feet is determined with a resulting NPSHA of 26.24 feet. This is greater than the NPSHR value of 23.31 feet.

3.5.6.3 Motor and Diesel Driven AF Pumps

The AF pumps normally take suction from the Condensate Storage Tank (CST). If the CST is not available, the AF pumps can be supplied by the SX system. The NPSHA for the AF pumps is currently evaluated using the CST at a temperature of 120°F. The NPSHA with suction from the SX system is significantly higher than the NPSHA when taking suction from the CST. Therefore, the NPSHA at the elevated UHS temperature of 105.2°F is bounded by the existing evaluation.

3.5.7 Diesel Driven AF Pump Operation during Loss of AC Power

In the event of a complete loss of onsite AC electrical power (i.e., Station Blackout (SBO)); the Diesel Driven AF pump (i.e., the 'B' AF pump) is credited for steam generator inventory makeup. The Braidwood Station licensing basis does not postulate an SBO to occur simultaneously with a UHS DBA. Therefore, water temperature experienced by the 'B' AF pump and its associated diesel driven SX booster pump at the start of an SBO event is limited to the proposed TS maximum temperature of 102°F.

During a SBO, the SX booster pump operates to provide cooling water to the 'B' AF pump's heat exchangers and coolers. Flow recirculates through the different heat exchangers and coolers back to the SX booster pump suction, resulting in isolation of the cooling water heat sinks and heat-up of the isolated SX booster pump cooling loop during the Braidwood Station SBO coping time of two hours.

The existing evaluation of NPSHA for this SBO recirculation mode was reviewed. The NPSHA evaluation utilized flow rates higher than the design flow rates. These higher flows support the higher cooling flow that is credited for the Diesel Driven Auxiliary Feedwater Pump Engine Closed Cycle Heat Exchanger (see section 3.5.3). The NPSHA determined in the existing evaluation is expected to decrease by up to 0.14 feet but will still remain higher than the NPSHR with the UHS temperature of 102°F.

The existing design analysis for this transient presently evaluates an initial UHS temperature of 102°F and concludes that the AF diesel engine closed cycle heat exchanger jacket water temperature will not exceed the high jacket water temperature trip setpoint during the two hour

SBO coping time. Therefore, the current design analysis remains applicable with the proposed increase in TS UHS temperature.

3.5.8 GL 96-06 Considerations

U.S. Nuclear Regulatory Commission Generic Letter 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," indicated concerns for possible water hammer events following either a LOCA or a Main Steam Line Break (MSLB) concurrent with a LOOP. The period of interest for the NRC GL 96-06 concern of water hammer is the first few minutes post-accident, while the pumps and fans are restarting following load shed. During this time, as shown in the temperature profile in Figure 1, the actual UHS temperature is below 102°F. The current design analysis reviewed the impact with an increase in SX temperature of 102°F and determined that a slight increase in fluid temperature will not result in significant changes to the amount of voiding and thus negligible impacts to void collapse and the existing results of this analysis.

3.5.9 Spent Fuel Pool Cooling

The spent fuel pool cooling heat exchanger is cooled by the CC system. Since the CC Heat Exchangers have been evaluated to be capable of removing the required heat load at the increased UHS temperature of 102°F during normal operation (see section 3.5.5), the spent fuel pool heat exchanger will continue to be able to perform its required design function. During a UHS DBA, the CC Heat Exchanger is also analyzed at 105.2°F and is capable of removing the required spent fuel pool heat exchanger heat load. Thus, the spent fuel pool cooling heat exchanger will remain capable of removing the required heat load ensuring the maximum pool bulk temperature is below the bounds of the design analysis.

3.5.10 Fire Protection

The Fire Protection pumps take suction from the Braidwood Station main cooling pond. The increase in UHS temperature has been evaluated not to impact the function of the fire protection system.

3.5.11 Conclusions

The results of the equipment analyses demonstrated that, with the increased SX temperature, margins in the design analyses were present which confirmed that the various components serviced by the SX and CC systems are acceptable without physical modification.

3.6 ACCIDENT ANALYSES

The accident analyses have been evaluated or reanalyzed for the increased UHS temperature. The affected analyses were analyzed for a UHS temperature of 104°F, as described in section 3.4.3. For non-LOCA analyses, using the temperature of 104°F is conservative because the UHS temperature analysis (Figures 1 and 2) show that the SX temperature does not approach 105.2°F until about 36 hours after the event and these analyses are analyzed for a duration significantly less than 36 hours. These analyses have been performed at the current licensed power level, including the Measurement Uncertainty Recapture (MUR) Uprate.

The following analyses have been reviewed and are not impacted by the UHS temperature increase:

- LOCA Analysis – Large Break - Best Estimate
- LOCA Analysis – Small Break
- LOCA Long Term Cooling/Post LOCA Boric Acid Precipitation
- LOCA Forces
- Evaluation of Auxiliary Equipment, Balance of Plant (BOP) and Nuclear Steam Supply System (NSSS) Design Transients
- Control Systems Operability / Margin to Trip/Component Sizing evaluations which reviewed the control and protection system setpoints to verify that the system capacities do not change
- Evaluation of the Cold Overpressure Mitigation System / Low Temperature Overpressure Protection System which protects the reactor vessel from potentially being exposed to conditions of fast propagating brittle fracture caused by design basis mass and heat input transients at low temperature operation
- Steam Generator Tube Rupture (SGTR) and SGTR Radiological/Doses
- I&C Systems / Equipment Qualification evaluation which considered the impact to the design, configuration, qualification and performance of the safety-related electrical components and systems
- Evaluation of the Containment Sump / GSI-191 analyses which included the effects of post-LOCA sump chemistry and composition on components downstream of the containment sump
- Evaluation of the Reactor Coolant Pump and Reactor Coolant Pump Motor limits on maximum CC and seal injection temperatures

The following analyses are impacted by the UHS temperature increase:

- LOCA Long Term/Short Term Mass and Energy (Containment Integrity)
- MSLB Inside Containment/Outside Containment Mass and Energy – Dose Steam Release (Containment Integrity)

While these two analyses are not directly affected by the UHS temperature increase, the heat removal performance for the RCFCs is used in the analysis and is affected by the UHS temperature increase because the RCFCs reject containment heat to the UHS.

3.6.1 LOCA Long Term/Short Term Mass and Energy (Containment Integrity)

The Braidwood Station Units were reanalyzed to assess an increase in the water temperature of the UHS to 104°F (see section 3.4.3). The largest impact on the LOCA containment analysis from the elevated UHS temperature would be the reduction of the performance of the RCFCs resulting in higher containment pressures for these events and reduced cooling by the CC heat exchangers.

Other changes were made to the LOCA containment analysis not related to the UHS temperature change. The analysis incorporated updated containment spray and safety injected flow rates. Additional changes to correct open items were 1) correction for the SG tube material to have the correct density and specific heat (Reference NSAL 14-2) 2) correction to the SATAN78 power shape selection option to select a chopped cosine power shape and

3) incorporation of an NRC approved model (Reference 3) for drift flux and break flow with inertia. In general, containment analysis peak pressure results would be expected to increase due to the proposed increase in UHS temperature and the associated impact to performance of the RCFCs. However, the SX temperature change coupled with the other changes described above resulted in peak pressure values similar to the current design analysis.

Results show that the new calculated peak pressure is below the existing Technical Specification Pa values of 42.8 psig for Unit 1 and 38.4 psig for Unit 2.

The following table summarizes the results.

Table 3: Containment Analysis Results

Break Location	Plant	Containment Peak Pressure for increased SX temperature (psig)	TS Pa (psig)
Double Ended Hot Leg (DEHL)	UNIT 1	42.1	42.8
	UNIT 2	37.7	38.4
Double Ended Pump Suction (DEPS)	UNIT 1	42.1	42.8
	UNIT 2	38.4	38.4

3.6.2 MSLB Inside Containment Mass and Energy (Containment Integrity)

The increase in SX temperature due to the elevated UHS temperature has an impact on the performance of the RCFCs, resulting in higher containment pressures and temperatures during the MSLB event. Therefore, the MSLB cases were reanalyzed for the increased UHS temperature. The results of all MSLB analyses at the elevated UHS temperature are bounded by the current design basis calculations.

3.6.2.1 MSLB Peak Containment Temperatures

The peak temperature response of all the Unit 1 MSLB cases analyzed is 322.1°F. This is lower than the maximum Unit 1 temperature of 333.6°F from the current design basis analyses. The peak temperature response of all the Unit 2 MSLB cases analyzed is 318.9°F. This is lower than the maximum Unit 2 temperature of 326.3°F from the current design basis analyses.

These peak temperatures were for a 1.0 ft^2 small double-end rupture (DER) break at 100% initial power, with a single failure of the main steam isolation valve in the faulted loop, with offsite power available, and 0% revaporization of the condensed liquid on the containment surfaces.

3.6.2.2 MSLB Peak Containment Pressures

The peak pressure response of all the MSLB cases for Unit 1 analyzed is 34.5 psig. The peak pressure response of all the MSLB cases for Unit 2 is 34.4 psig. Both cases for each Unit are well below the 50 psig design pressure acceptance criterion. The peak pressures for Unit 1 was calculated for a 0.90 ft^2 split break at 30% initial power, with a single failure of the main steam isolation valve in the faulted loop, and with offsite power available. The peak pressures for Unit 2 was calculated for a 0.83 ft^2 split break at 30% initial power, with a single failure of the main steam isolation valve in the faulted loop, and with offsite power available.

3.6.2.3 MSLB Composite Temperature and Pressure Profile (Unit 1 and Unit 2)

The composite containment temperature response for Unit 1 and Unit 2 were reviewed and were compared to the design Environmental Qualification (EQ) temperature profile. The revised temperature profile is enveloped by the existing design EQ profile. For EQ pressure, the EQ profile uses a flat 50 psig curve until 1200 seconds into the event and then a saturated pressure model after 1200 seconds. Therefore, the results of the analyses do not change the EQ curve.

3.7 OPERATOR ACTIONS

Operators read and record the UHS temperature on a shiftly basis in accordance with station procedures. Each unit has an operator that monitors SX pump discharge temperature. The control room indication for cooling water temperature is readily available from the plant process computer at each of the unit's computer consoles and main control board indications. Unit 1 and Unit 2 control room operators are both required to determine and record the SX pump temperature for the running SX trains for their respective units as part of their shiftly surveillance. The control room operator is required to record and compare the average SX pump discharge temperature from both units to the limits in TS SR 3.7.9.2. The SX pump discharge temperature (i.e., used to verify the TS SR 3.7.9.2 limit) is the average of each unit's running SX pump discharge temperature and could result in both units entering the required actions at the same time should SX temperature exceed the TS limit. In the event that there is an increase in UHS temperature such that a high alarm is received on the SX pump discharge temperature (i.e., high alarm setpoint is 96°F), operators log the SX pump discharge temperature more frequently. Operators will log the operating SX pumps discharge temperature hourly when the high alarm setpoint temperature of 96°F is reached. In the event that TS SR 3.7.9.2 limits are exceeded, both units would declare the UHS inoperable and follow the actions of TS 3.7.9 as currently required.

No operator actions regarding temperature monitoring will change as a result of the proposed licensed amendment. Existing Braidwood Station procedures presently provide guidance for high cooling lake temperatures including action to shutdown both units if temperatures cannot be maintained within TS limits.

The revised DBA for the UHS has determined that the limiting critical time period is that associated with four pump operation (i.e., the maximum UHS temperature reached with four SX

pump operation exceeds the maximum UHS temperature in which the evaluation of equipment was completed (105.2°F)). Because the maximum temperature in which the equipment has been evaluated is exceeded with four SX pump operation, it is necessary to limit operation with four SX pumps in the event of the DBA (i.e., LOCA with LOOP on one unit and loss of the main dike). Operation with four SX pumps is not required for normal operation or to respond to a design basis event. However, existing procedures currently allows operation with four SX pumps for operational flexibility (see section 3.4.3). The analysis demonstrates that four pump operation is only limited following loss of the manmade structure (dike) with coincident LOCA and LOOP on one unit with the safe non-accident shutdown of the other unit. For this event, four SX pumps are not required. The procedures which control response to this event will be revised prior to LAR approval to reflect the limitations of operation with four pumps (Regulatory Commitment #2).

3.8 MEASUREMENT UNCERTAINTY

To ensure the requested temperature limit is not exceeded, instrument uncertainty associated with the measurement of the UHS average water temperature is addressed in the surveillance procedures that are used to demonstrate compliance with the TS limit. The specific procedures are: 1BwOSR 0.1-1,2,3, 1BwOSR 0.1-4, 2BwOSR 0.1-1,2,3, and 2BwOSR 0.1-4.

In accordance with the Braidwood Station Technical Specifications Bases B 3.7.9, the average water temperature of the UHS is measured at the discharge of an SX pump. The surveillance procedures require that if the temperature of any operating SX pump exceeds 97°F, a precision temperature instrument, procured for this application, be used to verify the temperature. The difference between 97°F and the proposed Surveillance Requirement limit of less than ≤ 102°F is greater than the calculated instrument uncertainties associated with the installed instrumentation. Highly accurate measurement is accomplished by inserting the probe of the precision thermometer into spare thermowells adjacent to the installed instrumentation. The uncertainty of this precision thermometer is a maximum of 0.07°F. This instrumentation is valid for a calibrated range of up to 212°F, which bounds the new proposed maximum UHS temperature of 102°F. As part of the activities to implement the approved LAR, the temperature limit specified in the applicable surveillance procedures will be revised to 101.9°F to account for the uncertainty associated with this instrument.

4.0 <u>REGULATORY EVALUATION</u>

4.1 APPLICABLE REGULATORY REQUIREMENTS/CRITERIA

The design of the UHS satisfies the requirements of 10 CFR 50.36, "Technical Specifications," paragraph (c)(2)(ii), Criterion 3. This criterion states the following:

> (ii) A Technical Specification Limiting Condition for Operation (TS LCO) of a nuclear reactor must be established for each item meeting one or more of the following criteria:
>
> Criterion 3. A structure, system, or component that is part of the primary success path and which functions or actuates to mitigate a design basis accident or transient that either assumes the failure of or presents a challenge to the integrity of a fission product barrier.

The proposed change does not change the design function or purpose of the UHS, therefore, Criterion 3 of 10 CFR 50.36(c)(2)(ii) continues to be met.

General Design Criteria 2, "Design bases for protection against natural phenomena," and General Design Criteria 44, "Cooling water," of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," provides design considerations for the UHS. RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," Revision 2, dated January 1976, provides an acceptable approach for satisfying these criteria. The basis provided in RG 1.27, Revision 2, was employed for the temperature analysis of the Braidwood Station UHS.

General Design Criteria 5, “Sharing of structures, systems and components,” of Appendix A to 10 CFR Part 50 also provides design criteria applicable to the UHS, a shared system between Braidwood Station Units 1 and 2. The proposed change, including the re-analysis of the UHS DBA, was evaluated consistent with the existing methodology which considers a DBA event (i.e., a LOCA with LOOP) along with the safe non-accident shutdown and cooldown of the opposite unit. Therefore, GDC 5 criteria continue to be met by the reanalysis of the UHS DBA at the elevated initial UHS temperature of 102°F.

The proposed change continues to ensure that the plant's safety related equipment will maintain its design function at the higher UHS temperature. Therefore, there is no adverse impact of this change on Braidwood Station plant safety.

4.2 NO SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

In accordance with 10 CFR 50.90, "Application for amendment of license, construction permit, or early site permit," Exelon Generation Company, LLC (EGC) is requesting a change to the Technical Specifications (TS) of Facility Operating License Nos. NPF-72 and NPF-77 for Braidwood Station, Units 1 and 2.

The Ultimate Heat Sink (UHS) for Braidwood Station, Units 1 and 2 provides a heat sink for processing and operating heat from safety related components during a transient or accident, as well as during normal operation. This is done by utilizing the Essential Service Water (SX) System and the Component Cooling Water (CC) system. The UHS consists of an excavated essential cooling pond integral with the main cooling pond. The volume of the excavated essential cooling pond is sized to permit the safe shutdown and cooldown of both Braidwood Station units for a 30 day period, including a design basis event with no additional makeup water source. As discussed in the Braidwood Station Updated Final Safety Analysis Report (UFSAR), the design basis event for the Braidwood Station UHS is a Loss of Coolant Accident (LOCA) coincident with a Loss of Offsite Power (LOOP) in one unit, in conjunction with a normal shutdown of the other unit. The UHS provides a heat sink for process and operating heat from safety-related components during the UHS design basis event.

Currently, Surveillance Requirement (SR) 3.7.9.2 verifies the cooling water temperature supplied to the plant from the UHS is ≤100°F. If the temperature of the cooling water supplied to the plant from the UHS exceeds 100°F, the UHS must be declared inoperable in accordance with TS 3.7.9. Additionally, TS 3.7.9 Required Action A.1 requires that both units be placed in Mode 3 within 6 hours, and Required Action A.2 requires that both units be placed in Mode 5 within 36 hours.

The proposed change modifies the acceptance criterion in SR 3.7.9.2. The current TS SR 3.7.9.2 states: "Verify average water temperature of UHS is ≤100°F." The proposed TS SR 3.7.9.2 states: "Verify average water temperature of UHS is ≤102°F." There are no proposed changes to the TS Required Actions, Completion Times, Frequency of SR performance, or any other portions of TS 3.7.9.

The evaluations and analyses performed to support the proposed license amendment demonstrate that the plant's safety related equipment will maintain its design function at the higher UHS temperature.

According to 10 CFR 50.92, "Issuance of amendment," paragraph (c), a proposed amendment to an operating license involves no significant hazards consideration if operation of the facility in accordance with the proposed amendment would not:

1) Involve a significant increase in the probability or consequences of an accident previously evaluated;
2) Create the possibility of a new or different kind of accident from any accident previously evaluated; or
3) Involve a significant reduction in a margin of safety.

In support of this determination, an evaluation of each of the three criteria set forth in 10 CFR 50.92 is provided below:

1. Does the Proposed Change Involve a Significant Increase in the Probability or Consequences of an Accident Previously Evaluated?

   Response: No

The likelihood of a malfunction of any systems, structures or components (SSCs) supported by the UHS is not significantly increased by increasing the allowable Ultimate Heat Sink (UHS) temperature from ≤ 100°F to ≤ 102°F. The UHS provides a heat sink for process and operating heat from safety related components during a transient or accident, as well as during normal operation. The proposed change does not make any physical changes to any plant SSCs, nor does it alter any of the assumptions or conditions upon which the UHS is designed. The UHS is not an initiator of any analyzed accident. All equipment supported by the UHS has been evaluated to demonstrate that their performance and operation remains as described in the UFSAR with no increase in probability of failure or malfunction.

The SSCs credited to mitigate the consequences of postulated design basis accidents remain capable of performing their design basis function. The change in maximum UHS temperature has been evaluated using the UFSAR described methods to demonstrate that the UHS remains capable of removing normal operating and post-accident heat. The change in UHS temperature and resulting containment response following a postulated design basis accident has been demonstrated to not be impacted. Additionally, all the UHS supported equipment, credited in the accident analysis to mitigate an accident, has been shown to continue to perform their design function as described in the UFSAR.

Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the Proposed Change Create the Possibility of a New or Different Kind of Accident from any Accident Previously Evaluated?

   Response: No

The proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated. The proposed change does not introduce any new modes of plant operation, change the design function of any SSC, change the mode of operation of any SSC, or change any actions required when the TS limit is exceeded. There are no new equipment failure modes or malfunctions created as affected SSCs continue to operate in the same manner as previously evaluated and have been evaluated to perform as designed at the increased UHS temperature and as assumed in the accident analysis. Additionally, accident initiators remain as described in the UFSAR and no new accident initiators are postulated as a result of the increase in UHS temperature.

Therefore, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. Does the Proposed Change Involve a Significant Reduction in a Margin of Safety?

   Response: No

The proposed change continues to ensure that the maximum temperature of the cooling water supplied to the plant SSCs during a UHS design basis event remains within the evaluated equipment limits and capabilities assumed in the accident analysis. The proposed change does not result in any changes to plant equipment function, including setpoints and actuations. All equipment will function as designed in the plant safety analysis without any physical modifications. The proposed change does not alter a limiting condition for operation, limiting safety system setting, or safety limit specified in the Technical Specifications.

The proposed change does not adversely impact the UHS inventory required to be available for the UFSAR described design basis accident involving the worst case 30-day period including losses for evaporation and seepage to support safe shutdown and cooldown of both Braidwood Station units. Additionally, the structural integrity of the UHS is not impacted and remains acceptable following the change, thereby ensuring that the assumptions for both UHS temperature and inventory remain valid.

Therefore, since there is no adverse impact of this change on the Braidwood Station safety analysis, there is no reduction in the margin of safety of the plant.

4.3 CONCLUSIONS

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

EGC has evaluated this proposed operating license amendment consistent with the criteria for identification of licensing and regulatory actions requiring environmental assessment in accordance with 10 CFR 51.21, "Criteria for and identification of licensing and regulatory actions requiring environmental assessments." EGC has determined that this proposed change meets the criteria for a categorical exclusion set forth in paragraph (c)(9) of 10 CFR 51.22, "Criterion or categorical exclusion; identification of licensing and regulatory actions eligible for categorical exclusion or otherwise not requiring environmental review," and as such, has determined that no irreversible consequences exist in accordance with paragraph (b) of 10 CFR 50.92, "Issuance of amendment." This determination is based on the fact that this change is being proposed as an amendment to the license issued pursuant to 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," which changes a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, "Standards for Protection Against Radiation," or which changes an inspection or a surveillance requirement, and the amendment meets the following specific criteria:

(i) The amendment involves no significant hazards consideration.

As demonstrated in Section 4.2, "No Significant Hazards Consideration," the proposed change does not involve any significant hazards consideration.

(ii) There is no significant change in the types or significant increase in the amounts of any effluent that may be released offsite.

The proposed change does not result in an increase in power level, does not increase the production nor alter the flow path or method of disposal of radioactive waste or byproducts. The proposed change continues to ensure that the plant's safety related equipment will maintain its design function at the higher UHS temperature. Therefore, there is no impact of this change on Braidwood Station safety analyses including the consequences of such events.

Based on the above evaluation, the proposed change will not result in a significant change in the types or significant increase in the amounts of any effluent released offsite.

(iii) There is no significant increase in individual or cumulative occupational radiation exposure.

There is no net increase in individual or cumulative occupational radiation exposure due to the proposed change. The proposed action will not change the level of controls or methodology used for processing of radioactive effluents or handling of solid radioactive waste, nor will the proposed action result in any change in the normal radiation levels within the plant.

Based on the above information, there will be no increase in individual or cumulative occupational radiation exposure resulting from this change.

6.0 REFERENCES

1. Letter from Daniel J. Enright (EGC) to U.S. Nuclear Regulatory Commission, "Request for Enforcement Discretion for Technical Specification 3.7.9 'Ultimate Heat Sink,'" dated July 10, 2012
2. Engineering Change (EC) Evaluation 396478 Revision 0, "Support Analyses for the License Amendment Request to Raise the Maximum UHS Temperature for the UHS in TS LCO 3.7.9."
3. WCAP-10325-P-A, "Westinghouse LOCA Mass and Energy Release Model for Containment Design March 1979 Version," dated May, 1983
4. Procedure 0BwOA ENV-3, "Braidwood Cooling Lake Low Level Unit 0," Revision 102

Attachment 2

Mark-up of Proposed Technical Specification Page Change

3.7 PLANT SYSTEMS

3.7.9 Ultimate Heat Sink (UHS)

LCO 3.7.9 The UHS shall be OPERABLE.

APPLICABILITY: MODES 1, 2, 3, and 4.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. UHS inoperable.	A.1 Be in MODE 3. AND A.2 Be in MODE 5.	6 hours 36 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.7.9.1	Verify water level of UHS is ≥ 590 ft Mean Sea Level (MSL).	In accordance with the Surveillance Frequency Control Program
SR 3.7.9.2	Verify average water temperature of UHS is ≤ ~~100~~102°F.	In accordance with the Surveillance Frequency Control Program
SR 3.7.9.3	Verify bottom level of UHS is ≤ 584 ft MSL.	In accordance with the Surveillance Frequency Control Program

Attachment 3

Mark-up of Proposed Technical Specification Bases Pages Changes -

For Information Only

B 3.7 PLANT SYSTEMS

B 3.7.9 Ultimate Heat Sink (UHS)

BASES

BACKGROUND

The UHS provides a heat sink for processing and operating heat from safety related components during a transient or accident, as well as during normal operation. This is done by utilizing the Essential Service Water (SX) System and the Component Cooling Water (CC) System.

The UHS consists of an excavated essential cooling pond integral with the main cooling pond, and the piping and valves connecting the pond with the SX System pumps. The UHS is described in UFSAR, Section 9.2.5 (Ref. 1). The two principal functions of the UHS are the dissipation of residual heat after reactor shutdown, and dissipation of residual heat after an accident.

The basic performance requirements are that a 30 day supply of water be available, and that the design basis temperatures of safety related equipment not be exceeded. The UHS is sufficiently oversized to permit a minimum of 30 days of operation with no makeup.

Additional information on the design and operation of the system, along with a list of components served, can be found in Reference 1.

BASES

APPLICABLE SAFETY ANALYSES

The UHS is the sink for heat removed from the reactor core following all accidents and anticipated operational occurrences in which the unit is cooled down and placed on Residual Heat Removal (RHR) operation. The UHS is also the normal heat sink for condenser cooling via the Circulating Water System. Unit operation at full power represents the UHS maximum heat load. Its maximum post accident heat load occurs 20 minutes after a design basis Loss Of Coolant Accident (LOCA). Near this time, the unit switches from injection to recirculation and the containment cooling systems and RHR are required to remove the core decay heat.

The operating limits are based on conservative heat transfer analyses for the worst case LOCA. Reference 1 provides the details of the assumptions used in the analysis, which include worst expected meteorological conditions, conservative uncertainties when calculating decay heat, and worst case single active failure (e.g., single failure of a manmade structure). The UHS is designed in accordance with Regulatory Guide 1.27 (Ref. 2), which requires a 30 day supply of cooling water in the UHS.

The UHS satisfies Criterion 3 of 10 CFR 50.36(c)(2)(ii).

LCO

The UHS is required to be OPERABLE and is considered OPERABLE if it contains a sufficient volume of water at or below the maximum temperature that would allow the SX System to operate for at least 30 days following the design basis LOCA without the loss of Net Positive Suction Head (NPSH), and without exceeding the maximum design temperature of the equipment served by the SX System. To meet this condition, the UHS temperature should not exceed 102~~0~~°F and the level should not fall below 590 ft mean sea level during normal unit operation.

APPLICABILITY

In MODES 1, 2, 3, and 4, the UHS is required to support the OPERABILITY of the equipment serviced by the UHS and required to be OPERABLE in these MODES.

In MODE 5 or 6, the OPERABILITY requirements of the UHS are determined by the systems it supports.

BASES

ACTIONS

A.1 and A.2

If the UHS is inoperable, the unit must be placed in a MODE in which the LCO does not apply. To achieve this status, the unit must be placed in at least MODE 3 within 6 hours and in MODE 5 within 36 hours.

The allowed Completion Times are reasonable, based on operating experience, to reach the required unit conditions from full power conditions in an orderly manner and without challenging plant systems.

SURVEILLANCE REQUIREMENTS

SR 3.7.9.1

This SR verifies that adequate long term (30 day) cooling can be maintained. The specified level also ensures that sufficient NPSH is available to operate the SX pumps. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program. The 24 hour Frequency is based on operating experience related to trending of the parameter variations during the applicable MODES. This SR verifies that the UHS water level is ≥ 590 ft mean sea level United States Geological Society datum.

SR 3.7.9.2

This SR verifies that the SX System is available to cool the CC System to at least its maximum design temperature with the maximum accident or normal design heat loads for 30 days following a Design Basis Accident. This SR verifies that the average water temperature of the UHS is ≤ 102°F, as measured at the discharge of an SX pump. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program. ~~This SR verifies that the average water temperature of the UHS is ≤ 100°F, as measured at the discharge of an SX pump.~~

BASES

SURVEILLANCE REQUIREMENTS (continued)

SR 3.7.9.3

This surveillance verifies that the UHS contains adequate storage volume to supply the required design basis inventory to support the function of the essential service water system. SR 3.7.9.1 verifies the contained volume of the UHS, while this SR verifies that the UHS, if filled to the depth required by SR 3.7.9.1, can supply the water required to support the safety function of the system.

SR 3.7.9.3 assures that the bottom elevation of the UHS is less than or equal to 584 ft Mean Sea Level (MSL). This surveillance is performed by means of a hydrographic survey. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program.

REFERENCES

1. UFSAR, Section 9.2.5.
2. Regulatory Guide 1.27.

Attachment 4
Summary of Regulatory Commitments

COMMITMENT	COMMITTED DATE OR "OUTAGE"	COMMITMENT TYPE	
		ONE-TIME ACTION (Yes/No)	PROGRAMMATIC (Yes/No)
Regulatory Commitment #1: Existing design analyses supporting implementation of the proposed TS SR 3.7.9.2 increased UHS temperature will be updated prior to NRC approval of the license amendment	Prior to NRC approval of the license amendment request	Yes	No
Regulatory Commitment #2: Operating procedures associated with the response to the loss of dike event concurrent with a LOCA and LOOP which are impacted by limitation with four SX pump operation will be updated prior to NRC approval of the license amendment	Prior to NRC approval of the license amendment request	Yes	No

Attachment 5

Braidwood Station Analysis, “Thermal Performance of Ultimate Heat Sink (UHS) During Postulated Loss of Coolant Accident” (ATD-0109 Revision 4)

ATTACHMENT 1
Design Analysis Cover Sheet

Design Analysis		**Last Page No.** [6] Attachment F, Page F3	
Analysis No.: [1] ATD -0109		**Revision:** [2] 4 Major ☒	Minor ☐
Title: [3] Thermal Performance of UHS During Postulated Loss of Coolant Accident			
EC/ECR No.: [4] EC 396478		**Revision:** [5] 0	

		Component(s): [14]	
Station(s): [7]	Braidwood		
Unit No.: [8]	1/2	N/A	
Discipline: [9]	M, MED		
Descrip. Code/Keyword: [10]	UHS, M03, M13		
Safety/QA Class: [11]	Safety Related		
System Code: [12]	SX		
Structure: [13]	N/A		

CONTROLLED DOCUMENT REFERENCES [15]

Document No.:	From/To	Document No.:	From/To
ATD-0063	From		
MAD 83-0239	From		
BRW-99-0481-M	From		

Is this Design Analysis Safeguards Information? [16] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [17] Yes ☐ No ☒ If yes, ATI/AR#:

This Design Analysis SUPERCEDES: [18] BRW-00-0018-M **in its entirety.**

Description of Revision (list changed pages when all pages of original analysis were not changed): [19]

This revision increases the initial Ultimate Heat Sink (UHS) temperature to 102°F. The weather data is updated to include latest weather from 1948 to 2012, and the UHS heatload is updated per the latest revision of ATD-0063.

All pages revised (Main Body 19 pages + OAR Checklist 3 pages + Attachments 107 pages, Total of 129 pages)

	Print Name	Sign Name	Date
Preparer: [20]	Pawel Kut – S&L	[signature]	05-29-14

Method of Review: [21] **Detailed Review** ☒ **Alternate Calculations (attached)** ☐ **Testing** ☐

	Print Name	Sign Name	Date
Reviewer: [22]	Paul J. Szymiczek – S&L	[signature]	5/30/2014

Review Notes: [23] Independent review ☒ Peer review ☐

(For External Analyses Only)

	Print Name	Sign Name	Date
External Approver: [24]	Robert J. Peterson – S&L	[signature]	5-30-14
Exelon Reviewer: [25]	GIOVANNI PANICI	[signature]	5-30-2014

Independent 3rd Party Review Reqd? [26] **Yes** ☒ **No** ☐

	Print Name	Sign Name	Date
Exelon Approver: [27]	George R. Wilhelmsen	[signature]	6/2/2014

ATTACHMENT 2
Owner's Acceptance Review Checklist for External Design Analyses
Page 1 of 3

Design Analysis No.: ATD-0109 **Rev:** 4 PAGE 1A

No	Question	Instructions and Guidance	Yes / No / N/A
1	Do assumptions have sufficient documented rationale?	All Assumptions should be stated in clear terms with enough justification to confirm that the assumption is conservative. For example, 1) the exact value of a particular parameter may not be known or that parameter may be known to vary over the range of conditions covered by the Calculation. It is appropriate to represent or bound the parameter with an assumed value. 2) The predicted performance of a specific piece of equipment in lieu of actual test data. It is appropriate to use the documented opinion/position of a recognized expert on that equipment to represent predicted equipment performance. Consideration should also be given as to any qualification testing that may be needed to validate the Assumptions. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☑ Yes ☐ No ☐ N/A
2	Are assumptions compatible with the way the plant is operated and with the licensing basis?	Ensure the documentation for source and rationale for the assumption supports the way the plant is currently or will be operated post change and they are not in conflict with any design parameters. If the Analysis purpose is to establish a new licensing basis, this question can be answered yes, if the assumption supports that new basis.	☑ Yes ☐ No ☐ N/A Supports the UHS LAR
3	Do all unverified assumptions have a tracking and closure mechanism in place?	**If** there are unverified assumptions without a tracking mechanism indicated, **then** create the tracking item either through an ATI or a work order attached to the implementing WO. Due dates for these actions need to support verification prior to the analysis becoming operational or the resultant plant change being op authorized.	☐ Yes ☐ No ☑ N/A Supports the UHS LAR
4	Do the design inputs have sufficient rationale?	The origin of the input, or the source should be identified and be readily retrievable within Exelon's documentation system. If not, then the source should be attached to the analysis. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☑ Yes ☐ No ☐ N/A
5	Are design inputs correct and reasonable with critical parameters identified, if appropriate?	The expectation is that an Exelon Engineer should be able to clearly understand which input parameters are critical to the outcome of the analysis. That is, what is the impact of a change in the parameter to the results of the analysis? If the impact is large, then that parameter is critical.	☑ Yes ☐ No ☐ N/A
6	Are design inputs compatible with the way the plant is operated and with the licensing basis?	Ensure the documentation for source and rationale for the inputs supports the way the plant is currently or will be operated post change and they are not in conflict with any design parameters.	☑ Yes ☐ No ☐ N/A Supports the UHS LAR

ATTACHMENT 2
Owner's Acceptance Review Checklist for External Design Analyses
Page 2 of 3

Design Analysis No.: ATD-0109 **Rev:** 4 PAGE 1B

No	Question	Instructions and Guidance	Yes / No / N/A
7	Are Engineering Judgments clearly documented and justified?	See Section 2.13 in CC-AA-309 for the attributes that are sufficient to justify Engineering Judgment. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☑ ☐ ☐
8	Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	Ensure the justification for the engineering judgment supports the way the plant is currently or will be operated post change and is not in conflict with any design parameters. **If** the Analysis purpose is to establish a new licensing basis, **then** this question can be answered yes, if the judgment supports that new basis.	☑ ☐ ☐
9	Do the results and conclusions satisfy the purpose and objective of the Design Analysis?	Why was the analysis being performed? Does the stated purpose match the expectation from Exelon on the proposed application of the results? **If** yes, **then** the analysis meets the needs of the contract.	☑ ☐ ☐
10	Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	Make sure that the results support the UFSAR defined system design and operating conditions, or they support a proposed change to those conditions. If the analysis supports a change, are all of the other changing documents included on the cover sheet as impacted documents?	☑ ☐ ☐ Supports the UHS LAR
11	Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	Does the analysis support a temporary condition or procedure change? Make sure that any other documents needing to be updated are included and clearly delineated in the design analysis. Make sure that the cover sheet includes the other documents where the results of this analysis provide the input. Ref. EC 396478	☐ ☑ ☐ Supports the UHS LAR
12	Have margin impacts been identified and documented appropriately for any negative impacts (Reference ER-AA-2007)?	Make sure that the impacts to margin are clearly shown within the body of the analysis. If the analysis results in reduced margins ensure that this has been appropriately dispositioned in the EC being used to issue the analysis.	☐ ☐ ☑ Results are evaluated in other analyses
13	Does the Design Analysis include the applicable design basis documentation?	Are there sufficient documents included to support the sources of input, and other reference material that is not readily retrievable in Exelon controlled Documents?	☑ ☐ ☐
14	Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change?	Determine if sufficient searches have been performed to identify any related analyses that need to be revised along with the base analysis. It may be necessary to perform some basic searches to validate this. Ref. EC 396478	☑ ☐ ☐
15	Do the sources of inputs **and** analysis methodology used meet committed technical and regulatory requirements?	Compare any referenced codes and standards to the current design basis and ensure that any differences are reconciled. If the input sources **or** analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code	☑ ☐ ☐

ATTACHMENT 2
Owner's Acceptance Review Checklist for External Design Analyses
Page 3 of 3

Design Analysis No.: ATD-0109 **Rev:** 4 PAGE 1c

No	Question	Instructions and Guidance	Yes / No / N/A
16	Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	Based on the risk assessment performed during the pre-job brief for the analysis (per HU-AA-1212), ensure that sufficient reviews of any supporting documents not provided with the final analysis are performed. See ITPR RESULTS (PAGES 1d, 1e, 1f, 1g, 1h)	☑ Yes ☐ No ☐ N/A
17	Do operational limits support assumptions and inputs?	Ensure the Tech Specs, Operating Procedures, etc. contain operational limits that support the analysis assumptions and inputs. NOTE 1	☑ Yes ☐ No ☐ N/A

Create an SFMS entry as required by CC-AA-4008. SFMS Number: 44966

NOTE 1 This analysis supports the Ultimate Heat Sink LAR

ENERCON
Excellence—Every project. Every day.

May 23, 2014

Mr. John Panici
Exelon Nuclear
Braidwood Nuclear Generating Station
35100 South Route 53
Braceville, IL 60407

Subject: Independent Third Party Review for Braidwood Design Analysis "Thermal Performance of UHS During Postulated Loss of Coolant Accident" ATD-109, Revision 4, dated 16 May 2014

Dear Mr. Panici,

ENERCON has reviewed the subject design analysis revision under the requirements for third party review given by HU-AA-1212.

Due to the fact that the calculation used S&L computer program(s) to which ENERCON did not have access, this review is limited to an assessment of the overall approach and methodology along with the reasonableness of the inputs, assumptions, and conclusions.

The purpose and background of the calculation are found to be consistent with the requirements of the project. However, while section 1.0 states that the purpose of the calculation is to demonstrate the adequacy of the Ultimate Heat Sink (UHS) to provide sufficient cooling under the worst case environmental conditions, the determination of adequacy is not clearly demonstrated. This is considered to be a weakness.

The assumed water properties are judged to be acceptable as is the assumption of no makeup to the ultimate heat sink (UHS) from other sources.

The overall approach is found to be reasonable; the methodology section indicates that the approach follows the recommendations of Regulatory Guide 1.27. However, while RG 1.27 includes acceptability criteria for the UHS, the calculation draws no conclusions as to the acceptability of the results of the analyses.

Additional observations detailed within the attached comment/resolution form.

Please call if you have any questions or comments or wish to discuss.

Sincerely

J. P. Logatto
Lead Mechanical Engineer
ENERCON Northeast

Cc: R. Klacik (Enercon)

May 23, 2014
Mr. John Panici
Page 3 of 5

Attachment 1
Comment / Resolution Form

No.	Comment	Resolution	Concur (Y/N)
1	ATD-0109, 1.0: Section states that the purpose is to demonstrate the adequacy of the Ultimate Heat Sink (UHS) under the worst case environmental conditions. This objective is not met.	Purpose section was clarified as follows: *The purpose of this calculation is to determine the thermal response of the Ultimate Heat Sink (UHS) during the shutdown of both units after a Design Basis Accident (DBA) under worst case environmental conditions.*	Y/JPL
2	ATD-0109, P10: Basis for design input 4.2 not clear. The referenced calculation, MAD 83-0239, does not clearly establish the basis for the drawdown of the UHS.	Reference for the drawdown curve (Section 4.2) is changed to Ref. 5.4 which is a Area/Volume vs. Elevation plot. This plot is a part of calculation MAD 83-0239.	Y/JPL
3	ATD-0109: Section 6.0 does not adequately describe the computations being performed, with the exception of determination of a transit time calculated for the normal UHS level in subsection 6.2. For this reason, proper use of the design inputs cannot be fully assessed.	Section 6 only contains calculations that are not documented in other parts (Attachments) of the calculation. To avoid duplication it is proposed that this section remains as is.	Y/JPL
4	ATD-0109, Table 6-2: The design inputs are from section 4.0; the Design Basis column calls out design input numbers 2.1 & 2.3 for effective volume and flowrate, respectively.	This has been changed as follows 2.1 changed to 4.2 2.3 changed to 4.5	Y/JPL
5	ATD-0109: Section 7.0 presents results in the form of maximum plant inlet temperature, but draws no conclusions as to the acceptability of the resulting temperatures or the effect on plant cooldown.	Per discussion with Exelon the acceptability of the UHS temperatures will be performed in follow-on analysis. This calculation will only calculate thermal response. Purpose has been adjusted per comment # 1.	Y/JPL
6	Attachment A, PA5: What is the source of the circulating water flow of 1844.8 ft^3/s? Provide	This flow rate is selected to create a transit time of 3 hours through the lake.	Y/JPL

	reference.	This bullet point in Section 2.1 of Attachment A has been updated to clarify this calculation as follows: *The plant flow is set at 1844.8 ft^3/s to obtain a lake transit time of 3 hours (Plant Flow = Effective Lake Volume / Transit Time, 457.4 acre-ft * 43,356 ft^3/acre-ft / 10,800 s = 1844.8 ft^3/s).*	
7	Attachment A, PA5, 2.2: What is the basis for the temperature rise values given by the 5th bullet? Conflicts with temperature rise values given in Attachment C.	The basis for the temperature rise values given by the 5th bullet is provided in the second paragraph of Assumption 3.3 of Attachment A. This is an average of the temperature rise values provided in Attachment C.	Y/JPL
8	Attachment A, PA12, Table 6-7: How is the lake temperature a function of the number of pumps running? There should be a discussion of the results and an explanation of their significance.	The worst weather file changes based on the number of pumps in operation. Since the weather starts on different dates, the initial natural lake temperature will change based on the case being run. These temperatures are used as input in the main body of this calculation. Further explanation has been added to this paragraph as follows: *The initial natural temperature for each case is taken to be the natural temperature of the lake at the time step of the start date of the weather file. The natural lake temperature at these time steps is found in the results of the 'Worst_Weather_110' case from the file 'Worst_Weather_110.pltX'. These natural lake temperatures will be used to set the initial natural lake temperature in the worst weather LAKET runs made in the main body of this calculation. The initial natural temperatures are summarized in the table below.*	Y/JPL

9			

CALCULATION TABLE OF CONTENTS

1.0 PURPOSE AND BACKGROUND

1.1 Purpose

The purpose of this calculation is to determine the thermal response of the Ultimate Heat Sink (UHS) during the shutdown of both units after a Design Basis Accident (DBA) under worst case environmental conditions. One unit is postulated to have a loss of coolant accident (LOCA), with loss of off site power (LOOP), and the other unit is postulated to undergo normal shutdown. The main dam of the lake is also assumed to have been breached due to a seismic event making use of the Ultimate Heat Sink (which is a Category I structure) necessary.

Revision 4

The purpose of Revision 4 is to revise the existing Ultimate Heat Sink (UHS) analysis to increase the initial UHS temperature to 102°F. The revision also includes updated meteorological conditions from 7/5/1948 up to 12/31/2012 (using weather data from Peoria, IL and onsite meteorological data) as well as the weather selection methodology from Rev. 2 of Regulatory Guide 1.27 [Ref. 5.6]. This revision includes updates to the latest revision of UHS Heat Load Analysis [Ref. 5.2] with the post-MUR power level for 2, 3, and 4 Essential Service Water (SX) pumps in operation.

Following are the specific changes included in Revision 4:

- Initial UHS temperature increased to 102°F
- Updated weather (1948 to 2012), worst weather selection per Rev 2 of the Regulatory Guide 1.27
- UHS Heat Load updated per latest revision of the heat load calculation ATD-0063.
- Case runs (8 per day, every 3 hours starting at 12 AM) with 2, 3, and 4 SX pumps in operation plus 3 maximum evaporation cases, and 2 sensitivity cases.

The analysis determines following parameters:

- Maximum UHS temperature v.s. DBA start time
- Maximum UHS inventory loss

1.2 Background

The thermal performance of the Braidwood UHS was originally developed based on the initial UHS temperature of 98°F and hot weather condition from summer of 1955 for highest UHS temperature and summer of 1971 for highest UHS evaporation. Over the years the UHS analysis was revised to increase the initial UHS temperature to 100°F. This revision increases the initial UHS temperature to 102°F, updates to the latest meteorological conditions up to 12/31/2012, and latest revision of UHS Heat Load Analysis.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

The Sargent & Lundy (S&L) LAKET-PC computer program [Ref. 5.5] is utilized to determine the combined impact of plant heat load (both Units), SX flowrate, initial UHS temperature, and meteorological conditions on the UHS response. Based on the initial UHS temperature of 102°F and the worst meteorological conditions, the maximum UHS temperature is determined for 8 different start times (every 3 hours, starting at 12 AM) with 2, 3, and 4 SX pumps in operation. Additionally the worst evaporation (highest inventory loss) over the 30 days is determined.

LAKET-PC computer program [Ref. 5.5] is a one-dimensional thermal prediction model based on the plug flow model as described in the NUREG-0693 [Ref. 5.13]. Additional justification of applicability of LAKET-PC to Braidwood UHS is discussed in Attachment D.

2.1 Methodology

2.1.1 Regulatory Guide Criteria

Reg. Guide 1.27, Rev. 2 [Ref. 5.6] describes a method for considering meteorological conditions in the design of the UHS. A synthetic weather file is created using weather data from the critical time period (which depends on the total SX flow rate) due to design of the UHS, the worst 24 hours, and the worst 30 days, combined in this order. For the Braidwood UHS, the critical time period unique to the design of the UHS is the transit time, which depends on the number of SX pumps in operation. The transit time is 48 hours for two SX pumps in operation, 36 hours for three SX pumps in operation, and 24 hours for four SX pumps in operation (see Section 6.2).

2.1.2 Selection of Worst Weather and Worst Net Evaporation Data

The methodology used to determine the worst 24 hour, 36 hour, 48 hour and 30 day temperature periods is documented in Attachment A. The weather data considered in this analysis spans from July 1948 to December 2012 using weather data from Peoria, IL and Springfield, IL from July 1948 to December 1997 and from Braidwood Nuclear Generating Station and Peoria, IL from January 1998 to December 2012. This is described in more detail in Attachment A. Since cases will be run at varying start times, the worst weather for each of the time periods listed above will be found at each different starting time.

In addition to finding the worst weather time periods, the 30 day period resulting in the worst net evaporation is also determined. This is done following a similar methodology to finding the worst weather and is documented in Attachment A.

2.1.3 Plant Temperature Rise

The plant temperature rise (which is an input to the LAKET-PC model) is dependent on the heat load that is rejected to the UHS. The rejected heat load is determined in ATD-0063 [Ref. 5.2].

The temperature rise through the plant is determined by the following equation:

$$\Delta T = \frac{Q}{c_p m} \qquad \text{(Eq. 2-1)}$$

where:

ΔT = plant temperature rise [°F]

Q = heat rejection rate to the UHS [BTU/hr]

c_p = specific heat capacity of water [BTU/(lb_m-°F)]

m = mass flow rate [lb_m/hr], [Ref's. 5.11 and 5.12]

$$m = \frac{GPM \cdot 231\left(in^3/gal\right) \cdot 60\left(m/hr\right) \cdot 62.4}{1728\left(in^3/ft^3\right)} \qquad \text{(Eq. 2-2)}$$

where:

GPM = plant flow [gpm]

62.4 = water density [lb/ft^3, Assumption 3.1]

The LAKET-PC runs for Braidwood UHS are performed based on the 3 hour time steps. Therefore the plant temperature rise (ΔT) needs to be calculated for every time step. Since the heat rejection rate is decreasing rapidly during the first 24 hours [Ref. 5.2] the total heat rejected in any given time step in the first 24 hours is calculated by the trapezoidal rule integration as shown by the equation below:

$$Q_{time\_step} = \frac{\sum \frac{(t_i - t_{i-1}) \cdot (Q_i + Q_{i-1})}{2}}{60 \cdot 60 \cdot 3} \qquad \text{(Eq. 2-3)}$$

where:

Q_{time_step} = average heat rejection rate over the 3 hour time step [BTU/hr]

t = time [sec]

Q = heat rejection rate to the UHS [BTU/hr]

For the time steps after 24 hours and up to 222 hours, the heat rejection rate is linearly interpolated based on the available data. The heat rejection rate above the 222 hours is conservatively held as a constant value based on the last

available point from the UHS heat load calculation [Ref. 5.2]. The results of these calculations and the values entered into the LAKET-PC model are presented in Attachment C.

2.1.4 Wind Gradients

LAKET-PC models wind gradients (as a function of the elevation above ground level) per the following equation:

$$WNDCOR = 1.15\left[\frac{mph}{knots}\right]\cdot\left(6.56/WINDZ\right)^{0.3} \quad \text{(Eq. 2-4)}$$

where:

WNDCOR = wind correction factor to 2m above ground level
WINDZ = measurement elevation above ground level [ft]
1.15 = conversion factor from knots to mph

The wind speed extrapolation is a power law equation correcting the wind speed to an elevation of 2 meters (6.56 ft) above the ground level (the reference wind speed elevation used for wind functions in MIT Report No. 161 [Ref. 5.14]). There are a variety of exponential factors that have been used over the years in the power law equation, LAKET-PC uses a conservatively bounding value of 0.3 for the exponent.

2.1.5 LAKET-PC Case Runs

There are two different types of cases that are run in LAKET-PC: 1) Worst temperature cases and 2) Worst net evaporation cases.

A) Worst Temperature Cases - The worst temperature cases determine the maximum UHS outlet temperature based on an initial UHS temperature of 102°F. These cases are run at 8 varying start times throughout the day (every 3 hours, starting at 12 AM). Additionally, a limiting 4 SX pump case is rerun to determine the maximum UHS initial temperature that would result in maximum UHS temperature of 104°F. As a sensitivity case, a limiting 3 SX pump case is rerun with a reduced UHS inventory corresponding to 3" of sedimentation.

B) Worst Net Evaporation Cases - The net evaporation cases use the same input file as the corresponding worst weather case (2, 3, or 4 SX pumps), but are run with the most limiting 30-day net evaporation weather file. These cases are run with two, three, and four SX pumps in operation. The most limiting net evaporation weather is 6/1/1988 to 7/1/1988 (9 AM start) as determined in Attachment A.

A summary of all cases run for this analysis is shown below:

Table 2-1: List of LAKET-PC Cases

Case Name	Time Period	SX Pumps	Start Time	Weather File
Worst Temperature Cases – 2 SX Pumps				
Case 2_12AM	worst 48 hrs + worst 24 hrs + worst 30 days	2	0:00	12AM_2.txt
Case 2_3AM	worst 48 hrs + worst 24 hrs + worst 30 days	2	3:00	3AM_2.txt
Case 2_6AM	worst 48 hrs + worst 24 hrs + worst 30 days	2	6:00	6AM_2.txt
Case 2_9AM	worst 48 hrs + worst 24 hrs + worst 30 days	2	9:00	9AM_2.txt
Case 2_12PM	worst 48 hrs + worst 24 hrs + worst 30 days	2	12:00	12PM_2.txt
Case 2_3PM	worst 48 hrs + worst 24 hrs + worst 30 days	2	15:00	3PM_2.txt
Case 2_6PM	worst 48 hrs + worst 24 hrs + worst 30 days	2	18:00	6PM_2.txt
Case 2_9PM	worst 48 hrs + worst 24 hrs + worst 30 days	2	21:00	9PM_2.txt
Worst Temperature Cases – 3 SX Pumps				
Case 3_12AM	worst 36 hrs + worst 24 hrs + worst 30 days	3	0:00	12AM_3.txt
Case 3_3AM	worst 36 hrs + worst 24 hrs + worst 30 days	3	3:00	3AM_3.txt
Case 3_6AM	worst 36 hrs + worst 24 hrs + worst 30 days	3	6:00	6AM_3.txt
Case 3_9AM	worst 36 hrs + worst 24 hrs + worst 30 days	3	9:00	9AM_3.txt
Case 3_12PM	worst 36 hrs + worst 24 hrs + worst 30 days	3	12:00	12PM_3.txt
Case 3_3PM	worst 36 hrs + worst 24 hrs + worst 30 days	3	15:00	3PM_3.txt
Case 3_6PM	worst 36 hrs + worst 24 hrs + worst 30 days	3	18:00	6PM_3.txt
Case 3_9PM	worst 36 hrs + worst 24 hrs + worst 30 days	3	21:00	9PM_3.txt
Worst Temperature Cases – 4 SX Pumps				
Case 4_12AM	worst 24 hrs + worst 24 hrs + worst 30 days	4	0:00	12AM_4.txt
Case 4_3AM	worst 24 hrs + worst 24 hrs + worst 30 days	4	3:00	3AM_4.txt
Case 4_6AM	worst 24 hrs + worst 24 hrs + worst 30 days	4	6:00	6AM_4.txt
Case 4_9AM	worst 24 hrs + worst 24 hrs + worst 30 days	4	9:00	9AM_4.txt
Case 4_12PM	worst 24 hrs + worst 24 hrs + worst 30 days	4	12:00	12PM_4.txt
Case 4_3PM	worst 24 hrs + worst 24 hrs + worst 30 days	4	15:00	3PM_4.txt
Case 4_6PM	worst 24 hrs + worst 24 hrs + worst 30 days	4	18:00	6PM_4.txt
Case 4_9PM	worst 24 hrs + worst 24 hrs + worst 30 days	4	21:00	9PM_4.txt
Worst Net Evaporation Cases				
Case 2_evap	worst 30 days for evaporation	2	9:00	Net_Evap.txt
Case 3_evap	worst 30 days for evaporation	3	9:00	Net_Evap.txt
Case 4_evap	worst 30 days for evaporation	4	9:00	Net_Evap.txt

2.2 Acceptance Criteria

There are no specific acceptance criteria in this analysis. The maximum calculated UHS temperature and minimum UHS water level are to be used as input to the follow-on analysis.

2.3 Identification of Computer Programs

Post processing of the LAKET-PC results is done using Microsoft Excel® 2003 [Ref. 5. 7], which is commercially available. The validation of Excel is implicit in the detailed review of all spreadsheets used in this analysis. All computer runs were performed using PC No. ZL7923 under the Windows XP operating system.

LAKET-PC Version 2.3 [Ref. 5.5] was used to perform the lake transient analysis contained in this evaluation. This was run on S&L PC No. ZL7923 on the Windows XP operating system. Note that LAKET-PC computer code was also utilized in support of LaSalle UHS License Amendment Request.

3.0 ASSUMPTIONS

3.1 Water Properties - The density and specific heat of water in the UHS is assumed to be 62.4 lb/ft^3 and 1 Btu/lb-°F, respectively [Ref. 5.12]. The density varies from 62.4 lb/ft^3 at 60°F to 61.9 lb/ft^3 at 105°F which correspond to ~0.7% change. The specific heat varies from 1 Btu/lb-°F at 60°F to 0.998 Btu/lb-°F at 105°F which correspond to ~0.2% change. These changes are acceptable since they are very small and have negligible impact on the results of analysis.

3.2 Makeup, Blowdown, Runoff, etc. - It is assumed that there is no makeup, blowdown, runoff, or dam spill in the UHS.

4.0 DESIGN INPUTS

4.1 Seepage Rate - The seepage rate is 0.8 ft^3/s [Ref. 5.3].

4.2 Area Capacity Data - The normal UHS elevation is 590 ft and is used as the initial UHS elevation. The drawdown curve for the UHS is given in the table below [Ref. 5.4].

Table 4-1: UHS Drawdown Curve

Elevation (ft)	Gross Area (acres)	Gross Volume (acre-ft)	Effective Area* (acres)	Effective Volume* (acre-ft)
590.0	95.6	555.8	78.7	457.4
589.0	94.5	460.0	77.8	378.6
588.0	93.5	370.0	77.0	304.5
587.0	92.5	276.0	76.1	227.1
586.0	91.5	185.0	75.3	152.3
585.0	90.5	90.0	74.5	74.1

*Effective Area and Volume are 82.3% of Gross values per Design Input 4.4.

Note that for the sensitivity case (limiting 3 SX pump case) with 3" of sedimentation a gross UHS volume is reduced by 3/12*90=22.5 (acre-ft).

4.3 UHS Length - The total length of the UHS is 3076 ft [Ref. 5.1].

4.4 UHS Effectiveness – Effectiveness of the UHS pond is 82.3% as determined in Calculation MAD 83-0239 [Ref. 5.1].

4.5 SX Flow - The SX flow for operation with 3 pumps is taken is 64,000 gpm. This is conservatively higher than the calculated flow for 3 SX pumps as documented in the hydraulic calculation [Ref. 5.8].

For operation with 2 and 4 pumps, the SX flow is taken as 48,000 gpm and 96,000 gpm respectively. This flow rate is estimated from the rated flow capacity per pump (24,000 gpm) and the number of pumps [Refs. 5.9 and 5.10]. The value is greater than the flow that actually will occur because the pressure drop caused by the resistance of the system is larger than the design value and causes the pump to run back on its performance curve as shown in the hydraulic calculation [Ref. 5.8]. The use of an estimated flow which is greater than the actual value yields a conservative UHS temperature prediction. This is illustrated by the results in Section 7.1 which show an increased plant intake temperature with an increase of SX flow.

4.6 Heat Load to the UHS - The post-MUR heat load rejected to the UHS is taken from ATD-0063, page E9, Table 13 [Ref. 5.2].

4.7 Wind Sensor Elevation - The elevation of the wind sensor is 34 ft for maximum temperature cases and 20 ft for the maximum evaporation cases based on Attachment B. Note, that the wind speed is corrected to an elevation of 2 meters as specified in Section 2.1.4.

5.0 REFERENCES

Note: Revision level check was performed for References 5.1, 5.2, 5.4, 5.8, 5.9, 5.10, and 5.15 via the PASSPORT database on 5/14/2014.

5.1 Ultimate Heat Sink Update, Calculation MAD 83-0239, Rev. 1. 9-3-1985

5.2 Heat Load to the Ultimate Heat Sink During a Loss of Coolant Accident, Calculation ATD-0063, Rev. 5, 11-27-2012.

5.3 DIT No. BR-0234-0004, D.G. Bodine to S. Masini, 8-29-85. (Documented as part of MAD 83-0239 [Ref. 5.1]

5.4 Revised Area Capacity Curve for Ultimate Heat Sink. (Documented as part of MAD 83-0239 [Ref. 5.1]

5.5 LAKET-PC Computer Prog., Version 2.3, S&L Program No.03.7.292-2.3, with the following controlled files:

Name	Size	Type	Date Modified
LaketW.exe	2,220 KB	Application	5/27/2014 9:17 AM
stmfunc97_lf95.dll	711 KB	Application Extension	8/24/2004 3:42 AM

5.6 U.S. Atomic Energy Commission, Regulatory Guide 1.27, Rev. 2, January 1976, “Ultimate Heat Sink for Nuclear Power Plants,”

5.7 Microsoft® Excel 2003, SP 2, Sargent & Lundy LLC Program No. 03.2.434-1.0, dated 05/21/2007.

5.8 Hydraulic Calculation # BRW-99-0481-M, Rev 001E, "Essential Service Water System Flow Model".

5.9 Byron SX Pump Curve Drawing # 76071, Rev A, "1SX01PA Pump Curve"

5.10 SX Pump Drawing # B-33842X, Rev 0, " Bingham-Willamette Co. Spec No L2758A.

5.11 Crane Technical Paper No. 410, “Flow of Fluids through Valves, Fittings, and Pipe”, 1988.

5.12 "ASME Steam Tables, Thermodynamic and Transport Properties of Steam", 1967.

5.13 NUREG-0693, “Analysis of Ultimate Heat Sink Cooling Ponds,” Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission, November 1980.

5.14 MIT Report 161, “An Analytical and Experimental Study of Transient Cooling Pond Behavior,” Ryan and Harleman, Massachusetts Institute of Technology, Cambridge Massachusetts, 1973.

5.15 P&ID M-42, Sheet 6, Rev T, "Diagram of Essential Service Water".

5.16 Avallone, Eugene A. and Baumeister III, Theodore, “Marks’ Standard Handbook for Mechanical Engineers,” 10^{th} edition.

6.0 CALCULATIONS

6.1 Plant Temperature Rise

The plant mass flow rate used in calculation of the plant temperature rise is calculated based on equation 2-2 and presented in the Table 6-1.

Table 6-1: Plant Flow

Number of SX Pumps	Plant Volumetric Flow (gpm)	Plant Volumetric Flow (cfs)	Plant Mass Flow (lbm/hr)
2	48,000	106.94	24,025,000
3	64,000	142.59	32,030,000
4	96,000	213.89	48,050,000

Plant temperature rise for all cases is calculated based on the methodology from Section 2.1.3. The results of these calculations and the values entered into the LAKET-PC model are presented in Attachment C.

6.2 UHS Transit Time

The UHS transit time differs depending on the number of SX pumps in operation. The transit time is determined using the effective volume and UHS flow rate. This calculation is shown in Table 6-2.

Table 6-2: Transit Time Calculation

	Symbol	2 Pumps	3 Pumps	4 Pumps	Basis
Eff. Volume @ 590 ft (acre-ft)	V_e	457.4	457.4	457.4	Design Input 4.2
Conversion (ft^3/acre-ft)	C_1	43560	43560	43560	
Volume (ft^3)	V	19,924,344	19,924,344	19,924,344	$= V_e * C_1$
Flow Rate (gpm)	Q_{gpm}	48,000	64,000	96,000	Design Input 4.5
Conversion (ft^3/s / gpm)	C_2	0.002228	0.002228	0.002228	= (0.13368 gal/ft^3) / (60 s/min)
Flow Rate (ft^3/s)	Q	106.94	142.59	213.89	$= Q_{gpm} * C_2$
Total Transit Time (s)	t	186,306	139,730	93,153	= V / Q
Total Transit Time (hr)	t	51.8	38.8	25.9	= t / (3600 s/hr)

The weather files are screened in 3 hour time periods. To account for reduced transit time as the UHS loses volume due to evaporation and to match the LAKET-PC 3 hour time step, the total transit time is conservatively rounded down. This makes the UHS transit time 48 hours for two pumps in operation, 36 hours for three pumps in operation, and 24 hours for four pumps in operation.

6.3 Worst Weather Selection

Selection of the worst weather is done in Attachment A. The worst weather is found for three different time periods: 24 hours, 36 hours, 48 hours, and 30 days. Since cases are run at different start times, the worst weather is found for every analyzed start time. These results are summarized in the table below.

Table 6-3: Worst 30-Day Weather Results

Start Time	Worst 30-day Start Date
12AM	7/10/2011
3AM	7/9/2011
6AM	7/9/2011
9AM	7/9/2011
12PM	7/9/2011
3PM	7/9/2011
6PM	7/9/2011
9PM	7/9/2011

Table 6-4: Worst 24-hr, 36-hr, and 48-hr Weather Results

Start Time	Worst 24-hr Start Date	Worst 36-hr Start Date	Worst 48-hr Start Date
12AM	6/23/2009	7/6/2012	7/5/2012
3AM	6/23/2009	7/6/2012	7/5/2012
6AM	7/19/2011	7/6/2012	7/5/2012
9AM	7/6/2012	6/22/2009	6/22/2009
12PM	7/6/2012	6/22/2009	7/5/2012
3PM	7/6/2012	6/22/2009	7/5/2012
6PM	7/6/2012	7/5/2012	7/5/2012
9PM	7/26/1999	7/5/2012	7/5/2012

In addition, the 30 days leading to the worst net evaporation is determined in Attachment A. For all SX pump operating conditions the worst 30 day period was determined to start on June 1, 1988 at 9:00 AM.

Synthetic weather files are created from these worst weather and worst net evaporation time periods. Documentation of the creation of these weather files is provided in Attachment A.

6.4 Natural Lake Temperatures

LAKET-PC uses natural lake temperature as one of the inputs. The natural lake temperature is determined and documented in Attachment A, Table 6-7. The natural lake temperature is used as initial condition to set up the initial temperature of the non participating part of UHS. The non participating part of UHS is defined as the part of the UHS that does not see the plant heat load. In case of Braidwood UHS this constitutes 17.7% of the UHS (since the UHS effectiveness is 82.3%, see Design Input 4.4).

6.5 Wind Function Selection

In accordance with NUREG-0693 [Ref. 5.13] recommendation, Ryan and Harleman wind function is selected in LAKET-PC modeling for all cases.

6.6 Maximum UHS Temperature

LAKET-PC is run to determine the UHS response to the plant heat load under the worst environmental conditions. Cases are run with 2, 3, and 4 SX pumps in operation. The time of day which the accident occurs is critical when determining the maximum allowable initial temperature of the UHS. To account for the time of day at which the UHS transient may start, eight start times are used for each alignment of SX pumps. These cases are run using the synthetic weather files consisting of the worst weather periods developed in Attachment A. Results from the LAKET-PC runs are presented in Section 7.1.

6.7 Maximum Net Evaporation

Case 2_Evap, Case 3_Evap, and Case 4_Evap were run to determine the maximum expected UHS drawdown depending on the SX pump alignment. These cases are run using the worst 30-day net evaporation weather period, which was determined to be 6/1/88 to 7/1/88 (9:00 AM start) in Attachment A. The results of these cases are presented in Section 7.2.

6.8 3" of Sedimentation Sensitivity Case

As an additional case a limiting 3 SX pump case with 3" of sedimentation is run. For this run a gross UHS volume is reduced by 3/12*90=22.5 (acre-ft) which corresponds to the bottom 3" of the UHS. For this case the area capacity data from Design Input 4.2 is modified as follows:

Table 6-5: UHS Drawdown Curve - 3" Sedimentation

Elevation (ft)	Gross Area (acres)	Gross Volume (acre-ft)	Effective Area* (acres)	Effective Volume* (acre-ft)
590.0	95.6	533.3	78.7	438.9
589.0	94.5	437.5	77.8	360.1
588.0	93.5	347.5	77.0	286.0
587.0	92.5	253.5	76.1	208.6
586.0	91.5	162.5	75.3	133.7
585.0	90.5	67.5	74.5	55.6

*Effective Area and Volume are 82.3% of Gross values per Design Input 4.4.

7.0 RESULTS AND CONCLUSIONS

7.1 Maximum UHS Temperature

LAKET-PC was run to determine the maximum UHS temperature following an accident. All cases are run at an initial UHS temperature of 102°F. The results of these LAKET-PC runs are provided in Table 7-1 for 2 SX pumps in operation, in Table 7-2 for 3 SX pumps in operation, and in Table 7-3 for 4 SX pumps in operation.

Table 7-1: Worst Temperature Cases - 2 SX Pumps (48 hour transit time)

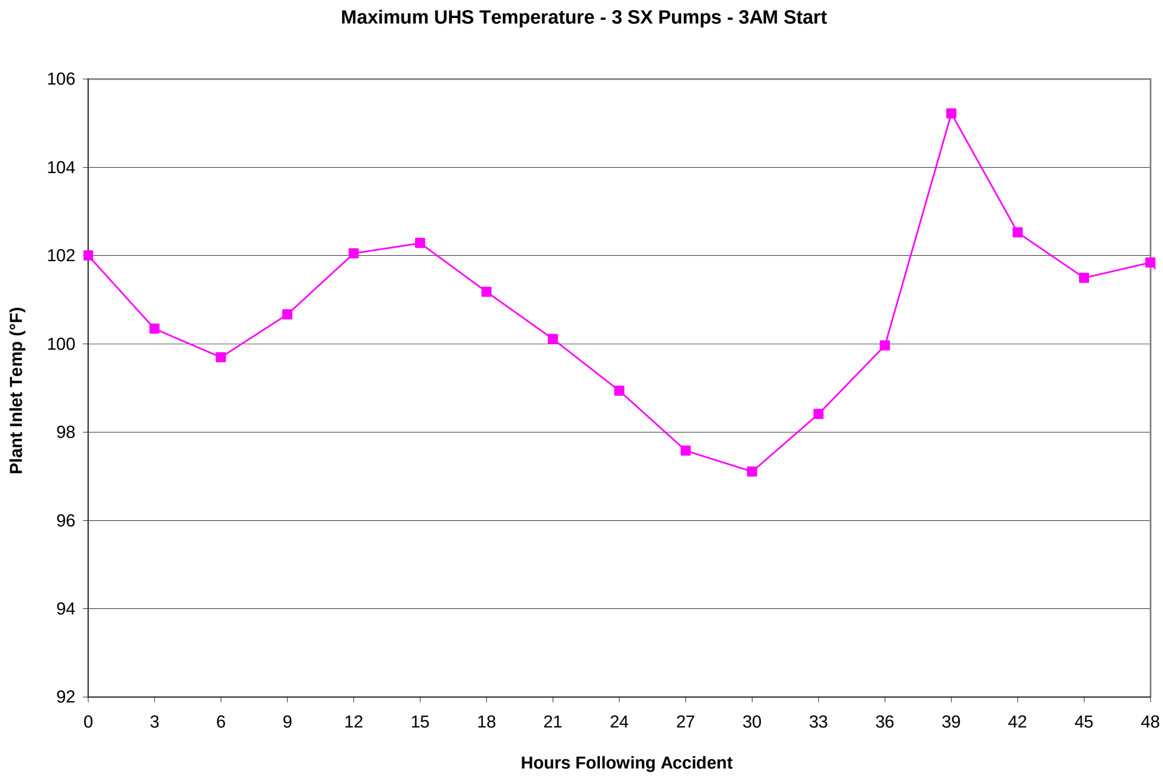
Case	Weather Data	SX Pumps	Initial UHS Temp. (°F)	Maximum Plant Inlet Temp. (°F)
Case 2_12AM	12AM_2.txt	2	102.0	102.0
Case 2_3AM	3AM_2.txt	2	102.0	102.5
Case 2_6AM	6AM_2.txt	2	102.0	**103.7**
Case 2_9AM	9AM_2.txt	2	102.0	103.6
Case 2_12PM	12PM_2.txt	2	102.0	103.1
Case 2_3PM	3PM_2.txt	2	102.0	102.2
Case 2_6PM	6PM_2.txt	2	102.0	102.0
Case 2_9PM	9PM_2.txt	2	102.0	102.0

Table 7-2: Worst Temperature Cases - 3 SX Pumps (36 hour transit time)

Case	Weather Data	SX Pumps	Initial UHS Temp. (°F)	Maximum Plant Inlet Temp. (°F)
Case 3_12AM	12AM_3.txt	3	102.0	104.5
Case 3_3AM	3AM_3.txt	3	102.0	**105.2**
Case 3_6AM	6AM_3.txt	3	102.0	104.4
Case 3_9AM	9AM_3.txt	3	102.0	103.6
Case 3_12PM	12PM_3.txt	3	102.0	103.3
Case 3_3PM	3PM_3.txt	3	102.0	104.0
Case 3_6PM	6PM_3.txt	3	102.0	104.7
Case 3_9PM	9PM_3.txt	3	102.0	103.4
Case 3_3AM_3"	3AM_3.txt	3	102.0	105.0

Note that the peak UHS temperatures for 3 SX pumps in operation cases occur ~39 hours after the DBA and it exceeds 104°F for less than 6 hours. This is shown in detail on the UHS temperature plot Figure 7-1.

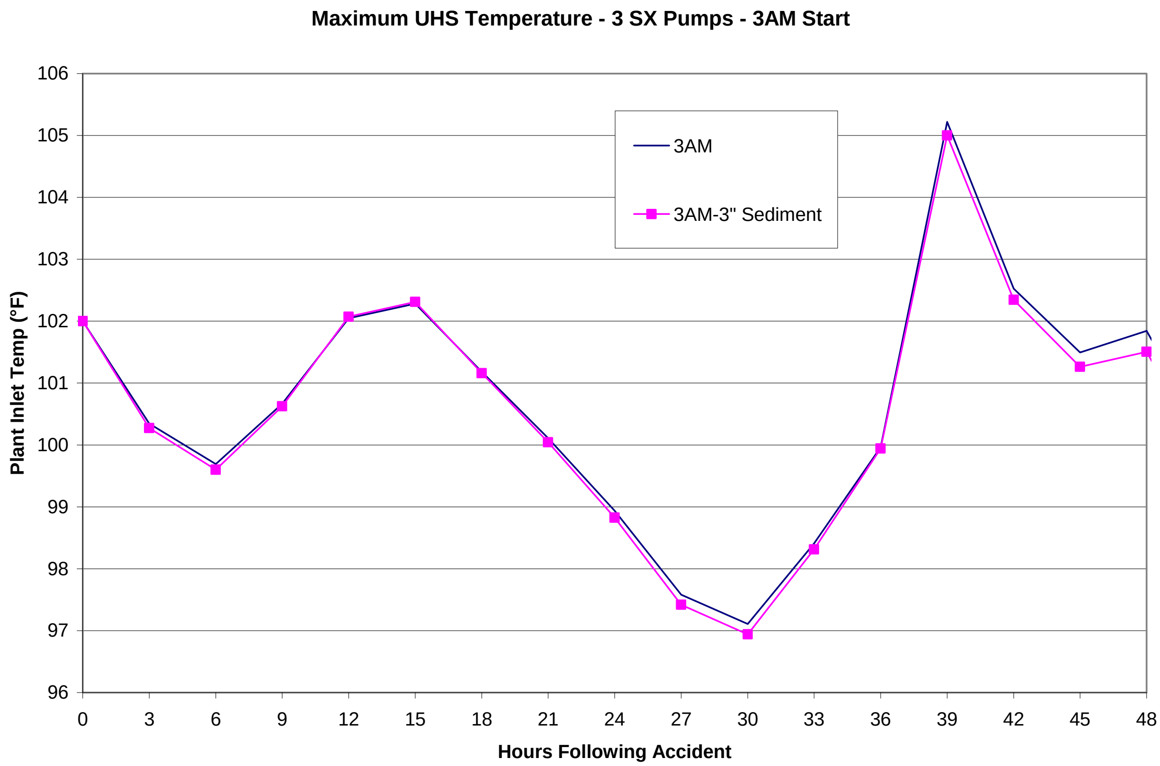
Figure 7-1: Limiting 3 SX Pump Case - 3AM Start



As seen on Figure 7-1 the UHS initially starts at 102°F. Since the accident begins at 3 AM the UHS temperature initially decreases as a result of cool environmental conditions during early morning hours. The UHS temperature then increases due to solar heat and hot environmental conditions throughout the day. Starting in the late afternoon and continuing throughout the night the UHS temperatures drops displaying a typical diurnal cycle. Beginning with ~36 hours after the DBA the plant heat comes back to the plant inlet peaking ~39 hours after the DBA. This is shown on Figure 7-1 as a sharp increase in the UHS temperature from ~102°F to ~105.2°F. The peak temperature excursion is short lived and it exceeds 104°F for less than 6 hours.

The 3AM Case with 3" of sedimentation (see Figure 7-2) demonstrates that the small changes to the UHS volume have negligible affects on the maximum UHS temperature.

Figure 7-2: Limiting 3 SX Pump Case - 3AM Start - 3" of Sediment



In the case with 3" of sedimentation, the volume at the bottom of the UHS is slightly reduced. The reduction is small enough that the model is still in a 36 hour transient time, however with the smaller volume the cooling of the UHS has a slightly larger effect. Therefore, the peak temperature after 36 hours is slightly lower (~0.2°F). However, looking at the first day peak, the temperature with 3" of sedimentation is slightly higher (~0.03°F), since it is easier to heat up the smaller volume. For the other start times the peak temperature may slightly increase with a slight reduction of volume (if the peak occurs on the first day). Overall, it is concluded that with small changes in UHS volume, the peak temperature change is negligible.

Table 7-3: Worst Temperature Cases - 4 SX Pumps (24 hour transit time)

Case	Weather Data	SX Pumps	Initial UHS Temp. (°F)	Maximum Plant Inlet Temp. (°F)
Case 4_12AM	12AM_4.txt	4	102.0	103.2
Case 4_3AM	3AM_4.txt	4	102.0	104.0
Case 4_6AM	6AM_4.txt	4	102.0	**105.9**
Case 4_9AM	9AM_4.txt	4	102.0	105.4
Case 4_12PM	12PM_4.txt	4	102.0	104.7
Case 4_3PM	3PM_4.txt	4	102.0	105.0
Case 4_6PM	6PM_4.txt	4	102.0	104.5
Case 4_9PM	9PM_4.txt	4	102.0	103.6
Case 4_6AM104	6AM_4.txt	4	**96.4**	104

As shown in the above tables the cases with 4 SX operating pumps results in the highest UHS temperatures. For the limiting 4 SX pump scenario (6AM start) an additional case is made to determine the maximum UHS initial temperature that results in maximum UHS temperature of 104°F. Plots of UHS temperatures for all cases are presented in Attachment E.

7.2 Maximum Net Evaporation

Three LAKET-PC cases were run to determine the maximum expected drawdown for 2, 3, and 4 SX pumps in operation. The results of these cases are provided in Table 7-4.

Table 7-4: Worst Temperature Cases

Case	Weather Data	SX Pumps	Initial UHS Temp. (°F)	Maximum UHS Drawdown (ft)
Case 2_Evap	NetEvap.txt	2	102	1.76
Case 3_Evap	NetEvap.txt	3	102	1.77
Case 4_Evap	NetEvap.txt	4	102	**1.78**

The maximum 30 day drawdown from the initial UHS elevation 590 ft occurs with 4 SX pump in operation. The minimum UHS elevation after the worst 30 day period is ~588.2 ft (1.78 ft reduction). Plots of UHS elevation for all three cases are presented in Attachment E.

Attachment A

LAKET-PC Weather File Creation

Prepared: Daniel W. Nevill Date 5/29/2014
Daniel W. Nevill - Sargent & Lundy LLC

Reviewed: Paul J. Szymiczek Date 5/29/2014
Paul J. Szymiczek - Sargent & Lundy LLC

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1.0 PURPOSE / OBJECTIVE

The purpose of this attachment is to determine the worst 24-hour, 36-hour, 48-hour and 30-day weather period and the worst 30-day period of net evaporation for Braidwood Nuclear Generating Station. This will be used as input in determining the maximum plant inlet temperature and evaporative drawdown of the Braidwood Ultimate Heat Sink (UHS), which determines the design basis UHS performance for 30 days following an accident. Weather data has been provided from July 5, 1948 through December 31, 2012.

2.0 METHODOLOGY

A LAKET-PC-compatible meteorological data file, 'PIABDW4812.txt', was created consisting of meteorological data for Braidwood Generating Nuclear Station and Peoria, IL from July 7, 1948 through December 31, 2012. See Design Input 4.1 for additional information on this file. After 1/1/1990 wind speed, wind direction, dew point temperature and dry-bulb temperature data were taken from an on-site meteorological tower at Braidwood Generating Nuclear Station. Humidity, precipitation type, cloud height, and cloud cover data were not available from the on-site meteorological tower, and were taken from a National Weather Service observing station at the Peoria, IL airport (approximately 100 miles southwest of Braidwood Generating Nuclear Station). Prior to 1990, all data is taken from Peoria with the exception of a period from 1/1/1952 to 1/31/1956 which uses data from Springfield, IL since hourly data was not available from Peoria. This weather data file is input to LAKET-PC [Ref. 5.2 of Att. A], and the worst weather and worst net evaporation time periods are found from the range of dates included in this file.

LAKET-PC runs are made for determining the worst weather at the time periods to be included in the weather files. This includes the UHS transit time, the worst 24 hours, and the worst 30 days. Therefore, worst weather periods are found for 24 hours (4 pump UHS transit time), 36 hours (3 pump UHS transit time), 48 hours (2 pump UHS transit time), and 30 days. Additionally, a LAKET-PC run is done to determine the worst 30 days for net evaporation. Due to options selected in the input file, the LAKET-PC run returns a plot file that includes the total evaporation (worst net evaporation cases only), precipitation (worst net evaporation cases only), natural lake temperature, lake inlet temperature (same as the plant outlet temperature), and the UHS outlet temperature (same as the plant inlet temperature).

Since LAKET-PC returns results in three hour increments, a rolling average over the time period being analyzed (i.e., 24-hr, 36-hr, 48-hr, 30-days) is created using Microsoft Excel [Ref. 5.1 of Att. A] by averaging the UHS outlet temperature of the selected time step along with the number of following time steps needed to comprise the analyzed time period (e.g., 7 additional time steps for worst 24 hours). The starting time of the worst weather for the analyzed time period is chosen as the time with the highest UHS outlet temperature rolling temperature average.

2.1 Worst 24-Hour, 36-Hour, 48-Hour and 30-Day Weather

A specific UHS model was created in LAKET-PC (based on the input file from Case 3_12AM) with a transit time that corresponds to the three hour time step period. The model is open cycle, which means water exiting the lake is discarded and new water enters the lake at predetermined conditions independent of the existing lake conditions. The UHS is set to the same initial temperature at the beginning of each three hour time step. Since initial conditions are the same for each time step, there are no residual effects due to the weather from the preceding time step. The UHS outlet temperature for each 3 hour period corresponds to the environmental effects on the UHS during these three

hours. From these results, it can be concluded that higher UHS outlet temperatures represent worse (hotter) weather conditions. The following changes were made to 'Case 3_12AM.dat' to create 'Worst_Weather_100.dat' and 'Worst_Weather_110.dat' for determining the worst weather conditions:

- The date range is changed to match the date range of weather file 'PIABWD4812.txt.'
- The initial lake temperature is set at 100°F or 110°F. (Assumption 3.1)
- The model is set as open cycle, so the UHS is at the same temperature (the initial temperature of 100°F or 110°F) at the beginning of each 3 hour interval.
- Anemometer height is set in accordance with the heights given Table 5 from Attachment B (Design Input 4.2). The FWINDZ function is used in LAKET-PC to vary the anemometer height over specified time periods.
- Lake elevation is fixed at 590-ft (Assumption 3.2).
- The plant flow is set at 1844.8 ft^3/s to obtain a lake transit time of 3 hours (Plant Flow = Effective Lake Volume / Transit Time, 457.4 acre-ft * 43,560 ft^3/acre-ft / 10,800 s = 1844.8 ft^3/s).
- The plant discharge water temperature (TPRISE variable in LAKET-PC) is set at 100°F (Assumption 3.3). For an open cycle model, this value is the lake inlet temperature.

The UHS outlet temperature for each 3 hour period corresponds to the environmental effects on the UHS during these three hours. From these results, it can be implied that higher UHS outlet temperatures represent worse (hotter) weather conditions.

2.2 Worst 30-Days of Net Evaporation

For determining the worst 30-days of net evaporation, three UHS models are created (one for two SX pumps, one for three SX pumps, one for four SX pumps) in LAKET-PC based on 'Case 2_Evap.dat' for two SX pumps, 'Case 3_Evap.dat' for three SX pumps, and 'Case 4_Evap.dat' for four SX pumps. The following changes were made to Case2_Evap, Case 3_Evap, and Case 4_Evap for determining the worst net evaporation conditions:

- The date range is changed to match the date range of weather file 'PIABDW4812.txt.'
- Anemometer height is set in accordance with the heights given Table 5 from Attachment B (Design Input 4.2). The FWINDZ function is used in LAKET-PC to vary the anemometer height over specified time periods.
- Lake elevation is fixed at 590-ft (Assumption 3.2).
- Initial temperature is set at 90°F as a representative summer UHS temperature (Assumption 3.1).

- The temperature rise through the plant (TPRISE variable in LAKET-PC) is set at the approximate average temperature rise of 9.5°F for two SX pumps, 7.1°F for three SX pumps, and 4.7°F for four SX pumps (Assumption 3.3).

The net evaporation is determined from output from the LAKET-PC runs as total evaporation less precipitation. The worst 30 days of net evaporation is determined using rolling averages, similar to the methodology used in determining the worst weather.

2.3 Weather File Creation for UHS Analysis

Weather files are created based on the worst weather period determined by this analysis. These weather files use the weather information provided in 'PIABDW4812.txt' with the following changes:

- The station code is set to zero. This input has no impact on the results of this analysis.
- The start date and time is set at 7/1/1900 at 12AM. This input has no effect on the results of this analysis.

Synthetic weather files are created using weather data from the critical time period due to the design of the UHS (48 hours with two SX pumps, 36 hours with three SX pumps, and 24 hours for four SX pumps), the worst 24 hours, and the worst 30 days. The start of the worst 24 hours and the worst 30 days is selected to maintain a 1 hour interval between time steps. For example, if the worst 36 hours (critical time period) ends at 11PM, the next time step will be at 12AM of the beginning of the worst 24 hours.

For the worst net evaporation, only one weather file will be created, corresponding to the dates and times determined to be the most limiting.

2.4 Computer Programs and Software

LAKET-PC Version 2.2 [Ref. 5.2 of Att. A] was used to perform the lake transient analysis contained in this evaluation. This was run on S&L PC No. ZD6661 on Windows XP operating system for files dated prior to 2/22/2014, and it was run on S&L PC No. ZD9392 on Windows XP operating system for files dated after 2/22/2014.

Postprocessing of the LAKET-PC results is done using Microsoft Excel® 2010 [Ref. 5.1 of Att. A], which is commercially available. The validation of Excel is implicit in the detailed review of all spreadsheets used in this analysis.

3.0 ASSUMPTIONS

3.1 Initial Lake Temperature - For the 24-hour, 36-hour, and 48-hour worst weather evaluation, the initial lake temperature is set at 110°F. For the 30-day worst weather evaluation, the initial lake temperature is set at 100°F. This matches the initial lake temperature with the assumed plant discharge water temperature (see Assumption 3.3).

For the worst net evaporation month, the initial lake temperature is assumed to be 90°F. This is used as a representative value for the lake temperature during the summer since the weather data file begins on July 5.

3.2 Fixed Lake Elevation - The lake elevation when determining the worst weather month is fixed at 590-ft. A constant lake elevation removes the effects of lake level in determining the weather effects on the UHS temperature.

3.3 Station Thermal Boundary Condition - The plant discharge water temperature when determining the worst weather day and month is assumed to be 100°F for the 30-day case and 110°F for the 24-hr, 36-hr, and 48-hr cases. This is the approximate average lake temperature during these time periods. Since the lake is modeled as open cycle, the lake starts at this temperature at the start of each 3 hour time interval. A constant initial temperature allows for isolation of the meteorological effects on the lake.

When determining the worst net evaporation month, the temperature rise through the plant is assumed to be constant at 9.5°F for two SX pumps, 7.1°F for three SX pumps, and 4.7°F for four SX pumps. This is the approximate average plant temperature rise (TPRISE value) over the accident transient. The average plant temperature rise is determined using the TPRISE values from Case 12AM_2, Case 12AM_3 and Case 12AM_4 of the main body of this calculation, which were determined from the heat loads documented in Attachment C. A constant temperature rise through the plant removes the effects of the plant heat load in determining the evaporation.

3.4 Seepage - When determining the worst weather periods and worst net evaporation periods, seepage from the UHS is assumed to be the same as used in cases in the main body of this calculation. The seepage rate is 0.8 ft^3/s.

4.0 DESIGN INPUTS

4.1 Weather Data File - The LAKET-PC-compatible meteorological data file is developed from weather data from Braidwood Nuclear Generating Station and Peoria/Springfield from 7/5/1948 to 12/31/2012 in Attachment B. This file has the following properties:

Name: PIABDW4812.txt
Size: 87,231 KB
Creation date/time: 1/30/2014 8:18 AM CST

4.2 Anemometer Height - The anemometer height for the data entered in 'PIABDW4812.txt' is provided in Attachment B.

Table 4-1 Historical Wind Sensor Height

Beginning Date	Ending Date	Sensor Height (ft)	Primary Wind Data Source
7/5/1948	11/21/1948	26	NWS-Peoria (KPIA)
11/22/1948	12/31/1951	50	NWS-Peoria (KPIA)
1/1/1952	12/31/1956	49	NWS-Springfield (KSPI)
1/1/1957	9/30/1959	50	NWS-Peoria (KPIA)
10/1/1959	12/31/1989	20	NWS-Peoria (KPIA)
1/1/1990	12/31/2012	34	On-site meteorological tower

5.0 REFERENCES

5.1 Microsoft® Office Excel 2010, Sargent & Lundy LLC Program No. 03.2.435-14.0, dated 7/1/2010.

5.2 LAKET-PC Computer Program, Version 2.2, S&L Program No. 03.7.292-2.2, 7/31/2013. Controlled File Path: \\SNLVS5\SYS3\OPS$\LAK29222\

6.0 CALCULATIONS AND RESULTS

Analysis of rolling averages determine the worst 24 hour, 36 hour, 48 hour and 30 day period for UHS temperature and the worst 30 day period for net evaporation for the weather file.

6.1 Worst Weather Conditions

The average lake temperature over the worst 30 days is approximately 100°F. Therefore, the worst weather selection for the worst 30-day period is based on an initial UHS temperature of 100°F. The UHS analysis will be done starting at eight different times, so the worst 30 days time period is determined for each start time.

Table 6-1: Worst 30-Day Weather Results

Start Time	Worst 30-day Start Date
12AM	7/10/2011
3AM	7/9/2011
6AM	7/9/2011
9AM	7/9/2011
12PM	7/9/2011
3PM	7/9/2011
6PM	7/9/2011
9PM	7/9/2011

The average UHS temperature for the first two days following an accident is approximately 110°F. Therefore, the worst weather selection for the worst 24-hr, 36-hr, and 48-hr time periods are based on an initial UHS temperature of 110°F. The UHS analysis will be done starting at eight different times, so the worst 24 hour, 36 hour, and 48 hour time periods are determined for each start time.

Table 6-2: Worst 24-hr, 36-hr, and 48-hr Weather Results

Start Time	Worst 24-hr Start Date	Worst 36-hr Start Date	Worst 48-hr Start Date
12AM	6/23/2009	7/6/2012	7/5/2012
3AM	6/23/2009	7/6/2012	7/5/2012
6AM	7/19/2011	7/6/2012	7/5/2012
9AM	7/6/2012	6/22/2009	6/22/2009
12PM	7/6/2012	6/22/2009	7/5/2012
3PM	7/6/2012	6/22/2009	7/5/2012
6PM	7/6/2012	7/5/2012	7/5/2012
9PM	7/26/1999	7/5/2012	7/5/2012

6.2 Worst Net Evaporation

LAKET-PC input files ‘Worst_NetEvap-2.dat’, ‘Worst_NetEvap-3.dat’, and ‘Worst_NetEvap-4.dat’ were compiled to determine the worst 30-day period of net

evaporation from 7/5/1948 to 12/31/2012. Using the results from LAKET-PC, the worst 30-day period in terms of net evaporation for all cases was determined to be the period beginning at 6/1/1988 at 9AM. Since the worst net evaporation occurs on the same day for each number of SX pumps in operation, a single 30 day weather file, 'Net_Evap.txt', will be created starting at 6/1/1988 9AM.

6.3 Weather File Creation for UHS Analysis

Weather files are created for two SX pumps in operation, three SX pumps in operation, and four SX pumps in operation. For two pumps, the transit time through the UHS is approximately 48 hours, so the synthetic weather file consists of the worst 48 hours, worst 24 hours, and worst 30 days. For three pumps, the transit time through the UHS is approximately 36 hours, so the synthetic weather file consists of the worst 36 hours, worst 24 hours, and worst 30 days. For four pumps, the transit time through the UHS is approximately 24 hours, so the synthetic weather file consists of the worst 24 hours, worst 24 hours, and worst 30 days. Weather files are created for eight different start times (12AM, 3AM, 6AM, 9AM, 12PM, 3PM, 6PM, and 9PM) for two, three, and four pump operation. In addition, a weather file is created for the worst 30 days of net evaporation.

Table 6-3: 2 Pump Operation Weather Files

Case	48-Hour Start	48-Hour End	24-Hour Start	24-Hour End	30-Day Start	30-Day End
12AM_3	7/5/12 12AM	7/6/12 11PM	6/23/09 12AM	6/23/09 11PM	7/10/11 12AM	8/8/11 11PM
3AM_3	7/5/12 3AM	7/7/12 2AM	6/23/09 3AM	6/24/09 2AM	7/9/11 3AM	8/8/11 2AM
6AM_3	7/5/12 6AM	7/7/12 5AM	7/19/11 6AM	7/20/11 5AM	7/9/11 6AM	8/8/11 5AM
9AM_3	6/22/09 9AM	6/24/09 8AM	7/6/12 9AM	7/7/12 8AM	7/9/11 9AM	8/8/11 8AM
12PM_3	7/5/12 12PM	7/7/12 11AM	7/6/12 12PM	7/7/12 11AM	7/9/11 12PM	8/8/11 11AM
3PM_3	7/5/12 3PM	7/7/12 2PM	7/6/12 3PM	7/7/12 2PM	7/9/11 3PM	8/8/11 2PM
6PM_3	7/5/12 6PM	7/7/12 5PM	7/6/12 6PM	7/7/12 5PM	7/9/11 6PM	8/8/11 5PM
9PM_3	7/5/12 9PM	7/7/12 PAM	7/26/99 9PM	7/27/99 8PM	7/9/11 9PM	8/8/11 8PM

Table 6-4: 3 Pump Operation Weather Files

Case	36-Hour Start	36-Hour End	24-Hour Start	24-Hour End	30-Day Start	30-Day End
12AM_3	7/6/12 12AM	7/7/12 11AM	7/6/12 12PM	7/7/12 11AM	7/9/11 12PM	8/8/11 11PM
3AM_3	7/6/12 3AM	7/7/12 2PM	7/6/12 3PM	7/7/12 2PM	7/9/11 3PM	8/9/11 2AM
6AM_3	7/6/12 6AM	7/7/12 5PM	7/6/12 6PM	7/7/12 5PM	7/9/11 6PM	8/9/11 5AM
9AM_3	6/22/09 9AM	6/22/09 8PM	7/26/99 9PM	7/27/99 8PM	7/9/11 9PM	8/9/11 8AM
12PM_3	6/22/09 12PM	6/23/09 11PM	6/23/09 12AM	6/23/09 11PM	7/10/11 12AM	8/9/11 11AM
3PM_3	6/22/09 3PM	6/24/09 2AM	6/23/09 3AM	6/24/09 2AM	7/9/11 3AM	8/8/11 2PM
6PM_3	7/5/12 6PM	7/7/12 5AM	7/19/11 6AM	7/19/09 5AM	7/9/11 6AM	8/8/11 5PM
9PM_3	7/5/12 9PM	7/7/12 8AM	7/6/12 9AM	7/7/12 8AM	7/9/11 9AM	8/8/11 8PM

Table 6-5: 4 Pump Operation Weather Files

Case	24-Hour Start	24-Hour End	24-Hour Start	24-Hour End	30-Day Start	30-Day End
12AM_4	6/23/09 12AM	6/23/09 11PM	6/23/09 12AM	6/23/09 11PM	7/10/11 12AM	8/8/11 11PM
3AM_4	6/23/09 3AM	6/24/09 2AM	6/23/09 3AM	6/24/09 2AM	7/9/11 3AM	8/8/11 2AM
6AM_4	7/19/11 6AM	7/20/11 5AM	7/19/11 6AM	7/20/11 5AM	7/9/11 6AM	8/8/11 5AM
9AM_4	7/6/12 9AM	7/7/12 8AM	7/6/12 9AM	7/7/12 8AM	7/9/11 9AM	8/8/11 8AM
12PM_4	7/6/12 12PM	7/7/12 11AM	7/6/12 12PM	7/7/12 11AM	7/9/11 12PM	8/8/11 11AM
3PM_4	7/6/12 3PM	7/7/12 2PM	7/6/12 3PM	7/7/12 2PM	7/9/11 3PM	8/8/11 2PM
6PM_4	7/6/12 6PM	7/7/12 5PM	7/6/12 6PM	7/7/12 5PM	7/9/11 6PM	8/8/11 5PM
9PM_4	7/26/99 9PM	7/27/99 8PM	7/26/99 9PM	7/27/99 8PM	7/9/11 9PM	8/8/11 8PM

Table 6-6: Worst Net Evaporation Weather Files

Case	Start Date	End Date
Net_Evap	6/1/1988 9AM	7/1/1988 8AM

The natural lake temperature refers to the temperature of the lake if it is reacting to purely natural influences. The initial natural lake temperature is the initial temperature of the lake that is not in the participating part of the UHS. This is the portion of the UHS that does not see the plant heat load, or the non-effective portion. This constitutes 17.7% of the UHS since the UHS effectiveness is 82.3% (see main body Design Input 4.4). The initial natural temperature for each case is taken to be the natural temperature of the lake at the time step of the start date of the weather file. The natural lake temperature at these time steps is found in the results of the 'Worst_Weather_110' case from the file 'Worst_Weather_110.pltX'. These natural lake temperatures will be used to set the initial natural lake temperature in the worst weather LAKET-PC runs made in the main body of this calculation. The initial natural temperatures are summarized in the table below.

Table 6-7: Natural Lake Temperature

Case	2 Pumps (°F)	3 Pumps (°F)	4 Pumps (°F)
12AM	97.38	98.47	96.30
3AM	96.80	97.84	95.57
6AM	96.88	98.05	95.59
9AM	95.16	95.16	99.57
12PM	100.11	97.06	101.40
3PM	100.81	98.09	102.07
6PM	99.87	99.87	101.51
9PM	99.08	99.08	100.06
Net_Evap	84.61	84.61	84.61

7.0 SUMMARY AND CONCLUSIONS

The worst weather 24 hour period, 36 hour period, 48 hour period, and 30 day period were determined by running LAKET-PC over a range of days spanning from 7/5/1948 to 12/31/2012. These worst weather periods were determined for eight different start times. For the worst 24 hours, worst 36 hours, and worst 48 hours, the worst weather period started on several different dates depending on the start time. These worst weather periods are summarized in Tables 6-1 and 6-2. The worst 30 day weather period started on 7/9/2011 or 7/10/2011 for all start times.

The worst 30 day period for net evaporation was also determined using LAKET-PC. It was determined that the 30 days starting at 6/1/1988 at 9AM results in the worst net evaporation for two, three, or four SX pumps in operation.

8.0 APPENDICES

List of Appendices

App.	Description	No. of Pages
8.1	Electronic File Listing	1

Appendix 8.1: Electronic File Listing

A summary of the electronic files and their purposes is provided below:

Worst Weather Screening Files

File Name	Size	Date
Worst_Weather_100.dat	1 KB	2/3/2014 2:54 PM
Worst_Weather_100.out	1,131 KB	2/3/2014 2:55 PM
Worst_Weather_100.pltX	11,042 KB	2/3/2014 2:55 PM
Worst_Weather_110.dat	1 KB	2/3/2014 2:55 PM
Worst_Weather_110.out	1,131 KB	2/3/2014 2:56 PM
Worst_Weather_110.pltX	11,042 KB	2/3/2014 2:56 PM

Worst Net Evaporation Screening Files

File Name	Size	Date
Worst_NetEvap-2.dat	1 KB	5/7/2014 1:00 PM
Worst_NetEvap-2.out	1,131 KB	5/7/2014 1:02 PM
Worst_NetEvap-2.pltX	15,827 KB	5/7/2014 1:02 PM
Worst_NetEvap-3.dat	1 KB	5/7/2014 1:26 PM
Worst_NetEvap-3.out	1,131 KB	5/7/2014 1:28 PM
Worst_NetEvap-3.pltX	15,827 KB	5/7/2014 1:28 PM
Worst_NetEvap-4.dat	1 KB	5/7/2014 1:29 PM
Worst_NetEvap-4.out	1,131 KB	5/7/2014 1:30 PM
Worst_NetEvap-4.pltX	15,827 KB	5/7/2014 1:30 PM

Weather Files

File Name	Size	Date
12AM_2.txt	123 KB	3/13/2014 8:10 AM
3AM_2.txt	123 KB	3/13/2014 8:12 AM
6AM_2.txt	123 KB	3/13/2014 8:14 AM
9AM_2.txt	123 KB	3/13/2014 8:16 AM
12PM_2.txt	123 KB	3/13/2014 8:21 AM
3PM_2.txt	123 KB	3/13/2014 8:22 AM
6PM_2.txt	123 KB	3/13/2014 8:23 AM
9PM_2.txt	123 KB	3/13/2014 8:24 AM
12AM_3.txt	123 KB	2/4/2014 3:59 PM
3AM_3.txt	123 KB	4/14/2014 4:19 PM
6AM_3.txt	123 KB	2/4/2014 4:06 PM
9AM_3.txt	123 KB	2/4/2014 4:09 PM
12PM_3.txt	123 KB	2/4/2014 4:11 PM
3PM_3.txt	123 KB	2/4/2014 4:12 PM
6PM_3.txt	123 KB	2/4/2014 4:15 PM

Appendix 8.1: Electronic File Listing

File Name	Size	Date
9PM_3.txt	123 KB	2/4/2014 4:16 PM
12AM_4.txt	120 KB	2/4/2014 4:22 PM
3AM_4.txt	120 KB	2/4/2014 4:27 PM
6AM_4.txt	120 KB	2/4/2014 4:28 PM
9AM_4.txt	120 KB	2/4/2014 4:29 PM
12PM_4.txt	120 KB	2/4/2014 4:30 PM
3PM_4.txt	120 KB	2/5/2014 8:06 AM
6PM_4.txt	120 KB	2/5/2014 8:08 AM
9PM_4.txt	120 KB	2/5/2014 8:09 AM
NetEvap.txt	112 KB	5/7/2014 2:58 PM

Attachment B

Update Hourly Meteorological Data Used for Cooling Lake Analysis

Prepared: _Erwin T. Prater_ Date _May 29, 2014_
Erwin T. Prater - Sargent & Lundy[LLC]

Reviewed: _[signature]_ Date _5/29/2014_
Daniel P. Laubenthal - Sargent & Lundy[LLC]

1.0 PURPOSE / OBJECTIVE

This attachment describes preparation of an updated meteorological data file used to support a LAKET-PC analysis for the Braidwood Nuclear Generating Station, near Braidwood, IL. The original UHS Analysis meteorological data file covers the period from 1948 through 1976. This update accomplishes two things:

- Adds data for 1977 through December 31, 2012. The resulting file includes data for July 5, 1948 through December 31, 2012.

- Uses data from an on-site meteorological tower for January 1, 1990 through December 31, 2012.

2.0 PARAMETERS INCLUDED IN THE METEOROLOGICAL DATA FILE

The updated file is compatible with the LAKET-PC program, which S&L uses to evaluate the thermal performance of cooling lakes. The parameter content and digital format of LAKET-PC meteorological files are listed in Table 1.

3.0 EXISTING METEOROLOGICAL DATA FILE

The existing file used data from the National Weather Service (NWS) in Peoria, IL (KPIA), with exception of a period from January 1, 1952 - December 31, 1956 which used NWS data from Springfield, IL (KSPI). Springfield, IL data were used because hourly data were not available from Peoria during that time. The specifications of the existing file are provided for reference below:

Existing meteorological data file:
Name: PS489661.TXT
Type: ASC text
Size: 64,905 Kb
File creation date/time: 4/6/2006 8:16 AM

4.0 METEOROLOGICAL DATA SOURCES USED TO UPDATE THE EXISTING DATA FILE

The updated file uses a combination of data from KPIA and an on-site multi-level instrumented tower at the Braidwood generating station. For January 1, 1990 through December 31, 2012, the on-site multi-level tower is the primary source of wind speed/direction, dry bulb temperature, and dew point temperature data. When those four parameters are not available from the tower, they are taken from KPIA.

For January 1, 1990 through December 31, 2012, KPIA is the primary source of parameters required for LAKET-PC, but not measured by the on-site tower. These parameters include cloud cover, cloud height and precipitation type.[1] Hourly precipitation is also taken from KPIA for consistency with the reported precipitation type and cloud observations. Primary and secondary data sources used in the updated meteorological data file are summarized in Table 2.

The on-site tower is instrumented at 30-34 ft. levels and the 199-203 ft. levels. The tower instrumentation configuration is summarized in Table 3. Since LAKET-PC requires data near the surface, the updated meteorological data file uses the dry bulb and dew point temperatures recorded at the 30-foot level and the wind speed/direction at the 34-foot level.

[1] These parameters are generally not measured by on-site meteorological towers used at nuclear facilities.

5.0 RAW METEOROLOGICAL DATA USED TO UPDATE THE EXISTING DATA FILE

The raw data for the on-site tower were available from S&L (2014). Raw meteorological data from KPIA were obtained from the National Climatic Data Center (NCDC). The data consist of surface weather observations and hourly precipitation data. These data are briefly described below.

(1) *Surface Weather Observations*

Raw surface weather observations in DS-3505 format (NCDC 2006) from KPIA covered January 1, 1990 through December 31, 2012. NCDC subjects meteorological data to rigorous quality control checks before archival (Del Greco *et al*. 2006). However, meteorological databases may occasionally include gaps and data values outside of valid ranges. The archived data included most of the weather parameters required by LAKET-PC (Table 1), with the following exceptions: solar radiation, atmospheric radiation, binary (zero or one) freezing precipitation code, and the partial pressure of water vapor. The binary precipitation code depends upon present weather type reported in surface weather observations. S&L estimated solar radiation using the approach of Meyers and Dale (1983). Atmospheric radiation was computed using methodology described by Jirka *et al*. 1978. The partial pressure of water vapor was computed using ASHRAE (1975), which implements the procedure described by List (1951). Formulation and validation of the algorithms used to compute solar radiation, atmospheric radiation, freezing precipitation code, and the partial pressure of water vapor are described below in Section 10.

(2) *Precipitation Data*

Raw hourly digital precipitation data in DS-3240 and text format (NCDC 2000 and NCDC 2012) from KPIA were available for January 1, 1990 through December 31, 2012.

Since the project required combining wind speed/direction, dry bulb temperature, and dew point temperature from an on-site meteorological tower with data collected KPIA, S&L developed a project-specific FORTRAN program which merged data from the on-site tower with data from KPIA. The program produced input files subsequently processed as described below.

6.0 CREATING INPUT METEOROLOGICAL DATA FOR LAKET-PC

S&L uses a series of modular computer programs collectively called the Surface Data Generator ("SURGEN") (S&L 1997) and judgments and adjustments by a qualified, experienced, professional meteorologist to create digital meteorological data files for input into LAKET-PC. Key requirements of LAKET-PC include a specific set of weather parameters and specific digital format (Table 1), and a complete meteorological

database with no bad (out of range), or missing, parameters. SURGEN modules are executed independently and perform the following functions:

- Interpret the unique digital formats of raw surface weather observations and precipitation data and extract required meteorological parameters.
- Convert numeric units of extracted parameters to those required by the LAKET-PC program.
- Scan hourly surface weather observations, and identify periods when values for selected parameters are either missing or invalid (outside of acceptable ranges). Those periods are identified by starting and ending date, and by the length of each gap (in hours).
- Scan hourly surface weather observations, identify periods within the digital file when whole days or specific hours are missing; insert new, or blank records into the file to fill time gaps.
- Estimate values for the following weather parameters: an indicator whether precipitation is liquid or frozen, solar radiation reaching the lake surface, atmospheric radiation reaching the lake surface, partial pressure of water vapor in the atmosphere, wet bulb temperature and dew point temperature.
- Perform simple linear interpolation of weather parameter values through short data gaps, and insert the new interpolated values into the database.
- Allow insertion of manually selected substitution values into gaps in the database that are judged not to be suitable for simple linear interpolation.
- Translate processed and adjusted databases into the format required by the LAKET-PC program.

7.0 REVIEW AND ADJUSTMENT OF METEOROLOGICAL DATA

As noted above, SURGEN identified short periods of missing, or bad (out of range), raw meteorological data and used linear interpolation to fill short gaps. The gaps were generally 1-2 hours long. However, there were a number of gaps in the on-site meteorological tower data that were considered to be too long for linear interpolation. Data were manually substituted from KPIA for those periods. Those periods are listed in Table 4. If either the wind speed, or wind direction, was missing from the on-site data, then both the wind speed and direction were substituted from KPIA so that the substituted wind vector consisted of a wind speed and wind direction from the same location.

To check the thermodynamic consistency of the meteorological data, S&L computes the hourly wet bulb temperature and relative humidity from the dry bulb and dew point temperature to ensure thermodynamic consistency among the temperature and humidity parameters. In cases when the dew point temperature from KPIA is substituted for a missing dew point reading from the on-site tower, and the dew point temperature from KPIA exceeds the on-site dry bulb temperature, the substituted dew point temperature is set equal to the on-site dry bulb temperature before computing the wet bulb temperature and relative humidity.

8.0 LAKET-PC METEOROLOGICAL DATA INPUT FILE

SURGEN produced a single LAKET-PC meteorological input file which was appended to the existing meteorological data text file. The specifications of the updated LAKET-PC meteorological data file are listed below:

Updated meteorological data file:
Name: PIABDW4812.TXT
Type: ASC text
Size: 87,231 Kb
File creation date/time: 1/30/2014 8:18 AM

9.0 WIND SENSOR HEIGHT

The wind speed/direction sensor height is an input in the LAKET-PC program. The wind sensor height (NCDC 2002) changed a number of times during the 1948-2012 period of record of the input meteorological data file. The historical wind sensor height is listed in Table 5. Some of the changes in wind sensor height are due to changes in the wind instrumentation at KPIA, while others are due to changes in the primary wind data source.

Wind speed data from KPIA were collected at the 20 ft. level during October 1, 1959 through September 30, 1995. Because 34-ft wind speed data were occasionally not available from the on-site meteorological tower during December 1, 1990 through September 30, 1995 (Table 4), it is necessary to combine relatively short periods of wind speed data from KPIA (20 ft. anemometer height) with wind speed data from the on-site tower (34 ft. anemometer height) for the January 1, 1990 through September 30, 1995 period. Although the anemometer height of the on-site tower differed from the anemometer height at KPIA during that period, LAKET-PC is expected to produce conservative results when using winds from KPIA since 20-ft. level wind speeds are expected to be less than wind speeds at the 34-ft level.

The anemometer height at KPIA was increased to its current height of 32.8 feet on October 1, 1995. The anemometer height at KPIA (32.8 ft.) is considered to approximate the anemometer height of the lowest level of the on-site tower (34 ft.) for the period from October 1, 1995 through December 31, 2012.

10.0 FORMULATION AND VALIDATION OF ALGORITHMS FOR COMPUTING SOLAR RADIATION, ATMOSPHERIC RADIATION, FREEZING PRECIPITATION CODE, AND PARTIAL PRESSURE OF WATER VAPOR

This section describes formulation and validation of algorithms used to compute solar radiation, atmospheric radiation, the freezing precipitation code, and the partial pressure of water vapor. The theoretical basis of each algorithm is described first, followed by validation.

10.1 Theoretical Basis for Algorithms

10.1.1 Estimation of Solar Radiation Reaching the Ground Surface

Computed solar radiation is a new analysis input for the Braidwood Nuclear Generating Station. The following approach is used to compute solar radiation. The approach follows the methods of Meyers and Dale (1983). Those methods were developed by the Midwest Agricultural Weather Center of the Department of Agronomy at Purdue University (West Lafayette, Indiana). The methods include a semi-physical model based on standard meteorological data. The radiation model includes the effects of: Rayleigh scattering, absorption by water vapor and permanent gases, and absorption and scattering by aerosols and clouds. Cloud attenuation is accounted for by assigning transmission coefficients based on cloud height and amount. The model was tested by Meyers and Dale with independent data from West Lafayette and Indianapolis Indiana, Madison Wisconsin, Omaha Nebraska, Columbia Missouri, Nashville Tennessee, Seattle Washington, Los Angeles California, Phoenix Arizona, Lake Charles Louisiana, Miami Florida, and Sterling Virginia. Excellent agreement was obtained for all stations tested. The model's performance judged by relative error was found to be independent of season and cloud amount for all seasons tested.

From Meyers and Dale (1983):

$$RAD = (I_o)\,(T_{a)})\,(T_R)\,(T_g)\,(T_w)\,[\,1+(alb)\,(ca)\,]\,(cov)\,(\cos(Z))\,(221.13)\,[\,(1-cov) + (cov)\,(T_i)\,]$$

Where:

RAD = irradiance at the ground, including the effects of a cloud layer [BTU/(ft^2 hr)]

I_o = extraterrestrial radiation flux at the top of the atmosphere on a surface normal to the incident radiation (W / m^2)

$$= (1353\ )\ [\ 1+ (0.034)\ [\ \cos\ [\ (6.28318)\ (n-1)\ /\ 365\ ]\ ]$$

1353 = conversion factor to produce results in numeric units of (W / m^2)

221.13 = conversion factor to convert radiation numeric units from (Langley/min) to [BTU/(ft^2 hr)]

Transmission coefficients:

T_a = transmission coefficient after absorption and scattering by aerosols = 0.925^{M}

T_w = transmission coefficient after absorption by water vapor = $1 - (0.077) [(u)(M)]^{0.3}$

T_R = transmission coefficient after Rayleigh (air molecule) forward scattering

T_g = transmission coefficient after absorption by "permanent" gases

$(T_R) (T_g) = 1.021 – [(0.084) [(M) [(949) (p) (10^{-5}) + 0.051]]^{0.5}]$

T_i = transmission coefficient after absorption by clouds as follows:

Cloud height range (ft.)	**Cloud layer coverage (tenths)**	**T_i**
>= 0 < 1000	0 < cov <= 9	.50
>= 0 < 1000	=10	.15
>= 1000 < 4000	0 < cov <= 9	.629
>= 1000 < 4000	=10	.312
>= 4000 < 10000	0 < cov <= 9	.525
>= 4000 < 10000	=10	.414
>= 10000 < 18000	0 < cov <= 9	.534
>= 10000 < 18000	=10	.455
>= 18000 < 30000	0 < cov <= 9	.746
>= 18000 < 30000	=10	.668
>= 30000	0 < cov <= 9	.90
>= 30000	=10	.85

Other parameters:

alb = ground surface albedo
= 0.2 with no snow cover
= 0.65 with snow cover

ca = cloud albedo
= 0.5 for cloud base < 5486 m (18000 ft.)
= 0.0 for cloud base >= 5486 m (18000 ft.)

Parameter "s" that is used to estimate precipitable water is defined as follows:

Site location latitude zone (degrees north)	**Season**			
	winter	**spring**	**summer**	**autumn**
>00 and <=10	3.37	2.85	2.80	2.64
>10 and <=20	2.99	3.02	2.70	2.93
>20 and <=30	3.60	3.00	2.98	2.93
>30 and <=40	3.04	3.11	2.92	2.94
>40 and <=50	2.70	2.95	2.77	2.71
>50 and <=60	2.52	3.07	2.67	2.93
>60 and <=70	1.76	2.69	2.61	2.61
>70 and <=80	1.60	1.67	2.24	2.63
>80 and <=90	1.11	1.44	1.94	2.02

Season definitions as follows:

Julian day	**season**
> 80 and <= 173	spring
> 173 and <= 264	summer
> 264 and <= 355	autumn
> 0 and <= 80 or > 355 and <= 366	winter

n = Julian day (1 – 366)

p = surface atmospheric pressure (kPa)

Td = surface dew point temperature (°F)

y = site location latitude

d = declination angle of the sun (radians)

H = hour angle

M = optical air mass at a pressure of 101.3 kPa
$= (35) / ((1224) (\cos^2 Z) + 1)^{0.5}$

u = precipitable water vapor = $\exp(0.1133 - \log_e(s+1) + (0.0393)(Td))$

ZEN = solar zenith angle = $90° - (\sin^{-1}(\sin(y)\sin(d) + \cos(y)\cos(d)\cos(H)))$

Z = solar zenith angle (in units of radians) = (ZEN) (6.28318/360)

(6.28318)(1/360) = multiplication factor to convert degrees to radians

cov = coverage of a cloud layer (0.0 - 1.0)

10.1.2 Estimation of Ground Snow Cover

It was necessary to include in the program an algorithm for estimating hourly snow cover, because the presence of snow cover is a component of the solar radiation algorithm. A description of ground snow cover is included in this section to provide a complete technical description of the solar radiation algorithm. However, the ground snow cover algorithm would not be exercised for certain applications of LAKET-PC, such as summertime maximum lake temperature analysis.

An algorithm was created to approximate snow accumulation. It was based on analysis of observations during four winters at Peoria, Illinois (NCDC 1989(b), 1990, 1991, 1992). A simple linear equation for snow depth was created from those data. Table 6 presents snow and temperature data from Peoria, Illinois that were used to construct a snow accumulation algorithm. Each row of data in Table 6 summarizes conditions during a snow event. Although the equation that was based on those data was intended to be applied to hourly weather conditions, the data used to construct the equation were based on the total snowfall on the ground during the event, and the maximum air temperature observed during the event. This approach was taken because available data included only one daily observation of snow depth on the ground. It was expected that the slope of the equation would be approximately the same regardless of whether hourly data during an event or data summarizing the entire event were used to construct the equation.

The program tracks snow depth from hour to hour. The depth of snow on the ground is increased when snow is observed and it has a finite amount greater than zero or a “trace”. When snow is observed, the rate of depth increase is based on the rate of water equivalent precipitation and the air temperature. After snowfall ends, the depth of snow is decreased

on an hourly basis according to air temperature. When snow depth is non-zero, snow cover is present for purposes of input to the solar radiation algorithm.

Any of the following weather types are considered snow that affects the ground snow depth.

- Any type of snow (light, moderate, or heavy)
- Any type of snow pellets
- Any type of snow shower
- Any type of snow squall
- Any type of snow grains

For any hour reporting on of the above types of precipitation, the accumulation of snow depth on the ground during that hour is predicted with the following equation:

Hourly increase in snow depth (inches) = (A) (-B)

Where:

A = Hourly water equivalent precipitation (inches)
B = (C-44.4) / (1.39)
C = Hourly air temperature (°F)

A "negative" hourly snow depth increase is not allowed to occur. That is, no snow depth increase is predicted if the air temperature is greater than or equal to 44.4 °F.

Theory was found to indicate that the process of snow depth reduction involves a complex heat balance, and is a function of cloud cover, solar angle, air temperature, and humidity (Colbeck 1980; Geiger 1965). An existing snow depth reduction algorithm was not located.

A simple method was selected to construct an algorithm to simulate combined melting and sublimation of snow. It was based on examination of winter data from Madison, Wisconsin (NCDC 1988(a), 1989(a)). Values for rates of snow depth reduction were derived from the 1988 Madison daily snow depth information by plotting temperature versus snow melt for periods during which there was still snow on the ground after melting. This was done for January, February, and December, 1988. Trends were subjectively identified, and amounts of melting were selected for each of several temperature ranges. Table 7 presents data that were used to construct the snow melt algorithm.

Reduction of snow depth uses as input hourly temperature data, and an indication whether there exists snow cover and its depth. The following table describes the snow depth decrease per hour predicted by the algorithm for each of six dry bulb temperature

ranges. No reduction is predicted when the temperature is less than the lower end of the lowest range.

Snow Melt Rates Predicted by the Program

Dry Bulb Temperature Range (°F)	**Snow Depth Decrease Per Hour (inches)**
10 – 19	0.021
19 – 32	0.042
32 – 36	0.083
36 – 41	0.166
41 – 46	0.333
> 46	0.667

The snow depth and snow accumulation algorithms operate simultaneously in the program, as it advances through hourly meteorological data.

10.1.3 Estimation of Atmospheric Radiation Reaching the Ground Surface

Infrared radiation emitted by the Earth's surface is partially absorbed by the water vapor of the atmosphere, which re-emits it. A portion of that re-emitted radiation is in a downward direction. It is absorbed by the ground and re-emitted upwards (Huschke 1980). Therefore, atmospheric infrared radiation is an important component of the radiation balance of a cooling lake water surface. The equation used by the program to estimate atmospheric radiation reaching the ground is as follows (Jirka *et al.*, 1978):

$$R = [(1.16)(10)^{-13} / 24][460 + T]^6 \; [1 + ((0.17)(C^2))]$$

Where:

R = Atmospheric radiation (BTU/(ft^2 hr))
T = Air temperature (°F)
C = Cloud cover (tenths, e.g., "0.8" represents 8/10)

10.1.4 Freezing Precipitation Code

LAKET-PC requires input hourly meteorological data. The meteorological data are produced by the SURGEN program (S&L (1997)). SURGEN extracts meteorological parameters from raw hourly surface weather observations and writes the extracted parameters to a LAKET-PC-compatible meteorological data file.

LAKET-PC performs solar radiation computations which require estimates of hourly snow cover. Estimation of hourly ground snow cover is described in detail in section 10.1.2 of this report. Per section 10.1.2, LAKET-PC requires an input (precipitation type) related to the occurrence of precipitation that affects hourly snow cover. Precipitation type (e.g., rain, snow, freezing rain) is included in raw hourly surface weather observations. Precipitation type is represented by a numerical code in surface weather observations (NCDC (2005)). Numerical precipitation type codes corresponding to freezing or frozen precipitation are listed in Table 8.

SURGEN reads raw meteorological data files, which include the precipitation type, and writes a binary (0 or 1) precipitation code to the output LAKET-PC-compatible meteorological file. SURGEN writes a binary precipitation code of one (1) when one of the precipitation codes in Table 8 is found in an input hourly weather observation. Otherwise, SURGEN writes a code of zero (0).

10.1.5 Partial Pressure of Water Vapor

LAKET-PC requires the partial pressure of water vapor in some of its computations. The partial pressure of water vapor is related to relative humidity and the saturation vapor pressure of water (e.g., Hess (1979)). The saturation vapor pressure of water is a function of atmospheric dry-bulb temperature (e.g., Iribarne and Godson (1981)). The relative humidity and dry-bulb temperature are included in hourly surface weather observations (NCDC (2005)).

SURGEN (S&L (1997)) processes hourly surface weather observations and produces LAKET-PC-compatible meteorological data input files which include the partial pressure of water vapor. SURGEN uses a FORTRAN subroutine "PVSF" (ASHRAE (1975); Figure 1) to compute the partial pressure of water vapor. PVSF uses equations from List (1951). The logic of the FORTRAN subroutine is described below.

Input

The subroutine PVSF requires the dry-bulb temperature x in Fahrenheit

Output

The subroutine PVSF returns the partial pressure of water vapor at saturated conditions (in inches, Hg.), VAPPR

Description of the Algorithm

The vapor pressure of water in saturated air (in inches, Hg.) is defined as:

$$\text{VAPPR} = 29.921 \times 10^{(P1+P2+P3+P4)} \qquad \text{(Eq. 1)}$$

where the parameters P1 through P4 depend on dry-bulb temperature *x* as described below.

First, the constants A1 through A6 and B1 through B4 are defined according to Table 9.

Next, define T = (x+459.688)/1.8, which is the dry–bulb temperature in Kelvin.

If T < 273.16 K, then define Z = 273.16/T and determine the parameters P1 through P4 in Eq. 1 from Table 10.

If T >= 273.16 K, then define Z = 373.16/T and determine the parameters P1 through P4 in Eq. 1 according to Table 11.

The subroutine computes the vapor pressure of water vapor at saturation, VAPPR, using Eq. 1 and returns the computed value of VAPPR to the calling program.

The partial pressure of water vapor is found in SURGEN from the relative humidity (RH) and the vapor pressure of water in saturated air (VAPPR) using the following equation (e.g., Hess (1979); page 60):

$$e = VAPPR \times (RH/100). \qquad \text{(Eq. 2)}$$

10.2 Validation

Validation of the atmospheric radiation algorithm was accomplished by manual calculations. The original source reference for the method (Jirka *et al*. 1978) was relied on as a validation of the theoretical approach. Performance of manual calculations versus computer calculations was expected to be very good in that case, within a couple of percent, because the calculations should not introduce significant uncertainty.

Validation of the integrated snow cover and solar radiation algorithms was accomplished via comparison of program predictions with randomly selected field observations of actual solar radiation phenomena. Performance in those cases was expected to be generally better than 70 percent. That expectation was based on the absolute errors reported by the authors of the theoretical basis in Table 7 of their technical paper (Meyers and Dale 1983).

Validation of the freezing precipitation code was performed by comparing program output with input raw surface weather observations. Validation of the partial pressure of

water vapor was performed by comparing results from SURGEN with a manual computation a published tabular value of vapor pressure.

10.2.1 Solar Radiation Reaching the Ground Surface - Validation

The solar radiation algorithm was validated via comparison of program predictions with solar radiation observations made by the National Oceanic and Atmospheric Administration (NOAA).

Table 12 through Table 15 present lists of processed weather data created by the program, for Madison Wisconsin, for the following dates: 25 January 1988, 28 July 1988, 30 July 1988, and 15 September 1988. Column 13 of the lists contains data labeled "SWRAD", meaning shortwave solar radiation in units of BTU/(ft^2 hr). Column 1 indicates hours of day.

Table 16 through Table 18 present lists of NOAA Madison, Wisconsin solar radiation measurements at Madison Wisconsin for months January 1988, July 1988, and September 1988 (NCDC 1988(b)). Table rows identify days of month. Table columns identify hours of day.

Conversion of the NOAA solar radiation measurements from units of (Watt-hr m^{-2}) to (BTU/(ft^2 hr)) to match program output numeric units was accomplished manually as follows.

A Langley is a unit of energy per unit area
1 Langley = 11.622 Watt-hr per square meter
1 Langley = 3.687 British thermal units per square foot

To convert NOAA radiation measurements to BTU/(ft^2 hr), a multiplication factor must be applied, as follows:

$$(\text{Watt-hr } m^{-2}) / 11.622 = (\text{Langleys})$$
$$(\text{Langleys})\ (3.687) = \text{BTU}/ft^2$$

Therefore,

$$(\text{Watt-hr } m^{-2})\ (3.687 / 11.622) = \text{BTU}/ft^2$$
or:
$$(\text{Watt-hr } m^{-2})\ (0.3172) = \text{BTU}/ft^2$$

The program assumes that the radiation energy flux is constant during the entire hour, so the final equation is as follows:

$$(\text{Watt-hr } m^{-2})\ (0.3172) = \text{BTU}/(ft^2 \text{ hr})$$

Figure 2 through Figure 5 present comparisons of program output predictions of solar radiation with NOAA measurements of solar radiation. Predictions and measurements are for Madison, Wisconsin during the following days: 25 January 1988, 28 July 1988, 30 July 1988, and 15 September 1988. The NOAA measurements were converted to the same numerical units as the program predictions, using the conversion factor described above.

The comparisons of estimated to measured solar radiation in Figure 2 through Figure 5 demonstrated that the solar radiation algorithm performs reasonably well and results are consistent with expectations. Those results validate the solar radiation algorithm.

Radiation prediction performance levels indicated by Figure 3 for 28 July 1988 and Figure 4 for 30 July 1988 are particularly good. As shown by hourly meteorological observations listed in Table 13, 28 July 1988 was a perfectly clear day at Madison. Column 10, titled “CL COV”, contains cloud cover information (tenths), and column 2, titled “CEIL”, contains cloud ceiling height information (feet). In contrast, as shown by hourly meteorological data listed in Table 14, 30 July 1988 included marked variation of cloud cover (column 10 in Table 14) from 2 tenths to 9 tenths between 6 am and 6 pm at Madison. Therefore, the program predicted the peak daily radiation level well on both cloudy and clear days.

On 25 January 1988 (Figure 2), the program conservatively over-predicted peak solar radiation by about 17 percent. That was during a day with snow on the ground, variable ceilings heights (column 2 in Table 12) and overcast (10/10) sky cover (column 10 in Table 12). On 15 September 1988 (Figure 5), the program over-predicted peak solar radiation by about 10 percent. Conditions on 15 September 1988 featured total overcast between 7 am and 6 pm (column 10 in Table 15). It is not obvious why program predictions were slightly less accurate during 25 January and 15 September. A possible explanation is that during those two days the cloud cover observation at the “top” of each hour may not have accounted effectively for cloud variations during that hour. Predictions for 25 January 1988 were less accurate than for the other three days, but still remarkably good. It is possible that the snow cover algorithm (which is an approximation) added some finite uncertainty during that day only.

10.2.2 Atmospheric Radiation Reaching the Ground Surface - Validation

To verify calculations of atmospheric longwave radiation, data for hour 5 of 25 March 1955 at Springfield Illinois were manually used in a calculation with the atmospheric radiation formula. Results were as follows.

$$R = [(1.16)\,(10)^{-13} / 24]\,[460 + 29]^{6}\,[1 + ((0.17)\,(1.0^{2}))] = 77.32 \text{ BTU/(ft}^{2}\text{ hr)}$$

Where:

Data for hour 5 of 25 March 1955 at Springfield, Illinois were as follows

Dry bulb temperature = 29°F
Cloud cover = 1.0 (ten tenths)

Table 19 presents a list of processed weather data created by the program, for Springfield, Illinois, for 25 March 1955. Column 14 of the list contains data labeled "LWRAD", meaning longwave atmospheric radiation. Column 1 indicates hour of day. The manually calculated value of 77.32 BTU/(ft^2 hr) exactly matches the program-calculated value for hour 5, validating the atmospheric radiation algorithm.

10.2.3 Freezing Precipitation Code – Validation

On December 3, 1996 the Peoria, IL National Weather Service recorded snow from 5 am until 9 am local standard time (LST). A portion of the raw meteorological data file (NCDC (2005)) containing weather observations from Peoria for December 3, 1996 is shown in Figure 6. The precipitation type observed at 5 and 6 am (precipitation type code 40, encoded as 04000 in the data file) is circled in the figure. Referring to precipitation type codes in Table 8, a precipitation type code 40 corresponds to light snow.

SURGEN processed the raw meteorological data (Figure 6) and produced a LAKET-PC-compatible meteorological data input file which included binary freezing precipitation codes. As explained above, SURGEN sets the binary precipitation type variable to one (1) in a LAKET-PC-compatible meteorological data input file when one of the precipitation types in Table 8 is observed. A portion of the LAKET-PC-compatible meteorological data input file from SURGEN corresponding to Figure 6 is shown in Figure 7. Binary freezing precipitation codes in the 5 and 6 am hourly records are circled in Figure 7. Figure 7 shows that the precipitation codes were set to one (1) in both records, which is consistent with the light snow (precipitation code 40 from Table 8) observed at those times. SURGEN recognized the occurrence of freezing precipitation in the raw weather observations and correctly set the binary freezing precipitation codes in the LAKET-PC meteorological data input file to one (1).

10.2.4 Partial Pressure of Water Vapor – Validation

The partial pressure of water vapor was manually computed using meteorological data. On July 30, 1996 at 2 am LST, the Peoria, IL National Weather Service recorded a dry-bulb temperature of 70°F and a relative humidity of 94% (Figure 8). The partial pressure of water vapor at those conditions is computed manually below using the logic of the PVSF subroutine described above.

The dry bulb temperature x = 70°F so that T is defined as

$$T = (70+459.688)/1.8 = 294.2711$$

Since T >= 273.16 K compute *z* as follows:

$$z = 373.16/T = 373.16/294.2711 = 1.26808$$

Terms P1, P2, P3, and P4 are computed using their definitions in Table 9 and Table 11

$$P1 = -7.90298\ (z-1) = -7.90298\ (1.26808 - 1) = -2.11865$$

$$P2 = 5.02808 \log_{10}(z) = 5.02808 \log_{10}(1.26808) = 0.51863$$

$$P3 = -1.3816 \times 10^{-7} \times (10^{(11.344\ (1-1/1.26808))}-1) = -0.00003$$

$$P4 = 8.1328 \times 10^{-3} \times (10^{(-3.49149\ (1.26808-1))}-1) = -0.00719$$

The partial pressure of water vapor at saturation (VAPPR) is computed using Eq. 1 and the above definitions of P1, P2, P3, and P4:

$$VAPPR = 29.921 \times 10^{(P1+P2+P3+P4)} = 0.73916 \text{ inches Hg.}$$

At a relative humidity of 94%, the partial pressure of water vapor (e) is computed using the partial pressure of water vapor in saturated air and Eq. 2 as follows:

$$e = VAPPR \times (RH/100) = 0.73916 *(94/100) = 0.69 \text{ inches Hg.}$$

The results of the manual computation are compared with results from SURGEN as follows. A portion of the raw meteorological data file (NCDC (2005)) containing the observed dry-bulb temperature and humidity at 2 am July 30, 1996 (70°F and 94% relative humidity) is shown in Figure 8. SURGEN processed this raw meteorological data file and computed the partial pressure of water vapor using the subroutine “PVSF” (Figure 1). The computed value was included as part of the LAKET-PC meteorological data input file. A portion the LAKET-PC meteorological data input file showing the input dry-bulb temperature (70°F), relative humidity (94%) and computed partial pressure of water vapor is shown in Figure 9. Figure 9 shows that the partial pressure of water vapor computed by SURGEN (0.69 inches Hg.) matches the manually computed value above (0.69 inches Hg.).

The manually computed partial pressure of water vapor and the value from SURGEN are compared with the vapor pressure published in standard reference (List (1951)). Figure 10 shows a portion of the saturation vapor pressure table from List (1951, page 356) for a dry-bulb temperature of 70.0°F. The value shown in Figure 10 (0.73916 inches Hg.) applies to saturated air (100% relative humidity), so the value in Figure 10 must be multiplied by the observed relative humidity (94%) to obtain the partial pressure of water vapor. Multiplying this value by 94% produces a partial vapor pressure of water of 0.69 inches Hg. (0.73916 x .94 = 0.69), which matches the manually computed value above

and the value computed by the PVSF subroutine in SURGEN (Figure 9). The subroutine PVSF, as implemented in SURGEN, correctly computed the partial pressure of water vapor.

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```
C##############################################################
C
C
      SUBROUTINE PVSF(X,VAPPR)
      DIMENSION A(6), P(4), B(4)
      DATA A/-7.90298, 5.02808,    -1.3816E-7,
     *       11.344,     8.1328E-3, -3.49149/
     1     B/-9.09718, -3.56654, 0.876793, 0.0060273/
      T =         (X+459.688)/1.8
      IF (T.LT.273.16) GO TO 3
      Z =         373.16/T
      P(1) =      A(1)*(Z-1)
      P(2) =      A(2)*LOG10(Z)
      Z1 =        A(4)*(1-1/Z)
      P(3) =      A(3)*(10**Z1-1)
      Z1 =        A(6)*(Z-1)
      P(4) =      A(5)*(10**Z1-1)
      GO TO 4
3     Z =         273.16/T
      P(1) =      B(1)*(Z-1)
      P(2) =      B(2)*LOG10(Z)
      P(3) =      B(3)*(1-1/Z)
      P(4) =      LOG10(B(4))
4     SUM =       0
      DO 5 I=1,4
5     SUM =       SUM+P(I)
      VAPPR =     29.921*10**SUM
      RETURN
      END
C
C
C##############################################################
```

Figure 1. The FORTRAN subroutine PVSF from ASHRAE (1975).

Figure 2. Comparison of Program Predicted Solar Radiation with Solar Radiation Measurements from Madison Wisconsin during 25 January 1988

SOLAR RADIATION (BTU/FT^2-HR)
MADISON, WI
25 JAN 1988

HOUR	OBSERVED	PREDICTED
1		
2		
3		
4		
5		
6		
7	5.7	11.3
8	33	49.8
9	52.7	84.3
10	64.7	107.7
11	100.2	117.3
12	79.9	112.1
13	53.2	92.7
14	45.7	61.2
15	22.8	17.9
16	6.7	0
17		
18		
19		
20		
21		
22		
23		
24		

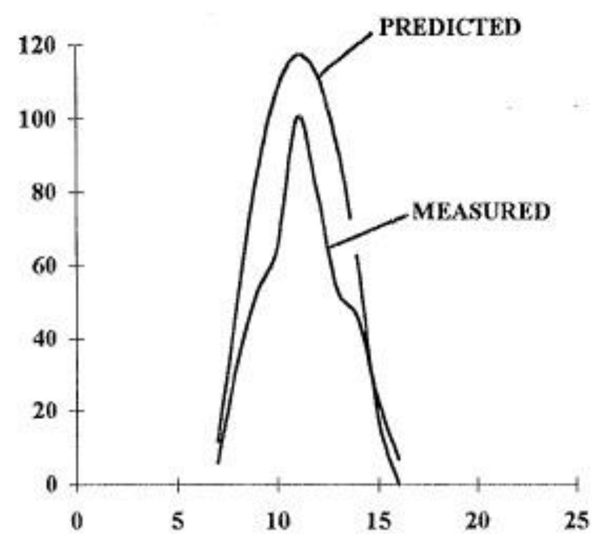


Figure 3. Comparison of Program Predicted Solar Radiation with Measurements from Solar Radiation Madison Wisconsin during 28 July 1988

SOLAR RADIATION (BTU/FT^2-HR)
MADISON, WI
28 JUL 1988

HOUR	OBSERVED	PREDICTED
1		
2		
3		
4	1.3	
5	23.2	43.6
6	70.4	104.6
7	100.6	163.1
8	182.1	215.4
9	227.7	256
10	260.4	281.3
11	275	289.9
12	282.6	280
13	267.4	254.2
14	230.9	214.2
15	183	162.4
16	127.5	103.5
17	69.5	45.1
18	22.5	
19	1.3	
20		
21		
22		
23		
24		

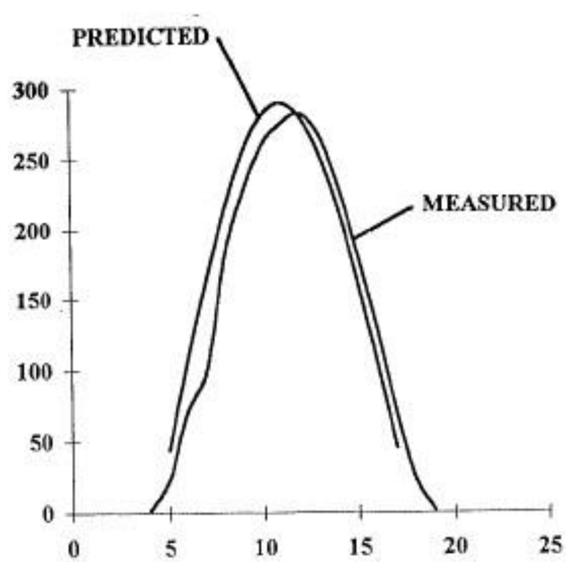


Figure 4. Comparison of Program Predicted Solar Radiation with Solar Radiation Measurements from Madison Wisconsin during 30 July 1988

SOLAR RADIATION (BTU/FT²-HR)
MADISON, WI
30 JUL 1988

HOUR	OBSERVED	PREDICTED
1		
2		
3		
4	0.6	
5	13.3	38.4
6	49.8	95.6
7	104	155.4
8	157.3	204.4
9	200.5	232.6
10	243.9	267.6
11	236.3	270
12	270	258.5
13	266.4	241.8
14	227.1	203.4
15	182.1	157.1
16	131.3	99.8
17	71.4	43.1
18		
19		
20		
21		
22		
23		
24		

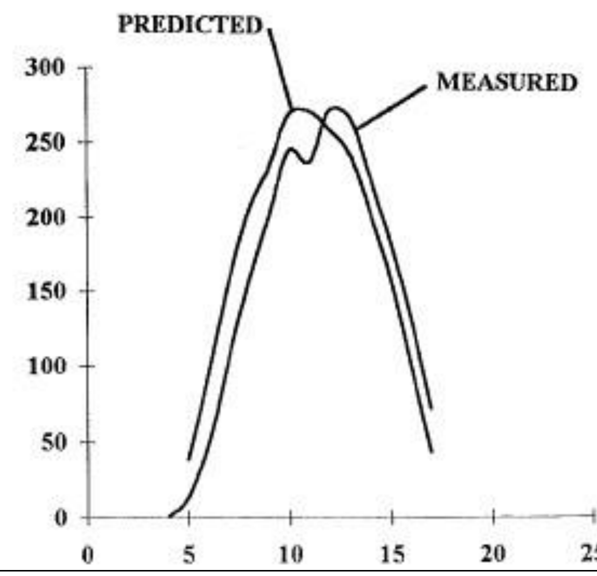
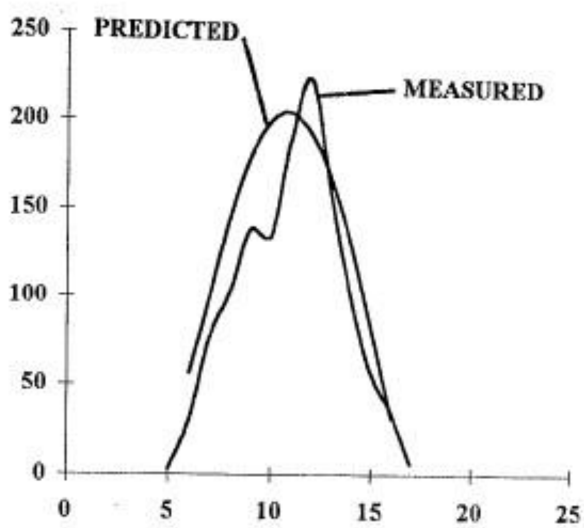


Figure 5. Comparison of Program Predicted Solar Radiation with Solar Radiation Measurements from Madison Wisconsin during 15 September 1988

SOLAR RADIATION (BTU/FT^2-HR)
MADISON, WI
15 SEP 1988

HOUR	OBSERVED	PREDICTED
1		
2		
3		
4		
5	2.5	
6	29.8	55.9
7	76.4	99.3
8	102.1	143.9
9	138	178.2
10	133.9	198.5
11	187.1	203.5
12	222.7	191.9
13	157	166
14	97.4	128
15	56.1	81.1
16	34.3	30.9
17	6	
18		
19		
20		
21		
22		
23		
24		



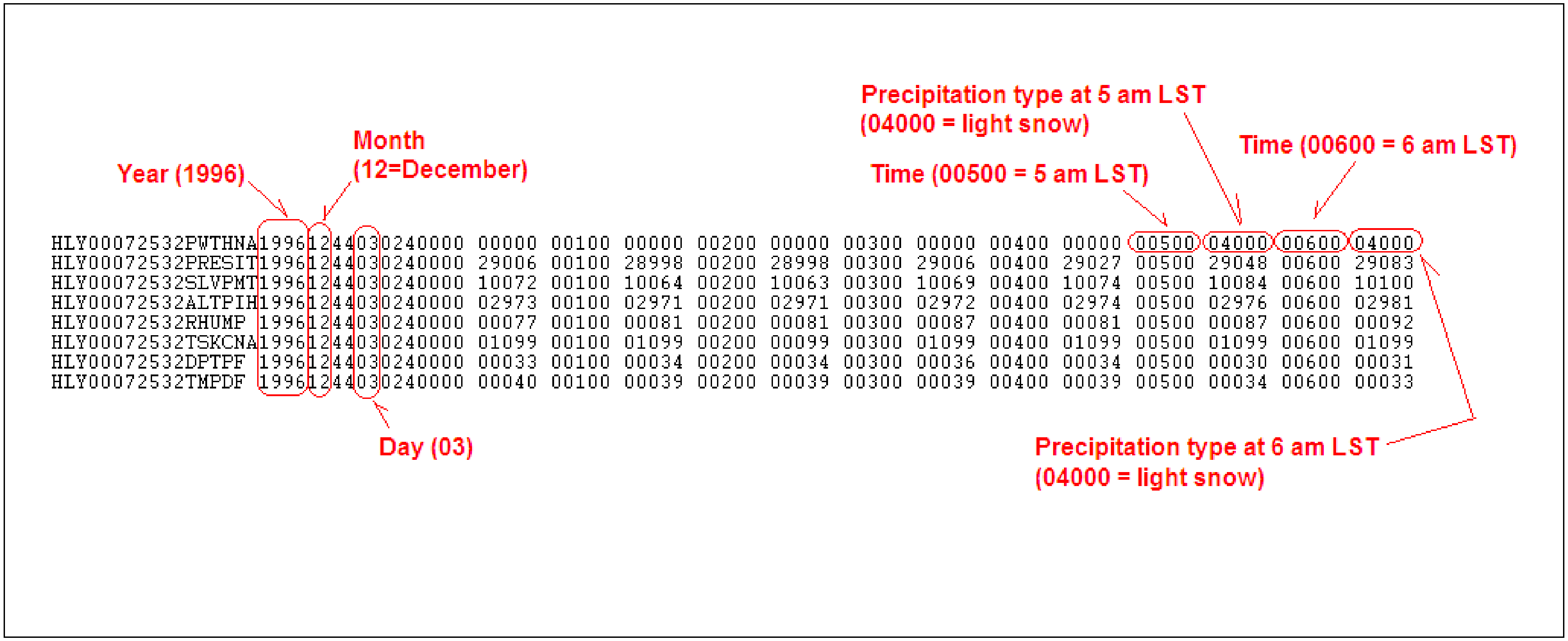


Figure 6. A portion of the meteorological weather record for Peoria, IL for December 3, 1996. Portions of the records for 5 and 6 am LST are annotated.

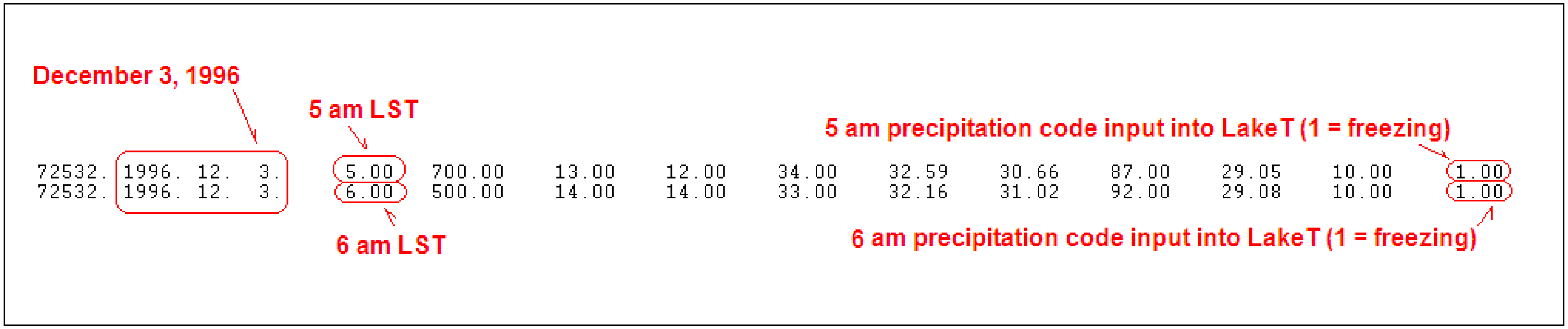


Figure 7. A portion of the LAKET-PC input file for 5 and 6 am LST December 3, 1996.

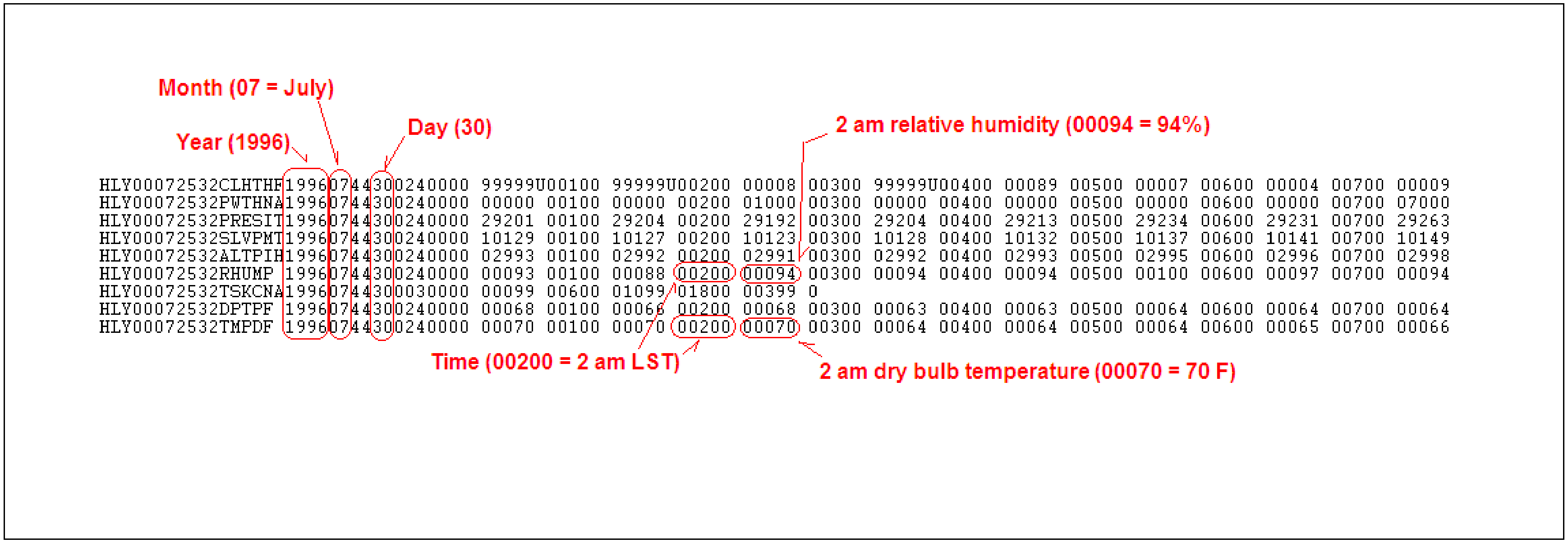


Figure 8. A portion of the meteorological weather record for Peoria, IL for July 30, 1996. Portions of the 2 am LST record are annotated.

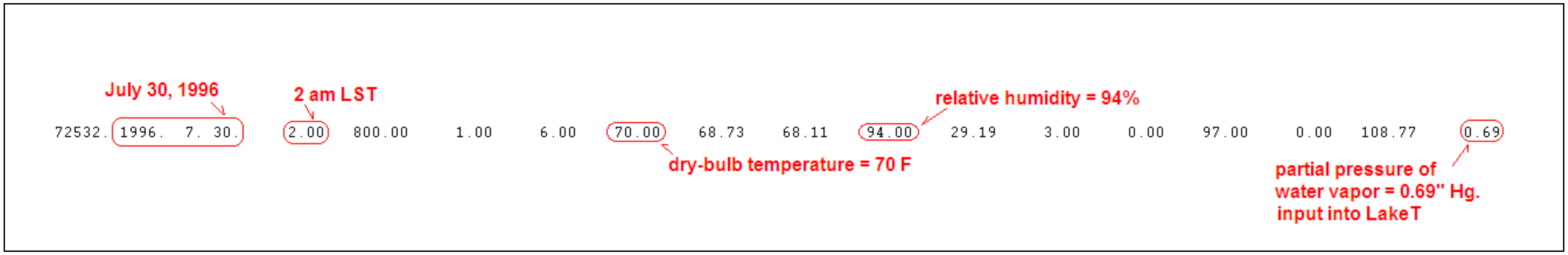


Figure 9. A portion of the LAKET-PC input file for 2 am LST July 30, 1996.

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TABLE 95 (CONTINUED)

SATURATION VAPOR PRESSURE OVER WATER

English units

Temperature	.0	.1	.2	.3	.4	.5	.6	.7	.8
°F.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.	in. Hg.
50	0.36240	0.36375	0.36511	0.36646	0.36783	0.36920	0.37057	0.37195	0.37333
51	.37611	.37751	.37891	.38031	.38172	.38314	.38456	.38598	.38741
52	.39028	.39172	.39317	.39462	.39608	.39754	.39901	.40048	.40195
53	.40492	.40641	.40790	.40940	.41090	.41241	.41393	.41544	.41697
54	.42003	.42157	.42311	.42466	.42621	.42777	.42933	.43090	.43248
55	0.43564	0.43723	0.43882	0.44042	0.44203	0.44364	0.44525	0.44687	0.44849
56	.45176	.45340	.45504	.45670	.45835	.46001	.46168	.46335	.46503
57	.46840	.47009	.47179	.47350	.47521	.47692	.47864	.48037	.48210
58	.48558	.48733	.48908	.49084	.49260	.49437	.49614	.49792	.49971
59	.50330	.50510	.50691	.50873	.51055	.51238	.51421	.51605	.51789
60	0.52160	0.52346	0.52533	0.52720	0.52908	0.53096	0.53285	0.53475	0.53665
61	.54047	.54239	.54432	.54625	.54818	.55013	.55208	.55403	.55600
62	.55994	.56192	.56391	.56590	.56790	.56990	.57191	.57393	.57595
63	.58002	.58206	.58411	.58616	.58823	.59029	.59237	.59445	.59654
64	.60073	.60284	.60495	.60707	.60919	.61133	.61347	.61561	.61777
65	0.62209	0.62426	0.62644	0.62862	0.63082	0.63302	0.63522	0.63743	0.63965
66	.64411	.64635	.64859	.65085	.65311	.65537	.65765	.65993	.66221
67	.66681	.66912	.67143	.67376	.67608	.67842	.68076	.68312	.68547
68	.69021	.69259	.69497	.69737	.69977	.70217	.70459	.70701	.70944
69	.71432	.71677	.71923	.72169	.72416	.72664	.72913	.73163	.73413
70	0.73916	0.74169	0.74422	0.74676	0.74931	0.75186	0.75443	0.75700	0.75958
71	.76476	.76736	.76997	.77259	.77521	.77785	.78049	.78314	.78579
72	.79113	.79381	.79650	.79919	.80190	.80461	.80733	.81006	.81279
73	.81829	.82105	.82382	.82659	.82938	.83217	.83497	.83778	.84060
74	.84626	.84910	.85195	.85481	.85768	.86055	.86344	.86633	.86923

Dry bulb = 70.0 F

saturation vapor pressure at 70.0 F

Figure 10. A portion of the saturation vapor pressure table from List (1951, page 356). The entry corresponding to a dry-bulb temperature of 70.0°F is annotated.

Table 1. Parameters and Digital Record Format of the Standard Weather Data File Used by S&L's LAKET-PC Program					
Field No.	**Parameter**	**Units**	**Lower Limit**	**Upper Limit**	**FORTRAN Format Specifier**
1	Station Code Number (5 digits)				F7.0
2	Year (4 digits)				F6.0
3	Month				F4.0
4	Day				F4.0
5	Hour of Day [00 (midnight)-23 (11 pm)]				F9.2
6	Cloud Ceiling Height above Ground Level	feet	0	70,000	F9.2
7	Direction Sector from which Wind Blows [1(N) – 16(NNW)]		1	16	F9.2
8	Wind speed	Knots	0	96	F9.2
9	Dry Bulb Temperature	deg F	-129	136	F9.2
10	Wet Bulb Temperature	deg F	-129	136	F9.2
11	Dew Point Temperature	deg F	-129	136	F9.2
12	Relative Humidity	percent	0	100	F9.2
13	Station Atmospheric Pressure	inches Hg	25.69	32.01	F9.2
14	Cloud Cover	Tenths	00	10	F9.2
15	Freezing Precipitation Code		0	1	F9.2
16	One-Hour Total Liquid Equivalent Precipitation	100ths inches	0	1,200	F9.2
17	Solar Radiation	BTU/ft^2-hour	0	4,000	F9.2
18	Atmospheric Radiation	BTU/ft^2-hour	5	220	F9.2
19	Partial Pressure of Water Vapor	inches Hg	0	2.00	F9.2

Table 2. Primary and Secondary Data Sources				
Beginning Date	**Ending Date**	**Parameter**	**Primary Data Source**	**Secondary Data Source**
July 5, 1948	December 31, 1951	All parameters	NWS-Peoria (KPIA)	None
January 1, 1952	December 31, 1956	All parameters	NWS-Springfield (KSPI)	None
January 1, 1957	December 31, 1989	All parameters	NWS-Peoria (KPIA)	None
January 1, 1990	December 31, 2012	Dry bulb temperature, dew point temperature, wind speed, wind direction	On-site meteorological tower	NWS-Peoria (KPIA)
January 1, 1990	December 31, 2012	Cloud cover, cloud height, precipitation type, precipitation	NWS-Peoria (KPIA)	None

Table 3. On-site Meteorological Tower Wind and Temperature Instrumentation	
Parameter	**Height (feet)**
Dry bulb temperature	30
Dew point temperature	30
Wind speed/direction	34
Sigma theta	34
Dry bulb temperature	199
Delta-T (vertical temperature difference)	30 – 199
Wind speed/direction	203
Sigma theta	203

Table 4. Missing Parameters from the On-site Tower and Substituted Parameters (DB = dry bulb temperature, DP = dew point temperature, WD = wind direction, WS = wind speed)

Beginning time		Ending time				
Date	**Hour (LST)**	**Date**	**Hour (LST)**	**Duration (hours)**	**Parameters Missing from the On-site Tower Data Set**	**Parameters Substituted from NWS-Peoria**
2/7/1990	7	2/7/1990	14	8	WS	WS,WD
5/30/1990	11	5/30/1990	16	6	DB	DB
10/18/1990	7	10/18/1990	14	8	DP	DP
10/20/1990	11	10/20/1990	18	8	DP	DP
10/22/1990	12	10/22/1990	18	7	DP	DP
10/23/1990	8	10/23/1990	23	16	DP	DP
12/21/1990	22	12/24/1990	3	54	WD	WS,WD
12/30/1990	11	12/31/1990	16	30	DP	DP
3/14/1991	19	3/15/1991	10	16	WS	WS,WD
3/30/1991	1	3/30/1991	13	13	WD	WS,WD
4/19/1991	8	4/21/1991	22	63	WD	WS,WD
5/1/1991	15	5/1/1991	24	10	WD	WS,WD
5/2/1991	9	5/3/1991	6	22	WD	WS,WD
5/3/1991	17	5/4/1991	9	17	WD	WS,WD
5/25/1991	16	5/26/1991	10	19	WS	WS,WD
6/22/1991	7	6/23/1991	5	23	WD	WS,WD
8/2/1991	17	8/2/1991	24	8	DP	DP
8/8/1991	17	8/12/1991	21	101	WD	WS,WD
12/19/1992	23	12/20/1992	11	13	WS	WS,WD
8/30/1993	23	9/1/1993	9	35	WS	WS,WD
11/26/1993	9	11/27/1993	5	21	WS,WD	WS,WD
6/9/1994	20	6/10/1994	7	12	WS	WS,WD
7/7/1994	17	7/8/1994	8	16	WS	WS,WD
10/8/1997	11	10/9/1997	6	20	WS,WD,DB,DP	WS,WD,DB,DP
10/10/1998	3	10/10/1998	9	7	WS,WD	WS, WD
11/10/1998	5	11/10/1998	13	9	WS,WD	WS, WD
1/8/1999	2	1/8/1999	8	7	DP	DP
3/4/1999	2	3/4/1999	11	10	DP	DP
1/28/2000	6	1/28/2000	13	8	DP	DP
2/7/2000	23	2/8/2000	9	11	WS	WS, WD
5/20/2000	23	5/24/2000	9	83	WS	WS, WD
4/20/2001	2	4/23/2001	10	81	DP	DP
4/21/2001	5	4/22/2001	10	30	WS	WS, WD

Table 4. Missing Parameters from the On-site Tower and Substituted Parameters
(DB = dry bulb temperature, DP = dew point temperature, WD = wind direction, WS = wind speed)

Beginning time		Ending time				
Date	**Hour (LST)**	**Date**	**Hour (LST)**	**Duration (hours)**	**Parameters Missing from the On-site Tower Data Set**	**Parameters Substituted from NWS-Peoria**
7/8/2001	15	7/9/2001	9	19	WS	WS, WD
10/23/2001	3	10/26/2001	12	82	WD	WS, WD
1/31/2002	21	2/1/2002	5	9	WS, WD	WS, WD
2/19/2002	3	2/28/2002	14	228	DP	DP
9/3/2002	0	9/4/2002	6	7	WS	WS, WD
9/4/2002	19	9/5/2002	5	11	WS	WS, WD
9/8/2002	20	9/9/2002	8	13	WS	WS, WD
9/11/2002	21	9/12/2002	8	12	WS	WS, WD
9/12/2002	18	9/13/2002	7	14	WS	WS, WD
9/16/2002	18	9/17/2002	8	15	WS	WS, WD
7/6/2003	14	7/6/2003	22	9	DP	DP
7/8/2003	14	7/8/2003	20	7	DP	DP
7/11/2003	15	7/11/2003	23	9	DP	DP
7/12/2003	21	7/13/2003	6	10	DP	DP
7/13/2003	20	7/14/2003	6	11	DP	DP
7/15/2003	4	7/15/2003	11	8	DP	DP
7/15/2003	23	7/16/2003	9	11	DP	DP
7/19/2003	19	7/20/2003	1	7	DP	DP
7/23/2003	21	7/24/2003	9	13	DP	DP
11/14/2003	16	11/15/2003	14	29	DP	DP
11/14/2003	10	11/14/2003	15	6	WS,WD,DB,DP	WS,WD,DB,DP
1/4/2004	9	1/4/2004	20	12	DP	DP
5/30/2004	7	5/30/2004	21	15	DP	DP
9/16/2004	15	9/17/2004	1	11	WS,WD,DB,DP	WS,WD,DB,DP
11/16/2004	5	11/16/2004	14	10	WS,WD,DB,DP	WS,WD,DB,DP
1/13/2005	7	1/14/2005	6	24	WS,WD,DB,DP	WS,WD,DB,DP
2/24/2005	15	2/24/2005	23	9	WS	WS, WD
5/14/2006	19	5/16/2006	8	38	WD	WS, WD
8/23/2007	15	8/23/2007	22	8	WS,WD,DB,DP	WS,WD,DB,DP
1/7/2008	22	1/8/2008	13	16	WS,WD,DB,DP	WS,WD,DB,DP
12/19/2008	2	12/21/2008	7	54	WS	WS,WD
11/21/2009	16	11/22/2009	8	17	WS,WD,DB,DP	WS,WD,DB,DP
3/7/2011	19	3/8/2011	12	18	WD	WS, WD
11/9/2011	5	11/9/2011	13	9	WD	WS, WD

Table 4. Missing Parameters from the On-site Tower and Substituted Parameters
(DB = dry bulb temperature, DP = dew point temperature, WD = wind direction, WS = wind speed)

Beginning time		Ending time				
Date	**Hour (LST)**	**Date**	**Hour (LST)**	**Duration (hours)**	**Parameters Missing from the On-site Tower Data Set**	**Parameters Substituted from NWS-Peoria**
11/13/2012	6	11/14/2012	13	32	WS,WD,DB,DP	WS,WD,DB,DP
11/23/2012	10	11/24/2012	9	24	WD	WS, WD

Table 5. Historical Wind Sensor Height Input for LAKET-PC			
Beginning Date	**Ending Date**	**Sensor Height (feet)**	**Primary Wind Data Source**
7/5/1948	11/21/1948	26	NWS-Peoria (KPIA)
11/22/1948	12/31/1951	50	NWS-Peoria (KPIA)
1/1/1952	12/31/1956	49	NWS-Springfield (KSPI)
1/1/1957	9/30/1959	50	NWS-Peoria (KPIA)
10/1/1959	12/31/1989	20	NWS-Peoria (KPIA) (Note 1)
1/1/1990	12/31/2012	34	On-site meteorological tower (Note 2)

Note 1: The anemometer height at NWS-Peoria was 20 feet through 9/30/1995.
Starting on 10/1/1995, the anemometer height at NWS-Peoria was increased to its current height of 32.8 feet.

Note 2: The wind sensor height in LAKET-PC is 34 feet which is the anemometer height of the lowest wind speed level of the on-site tower.

Table 6. Snow and Temperature Data from Peoria Illinois Used to Construct a Snow Accumulation Algorithm				
Maximum final snow depth on ground (inches)	**Total period water equivalent precipitation (inches)**	**Date**	**Maximum air temperature during time of precipitation (°F)**	**Final snow depth to liquid water ratio**
3	0.68	27 Dec 1988	29	4.4
4	0.17	4 Feb 1989	3	23.5
5	0.31	20 Feb 1989	31	16.1
6	0.36	10 Dec 1989	31	16.7
4	1.02	25 Jan 1990	36	3.3
3	1.06	22 Feb 1990	32	2.8
4	0.20	15 Jan 1992	22	20.0
5	0.64	5 Jan 1991	24	9.4

Table 7. Snow and Temperature Data from Madison Wisconsin Used to Construct a Snow Melt Algorithm

Air temp (°F)	Snow depth increase (inches per hour)	Air temp (°F)	Snow depth increase (inches per hour)	Air temp (°F)	Snow depth increase (inches per hour)
-2	0.000	16	0.021	35	0.083
-1	0.000	17	0.021	36	0.166
0	0.000	18	0.021	37	0.166
1	0.000	19	0.042	38	0.166
2	0.000	20	0.042	39	0.166
3	0.000	21	0.042	40	0.166
4	0.000	22	0.042	41	0.333
5	0.000	23	0.042	42	0.333
6	0.000	24	0.042	43	0.333
7	0.000	25	0.042	44	0.333
8	0.000	26	0.042	45	0.333
9	0.000	27	0.042	46	0.333
10	0.021	28	0.042	47	0.667
11	0.021	29	0.042	48	0.667
12	0.021	30	0.042	49	0.667
13	0.021	31	0.042	50	0.667
14	0.021	32	0.083	51	0.667
15	0.021	33	0.083	52	0.667
		34	0.083		

Table 8. Precipitation Type Codes Used in Surface Weather Observations (Source: NCDC 2005)

Precipitation code	Precipitation description	Precipitation code	Precipitation description
26	light freezing rain	54	moderate snow squall (Note 3)
27	moderate freezing rain	55	heavy snow squall (Note 3)
28	heavy freezing rain	56	light snow grains
36	light freezing drizzle	57	moderate snow grains
37	moderate freezing drizzle	58	heavy snow grains
38	heavy freezing drizzle	60	light ice pellet showers
40	light snow	61	moderate ice pellet showers
41	moderate snow	62	heavy ice pellet showers
42	heavy snow	63	light hail
43	light snow pellets (Note 1)	64	moderate hail (Note 4)
44	moderate snow pellets (Note 1)	65	heavy hail (Note 4)
45	heavy snow pellets (Note 1)	66	light small hail (Note 4)
46	light ice crystals (Note 2)	67	moderate small hail (Note 4)
47	moderate ice crystals	68	heavy small hail (Note 4)
48	heavy ice crystals (Note 2)	90	light ice pellets
50	light snow showers	91	moderate ice pellets
51	moderate snow showers	92	heavy ice pellets
52	heavy snow showers	93	hail showers (Note 5)
53	light snow squall (Note 3)	94	small hail/snow pellet showers (Note 5)

Note 1: Codes 43, 44, and 45 ended in June, 1996 and replaced with code 67.

Note 2: Code replaced with 47 in April, 1963.

Note 3: Code used through 1948.

Note 4: Prior to April, 1970 ice pellets were coded as sleet. Beginning April, 1970 sleet and small hail were redefined as ice pellets and are coded as 60, 61, or 62. Beginning in September, 1956 intensities of hail were no longer reported and all occurrences of hail were recorded as a 64. Beginning July, 1996 hail was defined as hailstones ¼ inch or larger in diameter; small hail and snow pellets are reported when less than ¼ inch in diameter and are coded as 64 and 67, respectively.

Note 5: Began July, 1996.

Table 9. Constants used in vapor pressure equation (Source: ASHRAE (1975))			
Constant	**Value**	**Constant**	**Value**
A1	-7.90298	B1	-9.09718
A2	5.02808	B2	-3.56654
A3	-1.3816×10^{-7}	B3	0.876793
A4	11.344	B4	0.0060273
A5	8.1328×10^{-3}		
A6	-3.49149		

Table 10. Constants used in vapor pressure equation for T < 273.16 K (Source: ASHRAE (1975))	
Parameter	**Definition**
P1	$B1(z-1)$
P2	$B2\ \log_{10}(z)$
P3	$B3(1-1/z)$
P4	$\log_{10}(B4)$

Table 11. Constants used in vapor pressure equation for T >= 273.16 K) (Source: ASHRAE (1975))	
Parameter	**Definition**
P1	$A1(z-1)$
P2	$A2\ \log_{10}(z)$
P3	$A3 \times (10^{(A4\ (1-1/z))} - 1)$
P4	$A5 \times (10^{(A6\ (z-1))} - 1)$

Table 12. Program Output Listing of Processed Meteorological Data from Madison Wisconsin for 25 January 1988

YEAR 1988, MONTH 1. DAY 25.

HOUR	CEIL	WINDD	WINDSP	DBTEMP	WBTEMP	DPTEMP	RELHUM	PRESS	CL COV	AT CODE	RAIN	SWRAD	LWRAD	PPH20
.00	1300.00	1.00	6.00	21.00	20.16	18.32	88.00	28.85	10.00	4000.00	2.00	.00	70.03	.10
1.00	800.00	1.00	5.00	21.00	20.16	18.32	88.00	28.83	10.00	4070.00	3.00	.00	70.03	.10
2.00	800.00	1.00	11.00	22.00	21.42	20.23	92.00	28.83	10.00	4070.00	1.00	.00	70.91	.10
3.00	800.00	1.00	14.00	16.00	15.30	13.38	88.00	28.84	10.00	4070.00	.00	.00	65.78	.08
4.00	800.00	1.00	15.00	15.00	13.93	10.72	81.00	28.84	10.00	4070.00	2.00	.00	64.95	.07
5.00	500.00	1.00	11.00	13.00	12.37	10.41	88.00	28.84	10.00	4070.00	1.00	.00	63.33	.07
6.00	500.00	1.00	12.00	13.00	12.16	9.49	84.00	28.84	10.00	4070.00	.00	.00	63.33	.06
7.00	2000.00	1.00	14.00	12.00	10.99	7.54	80.00	28.84	10.00	4000.00	.00	11.34	62.53	.06
8.00	4700.00	1.00	13.00	11.00	10.03	6.56	80.00	28.85	10.00	4000.00	.00	49.82	61.74	.05
9.00	5000.00	1.00	11.00	10.00	8.93	4.84	77.00	28.85	10.00	4000.00	.00	84.29	60.96	.05
10.00	5500.00	1.00	13.00	10.00	8.93	4.84	77.00	28.85	10.00	4000.00	1.00	107.67	60.96	.05
11.00	1000.00	1.00	10.00	10.00	9.07	5.59	80.00	28.84	10.00	4000.00	.00	117.33	60.96	.05
12.00	1000.00	1.00	13.00	12.00	10.84	6.78	77.00	28.82	10.00	4000.00	.00	112.08	62.53	.05
13.00	900.00	1.00	12.00	14.00	12.91	9.49	80.00	28.79	10.00	4000.00	1.00	92.69	64.14	.06
14.00	400.00	1.00	18.00	17.00	16.27	14.36	88.00	28.79	10.00	4000.00	3.00	61.22	66.61	.08
15.00	200.00	1.00	21.00	18.00	17.24	15.35	88.00	28.81	10.00	4000.00	4.00	17.94	67.45	.08
16.00	200.00	1.00	13.00	18.00	17.24	15.35	88.00	28.85	10.00	4100.00	2.00	.00	67.45	.08
17.00	200.00	1.00	17.00	18.00	16.99	14.40	84.00	28.88	10.00	4000.00	3.00	.00	67.45	.08
18.00	200.00	1.00	18.00	18.00	17.25	15.35	88.00	28.90	10.00	4000.00	2.00	.00	67.45	.08
19.00	300.00	1.00	21.00	18.00	17.25	15.35	88.00	28.93	10.00	4000.00	1.00	.00	67.45	.08
20.00	1500.00	1.00	19.00	17.00	16.27	14.36	88.00	28.96	10.00	4000.00	1.00	.00	66.61	.08
21.00	1500.00	1.00	20.00	16.00	15.30	13.38	88.00	28.97	10.00	4000.00	1.00	.00	65.78	.08
22.00	1500.00	1.00	20.00	15.00	14.32	12.39	88.00	28.98	10.00	4000.00	1.00	.00	64.95	.07
23.00	1500.00	1.00	19.00	14.00	13.57	12.30	92.00	28.99	10.00	4000.00	.00	.00	64.14	.07

Table 13. Program Output Listing of Processed Meteorological Data from Madison Wisconsin for 28 July 1988

YEAR 1988. MONTH 7. DAY 28.

HOUR	CEIL	WINDD	WINDSP	DBTEMP	WBTEMP	DPTEMP	RELHUM	PRESS	CL COV	AT CODE	RAIN	SWRAD	LWRAD	PPH20
.00	35000.00	1.00	.00	68.00	62.16	58.73	73.00	29.13	.00	.00	.00	.00	104.72	.51
1.00	35000.00	1.00	3.00	67.00	62.36	59.67	78.00	29.13	.00	.00	.00	.00	103.54	.52
2.00	35000.00	1.00	7.00	68.00	63.29	60.64	78.00	29.13	.00	.00	.00	.00	104.72	.54
3.00	35000.00	1.00	.00	69.00	63.77	60.86	76.00	29.13	.00	.00	.00	.00	105.92	.55
4.00	35000.00	1.00	.00	67.00	63.02	60.77	81.00	29.15	.00	.00	.00	.00	103.54	.54
5.00	35000.00	1.00	4.00	65.00	61.14	58.82	81.00	29.16	.00	.00	.00	43.64	101.21	.51
6.00	35000.00	1.00	.00	69.00	64.91	62.72	81.00	29.17	.00	.00	.00	104.59	105.92	.58
7.00	35000.00	1.00	8.00	78.00	67.15	61.52	58.00	29.18	.00	.00	.00	163.11	117.20	.56
8.00	35000.00	1.00	8.00	82.00	68.38	61.45	51.00	29.20	.00	.00	.00	215.36	122.53	.57
9.00	35000.00	1.00	9.00	85.00	68.10	59.17	43.00	29.20	.00	.00	.00	256.00	126.66	.52
10.00	35000.00	1.00	8.00	88.00	70.09	61.17	42.00	29.20	.00	.00	.00	281.29	130.90	.56
11.00	35000.00	1.00	10.00	90.00	70.48	60.76	39.00	29.20	.00	.00	.00	289.89	133.79	.56
12.00	35000.00	1.00	14.00	93.00	69.78	57.56	32.00	29.19	.00	.00	.00	279.95	138.23	.50
13.00	35000.00	1.00	12.00	94.00	69.59	56.52	30.00	29.18	.00	.00	.00	254.24	139.74	.49
14.00	35000.00	1.00	11.00	94.00	70.05	57.49	31.00	29.16	.00	.00	.00	214.16	139.74	.50
15.00	35000.00	1.00	8.00	94.00	70.94	59.33	33.00	29.15	.00	.00	.00	162.43	139.74	.53
16.00	35000.00	1.00	13.00	95.00	70.30	57.38	30.00	29.15	.00	.00	.00	103.49	141.26	.50
17.00	35000.00	1.00	12.00	94.00	69.58	56.52	30.00	29.14	.00	.00	.00	45.09	139.74	.49
18.00	35000.00	1.00	12.00	91.00	69.18	57.60	34.00	29.15	.00	.00	.00	.00	135.26	.50
19.00	35000.00	1.00	10.00	88.00	67.77	56.64	36.00	29.15	.00	.00	.00	.00	130.90	.48
20.00	35000.00	1.00	8.00	80.00	67.04	60.18	52.00	29.15	.00	.00	.00	.00	119.84	.54
21.00	35000.00	1.00	8.00	79.00	67.41	61.42	56.00	29.15	.00	.00	.00	.00	118.52	.56
22.00	35000.00	1.00	6.00	78.00	67.15	61.52	58.00	29.16	.00	.00	.00	.00	117.20	.56
23.00	35000.00	1.00	9.00	76.00	67.10	62.53	64.00	29.17	.00	.00	.00	.00	114.61	.58

Table 14. Program Output Listing of Processed Meteorological Data from Madison Wisconsin for 30 July 1988

YEAR 1988. MONTH 7. DAY 30.

HOUR	CEIL	WINDD	WINDSP	DBTEMP	WBTEMP	DPTEMP	RELHUM	PRESS	CL COV	AT CODE	RAIN	SWRAD	LWRAD	PPH20
.00	35000.00	1.00	9.00	79.00	71.95	68.91	72.00	29.07	4.00	.00	.00	.00	121.74	.72
1.00	35000.00	1.00	7.00	77.00	71.94	69.78	79.00	29.06	4.00	.00	.00	.00	119.05	.74
2.00	35000.00	1.00	10.00	76.00	71.75	69.93	82.00	29.05	4.00	.00	.00	.00	117.73	.75
3.00	35000.00	1.00	8.00	75.00	70.80	68.95	82.00	29.05	7.00	.00	.00	.00	122.78	.72
4.00	35000.00	1.00	8.00	74.00	70.57	69.05	85.00	29.06	8.00	7000.00	.00	.00	124.26	.72
5.00	35000.00	1.00	9.00	74.00	70.57	69.05	85.00	29.05	6.00	7000.00	.00	38.43	118.93	.72
6.00	35000.00	1.00	7.00	74.00	70.57	69.05	85.00	29.05	6.00	.00	.00	95.56	118.93	.72
7.00	35000.00	1.00	7.00	77.00	71.94	69.78	79.00	29.06	4.00	.00	.00	155.35	119.05	.74
8.00	35000.00	1.00	8.00	79.00	73.29	70.94	77.00	29.07	5.00	.00	.00	204.43	123.55	.77
9.00	35000.00	1.00	5.00	83.00	74.16	70.56	67.00	29.07	9.00	.00	.00	232.60	140.95	.77
10.00	35000.00	1.00	5.00	85.00	75.95	72.47	67.00	29.08	5.00	.00	.00	267.57	132.04	.82
11.00	35000.00	1.00	7.00	87.00	75.85	71.48	61.00	29.08	7.00	.00	.00	270.01	140.26	.79
12.00	35000.00	1.00	11.00	89.00	75.57	70.19	55.00	29.08	8.00	.00	.00	258.53	146.74	.76
13.00	35000.00	1.00	10.00	91.00	75.09	68.51	49.00	29.07	5.00	.00	.00	241.77	141.00	.72
14.00	35000.00	1.00	11.00	91.00	72.41	63.86	42.00	29.06	5.00	.00	.00	203.39	141.00	.62
15.00	35000.00	1.00	11.00	91.00	72.41	63.86	42.00	29.06	3.00	.00	.00	157.11	137.33	.62
16.00	35000.00	1.00	8.00	91.00	71.21	61.65	39.00	29.06	3.00	.00	.00	99.84	137.33	.57
17.00	35000.00	1.00	12.00	90.00	70.45	60.76	39.00	29.05	2.00	.00	.00	43.10	134.70	.56
18.00	35000.00	1.00	9.00	88.00	71.18	63.22	45.00	29.07	2.00	.00	.00	.00	131.79	.60
19.00	35000.00	1.00	7.00	82.00	70.88	65.77	59.00	29.08	1.00	.00	.00	.00	122.74	.65
20.00	35000.00	1.00	6.00	77.00	68.79	64.84	67.00	29.08	.00	.00	.00	.00	115.90	.63
21.00	35000.00	1.00	8.00	75.00	68.05	64.65	71.00	29.10	.00	.00	.00	.00	113.34	.63
22.00	35000.00	1.00	6.00	73.00	65.73	61.88	69.00	29.10	.00	.00	.00	.00	110.82	.57
23.00	35000.00	1.00	6.00	71.00	63.68	59.55	68.00	29.12	.00	.00	.00	.00	108.35	.52

Table 15. Program Output Listing of Processed Meteorological Data from Madison Wisconsin for 15 September 1988

YEAR 1988. MONTH 9. DAY 15.

HOUR	CEIL	WINDD	WINDSP	DBTEMP	WBTEMP	DPTEMP	RELHUM	PRESS	CL COV	AT CODE	RAIN	SWRAD	LWRAD	PPH20
.00	35000.00	1.00	.00	51.00	49.43	48.07	90.00	29.31	.00	.00	.00	.00	86.05	.34
1.00	35000.00	1.00	.00	49.00	47.49	46.11	90.00	29.33	.00	.00	.00	.00	84.05	.31
2.00	35000.00	1.00	.00	48.00	46.97	46.01	93.00	29.33	.00	.00	.00	.00	83.07	.31
3.00	35000.00	1.00	5.00	48.00	46.97	46.01	93.00	29.33	.00	.00	.00	.00	83.07	.31
4.00	35000.00	1.00	.00	47.00	45.99	45.03	93.00	29.35	.00	.00	.00	.00	82.09	.30
5.00	35000.00	1.00	5.00	46.00	45.01	44.05	93.00	29.36	1.00	.00	.00	.00	81.26	.29
6.00	35000.00	1.00	6.00	45.00	44.03	43.07	93.00	29.36	1.00	.00	.00	55.88	80.30	.28
7.00	35000.00	1.00	5.00	50.00	48.46	47.09	90.00	29.38	10.00	.00	.00	99.30	99.51	.33
8.00	35000.00	1.00	8.00	57.00	53.07	50.00	78.00	29.40	10.00	.00	.00	143.85	107.99	.37
9.00	35000.00	1.00	10.00	60.00	53.66	48.69	67.00	29.40	10.00	.00	.00	178.17	111.80	.35
10.00	25000.00	1.00	12.00	63.00	53.91	46.59	56.00	29.39	10.00	.00	.00	198.50	115.73	.33
11.00	25000.00	1.00	10.00	65.00	55.13	47.44	54.00	29.38	10.00	.00	.00	203.51	118.41	.34
12.00	35000.00	1.00	11.00	69.00	56.66	47.27	47.00	29.36	10.00	.00	.00	191.87	123.93	.34
13.00	35000.00	1.00	8.00	71.00	57.15	46.62	43.00	29.34	10.00	.00	.00	165.96	126.77	.33
14.00	25000.00	1.00	11.00	71.00	55.73	43.24	38.00	29.32	10.00	.00	.00	127.97	126.77	.29
15.00	25000.00	1.00	9.00	70.00	56.09	45.09	42.00	29.30	10.00	.00	.00	81.05	125.34	.31
16.00	14000.00	1.00	12.00	69.00	56.38	46.68	46.00	29.28	10.00	.00	.00	30.94	123.93	.33
17.00	14000.00	1.00	11.00	67.00	56.05	47.70	51.00	29.29	10.00	.00	.00	.00	121.14	.34
18.00	14000.00	1.00	10.00	64.00	55.88	49.86	61.00	29.29	10.00	.00	.00	.00	117.06	.37
19.00	14000.00	1.00	11.00	62.00	55.01	49.74	65.00	29.30	8.00	.00	.00	.00	108.42	.37
20.00	35000.00	1.00	9.00	59.00	52.76	47.74	67.00	29.31	7.00	.00	.00	.00	102.33	.34
21.00	35000.00	1.00	9.00	57.00	51.94	47.81	72.00	29.30	10.00	.00	.00	.00	107.99	.34
22.00	35000.00	1.00	5.00	55.00	51.02	47.72	77.00	29.29	10.00	.00	.00	.00	105.51	.34
23.00	35000.00	1.00	4.00	53.00	50.19	47.82	83.00	29.28	10.00	.00	.00	.00	103.07	.34

Table 16. NOAA January 1988 Madison Wisconsin Solar Radiation Measurements

MADISON, WI
JANUARY 1988

N43.08 E089.20 TIME ZONE +06 STATION # 14837
ELEV (FT. MSL) 866

GLOBAL RADIATION (WATT-HOURS/M^2)
MEASURED FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

HOURS

DAY	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
01	0	0	0	0	0	0	0	14	120	257	363	423	418	354	246	110	11	0	0	0	0	0	0	0	2316
02	0	0	0	0	0	0	0	17	134	259	353	408	404	344	234	107	11	0	0	0	0	0	0	0	2271
03	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
04	0	0	0	0	0	0	0	9	116	215	283	366	365	358	244	120	14	0	0	0	0	0	0	0	2090
05	0	0	0	0	0	0	0	14	120	257	366	425	424	363	256	121	15	0	0	0	0	0	0	0	2361
06	0	0	0	0	0	0	0	16	129	257	369	432	428	367	260	125	15	1	0	0	0	0	0	0	2399
07	0	0	0	0	0	0	0	11	68	177	285	415	392	133	0	0	0	0	0	0	0	0	0	0	1481
08	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
09	0	0	0	0	0	0	0	15	125	264	371	432	431	372	267	132	18	1	0	0	0	0	0	0	2428
10	0	0	0	0	0	0	0	25	150	271	425	450	429	368	264	129	17	0	0	0	0	0	0	0	2528
11	0	0	0	0	0	0	0	4	42	95	144	145	146	149	121	43	6	0	0	0	0	0	0	0	895
12	0	0	0	0	0	0	0	3	20	50	74	72	104	165	172	86	15	0	0	0	0	0	0	0	761
13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
14	0	0	0	0	0	0	0	11	54	150	213	281	301	263	155	78	15	0	0	0	0	0	0	0	1521
15	0	0	0	0	0	0	0	8	74	223	356	404	415	361	238	152	21	0	0	0	0	0	0	0	2252
16	0	0	0	0	0	0	0	12	60	125	222	177	171	117	117	68	8	0	0	0	0	0	0	0	1077
17	0	0	0	0	0	0	0	9	54	102	142	128	114	102	61	26	6	0	0	0	0	0	0	0	744
18	0	0	0	0	0	0	0	5	32	72	125	145	161	157	91	47	9	0	0	0	0	0	0	0	844
19	0	0	0	0	0	0	0	3	40	51	122	95	84	42	34	14	2	0	0	0	0	0	0	0	487
20	0	0	0	0	0	0	0	6	47	145	140	216	172	151	109	83	29	0	0	0	0	0	0	0	1098
21	0	0	0	0	0	0	0	20	141	271	400	457	473	135	308	166	34	2	0	0	0	0	0	0	2407
22	0	0	0	0	0	0	0	5	59	162	239	444	365	211	150	86	28	0	0	0	0	0	0	0	1749
23	0	0	0	0	0	0	0	22	118	213	288	369	337	220	170	66	16	1	0	0	0	0	0	0	1820
24	0	0	0	0	0	0	0	23	149	252	371	368	297	317	196	97	19	0	0	0	0	0	0	0	2089
25	0	0	0	0	0	0	0	18	104	166	204	316	252	168	144	72	21	0	0	0	0	0	0	0	1465
26	0	0	0	0	0	0	0	17	152	309	408	502	511	456	340	198	48	1	0	0	0	0	0	0	2942
27	0	0	0	0	0	0	0	53	206	300	425	515	491	353	207	117	32	1	0	0	0	0	0	0	2700
28	0	0	0	0	0	0	0	38	198	313	416	471	490	413	286	141	38	2	0	0	0	0	0	0	2806
29	0	0	0	0	0	0	0	24	151	286	413	399	396	375	260	141	31	0	0	0	0	0	0	0	2476
30	0	0	0	0	0	0	0	7	77	201	273	286	272	107	88	31	4	0	0	0	0	0	0	0	1346
31	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
MONTHLY STATISTICS																									
MEAN	0	0	0	0	0	0	0	15	101	202	289	339	328	256	186	95	18	0	0	0	0	0	0	0	1828

TOTAL OBSERVED SUNSHINE (MINUTES) = 8812 PERCENT TOTAL POSSIBLE SUNSHINE = 50%
HEATING DEGREE DAYS = 1586 DEPARTURE FROM NORMAL = + 55 COOLING DEGREE DAYS = 0 DEPARTURE FROM NORMAL = 0

Table 17. NOAA July 1988 Madison Wisconsin Solar Radiation Measurements

MADISON, WI
JULY 1988

STATION # -14837
N43.08 E089.20 TIME ZONE +06 ELEV (FT. MSL) 866

GLOBAL RADIATION (WATT-HOURS/M^2)
MEASURED FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

HOURS

DAY	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
01	0	0	0	0	25	144	309	500	661	806	924	912	865	888	642	459	514	290	121	14	1	0	0	0	8075
02	0	0	0	0	22	88	248	427	660	667	904	966	969	902	790	638	457	274	104	11	1	0	0	0	8128
03	0	0	0	0	19	121	283	461	634	759	877	960	935	822	759	582	439	257	99	12	0	0	0	0	8019
04	0	0	0	0	18	120	282	456	628	768	878	930	930	788	767	618	444	255	105	13	1	0	0	0	8001
05	0	0	0	0	16	115	270	444	612	751	852	906	910	850	735	582	405	232	92	12	0	0	0	0	7784
06	0	0	0	0	15	94	236	409	574	716	808	715	801	750	682	567	396	219	88	9	0	0	0	0	7079
07	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
08	0	0	0	0	10	81	220	421	602	742	842	905	878	825	594	509	386	236	92	11	0	0	0	0	7354
09	0	0	0	0	12	80	129	229	504	729	716	755	844	661	706	189	310	229	101	5	1	0	0	0	6200
10	0	0	0	0	6	26	66	161	111	128	641	276	636	625	612	534	389	292	107	11	1	0	0	0	4622
11	0	0	0	0	9	108	286	432	629	785	866	950	911	650	433	353	412	238	101	11	1	0	0	0	7175
12	0	0	0	0	15	73	119	159	287	696	850	905	961	673	731	626	451	266	102	9	1	0	0	0	6924
13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
14	0	0	0	0	11	108	271	456	632	765	879	940	942	892	752	603	446	266	111	8	1	0	0	0	8083
15	0	0	0	0	1	3	24	157	255	440	584	864	901	644	821	591	409	238	92	12	1	0	0	0	6037
16	0	0	0	0	1	1	8	47	149	304	685	54	56	133	480	607	405	247	69	6	1	0	0	0	3253
17	0	0	0	0	6	44	97	247	575	693	835	755	897	850	745	600	378	110	36	5	1	0	0	0	6874
18	0	0	0	0	3	18	47	90	92	139	186	312	228	372	508	461	117	237	87	8	1	0	0	0	2906
19	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
20	0	0	0	0	5	54	230	413	437	396	499	239	256	127	126	212	299	122	70	3	1	0	0	0	3489
21	0	0	0	0	3	22	165	162	315	522	724	815	326	323	363	371	303	255	71	6	0	0	0	0	4746
22	0	0	0	0	8	86	244	427	602	747	845	919	787	793	720	573	420	245	90	7	0	0	0	0	7513
23	0	0	0	0	7	85	235	412	589	738	848	650	917	841	715	590	411	228	84	7	0	0	0	0	7357
24	0	0	0	0	7	75	205	405	577	655	----	----	----	----	----	----	----	4	4	1	0	0	0	0	-----
25	0	0	0	0	4	80	203	389	600	----	----	----	----	----	----	----	----	0	11	4	0	0	0	0	-----
26	0	0	0	0	6	81	235	414	599	744	804	910	913	860	746	592	410	230	75	1	0	0	0	0	7620
27	0	0	0	0	3	50	208	373	575	732	860	782	----	----	----	551	404	223	76	3	0	0	0	0	-----
28	0	0	0	0	4	73	222	317	574	718	821	867	891	843	728	577	402	219	71	4	0	0	0	0	7331
29	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
30	0	0	0	0	2	42	157	328	496	632	769	745	851	840	716	574	414	225	0	0	0	0	0	0	6791
31	0	0	0	0	5	51	212	333	496	629	653	662	781	656	674	525	383	200	63	3	0	0	0	0	6326

MONTHLY STATISTICS

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
MEAN	0	0	0	0	9	71	193	336	499	631	766	748	766	692	648	523	392	216	79	7	0	0	0	0	6570

TOTAL OBSERVED SUNSHINE (MINUTES) = 20045 PERCENT TOTAL POSSIBLE SUNSHINE = 72%

HEATING DEGREE DAYS = 4 DEPARTURE FROM NORMAL = -8 COOLING DEGREE DAYS = 296 DEPARTURE FROM NORMAL = + 111

Table 18. NOAA September 1988 Madison Wisconsin Solar Radiation Measurements

MADISON, WI
SEPTEMBER 1988

N43.08 E089.20 TIME ZONE +06 STATION # 14837 ELEV (FT. MSL) 866

GLOBAL RADIATION (WATT-HOURS/M^2)
MEASURED FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

HOURS

DAY	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
01	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
02	0	0	0	0	0	0	----	----	128	489	577	668	596	592	596	310	203	18	0	2	0	0	0	0	-----
03	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
04	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
05	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
06	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
07	0	0	0	0	0	0	----	----	388	662	780	831	822	749	606	427	211	75	4	0	0	0	0	0	-----
08	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
09	0	0	0	0	0	0	----	175	503	649	751	815	806	722	597	409	227	65	2	0	0	0	0	0	-----
10	0	0	0	0	0	9	87	226	377	552	660	717	714	650	524	376	203	54	0	1	0	0	0	0	5150
11	0	0	0	0	0	8	88	235	405	556	660	678	593	658	446	317	194	60	1	0	0	0	0	0	4899
12	0	0	0	0	0	6	53	248	426	577	683	714	705	502	354	326	164	48	2	0	0	0	0	0	4808
13	0	0	0	0	0	9	113	293	472	622	730	789	786	709	580	413	227	50	1	0	0	0	0	0	5794
14	0	0	0	0	0	11	116	290	473	618	714	785	778	705	576	408	175	66	1	0	0	0	0	0	5716
15	0	0	0	0	0	8	94	241	322	435	422	590	702	495	307	177	108	19	1	0	0	0	0	0	3921
16	0	0	0	0	0	3	27	45	48	58	108	178	99	252	385	315	150	38	1	0	0	0	0	0	1707
17	0	0	0	0	0	7	80	240	417	574	691	732	721	653	528	370	190	38	1	0	0	0	0	0	5242
18	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----
19	0	0	0	0	0	2	12	20	36	246	265	389	271	368	82	52	34	40	1	0	0	0	0	0	1818
20	0	0	0	0	0	1	28	60	132	169	232	245	257	161	149	100	81	11	1	0	0	0	0	0	1627
21	0	0	0	0	0	3	23	71	100	198	372	716	724	664	266	116	52	8	0	0	0	0	0	0	3313
22	0	0	0	0	0	1	2	11	54	187	366	426	46	125	162	84	59	22	1	0	0	0	0	0	1546
23	0	0	0	0	0	6	90	265	449	600	678	695	724	671	509	311	205	29	1	0	0	0	0	0	5233
24	0	0	0	0	0	5	86	256	435	586	692	741	727	652	521	353	160	22	1	0	0	0	0	0	5237
25	0	0	0	0	0	5	75	234	415	567	673	710	706	635	500	336	151	18	1	0	0	0	0	0	5026
26	0	0	0	0	0	4	50	140	281	487	669	491	619	615	489	329	148	20	0	0	0	0	0	0	4342
27	0	0	0	0	0	4	52	160	355	469	502	488	578	386	411	279	118	19	0	0	0	0	0	0	3821
28	0	0	0	0	0	2	29	45	39	49	58	98	86	91	87	39	23	7	0	0	0	0	0	0	653
29	0	0	0	0	0	2	37	137	312	447	536	597	573	559	353	131	70	10	2	0	0	0	0	0	3766
30	0	0	0	0	0	3	49	152	338	437	513	571	455	381	341	238	76	9	0	0	0	0	0	0	3563

MONTHLY STATISTICS

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
MEAN	0	0	0	0	0	4	----	169	300	445	536	594	569	522	407	270	140	32	1	0	0	0	0	0	-----

TOTAL OBSERVED SUNSHINE (MINUTES) = 14699 PERCENT TOTAL POSSIBLE SUNSHINE = 65%
HEATING DEGREE DAYS = 107 DEPARTURE FROM NORMAL = -54 COOLING DEGREE DAYS = 54 DEPARTURE FROM NORMAL = + 40

Table 19. Program Output Listing of Processed Meteorological Data from Springfield Illinois for 25 March 1955

YEAR 1955. MONTH 3. DAY 25.

HOUR	CEIL	WINDD	WINDSP	DBTEMP	WBTEMP	DPTEMP	RELHUM	PRESS	CL COV	AT CODE	RAIN	SWRAD	LWRAD	PPH2O
.00	6500.00	1.00	13.00	33.00	29.91	25.05	70.00	29.39	10.00	.00	.00	.00	81.19	.13
1.00	11000.00	2.00	11.00	31.00	28.81	25.29	77.00	29.39	10.00	.00	.00	.00	79.24	.13
2.00	2500.00	3.00	8.00	31.00	28.71	25.00	76.00	29.37	10.00	.00	.00	.00	79.24	.13
3.00	2700.00	2.00	14.00	31.00	29.19	26.38	81.00	29.37	10.00	4000.00	.00	.00	79.24	.14
4.00	900.00	2.00	11.00	30.00	28.99	27.45	89.00	29.36	10.00	4000.00	.00	.00	78.27	.14
5.00	700.00	2.00	15.00	29.00	28.20	26.94	91.00	29.35	10.00	4000.00	1.00	.00	77.32	.14
6.00	500.00	2.00	14.00	28.00	27.57	26.88	95.00	29.34	10.00	4000.00	1.00	37.99	76.38	.14
7.00	900.00	2.00	18.00	27.00	26.50	25.66	94.00	29.32	10.00	4000.00	.00	93.92	75.44	.13
8.00	700.00	1.00	17.00	26.00	25.19	23.73	90.00	29.32	10.00	4000.00	.00	145.37	74.52	.12
9.00	600.00	16.00	18.00	25.00	24.29	22.98	91.00	29.36	10.00	4000.00	2.00	186.29	73.60	.12
10.00	400.00	16.00	17.00	23.00	22.34	21.00	91.00	29.37	10.00	4000.00	1.00	213.19	71.80	.11
11.00	400.00	16.00	21.00	23.00	22.34	21.00	91.00	29.35	10.00	4000.00	1.00	223.22	71.80	.11
12.00	800.00	16.00	19.00	22.00	21.29	19.77	90.00	29.35	10.00	4084.00	.00	216.15	70.91	.10
13.00	700.00	1.00	19.00	22.00	21.07	19.07	87.00	29.33	10.00	4084.00	.00	192.15	70.91	.10
14.00	700.00	1.00	21.00	22.00	20.78	18.08	83.00	29.35	10.00	4084.00	1.00	153.39	70.91	.09
15.00	500.00	16.00	21.00	21.00	19.96	17.60	85.00	29.35	10.00	4084.00	2.00	103.43	70.03	.09
16.00	1000.00	16.00	22.00	20.00	19.20	17.33	88.00	29.35	10.00	4084.00	1.00	47.49	69.16	.09
17.00	1000.00	15.00	20.00	18.00	17.19	15.12	87.00	29.38	10.00	4084.00	.00	.00	67.45	.08
18.00	7000.00	15.00	17.00	16.00	14.73	10.93	78.00	29.41	10.00	4084.00	.00	.00	65.78	.07
19.00	1700.00	15.00	19.00	15.00	14.00	10.97	82.00	29.43	10.00	4084.00	.00	.00	64.95	.07
20.00	7000.00	15.00	16.00	14.00	13.09	10.23	83.00	29.44	7.00	4084.00	.00	.00	59.38	.06
21.00	2500.00	15.00	19.00	14.00	13.14	10.47	84.00	29.43	10.00	4084.00	.00	.00	64.14	.07
22.00	5500.00	15.00	18.00	13.00	11.40	5.60	69.00	29.43	10.00	.00	.00	.00	63.33	.05
23.00	35000.00	15.00	17.00	11.00	9.52	3.68	69.00	29.43	.00	.00	.00	.00	52.77	.05

Table C1: Determination of 3 Hour Average Heat Loads For First 24 Hours

Time (hours)	Time (seconds)	Total Heat Load to the UHS (Worst Case from ATD-0063, page E9, Table 13) (Btu/Hr)	Trapezoidal Rule Integration Over Previous Time Step (Btu-sec/hr)	Sum of Previous Column Over Time Interval (Btu-sec/hr)	Average Heat Load Over Time Interval (Btu/hr)
0	0.0000E+00	0			
	1.0000E+01	8.30E+07	4.15E+08		
	2.0000E+01	8.30E+07	8.30E+08		
	2.1000E+01	5.85E+08	3.34E+08		
	3.3000E+01	5.75E+08	6.96E+09		
	5.0000E+01	5.68E+08	9.72E+09		
	1.0200E+02	5.54E+08	2.92E+10		
	1.3100E+02	5.47E+08	1.60E+10		
	1.9900E+02	5.33E+08	3.67E+10		
	2.8900E+02	5.22E+08	4.75E+10		
	3.4900E+02	5.17E+08	3.12E+10		
	4.5900E+02	5.08E+08	5.64E+10		
	5.9900E+02	4.99E+08	7.05E+10		
	6.9500E+02	4.94E+08	4.77E+10		
	6.9500E+02	7.87E+08	7.69E+05		
	8.9900E+02	7.93E+08	1.61E+11		
	9.9900E+02	7.96E+08	7.95E+10		
	1.0990E+03	7.95E+08	7.96E+10		
	1.1990E+03	7.86E+08	7.91E+10		
	1.2990E+03	7.77E+08	7.82E+10		
	1.3990E+03	7.68E+08	7.73E+10		
	1.7640E+03	7.34E+08	2.74E+11		
	2.2990E+03	6.35E+08	3.66E+11		
	2.8990E+03	5.60E+08	3.59E+11		
	3.5990E+03	5.19E+08	3.78E+11		
	4.9990E+03	4.58E+08	6.84E+11		
	6.9990E+03	3.79E+08	8.37E+11		
	9.9990E+03	3.32E+08	1.07E+12		
3	1.0800E+04	3.27E+08	2.64E+11	5.14E+12	4.76E+08
	1.9999E+04	2.67E+08	2.73E+12		
6	2.1600E+04	2.67E+08	4.27E+11	3.16E+12	2.92E+08
	2.9998E+04	2.67E+08	2.24E+12		
	2.9999E+04	5.51E+08	4.09E+08		
9	3.2400E+04	5.34E+08	1.30E+12	3.55E+12	3.28E+08
	3.9999E+04	4.80E+08	3.85E+12		
12	4.3200E+04	4.34E+08	1.46E+12	5.32E+12	4.92E+08
	4.9999E+04	3.36E+08	2.62E+12		
15	5.4000E+04	3.33E+08	1.34E+12	3.96E+12	3.66E+08
	5.9999E+04	3.28E+08	1.98E+12		
18	6.4800E+04	3.24E+08	1.57E+12	3.55E+12	3.28E+08
21	7.5600E+04	3.16E+08	3.45E+12	3.45E+12	3.20E+08
	7.9999E+04	3.12E+08	1.38E+12		
24	8.6400E+04	3.07E+08	1.98E+12	3.36E+12	3.11E+08
	8.9999E+04	3.04E+08	1.10E+12		

Table C2: Determination of Plant Temperature Rise For First 24 Hours

Time (hours)	Ave Heat Load (Btu/hr)	ΔT 2 Pumps (°F)	ΔT 3 Pumps (°F)	ΔT 4 Pumps (°F)
0 - 3	4.76E+08	19.793	14.846	9.896
3 - 6	2.92E+08	12.173	9.131	6.087
6 - 9	3.28E+08	13.66	10.25	6.832
9 - 12	4.92E+08	20.49	15.37	10.243
12 - 15	3.66E+08	15.25	11.44	7.623
15 - 18	3.28E+08	13.67	10.254	6.835
18 - 21	3.20E+08	13.31	9.986	6.656
21 - 24	3.11E+08	12.95	9.715	6.476

	Flowrates lbm/hr
2 Pumps	24025000
3 Pumps	32030000
4 Pumps	48050000

Cp	1	(Btu/hr-lbm-°F)

Table C3: Determination of Plant Temperature Rise For 24 To 2160 Hours

Time (seconds)	Time (hours)	Heat Load (Btu/hr)	ΔT 2 Pumps (°F)	ΔT 3 Pumps (°F)	ΔT 4 Pumps (°F)	
8.64E+04	24.00	3.07E+08	12.761	9.572	6.381	
9.00E+04	25.00	3.04E+08	12.637	9.479	6.318	
1.00E+05	27.78	2.96E+08	12.337	9.254	6.169	
8.00E+05	222.22	2.23E+08	9.274	6.956	4.637	
7.78E+06	2160.00	2.23E+08	9.274	6.956	4.637	**Assumed Constant**

	A	B	C	D	E	F
1	Formulas for Table C1					
2						
3	Time	Time	Total Heat Load	Trapezoidal Rule	Sum of	Average
4	(hours)	(seconds)	to the UHS	Integration Over	Previous Column	Heat Load Over
5			(Worst Case from ATD-0063, page E9, Table 13)	Previous Time Step	Over Time Interval	Time Interval
6			(Btu/Hr)	(Btu-sec/hr)	(Btu-sec/hr)	(Btu/hr)
7	0	0	0			
8		10	83000000	=(B8-B7)*(C8+C7)/2		
9		20	83000000	=(B9-B8)*(C9+C8)/2		
10		21	585000000	=(B10-B9)*(C10+C9)/2		
11		33	575000000	=(B11-B10)*(C11+C10)/2		
12		50	568000000	=(B12-B11)*(C12+C11)/2		
13		102	554000000	=(B13-B12)*(C13+C12)/2		
14		131	547000000	=(B14-B13)*(C14+C13)/2		
15		199	533000000	=(B15-B14)*(C15+C14)/2		
16		289	522000000	=(B16-B15)*(C16+C15)/2		
17		349	517000000	=(B17-B16)*(C17+C16)/2		
18		459	508000000	=(B18-B17)*(C18+C17)/2		
19		599	499000000	=(B19-B18)*(C19+C18)/2		
20		695	494000000	=(B20-B19)*(C20+C19)/2		
21		695.0012	787000000	=(B21-B20)*(C21+C20)/2		
22		899	793000000	=(B22-B21)*(C22+C21)/2		
23		999	796000000	=(B23-B22)*(C23+C22)/2		
24		1099	795000000	=(B24-B23)*(C24+C23)/2		
25		1199	786000000	=(B25-B24)*(C25+C24)/2		
26		1299	777000000	=(B26-B25)*(C26+C25)/2		
27		1399	768000000	=(B27-B26)*(C27+C26)/2		
28		1764	734000000	=(B28-B27)*(C28+C27)/2		
29		2299	635000000	=(B29-B28)*(C29+C28)/2		
30		2899	560000000	=(B30-B29)*(C30+C29)/2		
31		3599	519000000	=(B31-B30)*(C31+C30)/2		
32		4999	458000000	=(B32-B31)*(C32+C31)/2		
33		6999	379000000	=(B33-B32)*(C33+C32)/2		
34		9999	332000000	=(B34-B33)*(C34+C33)/2		
35	=B35/3600	10800	=(B35-B34)/(B36-B34)*(C36-C34)+C34	=(B35-B34)*(C35+C34)/2	=SUM(D8:D35)	=E35/10800
36		19999	267000000	=(B36-B35)*(C36+C35)/2		
37	=B37/3600	21600	267000000	=(B37-B36)*(C37+C36)/2	=SUM(D36:D37)	=E37/10800
38		29998	267000000	=(B38-B37)*(C38+C37)/2		
39		29999	551000000	=(B39-B38)*(C39+C38)/2		
40	=B40/3600	32400	=(B40-B39)/(B41-B39)*(C41-C39)+C39	=(B40-B39)*(C40+C39)/2	=SUM(D38:D40)	=E40/10800
41		39999	480000000	=(B41-B40)*(C41+C40)/2		
42	=B42/3600	43200	=(B42-B41)/(B43-B41)*(C43-C41)+C41	=(B42-B41)*(C42+C41)/2	=SUM(D41:D42)	=E42/10800
43		49999	336100000	=(B43-B42)*(C43+C42)/2		
44	=B44/3600	54000	=(B44-B43)/(B45-B43)*(C45-C43)+C43	=(B44-B43)*(C44+C43)/2	=SUM(D43:D44)	=E44/10800
45		59999	327900000	=(B45-B44)*(C45+C44)/2		
46	=B46/3600	64800	=(B46-B45)/(B48-B45)*(C48-C45)+C45	=(B46-B45)*(C46+C45)/2	=SUM(D45:D46)	=E46/10800
47	=B47/3600	75600	=(B47-B45)/(B48-B45)*(C48-C45)+C45	=(B47-B46)*(C47+C46)/2	=SUM(D47)	=E47/10800
48		79999	312100000	=(B48-B47)*(C48+C47)/2		
49	=B49/3600	86400	=(B49-B47)/(B50-B47)*(C50-C47)+C47	=(B49-B48)*(C49+C48)/2	=SUM(D48:D49)	=E49/10800
50		89999	303600000	=(B50-B49)*(C50+C49)/2		

	A	B	C	D	E	F	G	H
1	Formuilas for Table C2							
2								
3	Time	Ave	ΔT	ΔT	ΔT			
4		Heat Load	2 Pumps	3 Pumps	4 Pumps			
5	(hours)	(Btu/hr)	(°F)	(°F)	(°F)			
6	0 - 3	=AVE_HL!F35	=$B6/($G$8*$G$12)	=$B6/($G$9*$G$12)	=$B6/($G$10*$G$12)		Flowrates	
7	3 - 6	=AVE_HL!F37	=$B7/($G$8*$G$12)	=$B7/($G$9*$G$12)	=$B7/($G$10*$G$12)		lbm/hr	
8	6 - 9	=AVE_HL!F40	=$B8/($G$8*$G$12)	=$B8/($G$9*$G$12)	=$B8/($G$10*$G$12)	2 Pumps	24025000	
9	9 - 12	=AVE_HL!F42	=$B9/($G$8*$G$12)	=$B9/($G$9*$G$12)	=$B9/($G$10*$G$12)	3 Pumps	32030000	
10	12 - 15	=AVE_HL!F44	=$B10/($G$8*$G$12)	=$B10/($G$9*$G$12)	=$B10/($G$10*$G$12)	4 Pumps	48050000	
11	15 - 18	=AVE_HL!F46	=$B11/($G$8*$G$12)	=$B11/($G$9*$G$12)	=$B11/($G$10*$G$12)			
12	18 - 21	=AVE_HL!F47	=$B12/($G$8*$G$12)	=$B12/($G$9*$G$12)	=$B12/($G$10*$G$12)	Cp	1	(Btu/hr-lbm-°F)
13	21 - 24	=AVE_HL!F49	=$B13/($G$8*$G$12)	=$B13/($G$9*$G$12)	=$B13/($G$10*$G$12)			
14								
15								
16								
17	Formulas for Table C3							
18		Time	Heat Load	ΔT	ΔT	ΔT		
19				2 Pumps	3 Pumps	4 Pumps		
20	(seconds)	(hours)	(Btu/hr)	(°F)	(°F)	(°F)		
21	86400	=A21/3600	=AVE_HL!C49	=$C21/($G$8*$G$12)	=$C21/($G$9*$G$12)	=$C21/($G$10*$G$12)		
22	89999	=A22/3600	303600000	=$C22/($G$8*$G$12)	=$C22/($G$9*$G$12)	=$C22/($G$10*$G$12)		
23	99999	=A23/3600	296400000	=$C23/($G$8*$G$12)	=$C23/($G$9*$G$12)	=$C23/($G$10*$G$12)		
24	799999	=A24/3600	222800000	=$C24/($G$8*$G$12)	=$C24/($G$9*$G$12)	=$C24/($G$10*$G$12)		
25	7776000	=A25/3600	222800000	=$C25/($G$8*$G$12)	=$C25/($G$9*$G$12)	=$C25/($G$10*$G$12)	**Assumed Constant**	

Attachment D

MES-11.1 Stratification Review

Purpose

The purpose of this attachment is to verify the applicability of LAKET-PC computer program to Braidwood UHS. This is done by review of UHS stratification as presented in Sargent & Lundy standard MES-11.1. Since LAKET-PC uses a one-dimensional thermal prediction model, a stratification check confirms applicability of using the plug-flow model utilized by LAKET-PC computer program to evaluate Braidwood UHS.

Methodology

A method for determining if a lake is stratified is presented in Sargent & Lundy standard MES-11.1. This method consists of assuming the lake is stratified with the less dense hot water floating on top of the slightly more dense colder water. If the calculated value for the upper layer depth is close to or beneath the actual lake bottom, then the lake can be regarded as not stratified. The depth of the upper layer hot water is determined using Eq. 1.

$$h_u = \left[\frac{f_i Q^2 D_s^3 L}{4 g \beta \Delta T B^2} \right]^{1/4} \qquad \text{(Eq. 1)}$$

Where:

f_i - Interfacial shear coefficient, estimated as one-half of bottom friction coefficient

$$f_i = 0.5 * 8 * g / C_z^2 \qquad \text{(Eq. 2)}$$

C_z - Chezy coefficient

$$C_z = 1.47 * H^{1/6} / n \qquad \text{(Eq. 3)}$$

H - lake depth *(ft)*

n - Manning roughness coefficient - The Manning coefficient is assumed to be 0.02. This is an approximate, conservatively low value [Ref. 5.16, Table 3.3.17] based on the surface of crushed stone bedding, or earth.

Q - Circulating water flow *(ft^3/s)*

D_s - Dilution ratio (total lake flow / circulating water flow)

L - Lake length *(ft)*

g - gravity *(ft/s^2)*

β - Bulk expansion coefficient of water *(°F)*

$$\beta = 4.1 \times 10^{-6} * (T_{ave} - 39) \qquad \text{(Eq. 4)}$$

T_{ave}- Average temperature of discharge and receiving water temperature *(°F)*

ΔT - Temperature difference between upper and lower levels *(°F)*

B - Width of lake *(ft)*

For the case where a jet or plume is formed in the lake, the dilution ratio (D_s) is found from the following steps.

$$Fr = U_d / \sqrt{h_d g \beta \Delta T} \qquad \text{(Eq. 5)}$$

$$h_{\max} = 0.42 \cdot \sqrt{h_d b_d} (h_d / b_d)^{1/4} Fr \quad \text{(Eq. 6)}$$

$$D_s^* = 1.4\sqrt{1 + Fr^2} (h_d / b_d)^{1/4} \quad \text{(Eq. 7)}$$

Where:

Fr - discharge Froude number
U_d - Velocity at discharge structure *(ft/s)*
h_d - Depth of discharge structure *(ft)*
b_d - ½ width of discharge structure *(ft)*
D_s^* - Dilution ratio without correction for lake bottom

If the maximum depth of the plume (h_{max}) is greater than the depth of the lake, a correction factor is applied to the dilution ratio.

$$r = (0.75H / h_{\max})^{3/4} \quad \text{(Eq. 8)}$$

$$D_s = rD_s^* \quad \text{(Eq. 9)}$$

Where:

r - Dilution correction factor

The upper layer depth (h_u) is used to determine the degree of stratification in the lake. If the volume of the lake below the upper layer depth is small compared to the total volume of the lake, then a plug flow model such as LAKET should be valid. When the volume below the upper layer depth is greater than one half the total volume of the lake, a different model that accounts for stratification should be used.

<u>Evaluation</u>

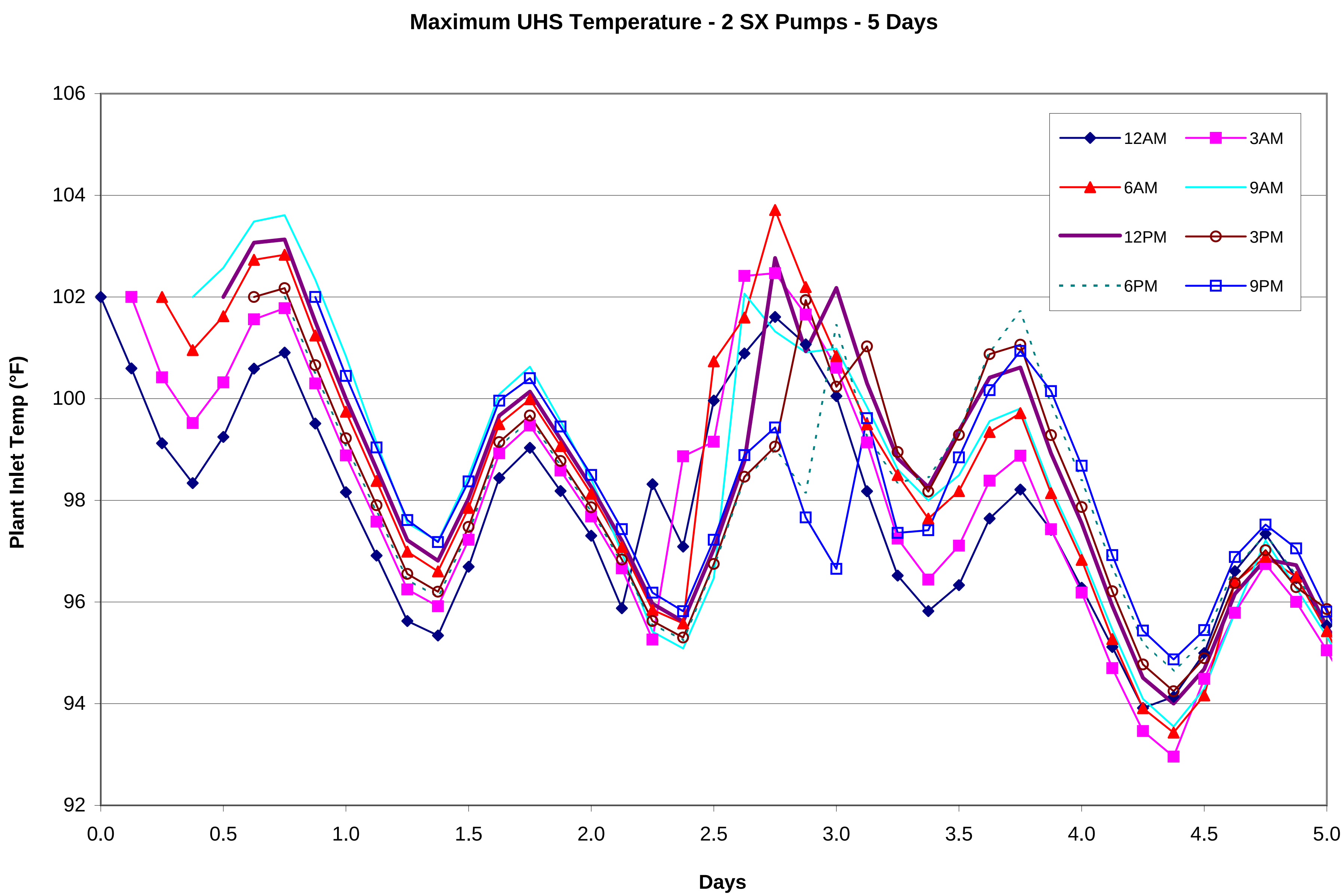
The calculation of the upper layer depth was done for the UHS at Braidwood in order to determine the degree of stratification. The following table shows the calculation of the upper layer depth, which is done according to the methodology presented in the previous section. This calculation is done for varying number of operating SX pumps to match the cases evaluated in the main body of the calculation. The temperature difference between the upper and lower layers is calculated as the difference between the plant outlet temperature and the initial UHS temperature of 102°F. Note that only hot summer conditions (102°F) are considered since this it the time the highest UHS temperatures are expected.

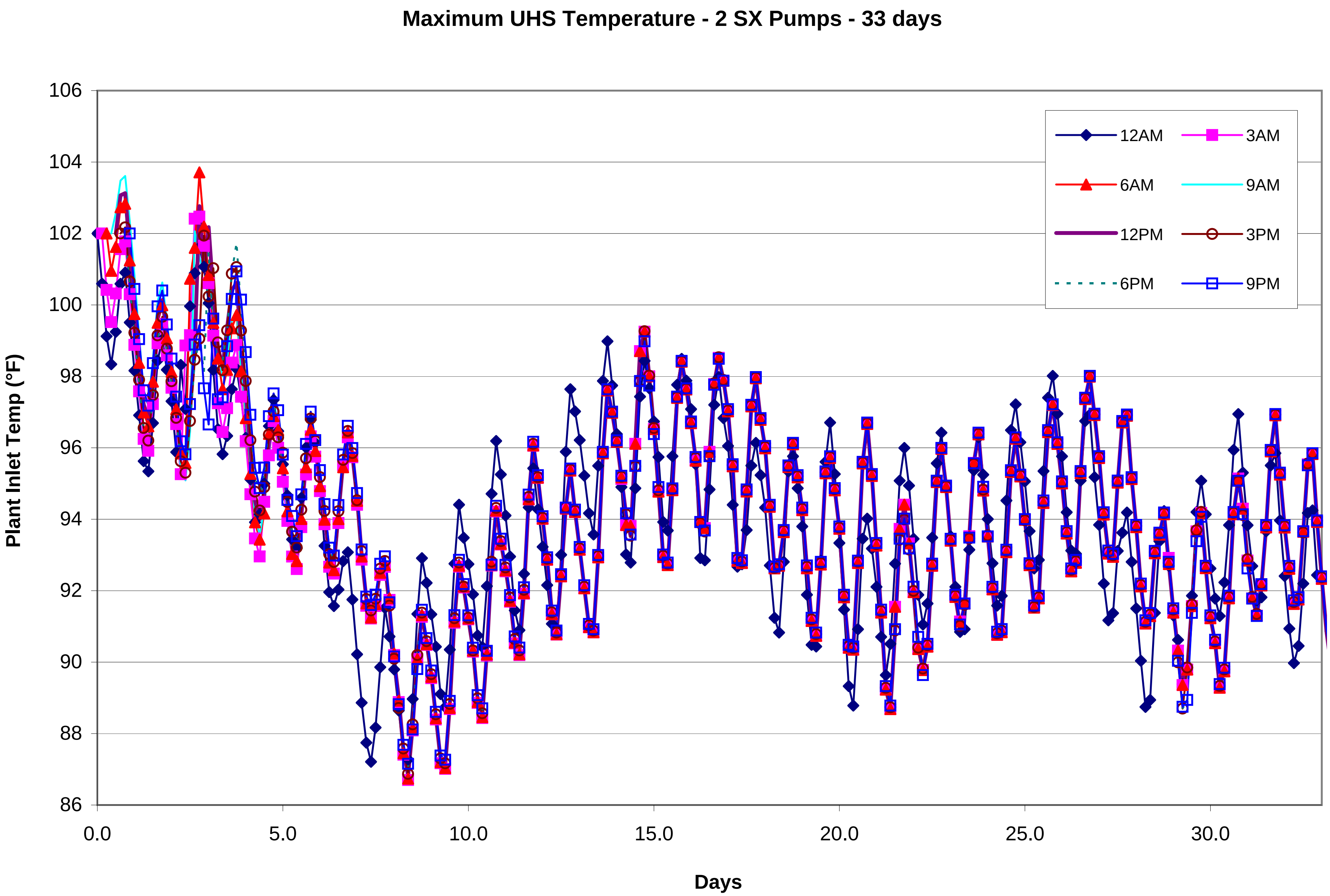
Table 1: Calculation of Upper Layer Depth

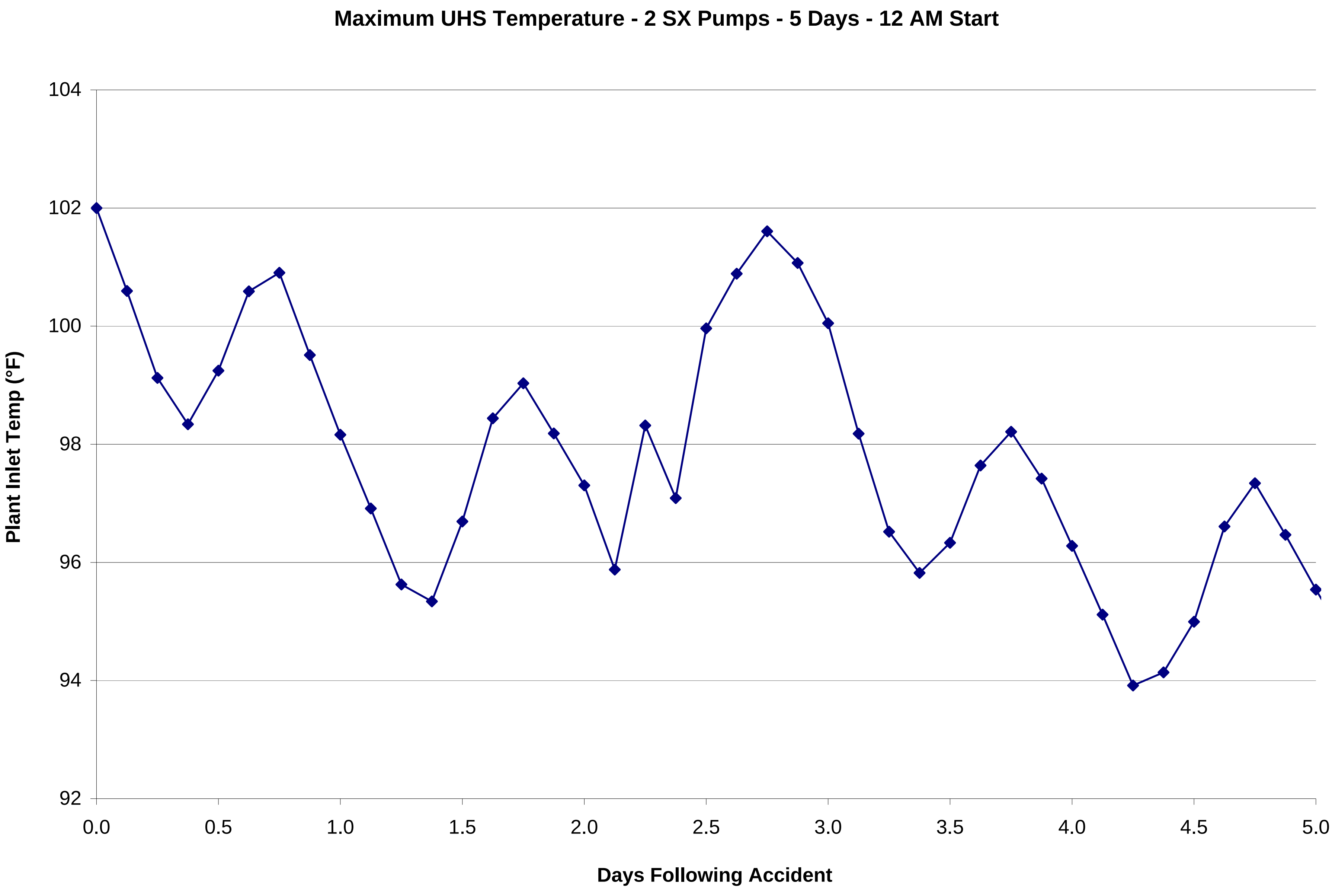
Parameter	Symbol	Units	2 SX Pumps	3 SX Pumps	4 SX Pumps	Basis
Gross Lake Area	A	Acres	95.6	95.6	95.6	ATD-0109
Gross Lake Volume	V	Acre-ft	555.8	555.8	555.8	ATD-0109
Average Depth	H	ft	5.81	5.81	5.81	= V / A
Flow Rate	Q	cfs	106.94	142.59	213.89	ATD-0109
Plant Inlet Temperature	T_i	°F	102	102	102	ATD-0109
Temperature Rise through Plant	ΔT_p	°F	9.5	7.1	4.7	ATD-0109
Lake Length	L	ft	3076	3076	3076	ATD-0109
Lake Width	B	ft	1354	1354	1354	= A * 43650 / L
Width of Discharge Structure	B_d	ft	7.1	7.1	7.1	2x48" pipes [Ref. 5.15]
Depth of Discharge Structure	h_d	ft	3.5	3.5	3.5	2x48" pipes [Ref. 5.15]
Discharge Velocity	V_d	ft/s	4.255	5.673	8.510	= Q / (B_d * h_d)
Assumed Lake Temp	T	°F	102	102	102	ATD-0109
Assumed Manning Roughness Coeff.	n	(-)	0.02	0.02	0.02	10th Ed., Marks' Handbook, Table 3.3.17 [Ref. 5.16]
Bulk Expansion Coefficient	β	°F	2.58E-04	2.58E-04	2.58E-04	Eq. 4
Discharge Froude Number	Fr	(-)	8.05	12.39	22.76	Eq. 5
Maximum Plume Depth	h_{max}	ft	11.98	18.44	33.89	Eq. 6
Dilution ratio (uncorrected)	D_s*	(-)	11.35	17.40	31.89	Eq. 7
Dilution Ratio Correction Factor	r	(-)	0.47	0.34	0.21	Eq. 8
Dilution Ratio (corrected)	D_s	(-)	5.32	5.90	6.85	Eq. 9
Chezy's Coefficient	C_z	(-)	98.56	98.56	98.56	Eq. 3
Interfacial Friction Coefficient	f_i	(-)	0.013	0.013	0.013	Eq. 2
Upper Layer Depth	h_u	ft	3.32	4.45	6.75	Eq. 1
Test for Lake Stratification						
Gross Volume	V	Acre-ft	555.8	555.8	555.8	ATD-0109
Volume Below Upper Layer	V_b	Acre-ft	246.9	142.2	0.0	Interpolation of volume curve in ATD-
Fraction of Lake Volume Below h_u		(-)	0.44	0.26	0.00	= V_b / V

Conclusion

As seen in Table 1, the most conservative calculated upper layer depth for the Braidwood UHS is 3.32 ft, which occurs with 2 SX pumps in operation. Using this depth, the fraction of the UHS below the upper layer depth is 44%. According to MES-11.1, LAKET is applicable to a certain lake if this fraction is less than 50%. Therefore, LAKET is acceptable for analyzing the Braidwood UHS.


Maximum UHS Temperature - 2 SX Pumps - 5 Days
Plant Inlet Temp (°F)
Days
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


Maximum UHS Temperature - 2 SX Pumps - 33 days
Plant Inlet Temp (°F)
Days
106
104
102
100
98
96
94
92
90
88
86
0.0
5.0
10.0
15.0
20.0
25.0
30.0
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM


Maximum UHS Temperature - 2 SX Pumps - 5 Days - 12 AM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
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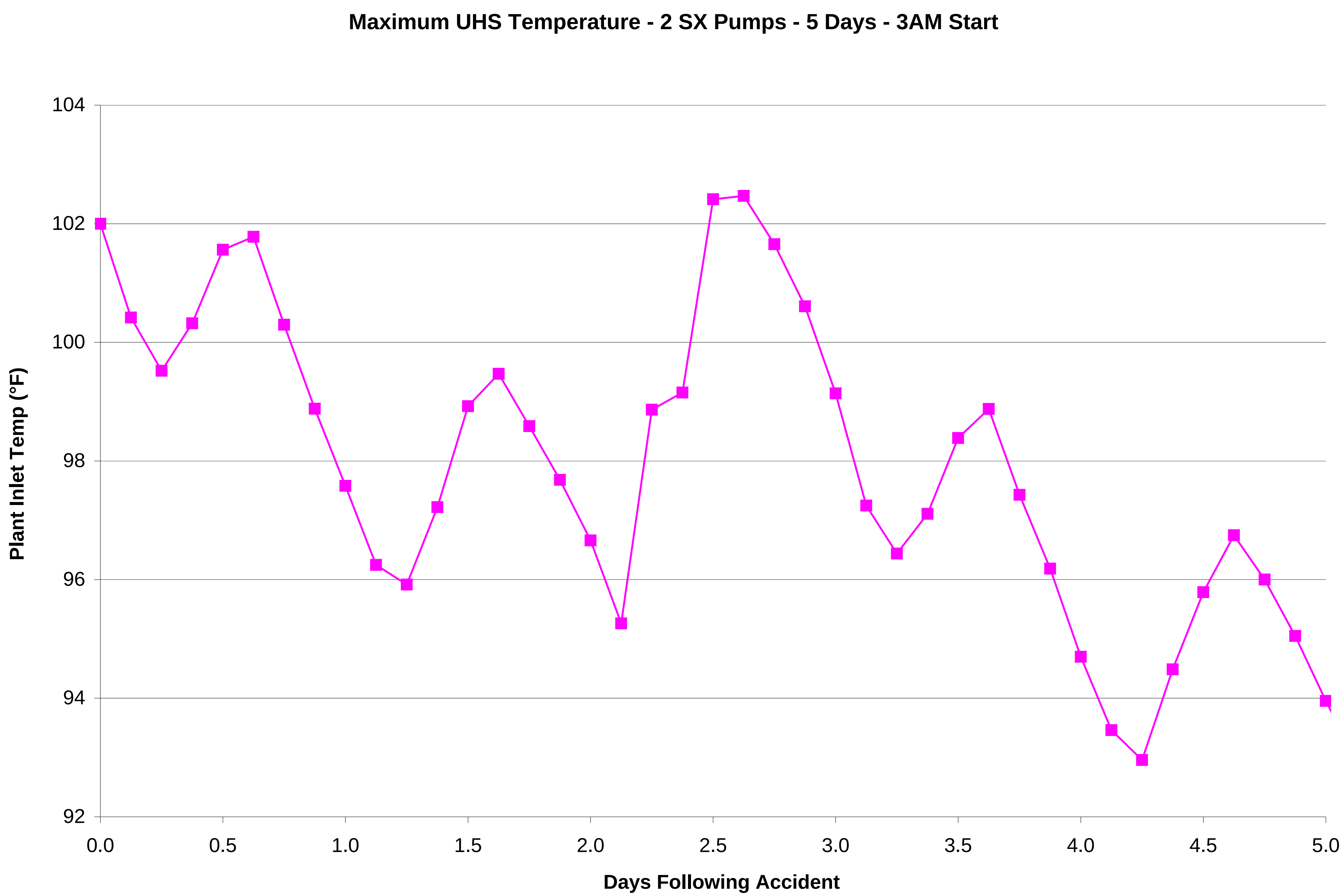
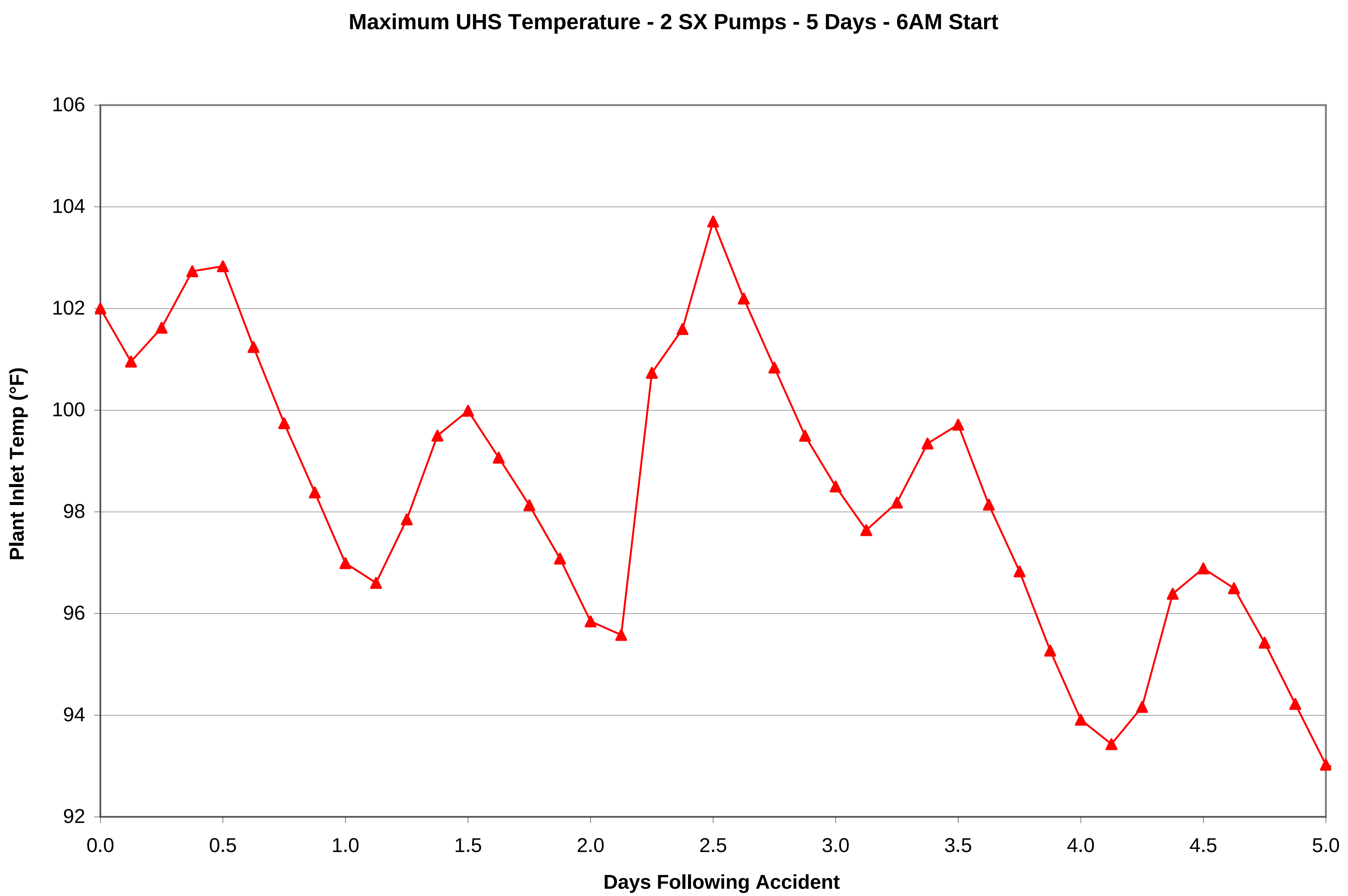
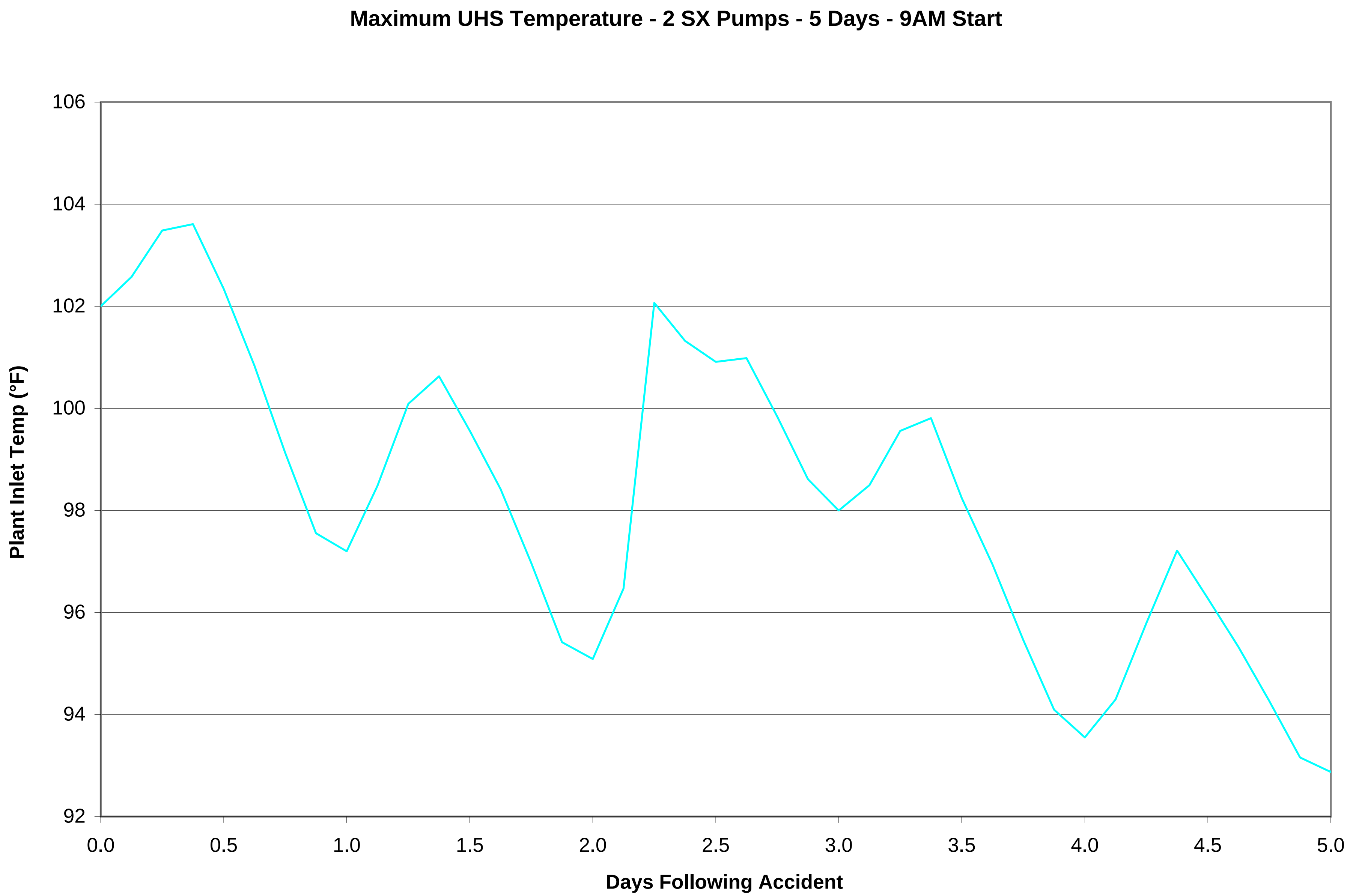
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 2 SX Pumps - 5 Days - 3AM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 2 SX Pumps - 5 Days - 6AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 2 SX Pumps - 5 Days - 9AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
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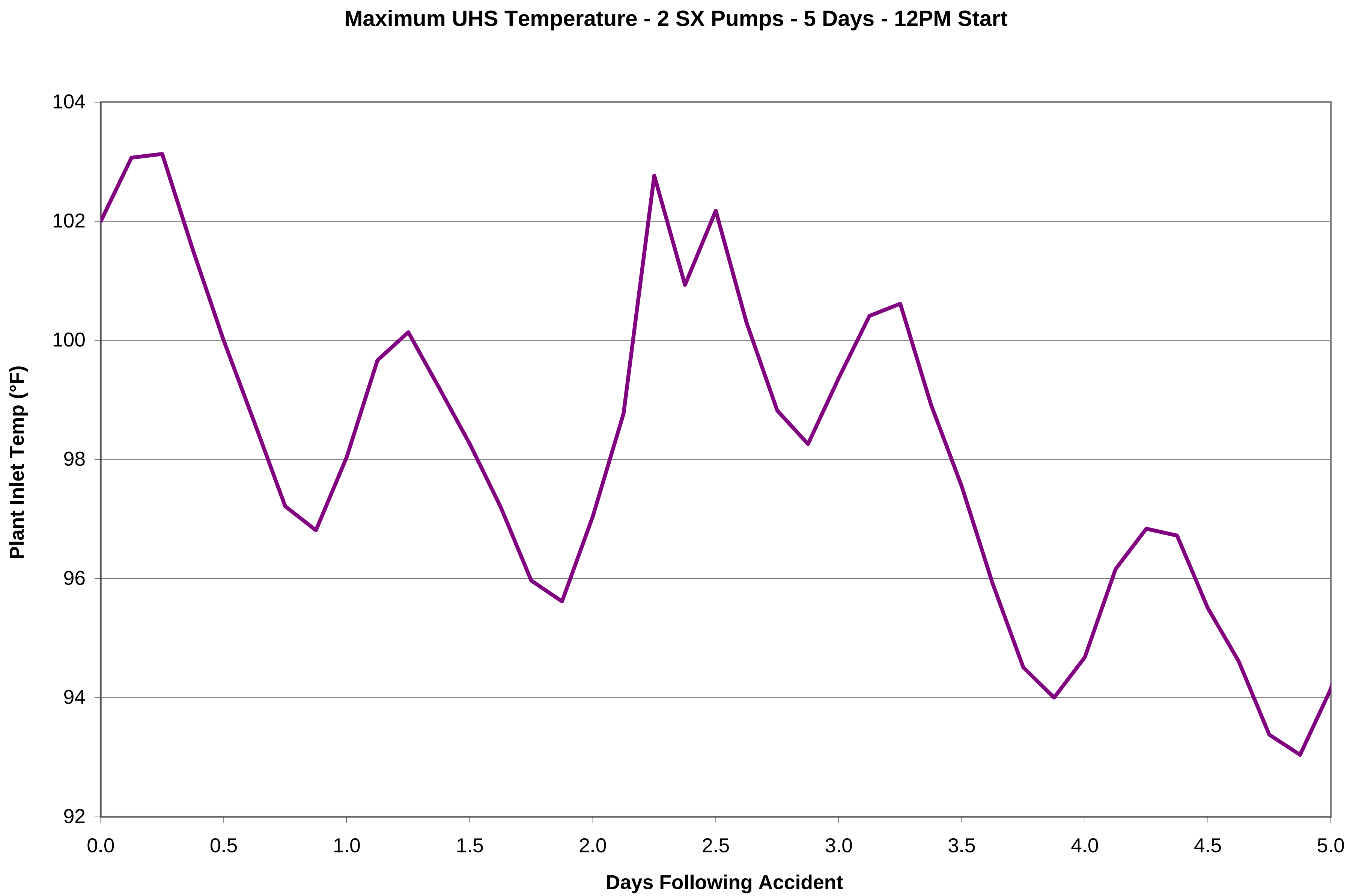
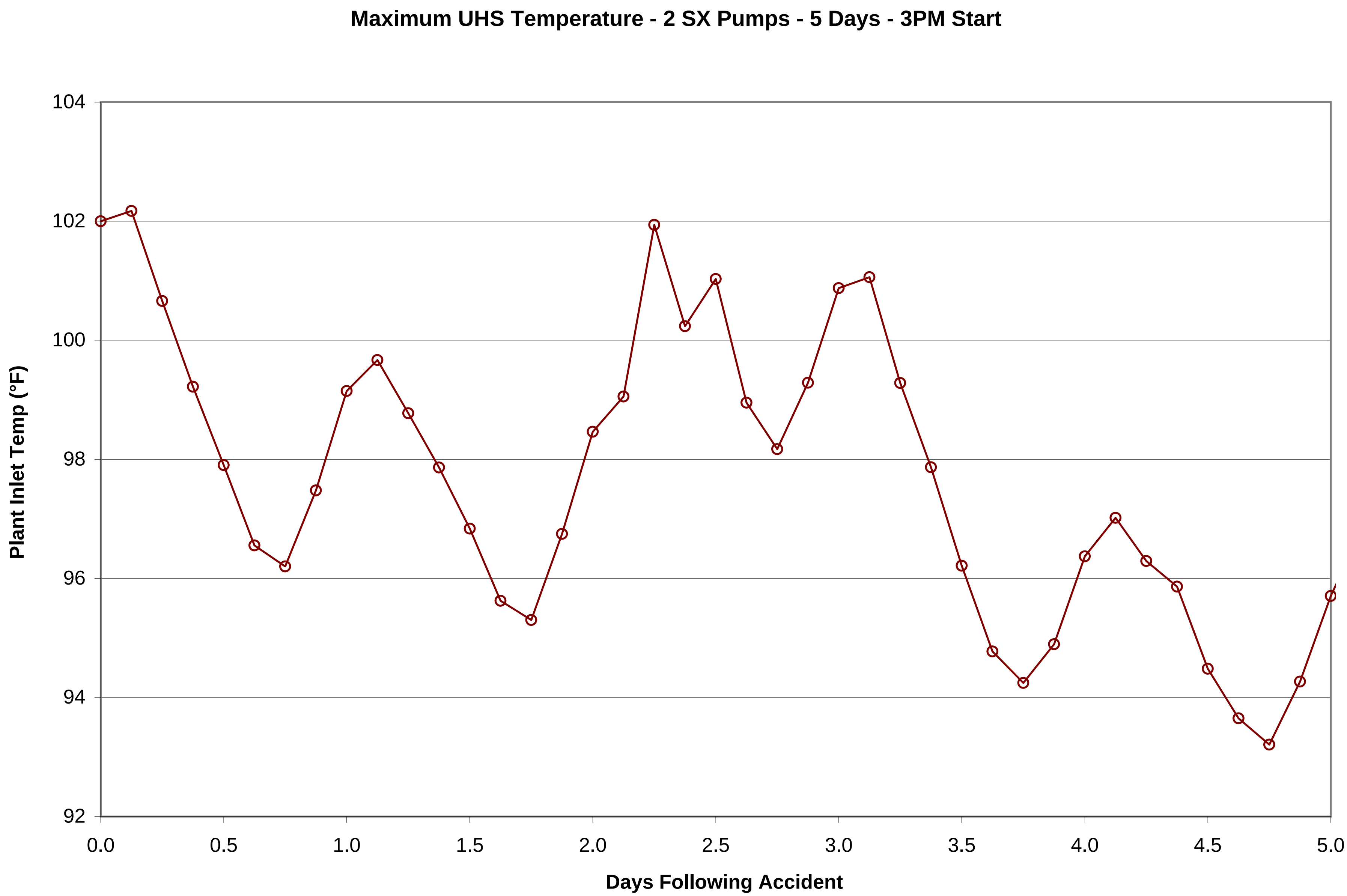
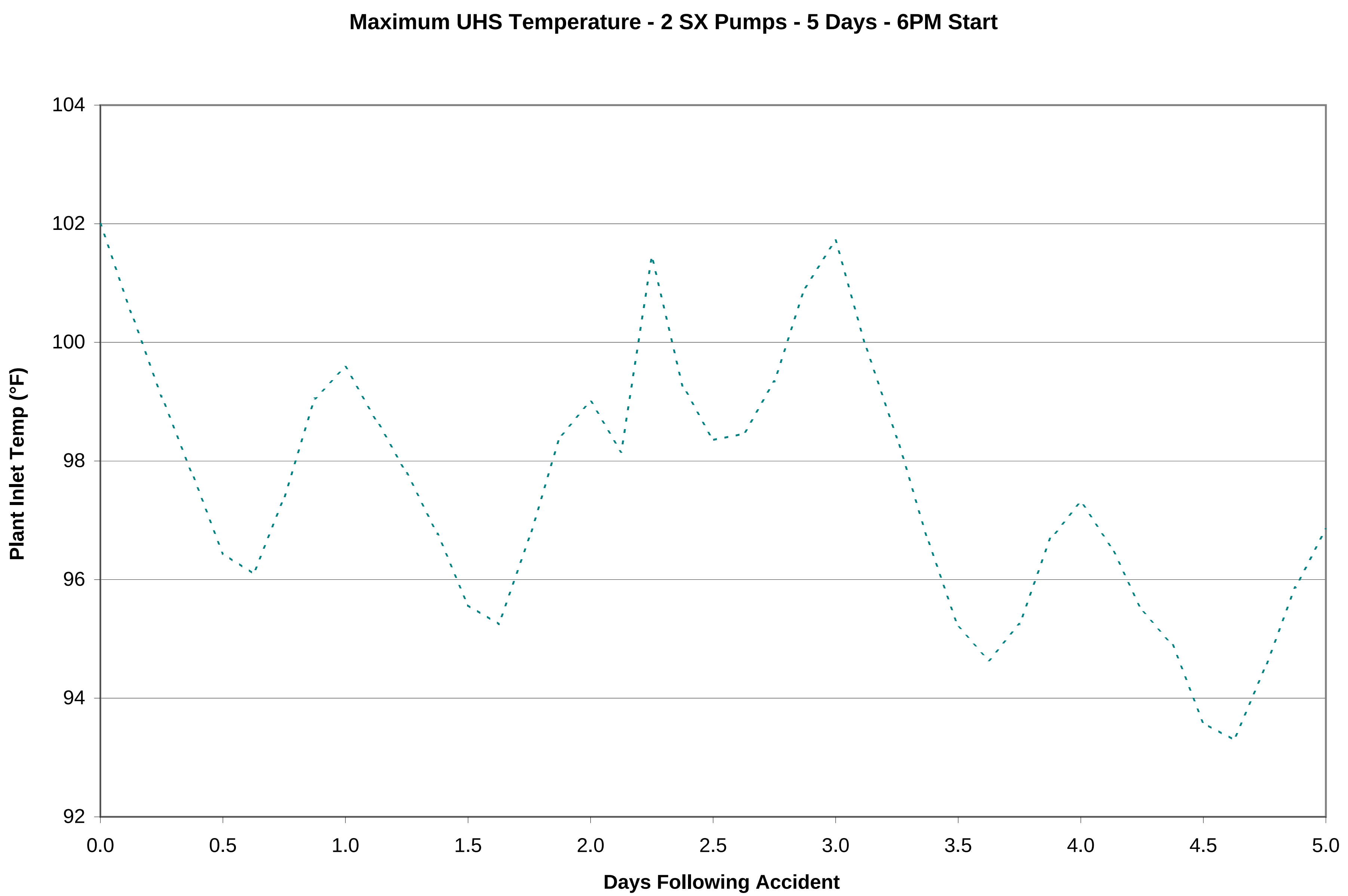
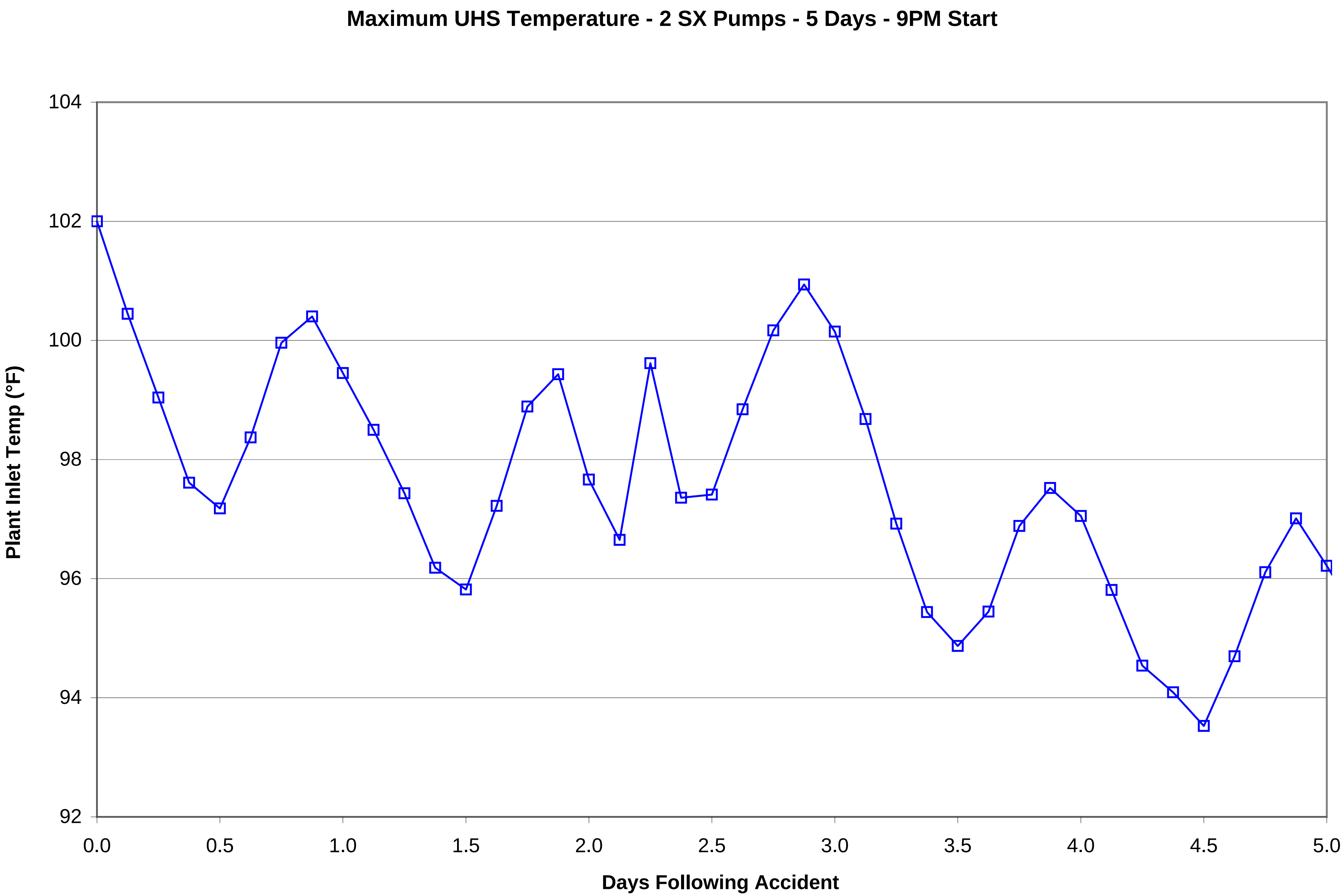
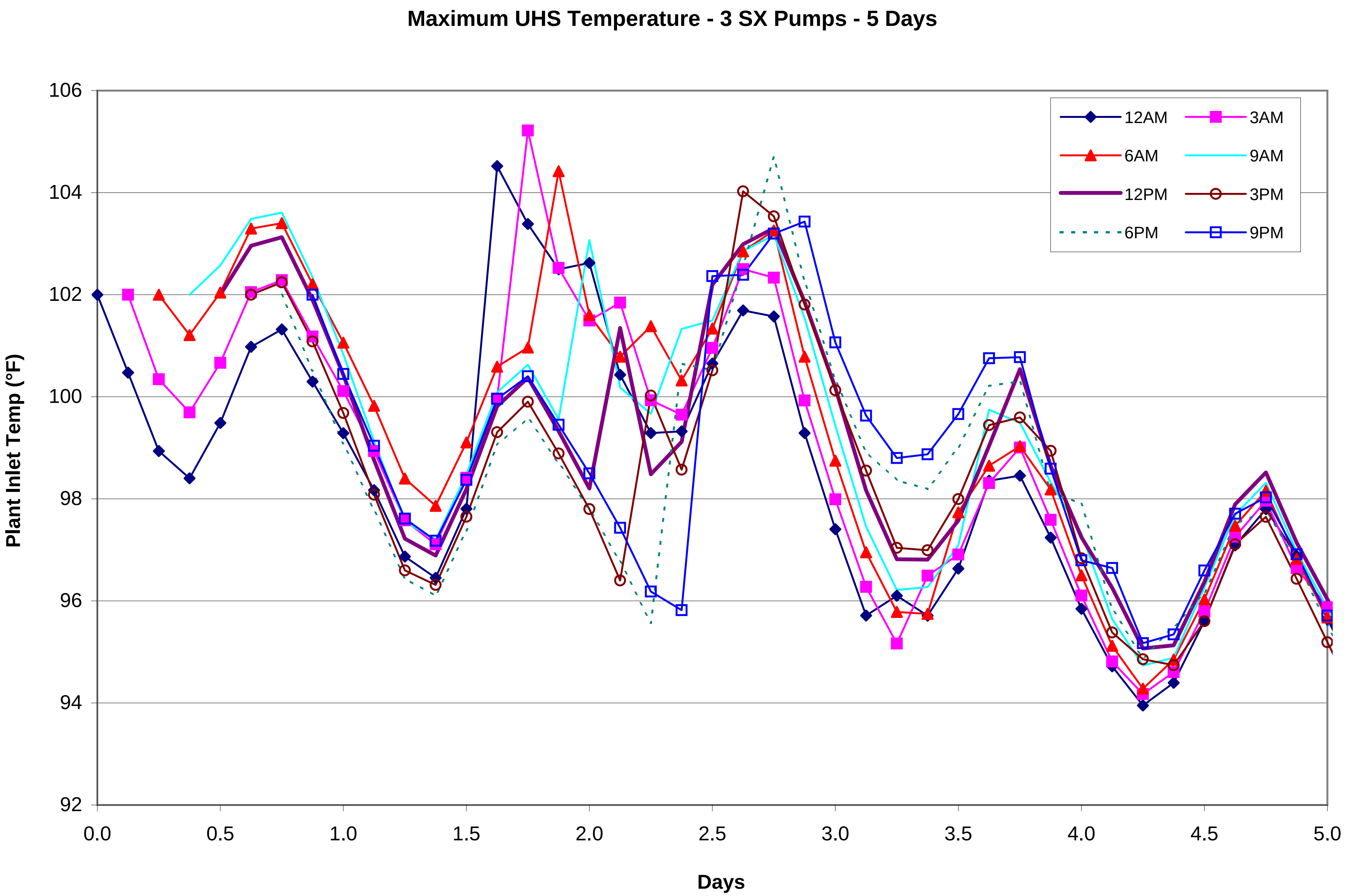
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

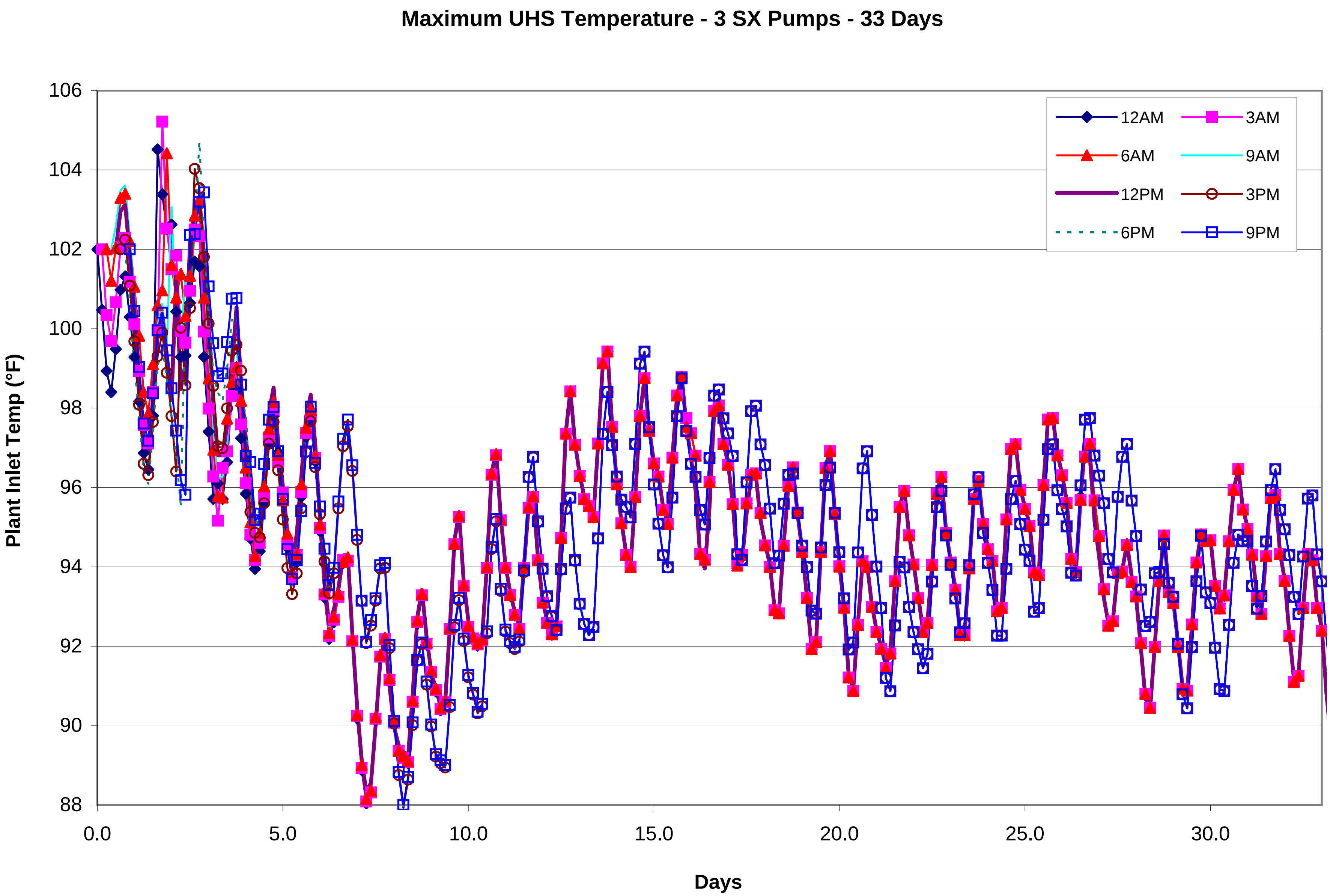

Maximum UHS Temperature - 2 SX Pumps - 5 Days - 12PM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 2 SX Pumps - 5 Days - 3PM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

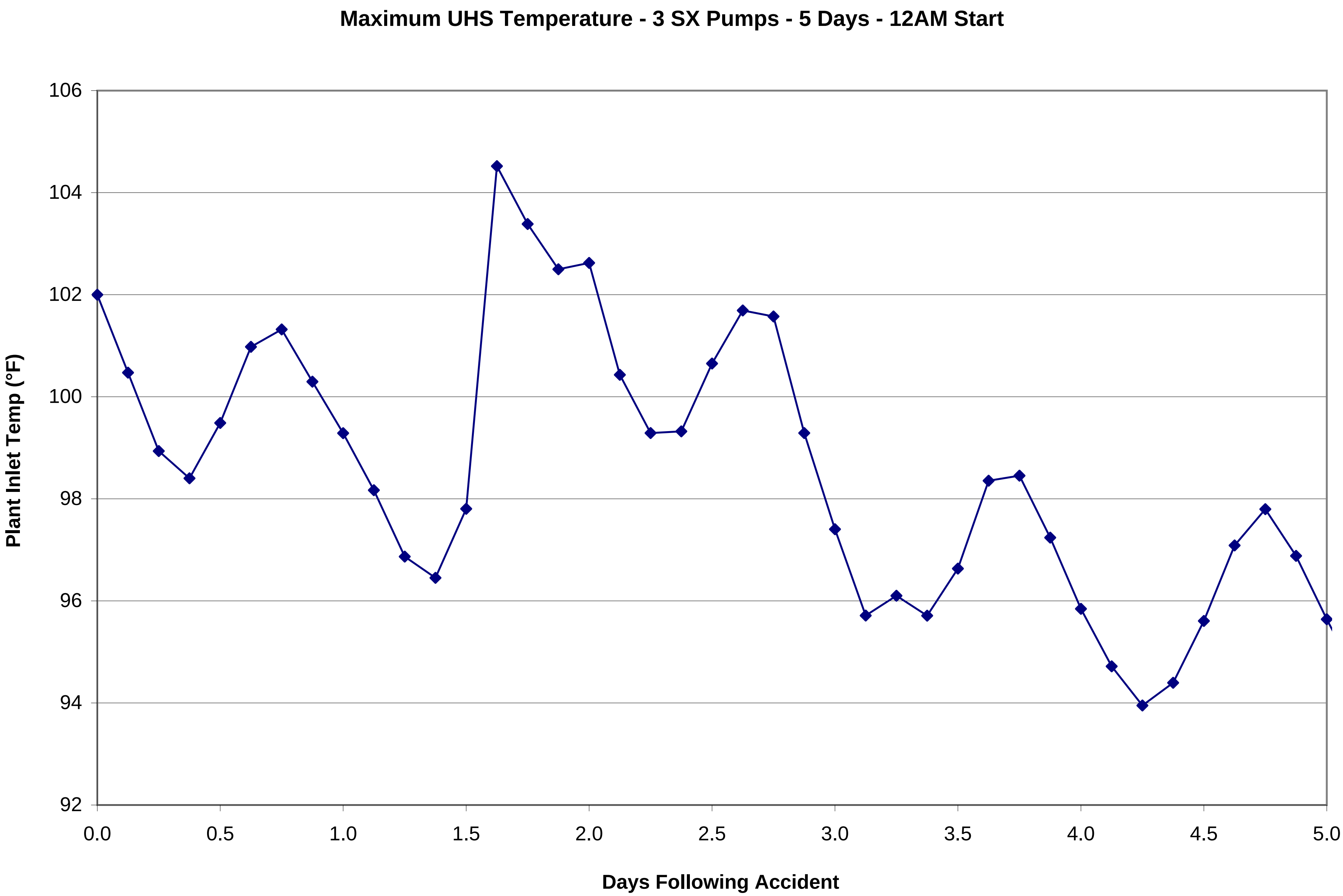

Maximum UHS Temperature - 2 SX Pumps - 5 Days - 6PM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

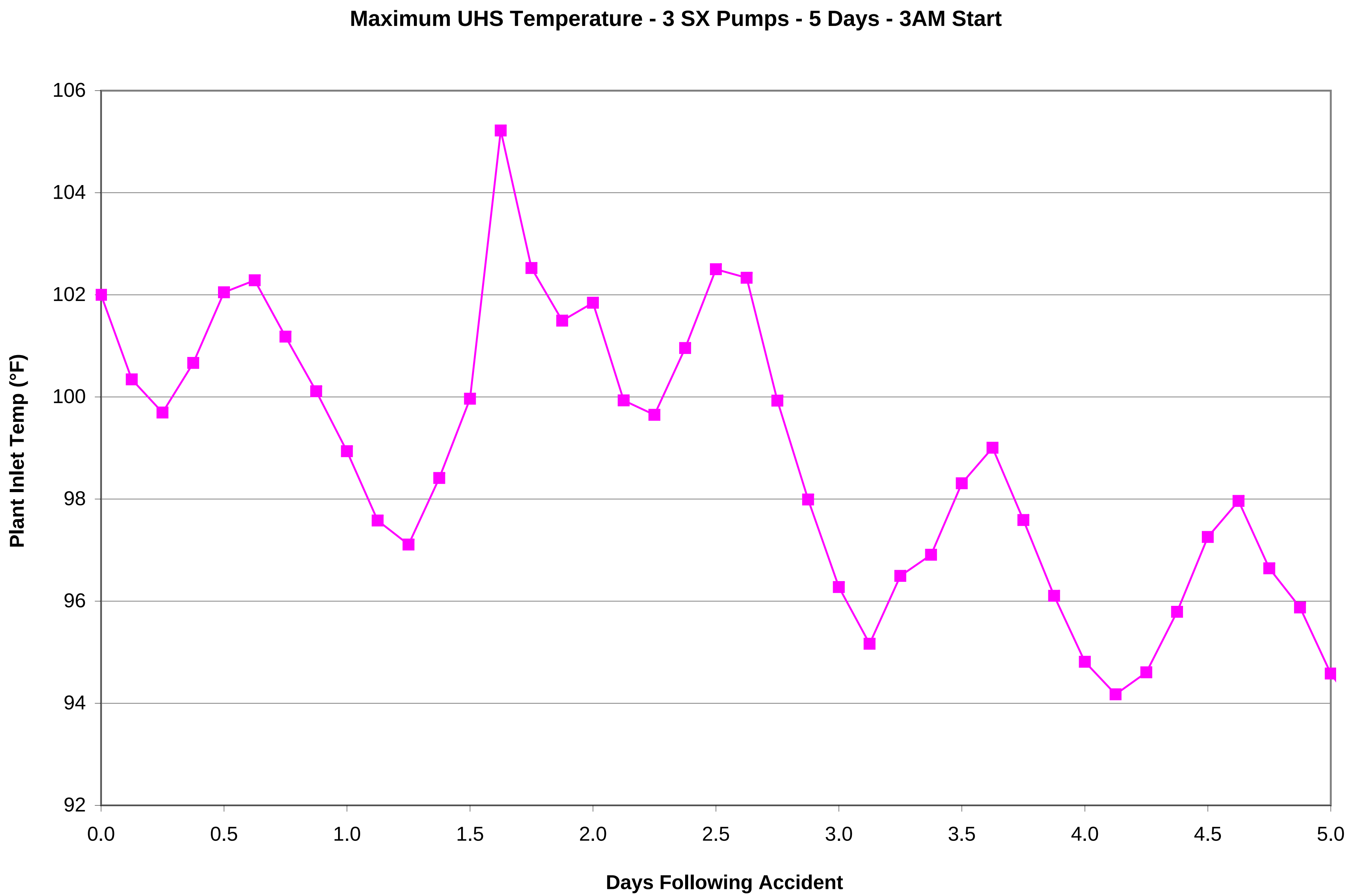

Maximum UHS Temperature - 2 SX Pumps - 5 Days - 9PM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

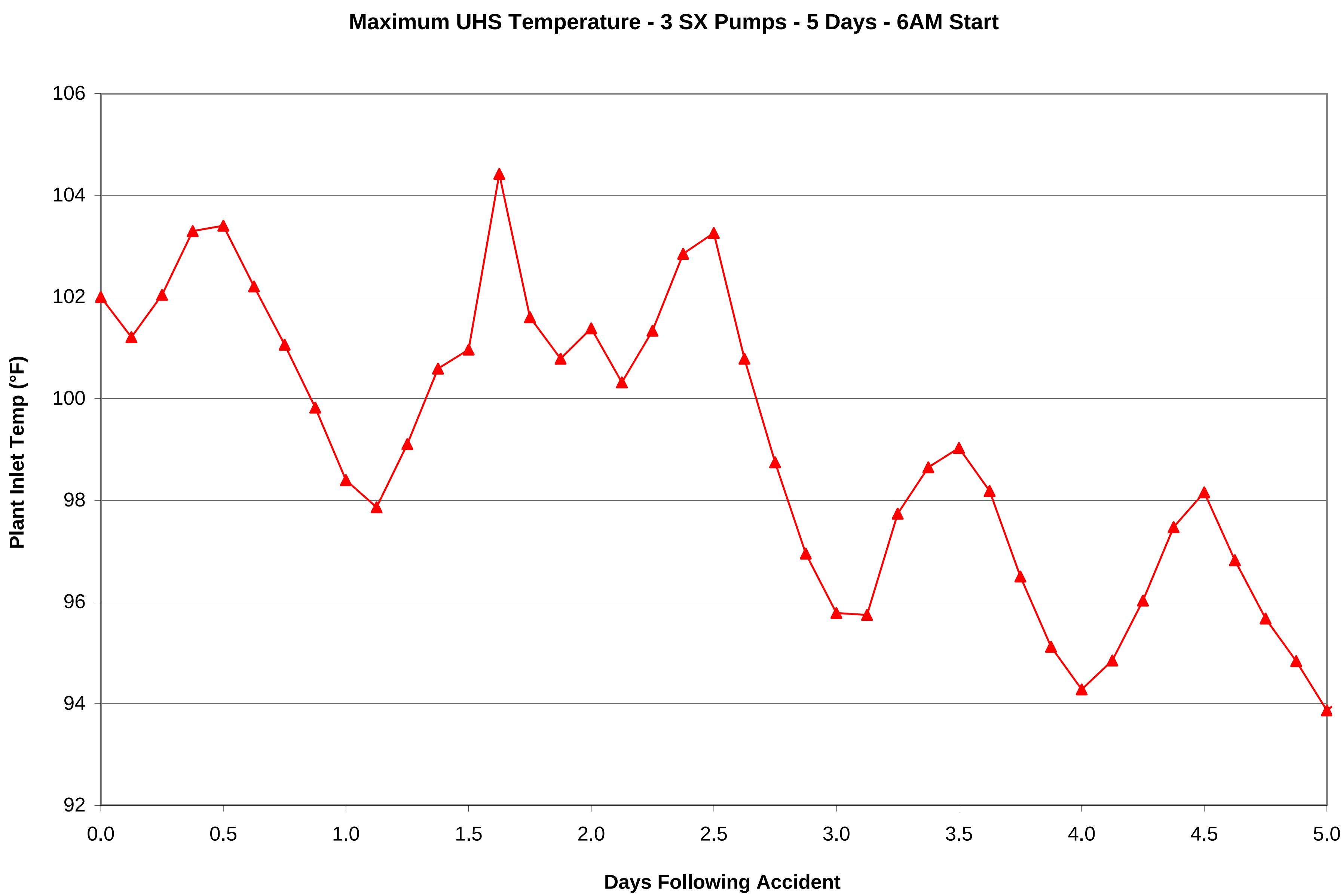

Maximum UHS Temperature - 3 SX Pumps - 5 Days
Plant Inlet Temp (°F)
Days
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM

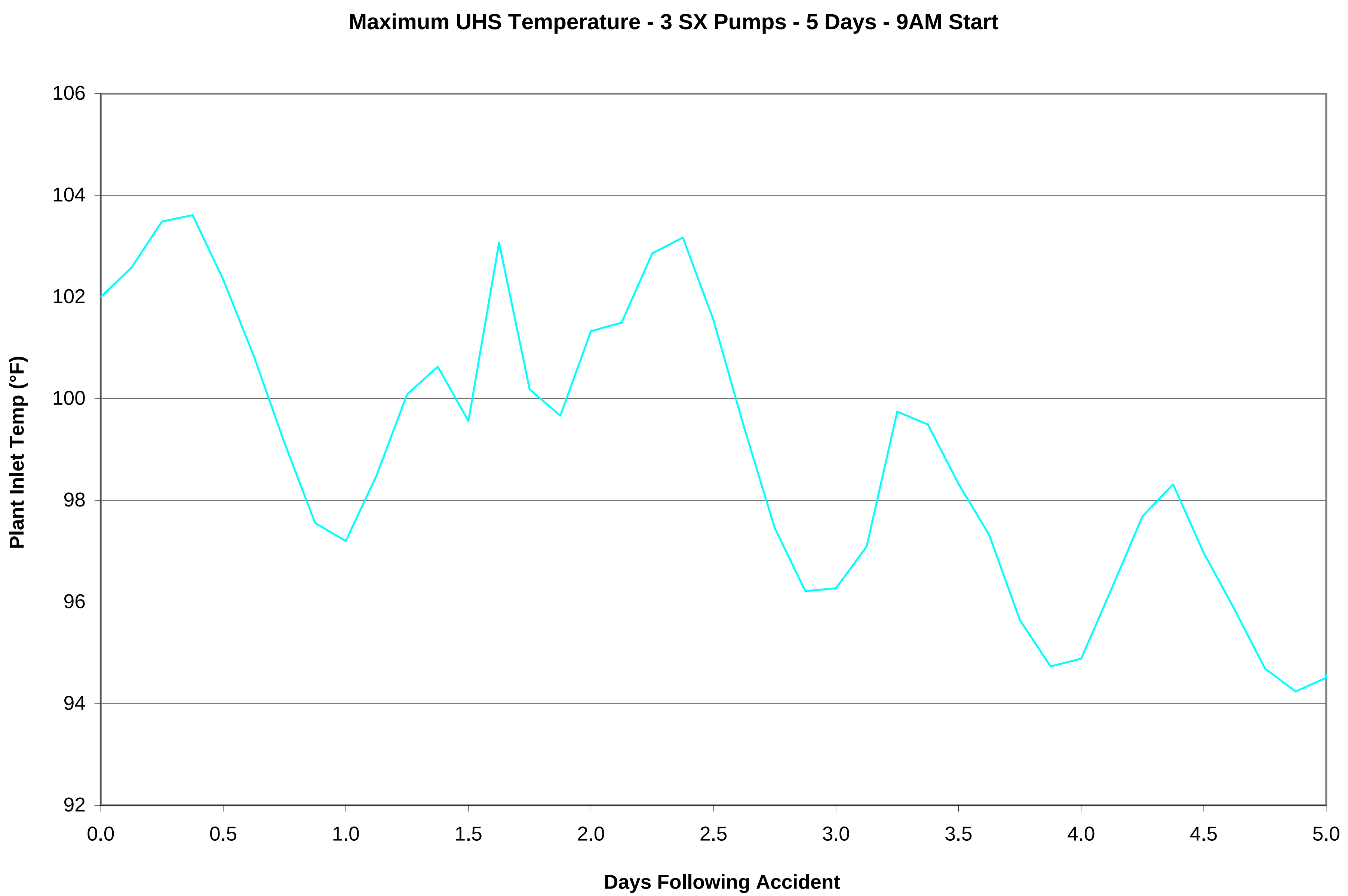


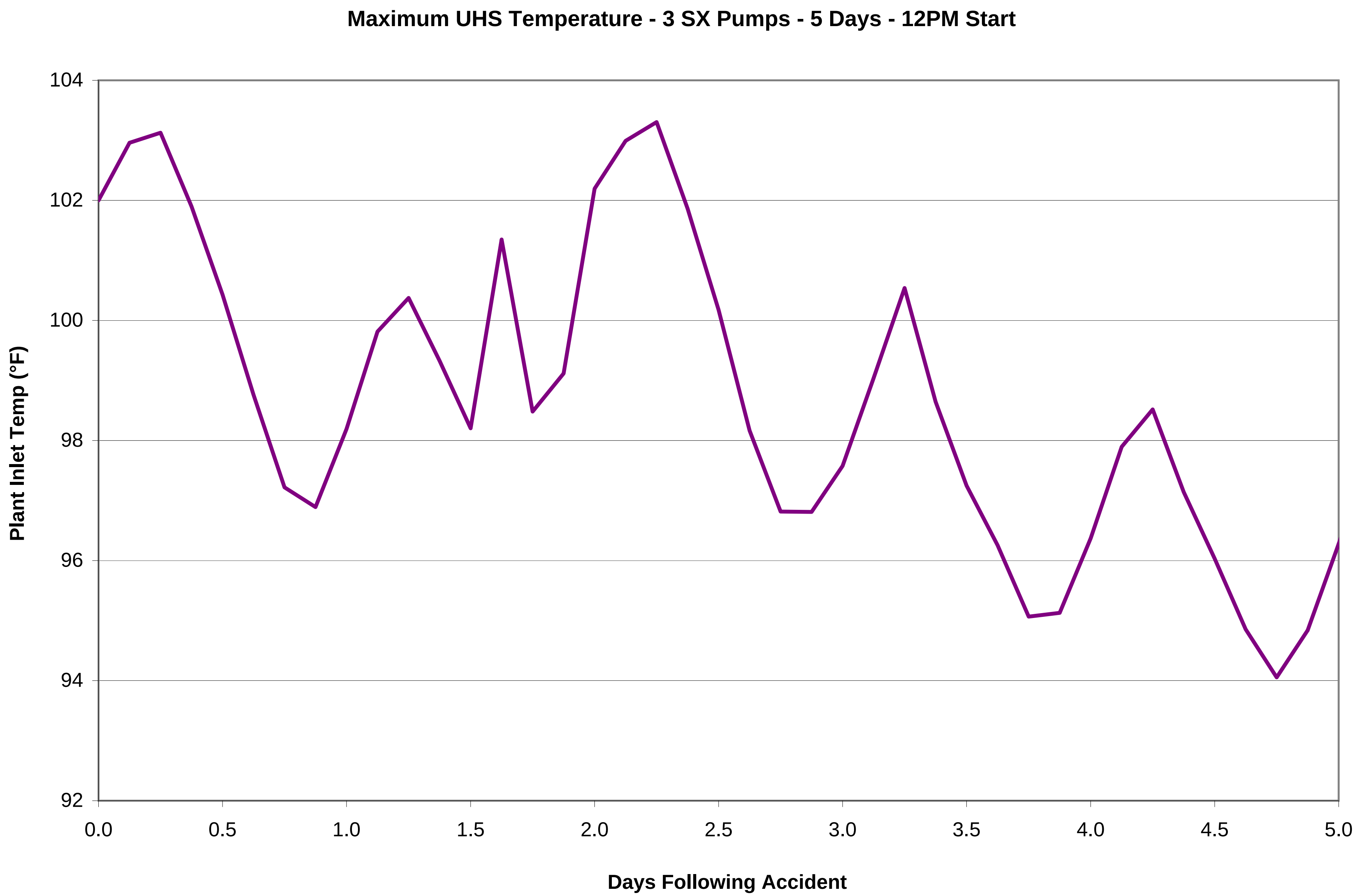
Maximum UHS Temperature - 3 SX Pumps - 33 Days
Plant Inlet Temp (°F)
Days
106
104
102
100
98
96
94
92
90
88
0.0
5.0
10.0
15.0
20.0
25.0
30.0
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM

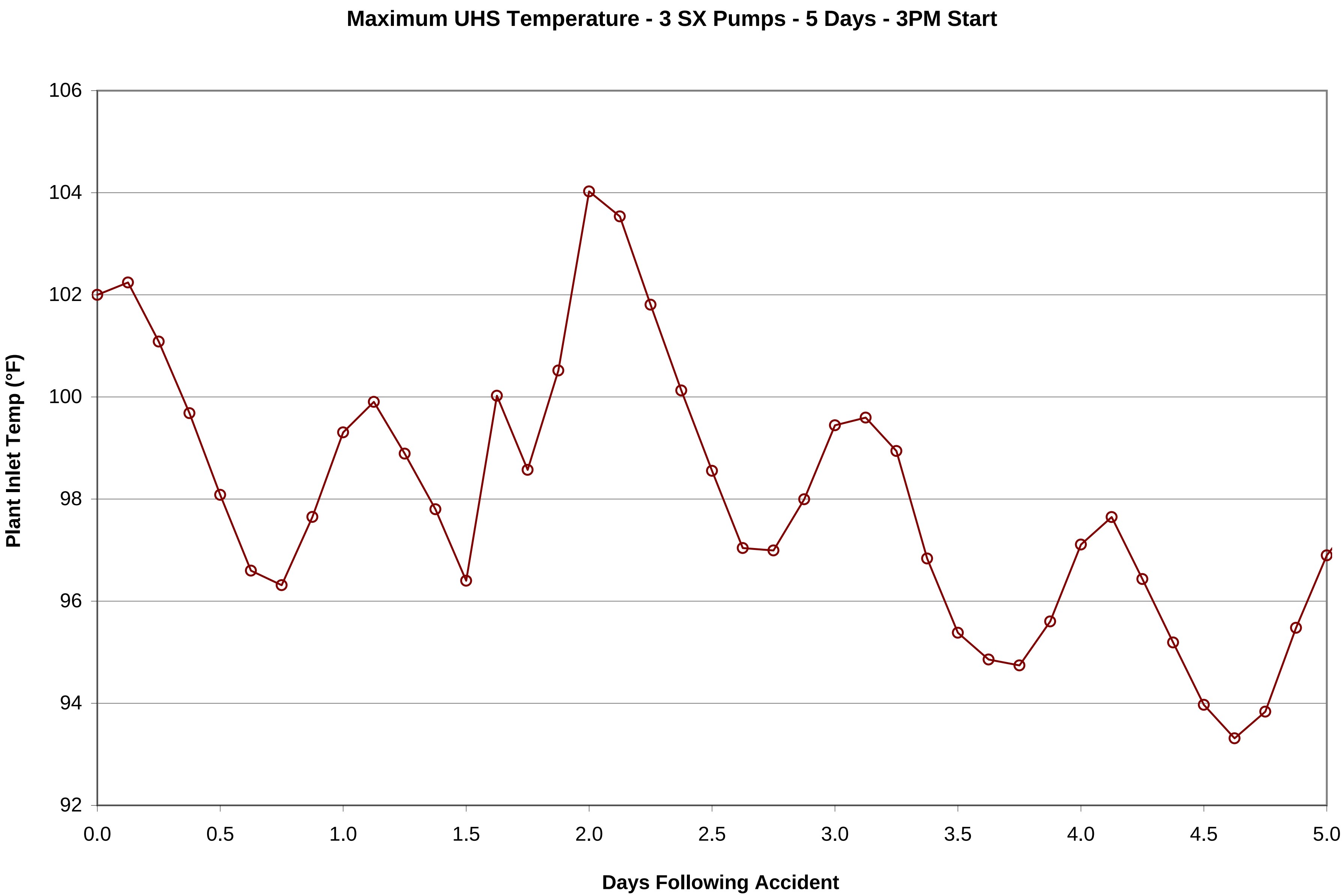

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 12AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

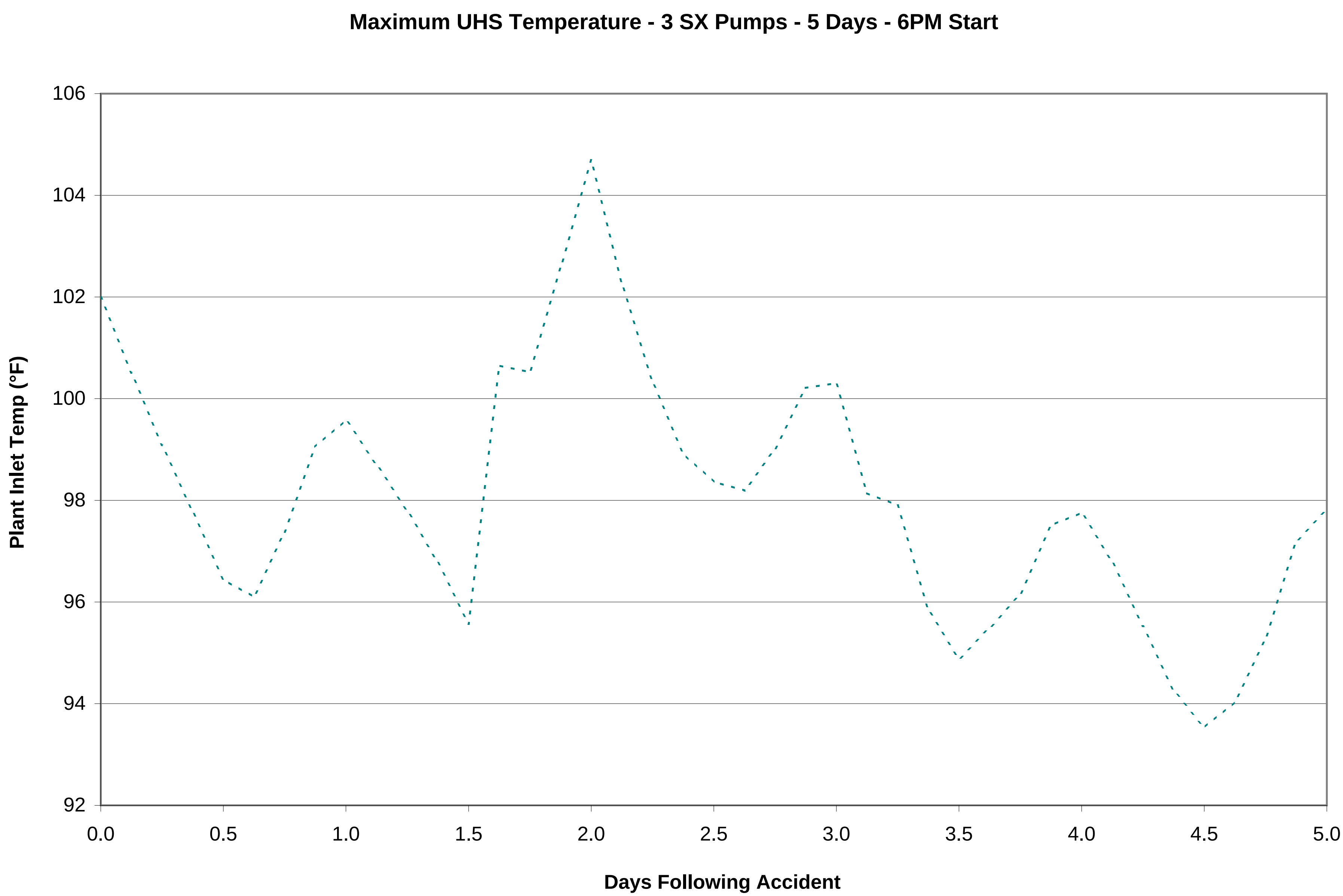

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 3AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

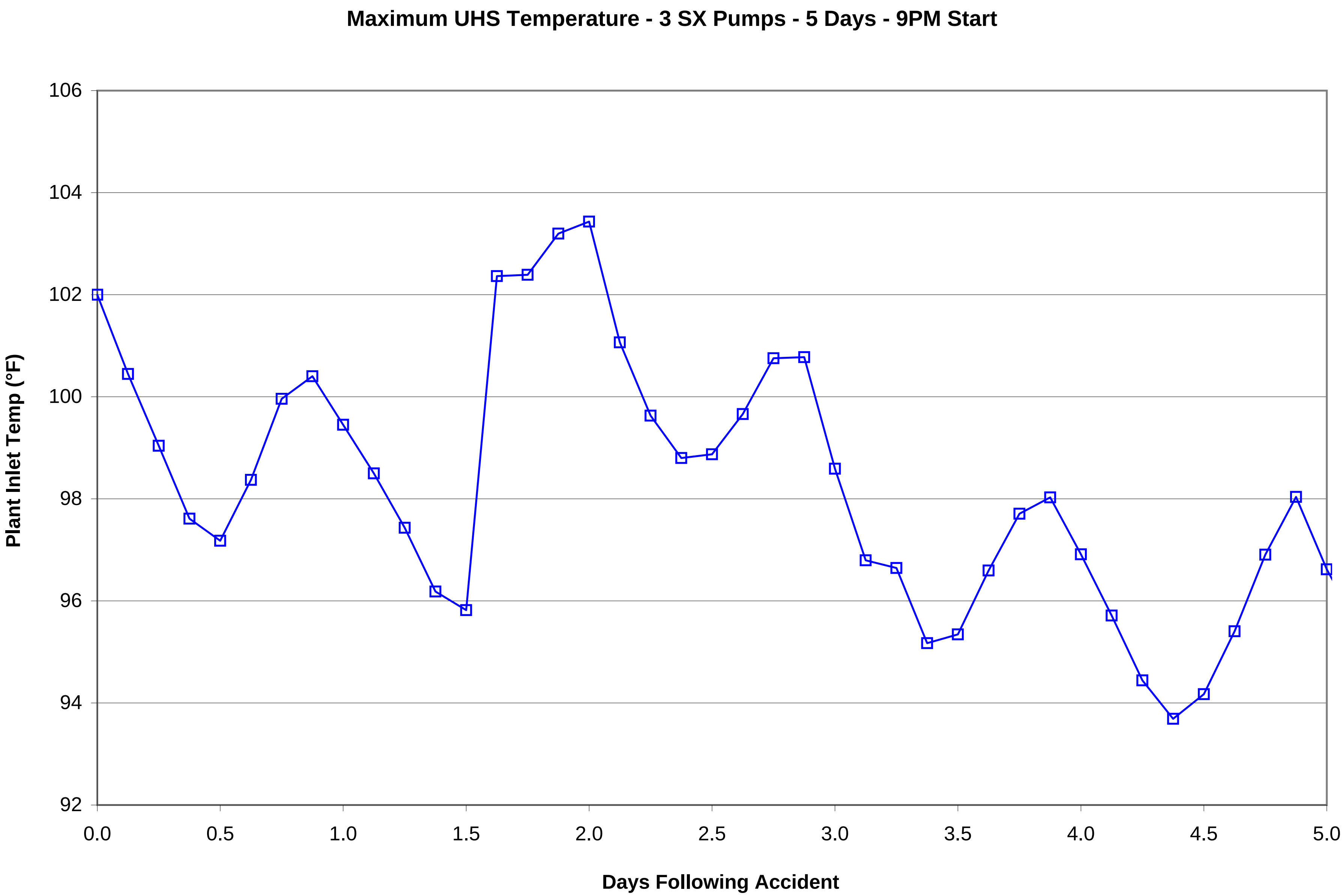

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 6AM Start
106
104
102
100
98
96
94
92
Plant Inlet Temp (°F)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 3 SX Pumps - 5 Days - 9AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

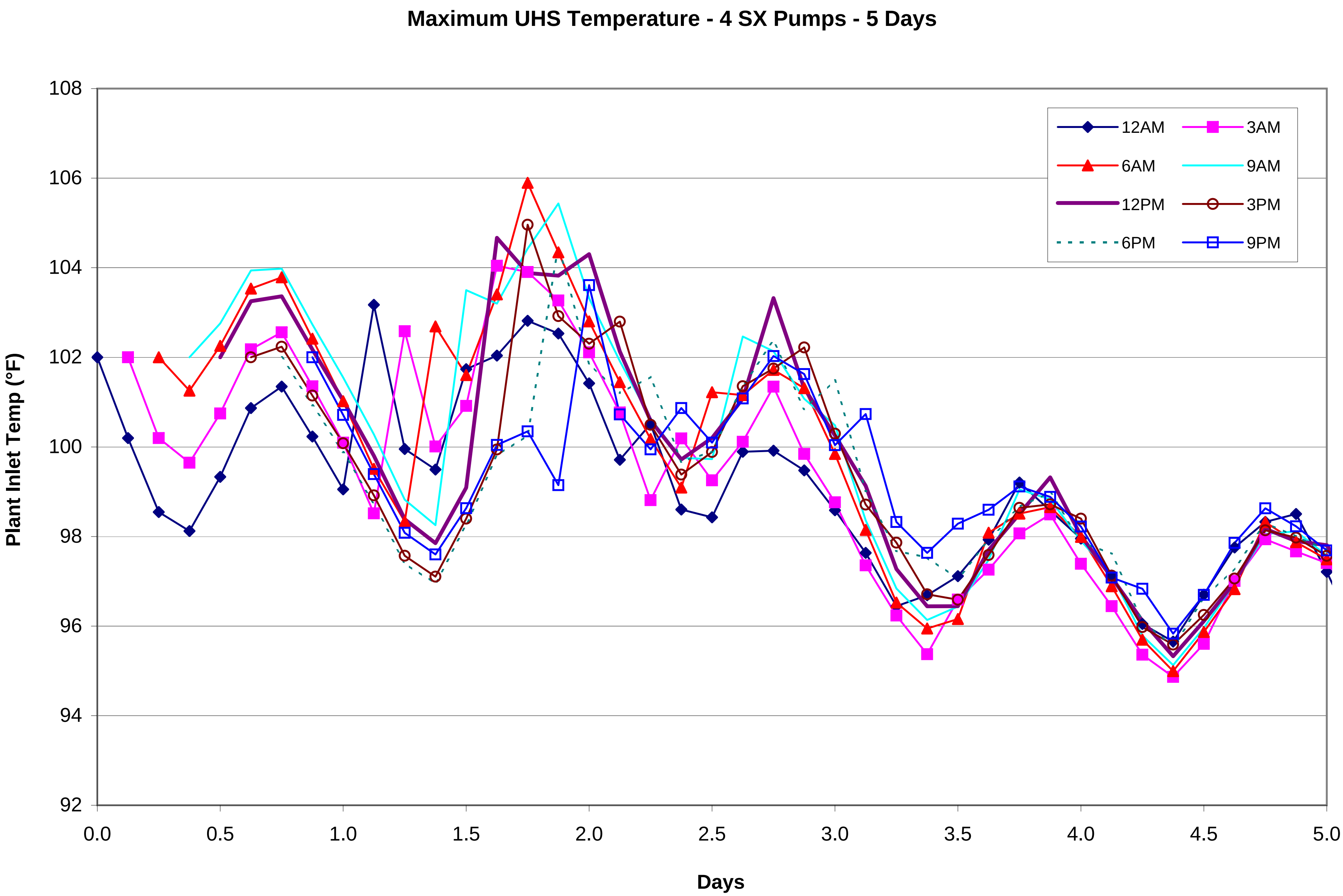

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 12PM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

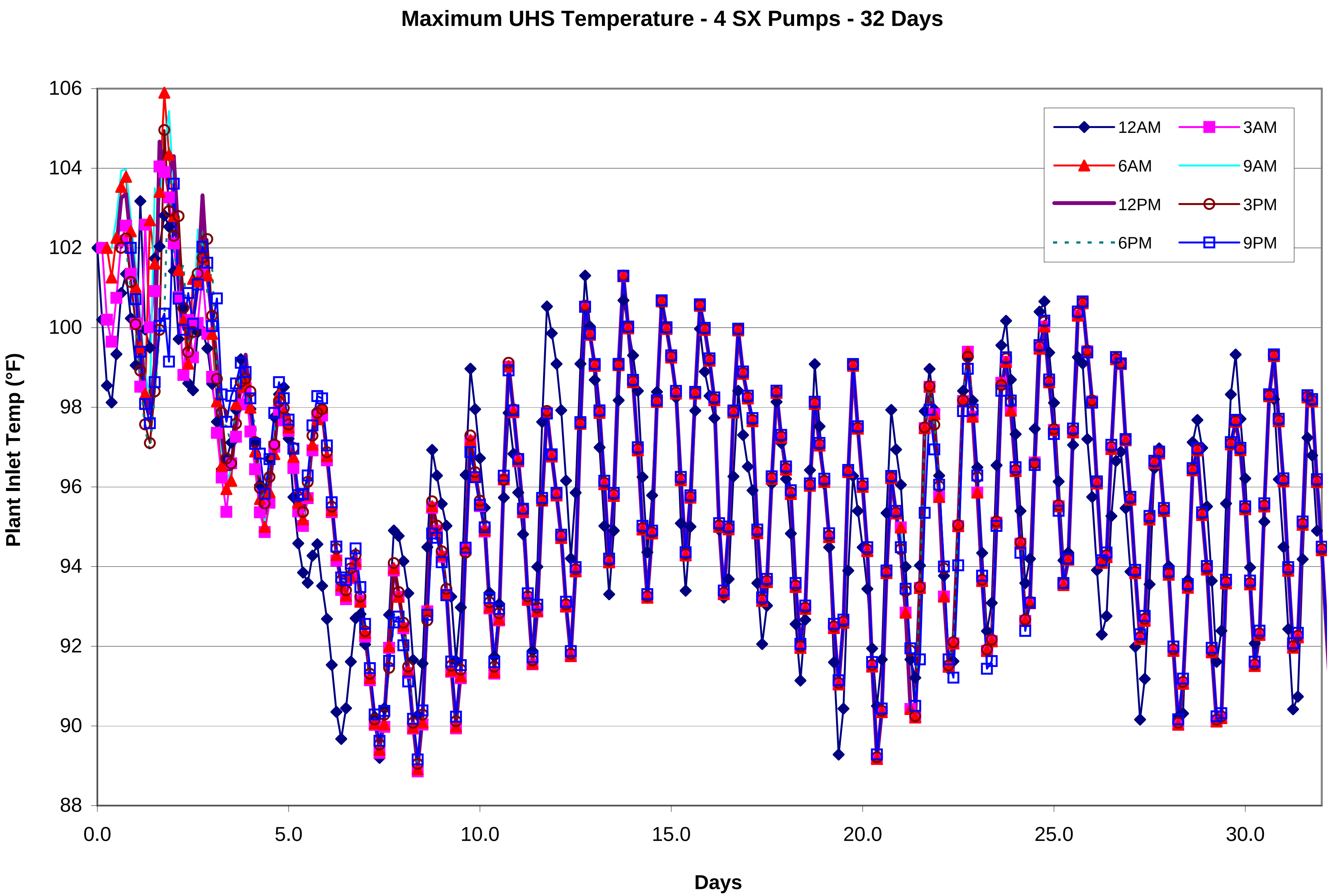

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 3PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

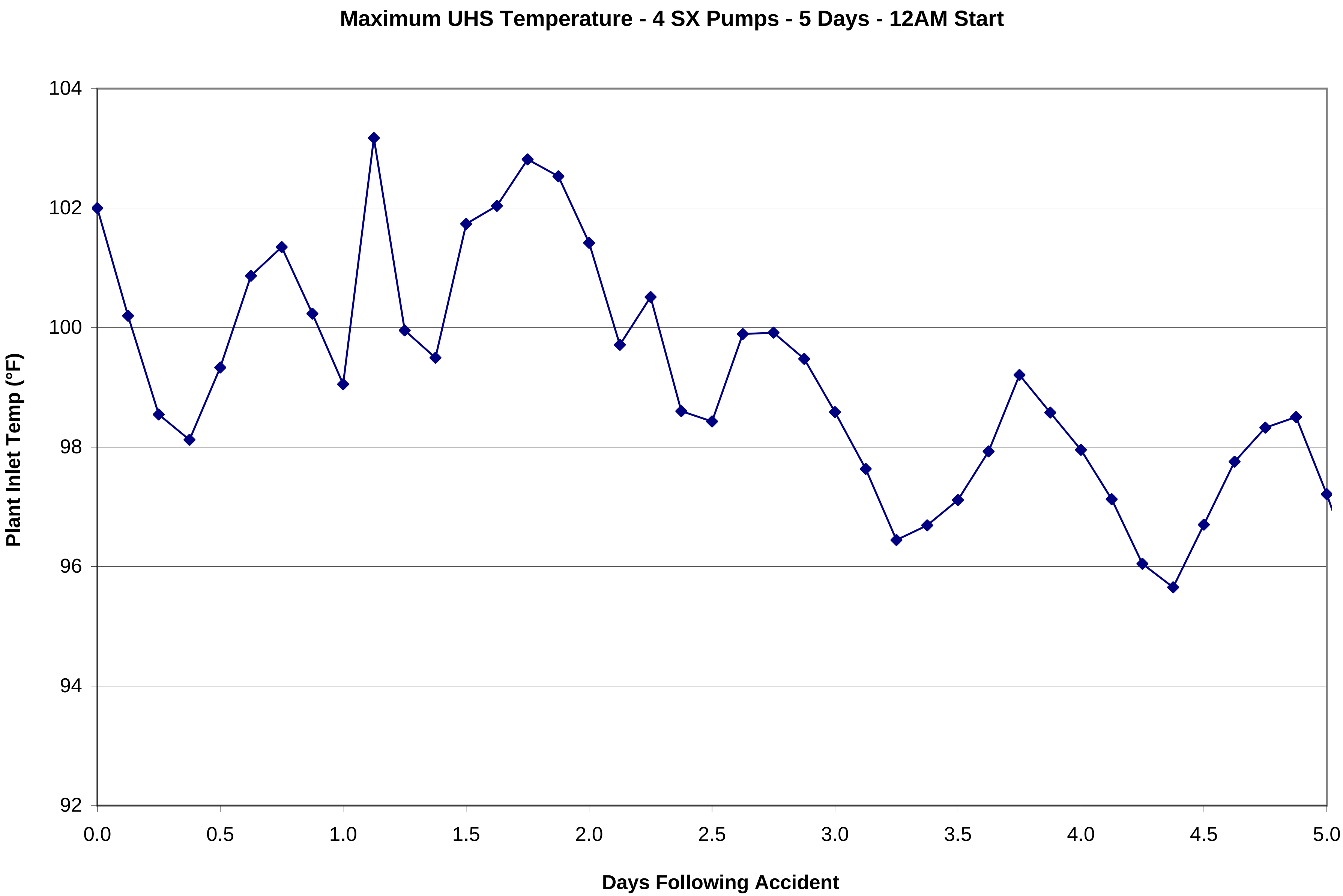

Maximum UHS Temperature - 3 SX Pumps - 5 Days - 6PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

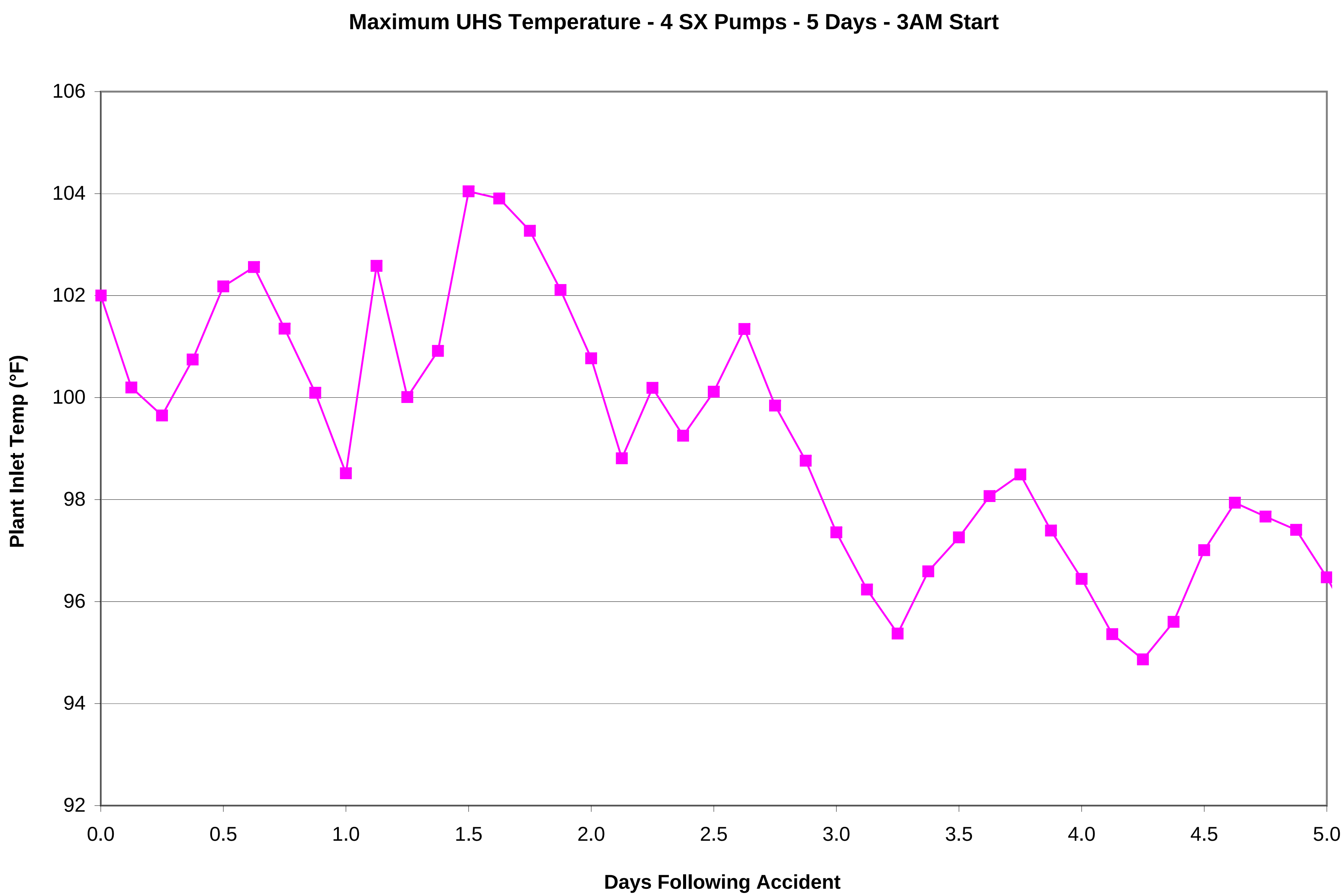


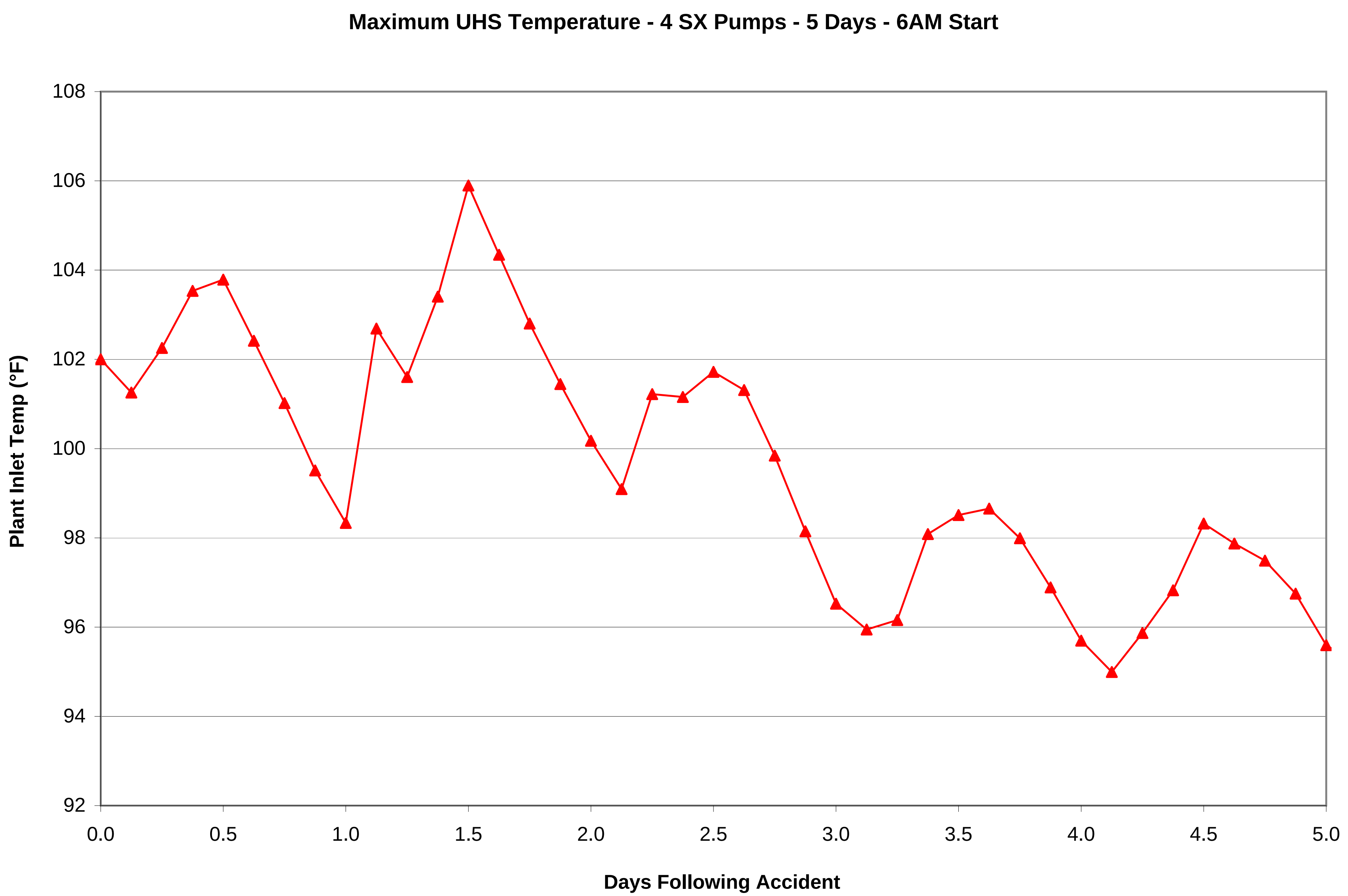
Maximum UHS Temperature - 3 SX Pumps - 5 Days - 9PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

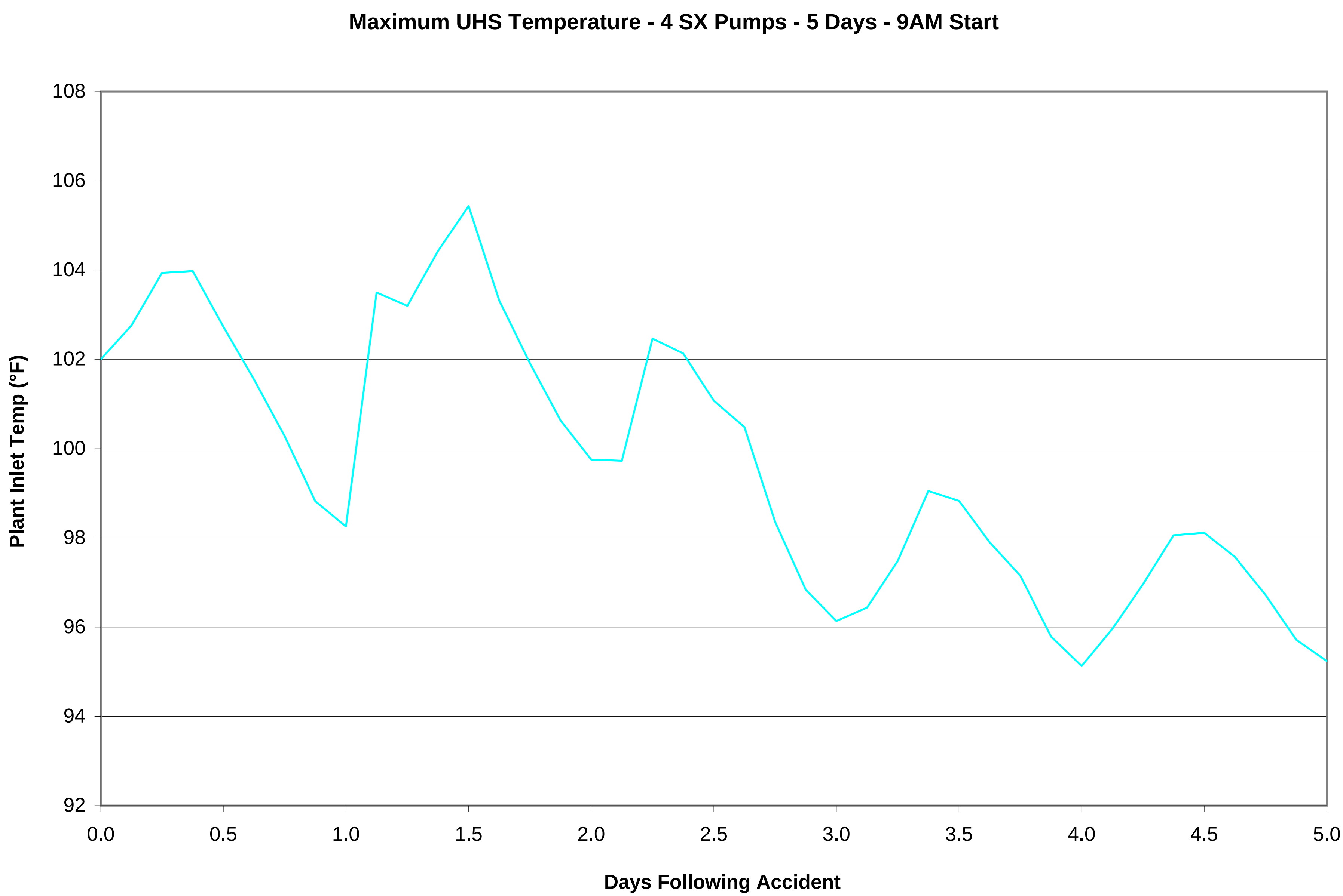

Maximum UHS Temperature - 4 SX Pumps - 5 Days
Plant Inlet Temp (°F)
Days
108
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM

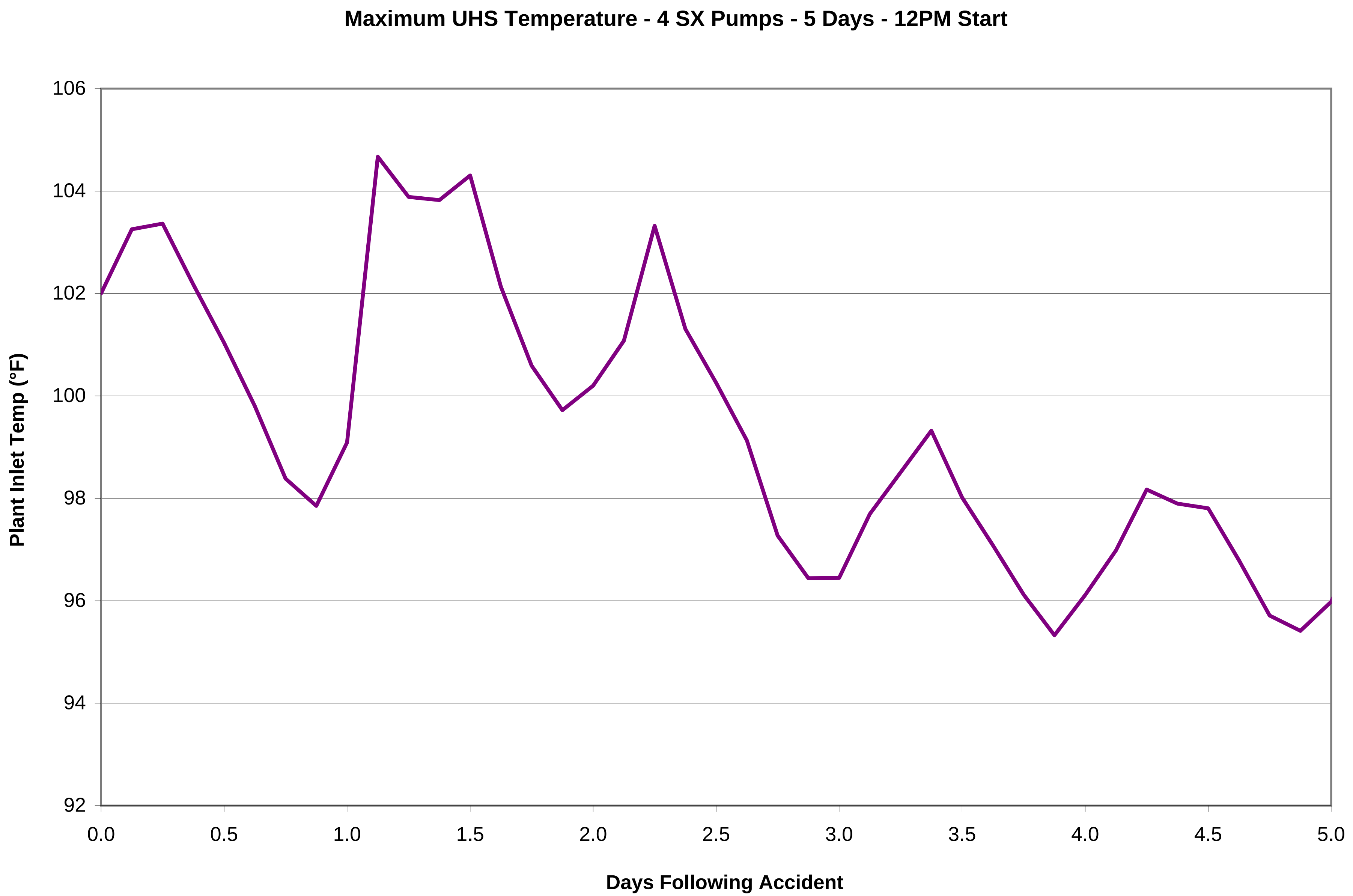

Maximum UHS Temperature - 4 SX Pumps - 32 Days
Plant Inlet Temp (°F)
Days
106
104
102
100
98
96
94
92
90
88
0.0
5.0
10.0
15.0
20.0
25.0
30.0
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM

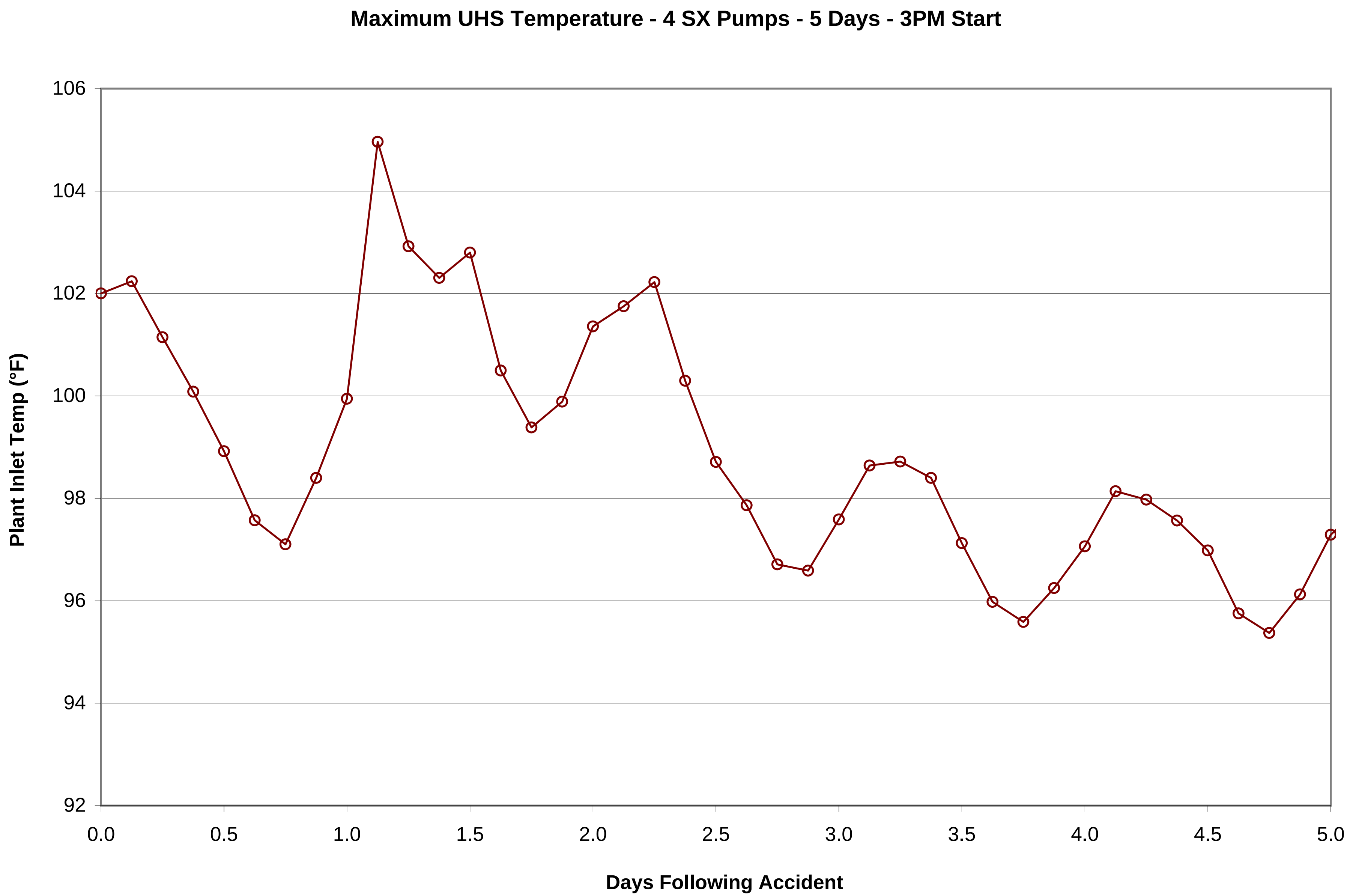

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 12AM Start
Plant Inlet Temp (°F)
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

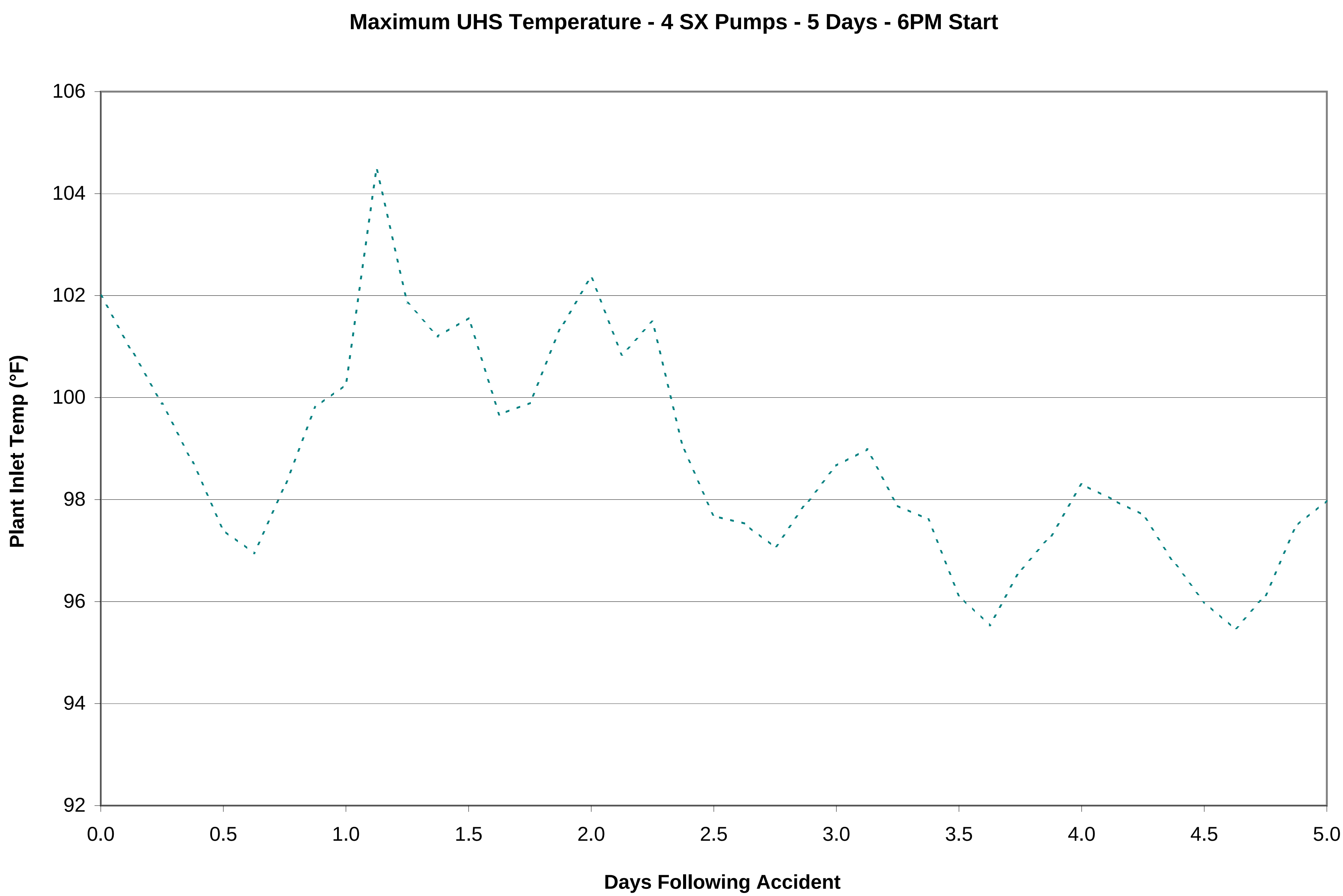

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 3AM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

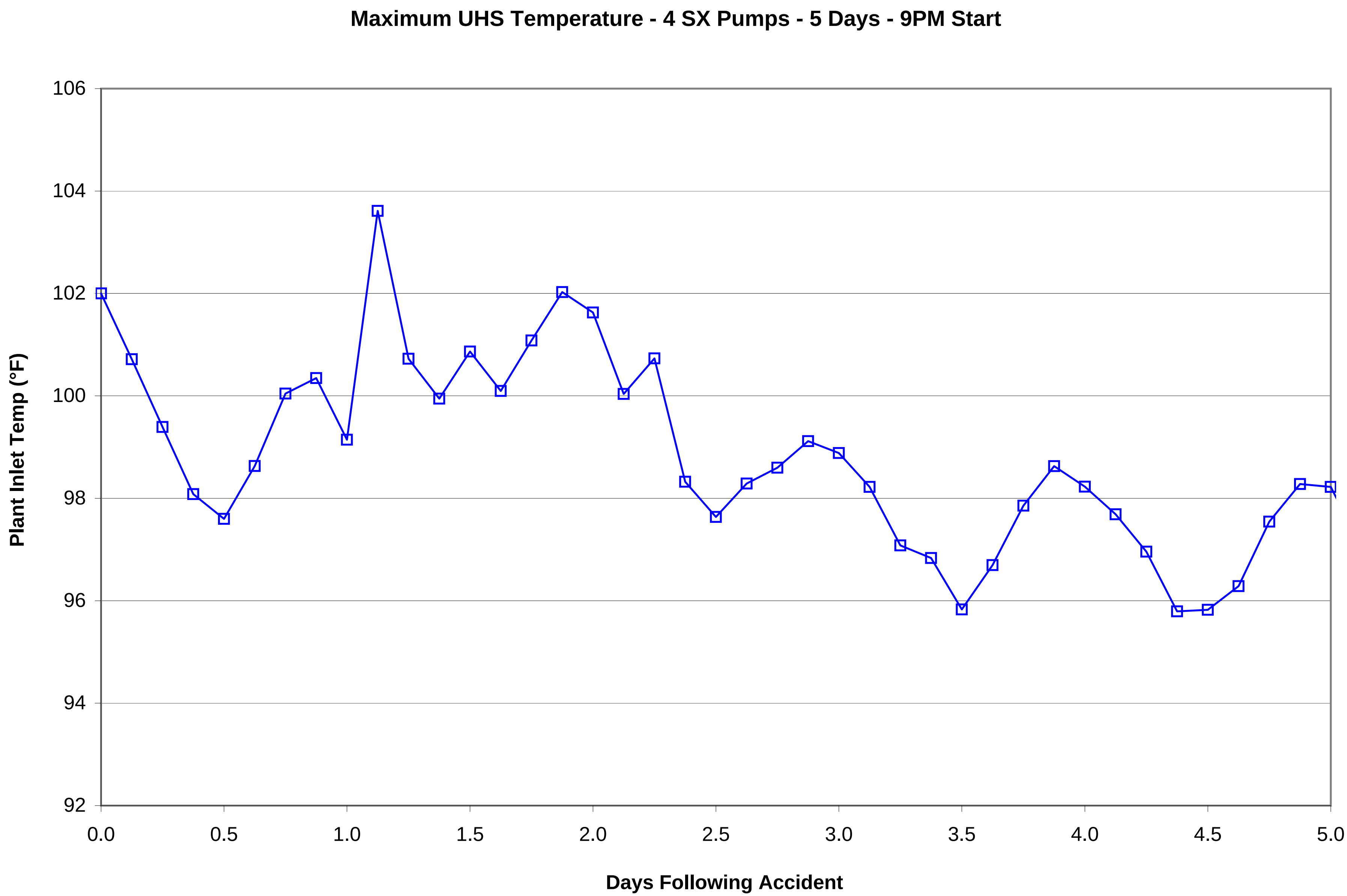

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 6AM Start
Plant Inlet Temp (°F)
108
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

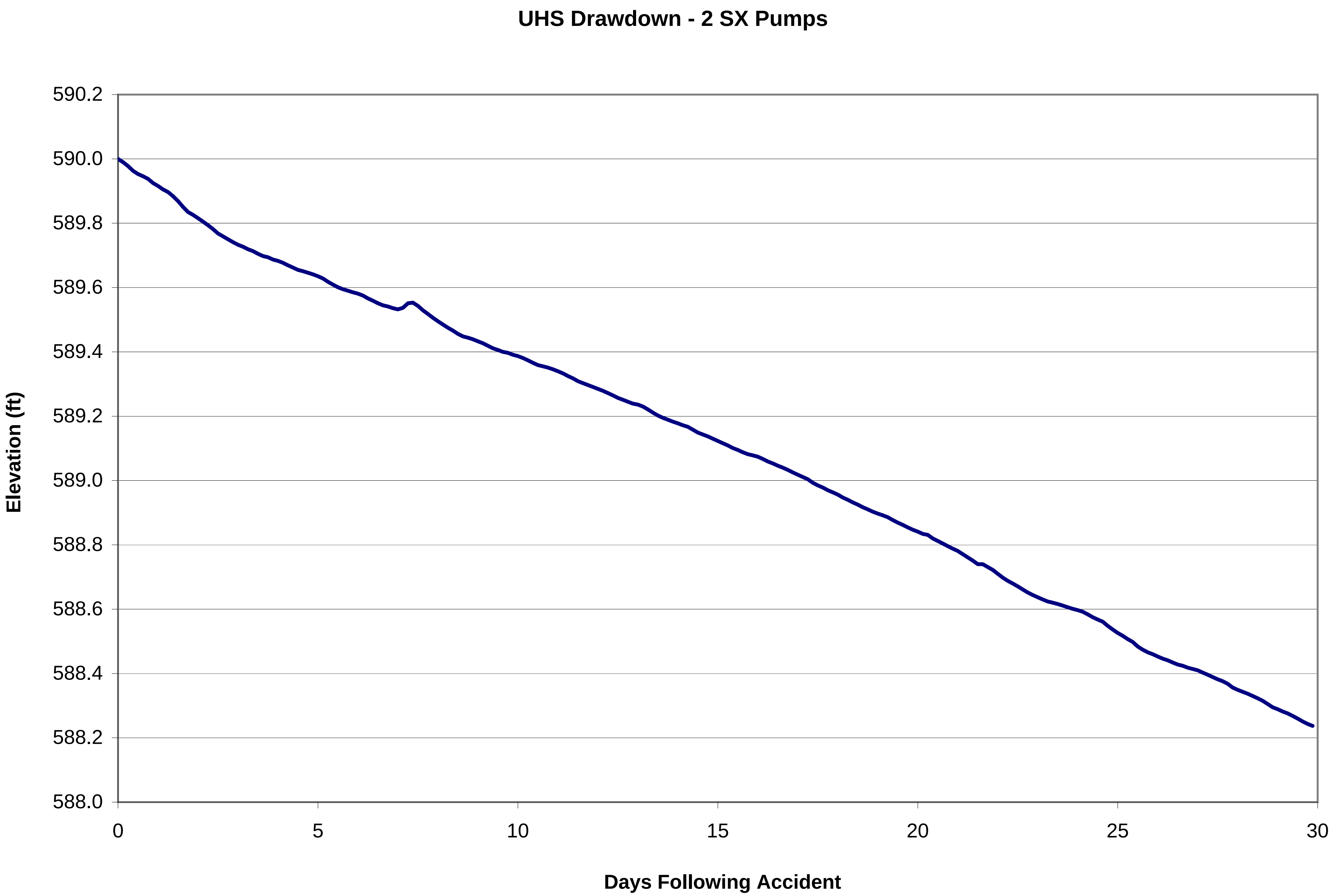

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 9AM Start
Plant Inlet Temp (°F)
108
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

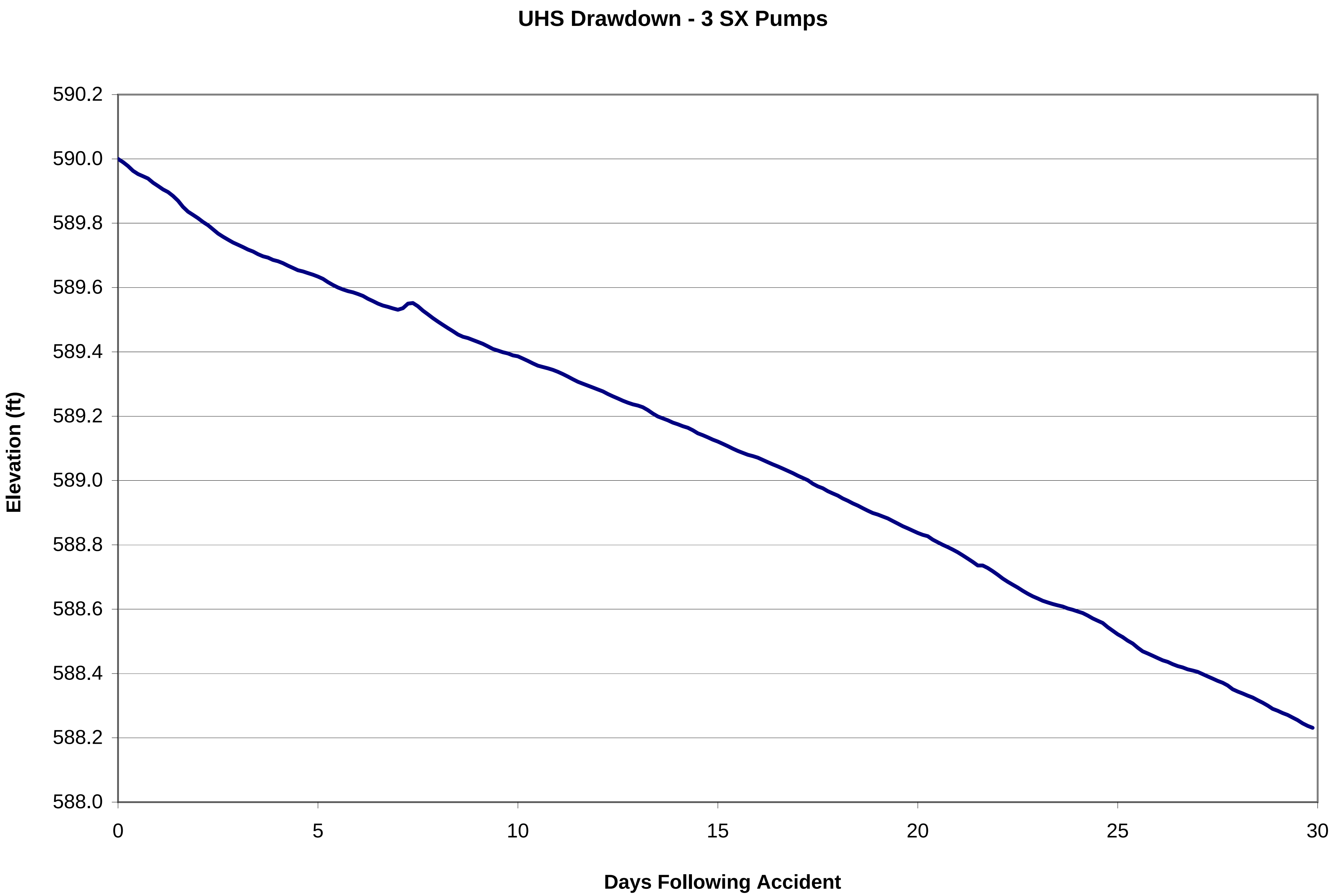

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 12PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident

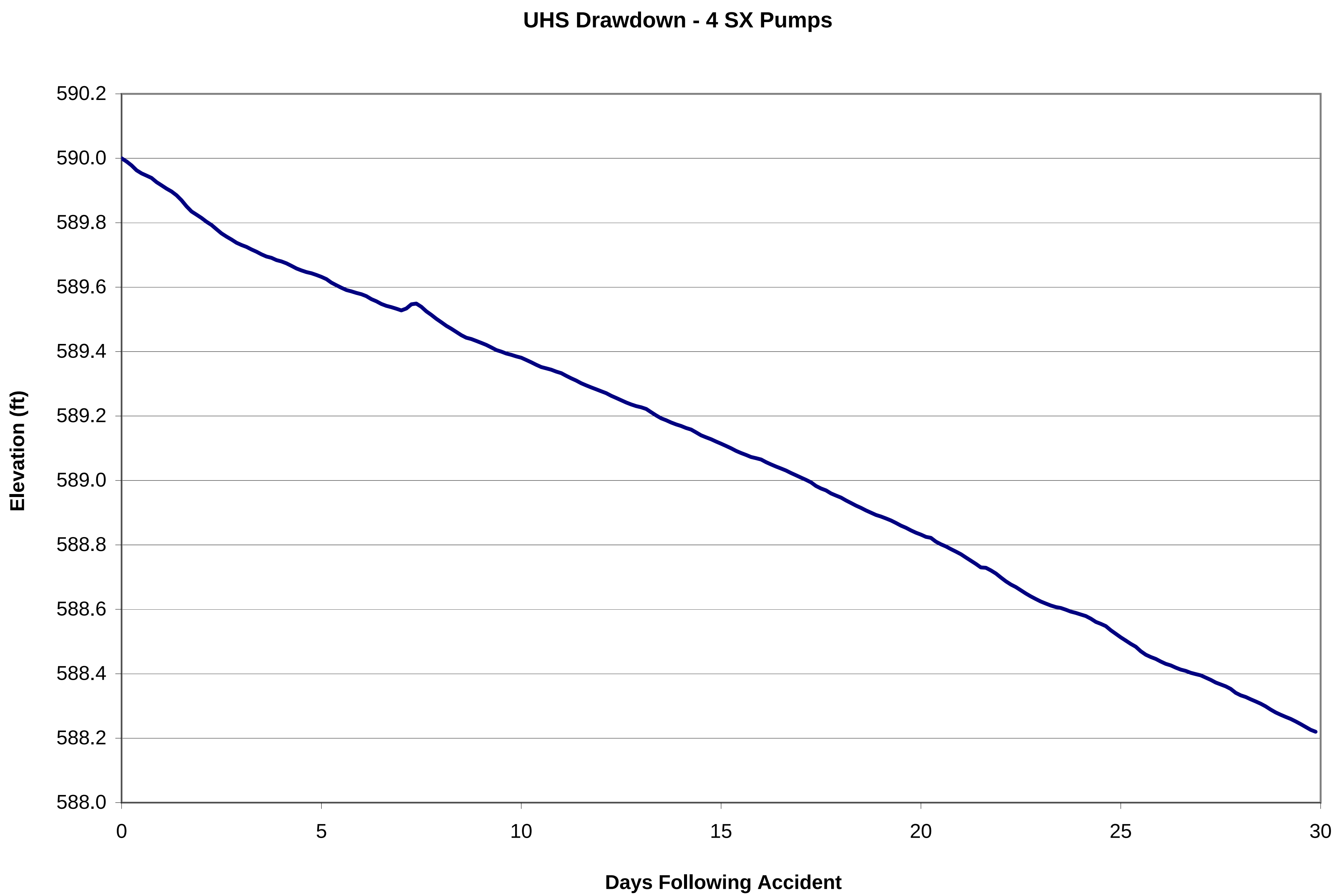

Maximum UHS Temperature - 4 SX Pumps - 5 Days - 3PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 4 SX Pumps - 5 Days - 6PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


Maximum UHS Temperature - 4 SX Pumps - 5 Days - 9PM Start
Plant Inlet Temp (°F)
106
104
102
100
98
96
94
92
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Days Following Accident


UHS Drawdown - 2 SX Pumps
590.2
590.0
589.8
589.6
589.4
589.2
589.0
588.8
588.6
588.4
588.2
588.0
Elevation (ft)
0
5
10
15
20
25
30
Days Following Accident


UHS Drawdown - 3 SX Pumps
Elevation (ft)
590.2
590.0
589.8
589.6
589.4
589.2
589.0
588.8
588.6
588.4
588.2
588.0
0
5
10
15
20
25
30
Days Following Accident


UHS Drawdown - 4 SX Pumps
Elevation (ft)
590.2
590.0
589.8
589.6
589.4
589.2
589.0
588.8
588.6
588.4
588.2
588.0
0
5
10
15
20
25
30
Days Following Accident

Attachment F

Electronic Files List

(Additional electronic files are included with Attachments A and B)

2 SX Pump Cases

Name	Size	Type	Date Modified
Case 2_3AMRhl.dat	6 KB	DAT File	4/25/2014 4:35 PM
Case 2_3PMRhl.dat	6 KB	DAT File	4/28/2014 1:51 PM
Case 2_6AMRhl.dat	6 KB	DAT File	4/28/2014 11:18 AM
Case 2_6PMRhl.dat	6 KB	DAT File	4/28/2014 2:59 PM
Case 2_9AMRhl.dat	6 KB	DAT File	4/28/2014 11:20 AM
Case 2_9PMRhl.dat	6 KB	DAT File	4/28/2014 3:25 PM
Case 2_12AMRhl.dat	6 KB	DAT File	4/28/2014 11:05 AM
Case 2_12PMRhl.dat	6 KB	DAT File	4/28/2014 11:23 AM
Case 2_evap.dat	6 KB	DAT File	5/16/2014 1:11 PM
Case 2_3AMRhl.out	89 KB	OUT File	5/27/2014 3:23 PM
Case 2_3PMRhl.out	89 KB	OUT File	5/27/2014 3:25 PM
Case 2_6AMRhl.out	89 KB	OUT File	5/27/2014 3:24 PM
Case 2_6PMRhl.out	89 KB	OUT File	5/27/2014 3:25 PM
Case 2_9AMRhl.out	89 KB	OUT File	5/27/2014 3:24 PM
Case 2_9PMRhl.out	89 KB	OUT File	5/27/2014 3:26 PM
Case 2_12AMRhl.out	89 KB	OUT File	5/27/2014 3:14 PM
Case 2_12PMRhl.out	89 KB	OUT File	5/27/2014 3:25 PM
Case 2_evap.out	88 KB	OUT File	5/27/2014 4:40 PM
Case 2_3AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:23 PM
Case 2_3PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:25 PM
Case 2_6AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:24 PM
Case 2_6PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:25 PM
Case 2_9AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:24 PM
Case 2_9PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:26 PM
Case 2_12AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:14 PM
Case 2_12PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:25 PM
Case 2_evap.pltX	18 KB	PLTX File	5/27/2014 4:40 PM

3 SX Pump Cases

Name	Size	Type	Date Modified
Case 3_3AMRhl3.dat	6 KB	DAT File	5/28/2014 9:15 AM
Case 3_3AMRhl.dat	6 KB	DAT File	4/22/2014 2:20 PM
Case 3_3PMRhl.dat	6 KB	DAT File	4/22/2014 4:24 PM
Case 3_6AMRhl.dat	6 KB	DAT File	4/22/2014 2:26 PM
Case 3_6PMRhl.dat	6 KB	DAT File	4/22/2014 4:26 PM
Case 3_9AMRhl.dat	6 KB	DAT File	4/22/2014 3:51 PM
Case 3_9PMRhl.dat	6 KB	DAT File	4/23/2014 9:57 AM
Case 3_12AMRhl.dat	6 KB	DAT File	4/22/2014 2:23 PM
Case 3_12PMRhl.dat	6 KB	DAT File	4/22/2014 3:54 PM
Case 3_evap.dat	6 KB	DAT File	5/16/2014 1:11 PM
Case 3_3AMRhl3.out	89 KB	OUT File	5/28/2014 9:20 AM
Case 3_3AMRhl.out	89 KB	OUT File	5/27/2014 3:30 PM
Case 3_3PMRhl.out	89 KB	OUT File	5/27/2014 3:40 PM
Case 3_6AMRhl.out	89 KB	OUT File	5/27/2014 3:30 PM
Case 3_6PMRhl.out	89 KB	OUT File	5/27/2014 3:41 PM
Case 3_9AMRhl.out	89 KB	OUT File	5/27/2014 3:39 PM
Case 3_9PMRhl.out	89 KB	OUT File	5/27/2014 3:42 PM
Case 3_12AMRhl.out	89 KB	OUT File	5/27/2014 3:29 PM
Case 3_12PMRhl.out	89 KB	OUT File	5/27/2014 3:39 PM
Case 3_evap.out	88 KB	OUT File	5/27/2014 4:39 PM
Case 3_3AMRhl3.pltX	16 KB	PLTX File	5/28/2014 9:20 AM
Case 3_3AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:30 PM
Case 3_3PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:40 PM
Case 3_6AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:30 PM
Case 3_6PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:41 PM
Case 3_9AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:39 PM
Case 3_9PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:42 PM
Case 3_12AMRhl.pltX	16 KB	PLTX File	5/27/2014 3:29 PM
Case 3_12PMRhl.pltX	16 KB	PLTX File	5/27/2014 3:39 PM
Case 3_evap.pltX	18 KB	PLTX File	5/27/2014 4:39 PM

4 SX Pump Cases

Name	Size	Type	Date Modified
Case 4_3AMRhl.dat	6 KB	DAT File	4/23/2014 1:32 PM
Case 4_3PMRhl.dat	6 KB	DAT File	4/23/2014 3:46 PM
Case 4_6AMR104.dat	6 KB	DAT File	5/15/2014 11:21 AM
Case 4_6AMRhl.dat	6 KB	DAT File	4/23/2014 1:35 PM
Case 4_6PMRhl.dat	6 KB	DAT File	4/23/2014 3:48 PM
Case 4_9AMRhl.dat	6 KB	DAT File	4/23/2014 1:38 PM
Case 4_9PMRhl.dat	6 KB	DAT File	4/23/2014 3:50 PM
Case 4_12AMRhl.dat	6 KB	DAT File	4/23/2014 1:26 PM
Case 4_12PMRhl.dat	6 KB	DAT File	4/23/2014 1:40 PM
Case 4_evap.dat	6 KB	DAT File	5/16/2014 1:12 PM
Case 4_3AMRhl.out	89 KB	OUT File	5/27/2014 4:32 PM
Case 4_3PMRhl.out	89 KB	OUT File	5/27/2014 4:34 PM
Case 4_6AMR104.out	89 KB	OUT File	5/27/2014 4:35 PM
Case 4_6AMRhl.out	89 KB	OUT File	5/27/2014 4:32 PM
Case 4_6PMRhl.out	89 KB	OUT File	5/27/2014 4:34 PM
Case 4_9AMRhl.out	89 KB	OUT File	5/27/2014 4:32 PM
Case 4_9PMRhl.out	89 KB	OUT File	5/27/2014 4:34 PM
Case 4_12AMRhl.out	89 KB	OUT File	5/27/2014 4:31 PM
Case 4_12PMRhl.out	89 KB	OUT File	5/27/2014 4:34 PM
Case 4_evap.out	88 KB	OUT File	5/27/2014 4:38 PM
Case 4_3AMRhl.pltX	15 KB	PLTX File	5/27/2014 4:32 PM
Case 4_3PMRhl.pltX	15 KB	PLTX File	5/27/2014 4:34 PM
Case 4_6AMR104.pltX	15 KB	PLTX File	5/27/2014 4:35 PM
Case 4_6AMRhl.pltX	15 KB	PLTX File	5/27/2014 4:32 PM
Case 4_6PMRhl.pltX	15 KB	PLTX File	5/27/2014 4:34 PM
Case 4_9AMRhl.pltX	15 KB	PLTX File	5/27/2014 4:32 PM
Case 4_9PMRhl.pltX	15 KB	PLTX File	5/27/2014 4:34 PM
Case 4_12AMRhl.pltX	15 KB	PLTX File	5/27/2014 4:31 PM
Case 4_12PMRhl.pltX	15 KB	PLTX File	5/27/2014 4:34 PM
Case 4_evap.pltX	18 KB	PLTX File	5/27/2014 4:38 PM

Attachment 6

Vendor Data Sheet for the Emergency Diesel Generator (EDG) Jacket Water Coolers

P-20003 August 19, 1976

COOLER - OIL ☐ COOLER - WATER ☒
INTERCLR ☐ AFTERCLR ☐

UNIT TYPE

Make American Standard Model 2-23102 CPK Series TEMA Type AEW

Customer Commonwealth Edison Location

DESIGN & PERFORMANCE DATA for ONE UNIT

	Shell Side	Tube Side
Fluid Circulated	Jacket Water	Water
	455 GPM	1641 GPM
Total Fluid Entering	222,072 #/Hr.	815,898 #/Hr.
Vapors		
Non-Condensables		
Fluid Vaporized or Condensed		
Molecular Wt. - Vapors		
Specific Heat - Liquids	B.T.U./Lb.	B.T.U./Lb.
Specific Heat - Vapors	B.T.U./Lb.	B.T.U./Lb.
Temperature In	170 °F	100 °F
Temperature Out	115 °F	115 °F
Operating Pressure Absolute ☐ Gage ☐	p.s.i.	p.s.i.
No. of Passes	One	Two
Velocity	f.p.s.	7.5 f.p.s.
Pressure Drop	11# Total p.s.i.	8# Total p.s.i.
Fouling Factor	.001	.0015

Heat Exchanged 12,214,000 B.T.U./Hr. L.M.T.D. (Corrected) 29.56

Transfer Surface 1792 Total Sq. Ft.

Transfer Rate - Service 230.5 Clean 639.4

CONSTRUCTION

	Shell Side	Tube Side
Design Pressure	150 p.s.i.g.	125 p.s.i.g.
Test Pressure	225 p.s.i.g.	188 p.s.i.g.
Design Temp.	225 °F	225 °F

TUBES — Mat'l. 90/10 CuNi No. 644 O.D. 5/8 B.W.G. 18 Leng. 102"

TUBES — Pitch Tri ☒ Sq. ☐ Fins. ☐ Mat'l. 13/16" Pitch Type Bundle - Removable ☒ Fixed ☐

SHELL — Mat'l. Steel A106 Diam. 24" HEADS — Mat'l.

TUBE SHEETS — Stationary: Mat'l. Rolled Naval Brass Thickness

TUBE SHEETS — Floating: Mat'l. Rolled Naval Brass Thickness

BAFFLES — Cross: Mat'l. Steel Spacing 6" Thickness

CHANNELS ☒ BONNETS ☐ C. Steel

CONNECTIONS — Shell In 6" Out 6" Series 150# ANSI

Tube In 10" Out 10" Series 150# ANSI

CORROSION ALLOWANCE — Shell Side

TIE RODS — Mat'l. No. Dia. SPACERS —

OVERALL LENGTH 136 1/8" Weight (empty) (full)

CODE REQUIREMENTS ASME ☒ TEMA - B ☐ - C ☒ - R ☐ C-B SD-121 ☐ SD-121-1 ☒ SC-23-1 ☒

SD-121-2

REMARKS ASME Section III, Class 3
Coolers stacked nozzle-to-nozzle Stacking cradles included
Counter current flow must exist between shells

Calculation BRW-99-0306-M
Revision 1
Attachment A
Page A1 of A1 (FINAL)

COOPER-BE

DRAWN	CHECKED

REV. NO.	REVISION	DATE
ISSUE		

SHEET OF SHEETS

1018 PRINTED IN U.S.A.

Attachment 7

Vendor Data Sheet for the Main Control Room Chiller Condenser

UNIT DATA

Equipment No.	OW001CA/CB
Equipment Name	Control Room Refrigeration Unit Condenser
Manufacturer	MSD/Carrier
Model No.	19EA7747DB
Refrigerant type	R-114

PHYSICAL DATA

DATA	SUPPLIED
Type of tubes	Skip Finned
No. of tube passes	2
Total eff. tube surface (sq. ft.)	3360 ft^2
Tube water velocity (fpm)	6.4 ft/Sec
Tube material	ASTM Alloy 706 ASME SB359

REFERENCES

Purchase specification	L-2778
Vendor drawing	A-12
Other	

CONDENSER DATA

WATER COOLED

DATA	SPECIFIED	SUPPLIED
Condenser pressure (psig)	-	45.83
Condenser temp (°F)	-	116.9
Entering temp (°F)	(Max/Min) 100/35	100.0
Leaving temp (°F)		107.7
Pressure drop (psig)	20	7.9
Flow rate (gpm)	950	950
Refrig. suction temp (°F)	-	38°F
Capacity (BtuH)	-	3,687,000
Fouling factor	0.0015	0.0015

R

S&L-MEHTA-01-17-90 PAGE 46

RELEASE RECORD

Rev	Prepared	Reviewed	Approved
0	[signature]	[signature]	[signature] 10-20-89
1	[signature]	[signature]	[signature] 12/14/89

CONDENSER DATA SHEET

Commonwealth Edison Company

Station Braidwood Unit 1&2

SARGENT & LUNDY ENGINEERS

Page 1 of 1

M3060 002 09-89