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Technical Evaluation Report Related to the Exelon Generation Company, LLC, License Amendment Request to Braidwood Station, Units 1 and 2, Technical Specification 3.7.9, “Ultimate Heat Sink.”
Docket Nos. STN 50-456 and STN 50-457

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CONTENTS

Page

TABLES

1 BACKGROUND

On August 19, 2014, Exelon Generating Company, LLC (the licensee) requested an amendment to Facility Operating License Nos. NPF–72 and NPF–77 for Braidwood Station, Units 1 and 2, to allow continued operation with a higher measured temperature limit in the ultimate heat sink (UHS) pond of 102 °F (EGC, 2014a). The UHS provides a heat sink for the removal of 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 use 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.

The limit on the UHS pond temperature is meant to restrict the initial UHS temperature such that the maximum temperature of the cooling water supplied to the plant safety systems from the UHS experienced during the UHS design basis event would not result in plant equipment cooled by the UHS to operate outside design limits. If the temperature of the cooling water supplied by the main cooling reservoir exceeds the licensee's proposed 102 °F limit in the technical specification (TS), then both units would be placed in Mode 3 within 6 hours and Mode 5 within 36 hours. The licensee has carried out analyses and evaluations to demonstrate that the plant's safety-related equipment will maintain their design functions at the proposed higher temperature. The proposed measured temperature limit of 102 °F would essentially become the starting temperature in the UHS pond should its use become necessary because of loss of the main cooling reservoir. Temperature would rise from this starting temperature as a function of the amount of heat added to the UHS from the shutdown of the two reactor units, as well as heat gained from the environment during the course of the day.

The UHS is a nearly rectangular excavation entirely within the main cooling reservoir. It would provide cooling water and nonessential service water in the event of the loss of water supply from the main cooling reservoir, which provides circulating water for the normal operation of the plant. The UHS is estimated to have a total surface area when full of 95.6 acres and total volume of 555 acre-ft.

For the Braidwood plant, the maximum UHS heat load occurs as a result of the design basis accident (DBA) in which one of the two units is being shut down following a full power run and the other unit is in a cool-down following a DBA loss-of-coolant accident (LOCA) with an accompanying loss of offsite power (LOOP). The analyzed condition is consistent with the requirements of Regulatory Guide (RG) 1.27 and places a significant heat load on the UHS.

The UHS pond is designed so that a failure of any of the Category II dikes containing the main reservoir would still leave a volume of water adequate for safe shutdown of the plant, as well as emergency makeup water for the spent fuel pool and fire protection. The UHS pond is designed to remain in operation following the safe shutdown earthquake and the probable maximum flood.

The SX provides cooling to safety related components including the Component CC systems. SX would take water from the UHS pond during the DBA (i.e., the event that would result in the maximum heat load on the UHS), pump it through the cooled components, and back to the UHS. There are four SX pumps, two per reactor unit that would supply the necessary water.

The licensee provided a technical justification for the 102 °F temperature limit based on computer models, using heat rejected to the pond, flow rates, and meteorological data, to calculate highest temperature being returned from the pond, as well as water use for a minimum of 30 days. The licensee has relied on more-up-to-date meteorological data, and at times on reduced margin (with respect to the specifications) when compared to their previous calculations.

This technical evaluation report (TER) provides a review of the licensee's analyses, including the August 19, 2014, license amendment request (EGC, 2014a), and their responses to several rounds of requests for additional information (RAIs) (NRC, 2015a,b,c,d; EGC, 2016, 2015a,b,c,d). The Southwest Research Institute® (SwRI®) staff carried out an audit-type review and focused on the determination of peak return water temperature from the UHS pond with at least 30-day water supply (EGC, 2014a), and the adequacy of plant equipment using cooling water at an increased temperature. Furthermore, SwRI staff has also performed limited confirmatory calculations with its own models to determine the adequacy of the licensee's performance analyses and meteorological data used to determine the peak return temperature from the UHS pond. But SwRI relied on the information supplied by the licensee for accuracy, including heat rejection and flow rates to the pond, the dimensions of the pond, water level and sedimentation, meteorological data, the acceptability of the stated temperature limit for water returned from the pond, and the information related to potential effects of the higher measured-UHS-temperature limit on equipment credited in accident analyses.

2 SUMMARY OF LICENSEE'S LAR AND SUPPORTING ANALYSES

This section presents the licensee's evaluation of UHS pond performance, UHS–cooled equipment performance, UHS net positive suction head impacts, and UHS-impacted accident analyses in the August 19, 2014, License Amendment Request (LAR) to Braidwood Station, Units 1 and 2, Technical Specification 3.7.9 (EGC, 2014a), and in several other documents related to RAI requests. The SwRI evaluation of the technical analysis and confirmatory analysis are presented in Section 4.

2.1 Licensee's Evaluation of UHS Pond Performance

The licensee calculated temperature returning from the UHS pond using a one-dimensional computer model, LAKET-PC (EGC, 2014b). The surface area and volume are reduced to "effective" values; however, to account for nonideal behavior of circulation in the pond to values of 78.7 acres and 457 acre-ft for area and volume, respectively. The effective surface area and volume represent 82.3 percent of the actual surface area and volume, respectively, of the pond.

The analysis of UHS pond performance for the initial licensing of the Braidwood plant specified a limit on the average temperature in the UHS pond of 98 °F under normal operating conditions, which was used for the initial technical specifications (EGC, 2014a, Page 3). A subsequent amendment issued by the U.S. Nuclear Regulatory Commission (NRC) on June 13, 2000, increased the temperature limit to 100 °F. The current LAR proposes to specify a temperature limit of 102 °F to take into account recently experienced meteorological conditions that resulted in high air temperature and humidity and low wind speed during the period July 4, 2012 through July 6, 2012. These meteorological conditions are beyond those used in the previous analyses used to set the current technical specification (EGC, 2014a). Peak return temperatures calculated by the licensee for various operating states of the plants (i.e., number of pumps in operation) are shown in Table 1. The most adverse times for the start of the DBA and the time period of data yielding the highest temperatures are shown in Table 2.

The pond was modeled as a series of segments of equal surface area and volume. Heat load from both units was provided. The pond volume and depth depended on the assumption of how much sediment had accumulated. The licensee assumed two cases for sedimentation: (i) no sedimentation and (ii) a fixed amount, 3 inches, of sediment uniformly spread over the pond (EGC, 2014c, Section 2.1.5, Part A, Page 6 of 19). Including sediment in the performance model displaces water in the pond, thereby reducing the available volume, but has only a small effect on return water temperature.

The licensee's LAKET-PC model used the Ryan and Harleman relationships for heat transfer with the environment (Ryan and Harleman, 1973). The UHS pond was modeled as strictly plug flow in discrete segments, each segment's length being equivalent to a 3-hour travel time. Hot water from the plant enters the first segment, exchanges heat with the environment, and then passes to the next segment. Water does not mix between segments. The number of segments depends on the flow rate through the pond, which in turn depends on the number of SX pumps (2, 3, or 4) in operation.

The licensee used their LAKET-PC code to determine the peak return water temperature in response to the plant heat load and the worst weather conditions, starting at the 102 °F temperature specified in the proposed technical specification. The same code was also used to determine 30-day water loss under the worst weather conditions for evaporation. This

Table 1: Peak Temperature Estimated by the Licensee With Different Number of Essential Service Water (SX) Pumps in Operation			
Number of SX Pumps	**Start Time of DBA**	**Travel Time Through Pond, Hr**	**Maximum Return Temperature, °F**
2	6 AM	48	103.7
3*	3 AM	36	105.2
4	6 AM	24	105.9
*Base case			

Table 2. Worst 24-Hr, 36-Hr, and 48-Hr Weather Periods Selected by the Licensee (Table 6-4 of the LAR)			
Start Time	**Worst 24-Hr Start Date**	**Worst 36-Hr Start Date**	**Worst 48-Hr Start Date**
12 AM	6/23/2009	7/6/2012	7/5/2012
3 AM	6/23/2009	7/6/2012	7/5/2012
6 AM	7/19/2011	7/6/2012	7/5/2012
9 AM	7/6/2012	6/22/2009	6/22/2009
12 PM	7/6/2012	6/22/2009	7/5/2012
3 PM	7/6/2012	6/22/2009	7/5/2012
6 PM	7/6/2012	7/5/2012	7/5/2012
9 PM	7/26/1999	7/5/2012	7/5/2012

calculation did not take into account any water added to the UHS pond through make-up flow or by rainfall during the 30-day period, but included a seepage rate out of the pond of 0.8 cubic feet per second (CFS).

Maximum return water temperature to the plant depended on the number of pumps in operation, and the starting time of the DBA. Table 1 shows the peak temperature for the 2, 3, or 4 SX pump cases, and the start times of the DBA that resulted in the maximum return temperature for each case.

The temperature calculation also included a 0.1 °F allowance to account for measurement uncertainty in temperature instruments, estimated to be 0.07 °F or less. This 0.1 °F correction would be subtracted from the 102 °F technical specification limit. The licensee calculated that the peak temperature of 105.2 °F would occur about 1.62 days after the start of the DBA for the base case of 3 SX pumps in operation (EGC, 2014a, Attachment 1, Figure 1).

The Braidwood LAR provides for a local measurement of SX temperature. For this, the high-precision temperature instruments are placed in the previously installed spare thermo-wells located adjacent to the currently installed instrumentation used to measure SX temperature. These instruments measure the temperature of the water that is flowing through the discharge piping of the SX pumps. Surveillance procedures direct that if an SX pump temperature exceeds 97 °F a high precision temperature instrument, with a stated measurement uncertainty of 0.07 °F, procured specifically for this application will be used to measure the thermo-well temperature.

The licensee states that the maximum number of SX pumps are expected to be in operation is three, and that a fourth SX pump could be started manually if needed for the unit undergoing a normal shutdown (EGC, 2014a, Attachment 1, Section 3.1, Page 4 of 25).

The limiting DBA is one unit with a post-LOCA and LOOP with the second unit undergoing a safe nonaccident shutdown. Heat that would have to be dissipated by the UHS pond following the DBA would come from containment heat removal from the reactor containment fan coolers (RCFCs), containment heat removal and reactor residual heat from the containment sumps, and Engineered Safety Features equipment.

2.2 Licensee's Evaluation of UHS-Cooled-Equipment Performance

The SX system provides cooling flow for the following safety-related equipment: (i) cubicle coolers, (ii) pump coolers, (iii) diesel engine coolers, (iv) component cooling heat exchangers, (v) reactor compartment fan coolers, and (vi) chiller condenser. The CC water system cools the following: (i) regenerative heat removal system, (ii) chemical and volume control system, (iii) reactor coolant system (RCS) and other process sampling coolers, and (iv) the spent fuel pool (SFP) cooling system.

The LAR contains analysis for different combinations of SX pumps operating and provides for a conservative bias in the calculated flow rates by not taking into account the increased head loss with increased numbers of pumps running on flow rate calculations. This provides a conservative bias towards a higher UHS heat input term.

As part of their analysis, the licensee performed a formal engineering evaluation to determine the plant's ability to continue to provide margin on all SX cooled equipment from the onset of the DBA event through the temperature peak of 105.2 °F and the subsequent decrease in temperature. The following equipment was evaluated for impact by the licensee.

- Cubicle coolers were evaluated at the maximum postulated post-accident value of 105.2 °F. All coolers had at least 10 percent margin between the calculated heat removed and the design heat load.

- Oil coolers were evaluated using the maximum postulated post-accident value of 105.2 °F. All coolers had at least 10 °F between the maximum oil temperature reached and the "limiting" oil temperature.

- Engine coolers for emergency diesel generators (EDGs) and auxiliary feed-water pumps were evaluated using the maximum postulated post-accident value of 105.2 °F. Both were identified as having greater than 5 °F margin between the maximum jacket water temperature reached and the jacket water high temperature alarm.

- Main control room (MCR) chiller condenser was evaluated using the maximum postulated post-accident value of 105.2 °F, identified as being able to remove the design heat load with 25 percent margin.

- Component cooling heat exchangers were evaluated using the maximum postulated SX post-accident temperature of 105.2 °F, as well as the maximum operating temperature of 102 °F. Post-accident margin exceeds 50 percent of design. Normal operating margins were more limiting due to the fact that CC temperatures are limited to a maximum of 105 °F during normal operations but have an accident limit of 128 °F. Since the CC system is able to operate within its temperature limits, associated CC cooled equipment, such as the spent fuel pool, will continue to be adequately cooled.

2.3 Licensee's Evaluation of UHS Net Positive Suction Head (NPSH) Impacts

Multiple pumps at Braidwood either take suction directly from the UHS or from the SX system. Both the SX pumps and the fire pumps take their suction directly from the UHS. Both have been assessed for the increased UHS temperature and will continue to remain operable.

SX booster pumps and motor and diesel driven auxiliary feed water (AFW) pumps normally take suction from the SX system when aligned for this flow path. These pumps were evaluated by the licensee in Section 3.5.6 of the LAR for operation at 105.2 °F and found to have adequate NPSH. During a station black out (SBO) the 'B' AFW pump and its associated SX booster pump are credited as the source of inventory for the steam generators. NPSH requirements for these were analyzed at a temperature of 102 °F (UHS DBA and a SBO are not assumed to occur concurrently) and with a higher flowrate and were adequate. SwRI staff agrees with the licensee's assessment that NPSH would be adequate at the 105.2 °F water temperature.

2.4 Licensee's Evaluation of UHS Impacted Accident Analyses

The licensee performed a review of their previous accident analyses and determined that only two were potentially impacted by higher water temperature. Both of these analyses address containment integrity and are potentially impacted due to the increased temperature of water flowing to the RCFCs and their subsequent decrease in heat removal from the containment structure. As discussed above RCFC fan cooler performance was evaluated for an accident temperature of 104 °F and found to remove heat adequately. The analyses the licensee identified in Section 3.6 of Attachment 1 of the LAR as affected are: (i) "LOCA Long Term/Short Term Mass and Energy (Containment Integrity)" and (ii) "MSLB Inside Containment/Outside Containment Mass and Energy–Dose Steam Release (Containment Integrity)."

The licensee reanalyzed both cases potentially affected. In all cases, examined peak containment pressures remained less than the maximum design pressure of 50 psig. SwRI staff addresses the licensee's analyses in Section 5 of this TER.

3 REGULATORY BASIS FOR SwRI'S REVIEW

This review follows General Design Criteria (GDC) 2, 38, and 44, Standard Review Plan (NUREG–0800) Section 9.2.5; RG 1.27, Revision 3 (NRC, 2015e); and NUREG–0693 (NRC, 1980). The regulatory basis is stated in RG 1.27, Regulatory Position 1, which for this review can be summarized as follows:

- *"Sufficient conservatism should be provided to ensure that a 30-day cooling supply is available and that design basis temperatures of safety-related equipment are not exceeded…"*

- *"The meteorological conditions resulting in minimum water cooling should be the worst combination of controlling parameters, including diurnal variations where appropriate, for the critical time period(s) unique to the specific design of the sink…"*

- *"…Select the most severe combination of controlling parameters, including diurnal variations where appropriate, for the total of the critical time period(s), based on examination of regional climatology measurements that are demonstrated to be representative of the site…"*

- *GDC 38 Containment heat removal: "A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels."*

- *GDC 44 Cooling Water: "A system to transfer heat form structures, systems, and components important to safety to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions."*

4 SWRI EVALUATION OF LICENSEE'S LAR ANALYSES— UHS POND PERFORMANCE

This section presents the SwRI staff's reviews of the licensee's assumptions, data and analysis used in their assessment of the performance of the UHS pond. This section also presents the SwRI staff's independent confirmatory analyses, limited to the temperature of returning water supplied by the UHS pond after the DBA.

4.1 Meteorological Data

4.1.1 Licensee's Weather File Creation

The licensee created a file of meteorological data from three sources: (i) the onsite meteorological tower, (ii) the weather station at Peoria, Illinois, and (iii) the weather station at Springfield, Illinois. The Braidwood Station is located about 100 miles northeast of Peoria, about 165 miles northeast of Springfield, and about 50 miles southwest of the nearest large water body, Lake Michigan. Springfield is about 76 miles south of Peoria. The file covered the period from July 7, 1948 through December 31, 2012. Onsite data were available from January 1, 1990 through December 31, 2012, and furnished only part of the information necessary for running the LAKET-PC code (EGC, 2014b) (i.e., dry bulb temperature, dew point, and wind speed). Other data for the 1990–2012 period, namely cloud height, cloud cover, and atmospheric pressure, came from Peoria. In addition, data from Peoria was used to fill in gaps in the record of data from the onsite tower. The licensee made checks of the weather record to determine the validity of the data, and identify periods when data were missing or out of range. They used linear interpolation between available onsite data, or substituted data from Peoria to fill in the record for longer periods. They also checked the thermodynamic consistency of the data between the temperature and humidity. When dew point from Peoria was substituted for missing dew point from the onsite tower, there was a check to make sure that dew point did not exceed dry bulb temperature. If so, the dew point was set equal to the dry bulb temperature (i.e., not greater than 100 percent relative humidity). Prior to January 1, 1990 (a period of ~42 years), all data in the file were collected from Peoria with the exception of the period January 1, 1952 to January 31, 1956 (a period of ~4 years), when data were taken from Springfield (EGC, 2014c, Attachment A, Page A4). Other data such as wind direction and precipitation were recorded in the data file, but not used in the LAKET-PC analyses.

4.1.2 Licensee's Meteorological Data Screening

The licensee's screening for identifying worst-weather periods used the LAKET-PC computer code in "open mode" (i.e., starting with a fixed water temperature entering the pond, no recirculation back to the plant, and also using a 3-hour travel time through the pond). The initial temperature of the pond was reset to the same initial temperature at the start of each run (EGC, 2014c, Attachment A, Page A4). Temperature was calculated using the weather data file developed from the site, Peoria and Springfield. For the peak temperature screening, the licensee determined the highest temperature that would occur with water at a fixed starting temperature of 110 °F and travel times of 24, 36, or 48 hours based on a flow rate provided by 4, 3, or 2 SX pumps, respectively. The choice of 110 °F starting temperature for screening was not critical, as only the time period of worst performance was being screened. A "rolling average" temperature over a 24 hour period was calculated from the results of LAKET-PC in order to define the "worst day" for peak temperature as a function of starting time of the DBA. Weather scenarios considered were:

- The DBA starting at 12 AM, 3 AM, 6 AM, 9 AM, 12 PM, 3 PM, 6 PM, or 9 PM
- Combining the worst time period from the screening followed by the worst 24 hour period, and also followed by the worst 30-day period
- Periods shorter than the circulation time of the pond
- Sensitivity cases for the effect of reduction of wind speed as a function of height and time of day

The licensee's screening produced a number of data sets that they expected to produce the peak return water temperature to the plant, and also the maximum 30-day water loss from evaporation. Each data set for a maximum temperature run of the LAKET-PC code was specified for the number of SX pumps in operation (2, 3, or 4) and one of the eight DBA starting times. The worst 24-, 36-, or 48-hour weather periods selected by the licensee to estimate peak return temperature are shown in Table 2 of this TER. The table shows that for 64 years of weather data used in the analysis, the 24-, 36-, and 48-hour weather occurred in the last 3 to 4 years of the data record except for one 24-hour case that occurred in 1999.

To determine the worst weather period for the maximum 30-day water loss, the licensee performed a similar screening but used a starting temperature of 100 °F.

Other necessary inputs to the LAKET-PC code were:

- A set of parameters for the volume and surface area of each UHS pond segment
- A factor to adjust wind speeds measured on the meteorological towers to a height of 2 m (meters) above the water surface necessary for the Ryan-Harleman heat transfer formulas
- The hourly heat load to the UHS pond. The time step for the LAKET-PC code was 3 hours, so the licensee used the integrated heat load from the hourly hours input table

The licensee determined the maximum return water temperature to be 105.2 °F for 3 SX pumps and 105.9 °F using 4 SX pumps (see Table 1 of the TER). However, subsequent evaluations of plant equipment used only the three SX pump result because it was the most likely scenario for UHS operation. They also calculated the maximum water loss using what they determined to be the worst 30-day meteorological period, and found it to be adequate for 30 days or longer.

4.1.3 SwRI Staff Verification of the Meteorology Data

SwRI staff used the METD suite of codes (NRC, 1982) to check for data consistency. All 565,344 hours of data contained in the UHS data file was converted to the NRC standard format for input to the METD codes. The DATE program found about 500 gaps in the dating sequence of the data, all before January 1976. Two other codes in the suite were run on data from May 1976 through September 2012, almost 320,000 hours. The MISS code checks for blocks of missing data. There were about 7,700 hours of missing data, with the largest block being 17 hours long. There were 25 blocks of missing data longer than 12 hours. The QA code checks for meteorological abnormalities for wind directions and temperature. There were approximately 6,300 diagnostics in this code, which is about 1 for every 50 hours. No wind speed abnormalities were observed. Generally speaking, the UHS data seems to have a minimum of aberrant behavior, none of which were a concern for the UHS study.

4.2 Pond Characteristics

4.2.1 Sedimentation in UHS Pond

Sedimentation accumulation (0 or 3 inches deep) displacing pond water affects travel time of water though the pond, and could alter the licensee's calculations of peak temperature and stratification.

The licensee considered 3 inches of sedimentation in the UHS calculations for a sensitivity analysis. The Updated Final Safety Analysis Report (UFSAR) Figure 2.4-48 shows a bottom/pond elevation of 584'-0". Surveillance Requirement (SR) 3.7.9.3 verifies bottom elevation less than 584 ft mean sea level (MSL) in accordance with the Surveillance Frequency Control Program. The licensee's sensitivity analysis showed insignificant effect on peak UHS temperature with 3 inches of sedimentation. Other licensees have considered as much as 18 inches of sedimentation in their UHS pond analyses (SwRI, 2015). To understand the basis for 3 inches of sedimentation, NRC requested through SBPB RAI-8 (NRC, 2015d) that the licensee discuss whether SR 3.7.9.3 verifies validity of the design input of less than 3 inches of sedimentation for the UHS calculation by addressing accuracy of measurements, how often measurements are taken and any historical trends that support the frequency of measurements.

In response (EGC, 2015d), the licensee stated that they implemented SR 3.7.9.3, which requires the surveillance every 18 months. The survey is done using Global Positioning System (GPS) Real Time Kinematic (RTK) base station to ensure accurate locations and elevations. Prior to beginning the survey, the licensee had conducted a bar check, sound velocity casts, and manual depth measurement to verify accurate depth measurements. The surveillance recorded over 35,000 depth points. The surveillance procedure, BwVSR 3.7.9.3 (EGC, 2015d) verifies the validity of the design input of a maximum depth of 3 inches for the sedimentation layer. No historical trend of sedimentation build-up above elevation 584 ft was recorded. The Braidwood UHS has low susceptibility to sedimentation build-up above elevation 584 ft, as discussed in UFSAR, Section 2.4.11.6.

4.2.2 Description of the UHS outfall

Based on the LAR, the thermal discharge from the plant would be transported to the UHS pond by two 48-inch diameter pipes, but there was no description of how heated water would be rejected to the pond, nor the complex circulation caused by release from the discharge structure (outfall). At an NRC audit conducted at the Braidwood site in July 2015, the NRC staff noted that the water is discharged to the cooling reservoir straight up through two large pipes that were above the lake level.

SwRI staff requested (through SBPB RAI-4 (NRC, 2015d) for the licensee to provide a detailed description of the UHS outfall and water supply pipes,, results of any testing of the circulation in and around the outfall, and any model or field studies of the outfall (e.g., dye tracer experiments) conduction with regard to its operation.

The licensee responded (EGC, 2015d) that it did not test the circulation in or around the UHS outfall. Therefore, there are no results of any testing of the UHS outfall that can be provided, nor analytical models or prototype studies that have been performed. EGC provided a description of the UHS outfall, including plant drawing M-900 Sh. 1Y, Revision K, Outdoor Piping Arrangement Units 1 and 2 (EGC, 2015c, Attachment 2), which shows the configuration of the two submerged 48-inch diameter water supply pipes.

4.2.3 Calculating gross and effective volumes and surface areas

Table 4.1 on page 55 of EGC (2014c) describes the gross pond volume and surface area of the UHS pond versus surface elevation. A sharper drop is observed in the gross volume and the corresponding effective volume at the elevation of 585 ft MSL (EGC, 2014c, Page 10 of 19) when compared to other elevations. The design input table does not explain this large drop in the gross volume. Because of a concern that the use of smaller volume could result in faster heating of the pond, SwRI staff reviewed UFSAR, Figures 2.4-47 and 2.4-48 on volume-area rating curves that show that the surface area decreases an acre per every foot decrease in elevation and the volume decreases about 90–100 acre-ft for every foot decrease in elevation. This appears consistent with Table 4-1.

4.3 UHS Pond Modeling

4.3.1 Determination of solar radiation

Solar radiation is an important term in the heat transfer relationships for the pond evaluation. The licensee described the use of a semi-physical model that used available meteorological information on cloud cover and cloud height, latitude, atmospheric pressure, dew point, time of year, atmospheric transmission factors, and surface and cloud albedo, to generate solar radiation incident on the UHS pond (EGC, 2014c, Attachment B, Page B7).

To validate the solar radiation algorithm, the LAR compares estimated to measured solar radiation for Madison Wisconsin collected by National Oceanic and Atmospheric Administration (NOAA) and concludes that the solar radiation algorithm performs reasonably well and results are consistent with expectations (EGC, 2014c, Attachment B, Page B25).

A comparison between the predicted solar radiation and the solar radiation measurements from Madison Wisconsin during September 15, 1988, shows that the predicted peak radiation is lower than the measured peak between 10 and 14 hours. The LAR states that it is not obvious why program predictions were slightly less accurate during January 25, 1988 and September 15, 1988 and then provides a possible explanation that the cloud cover observation at the “top” of each hour may not have accounted effectively for cloud variations during that hour. However, the area under the predicted solar radiation curves was greater (about 19 percent) than the measured value, despite the fact that the peak values for the predicted curve was smaller. Given that the UHS pond would have a significant mass of water and therefore a large thermal inertia, the SwRI staff considers that the solar radiation predictions are reasonable and conservative from the standpoint of estimating peak pond temperature and evaporation.

4.3.2 Hydraulic Model(s) for the UHS Pond

The analysis of UHS thermal performance presented in the LAR portrays the pond as a series of equal-sized segments with water flowing through at a fixed rate, with no lateral, longitudinal, or vertical mixing. The licensee calculated a smaller effective area and volume of the UHS pond using an empirical method for cooling ponds in general (MES-11.1, Sargent and Lundy, 2014), (EGC, 2015d). The effective area and volume of the pond is taken as 82.3 percent of the actual volume and area to account for non-idealized flow and transport of hot water.

To determine if the licensee's plug flow analysis results in a conservative evaluation of peak return temperature, SwRI staff requested the licensee through an RAI (NRC, 2015d, SBPB

RAI-2) to provide a detailed description of their methodology for estimating effective area and volume. This request was made in light of the evidence from review of the LaSalle UHS pond that the hydraulics of the pond may not be well represented by a one-dimensional plug flow with each plug corresponding to 3 hours of pump flow. Evidence of the complex circulation caused by jet discharge can be found in the computational fluid dynamics (CFD) analysis done by the licensee for the LaSalle UHS pond (EGC, 2013).

SwRI staff concluded that the licensee's approach did not adequately address all issues that would affect the UHS pond cooling performance. For example, based on information in the licensee's application, discharged water would enter the pond through the vertical discharge structure at speeds up to 8.51 ft/sec (for 4 SX pumps), depending on the number of SX pumps in operation. Based on an audit conducted at the Braidwood site in July 2015, the NRC staff believed that the water is discharged straight up and above the lake level. The top of the discharge structure is 7.75 ft above the nominal water surface of the UHS pond upon failure of the main cooling reservoir, and would fall back to the water surface at about 24 ft/sec for 4 SX pumps in operation. This discharge could lead to a high rate of vertical and horizontal mixing, and the inducement of significant circulation throughout the pond. Such mixing could either positively or negatively affect UHS pond performance, but was not adequately characterized in the Licensee's analysis for any firm conclusion to be drawn by the SwRI staff.

Irrespective of this mixing in the near field of the discharge structure, the discharged water would also result in a wide distribution of travel times between the discharge and intake, caused by the spread of the water to conform to the nearly rectangular shape of the pond rather than a single travel time as portrayed in the plug-flow model.

The licensee's analysis recognizes the spread and the distribution of travel times to predict that the effective area and volume of the UHS pond would be 82.3 percent of the actual area and volume based on MES-11.1 (Sargent and Lundy, 2014).

Given the unusual nature of the discharge structure and other factors such as pond shape, NRC requested the licensee to provide any evidence, based on actual measurements of circulation in the UHS pond, model studies, or analogs, on the actual pond hydraulics, or to perform sensitivity studies with the licensee's performance model over a range of effective volumes and surface areas that would encompass and exceed their estimate of 83.2 percent efficiency.

In response, the licensee stated that actual measurements, model studies, or analogs for the actual pond hydraulics are not available. Instead, it conducted a sensitivity study of the calculated peak temperature at the plant intake as a function of the pond effectiveness value in LAKET-PC. For constructing the sensitivity case, the licensee (i) varied the pond effectiveness value to the extent that it would change the travel time (i.e., effective volume of the pond divided by the flow rate), rounded to the nearest 3-hour increment, (ii) updated the worst weather files to reflect the change in travel time, and (iii) adjusted the DBA start time that would maximize the peak pond temperature. The licensee's Table 1 in their RAI responses (EGC, 2015d) shows the nominal case effectiveness value of 82.3 percent (travel time of 36 hours) being changed to the sensitivity case of 76 percent (33 hour travel time). The licensee's results, presented in the following Table 3 of this TER, show that reducing the pond effectiveness value by 6.3 percent

Table 3. Licensee's Sensitivity Study Results (EGC, 2015d)

Table 2: Results of Sensitivity Study for RAI-2 Response

Case	Peak Calculated Lake Outlet / Plant Inlet Temperature (°F)
76% Effectiveness Case	105.9
82.3% Effectiveness (Case 3_3AM from Calc)	105.2
87% Effectiveness Case	104.4

(i.e., corresponding to a travel time reduction by 3 hours) result in an increase in the peak calculated temperature by 0.7°F.

SwRI staff performed computational experiments to determine the sensitivity of peak return temperature to assumptions about pond effective surface area and volume in its confirmatory analysis in Section 4.4 of this TER.

4.3.3 Other Considerations for Licensee's UHS Performance Predictions

4.3.3.1 Stratification

Another analysis that was involved in the licensee's determination of peak return temperature was the evaluation of the potential for thermal stratification, which could result mainly from the discharge of heated water into the cooler and denser ambient pond water, potentially enhancing flow along the surface and reduce the travel time through the pond (EGC, 2014c, Attachment D, Page D2). A necessary condition for use of the LAKET-PC model is that no stratification is present. The licensee defends its conclusion that the pond would not be stratified on the basis of a theoretical model for the behavior of a distinct two-layer system representing water density variation (i.e., hot water sitting on top of cool water), and no interfacial mixing except in the entrance region (Octavio et al., 1979). This procedure is generally known as the "pond number" approach (Helfrich et al., 1982). The licensee concluded from the calculation that there would be no appreciable stratification for 2, 3, or 4 SX pumps in operation.

Entrance mixing in the calculation is for the specific condition of a horizontal surface discharge. The Braidwood discharge is from vertically oriented pipes that are above the water surface, and do not resemble a horizontal surface discharge. The SwRI staff requested information on the discharge structure, including an assessment of how discharged water would mix into the pond. The licensee could not provide any information on the behavior of the discharged water, and how the resulting mixing would fit into the analysis for thermal stratification. Therefore, the SwRI staff has no basis for concluding that the stratification analysis is valid, and that the necessary condition for use of the LAKET-PC code is satisfied. SwRI staff did not have adequate resources or time to independently assess the mixing and potential stratification in the Braidwood UHS pond. However, the SwRI staff has performed several sensitivity calculations (see Section 4.4 of this TER) on the potential effect of stratification to determine whether or not this is an important consideration for predicting the performance.

4.3.3.2 Licensee's Adjustment for Wind-Sensor Elevation

Wind speed was determined from a number of different sensor elevations at the site, Peoria and Springfield towers. Wind speed {generally measured 10-m above ground level (AGL)} was adjusted to a standard 2-m elevation above water surface as specified in the Ryan-Harleman heat transfer model (Ryan and Harleman, 1973) for use in the LAKET-PC calculations using an exponential reduction factor (EGC, 2014a, Attachment 1, Section 3.4.2). SwRI staff generally agrees that the wind speed reduction factor chosen by the licensee is reasonable to conservative, but this factor is sensitive to a number of environmental variables including surface topography, presence of water bodies, and atmospheric stability. SwRI's confirmatory calculations in Section 4.4 explore the sensitivity of peak return water temperature to this and other parameters.

4.3.4 Licensee Determination of Maximum UHS Temperature

The licensee determined that the 3 AM start would give the highest temperature peak for the 3 SX pump case (EGC, 2014c, Table 7-1, Page 16 of 19) whereas the 6 AM start gives the highest temperature peak for the 2 and 4 SX pump cases (EGC, 2014c, Tables 7-2 and 7-3, Page 17–19 of 19). Although these results are not intuitive, they probably occur because of the complicated effects of competing heat inputs and losses from the pond surface (e.g., solar radiation), heat input from the plant, and the travel times caused by different flow rates for the 2, 3, and 4 pump scenarios. The SwRI staff's confirmatory analysis in Section 4.4 arrived at a different conclusion that there was no difference in peak return temperature as a function of the number of pumps, except for a worst-case scenario that showed a small effect.

4.3.5 Licensee's Conclusions About UHS Pond Performance

On the basis of their calculations, the licensee developed a revised TS that allows a higher return water temperature of 105.2 °F, for a pond temperature starting at 102 °F. The maximum return temperature determined from the licensee's LAKET-PC runs was 105.9 °F (Table 1 of this TER), for a DBA start time of 6 AM, using 4 SX pumps. However, the licensee states that the maximum number of SX pumps in operation would be three (a peak temperature of 105.2 °F as summarized in Table 1), and a fourth SX pump could be started manually later in the progression of the DBA.

The licensee's analysis concluded that the inclusion of 3 inches of sedimentation in the pond would have a negligible effect on peak temperature (EGC, 2014c, Page 15 of 19).

The maximum predicted 30-day water loss results in a drawdown of 1.78 ft for 4 SX pumps in operation. The number of pumps used made only a small difference in the total water loss.

4.4 SwRI Confirmatory Analysis

4.4.1 Introduction

This section presents SwRI's independent evaluation of the licensee's results. The licensee provided the following information discussed in Section 2.1:

- Dimensions of the UHS pond, including shape, depth and sediment thickness
- Raw meteorological data collected at the Braidwood site, Peoria and Springfield Illinois
- Processed data that combined and adjusted raw meteorological data into a single file

- Reduction factors to adjust 10-m wind speeds to 2-m for heat transfer relationships
- Flow rate through the pond under various operating modes
- Heat load to the pond versus time

The SwRI confirmatory analyses concern only the thermal performance of the pond. Staff has made a summary conclusion that pond water supply is adequate for 30 days of continuous operation, and that peak temperatures would not be appreciably affected by dropping water levels. Furthermore, the confirmatory analysis did not take into consideration the effect of sedimentation or temperature measurement error because they are expected to be minor. The details of SwRI's independent confirmatory analyses are documented in a scientific notebook.

4.4.2 SwRI's Computational Model for Peak Return Temperature

SwRI developed a computer model, BRPLUG, which is a minor modification of the LAPLUG model used in the LaSalle UHS review (SwRI, 2015, Appendix A). The BRPLUG computer program addressed one-dimensional flow with heat transfer and evaporation from the pond surface, using the Ryan-Harleman heat transfer formulation (Ryan and Harleman, 1973), with the option to substitute the more-conservative Brady wind function (Brady et al., 1969). There is also an option to reduce the heat transfer from evaporation by a factor based on actual heated pond and reservoir data (EPRI, 1987). The SwRI staff considers only the Ryan-Harleman heat transfer formulas in this evaluation, but with reduction factors from evaporation in sensitivity analyses.

The model was similar to SwRI staff's understanding of the LAKET-PC model, but with several distinctions:

- The licensee's model used only the Ryan-Harleman formulation.

- The licensee's model accounted for reflection of long wave and short wave radiation from the water surface, whereas the SwRI model conservatively ignored reflection.

- The licensee's model conservatively included a provision that reduced surface heat transfer to the environment when the pond temperature was less than 2.5 °F above the "natural temperature." The natural temperature was defined as the temperature of the pond under the influence only of natural environmental factors, with no addition of heat. The SwRI model did not include this provision, but concludes that, while it is conservative, it is not physically realistic.

- The licensee's model treats the pond as a succession of segments of equal surface area and volume. SwRI's model can account for different depth and surface areas in each segment.

- The licensee's model uses a strictly plug-flow formulation that treats the movement of hot water discharged from the plant through the pond with no mixing or longitudinal dispersion. While plug flow enhances heat transfer between the water and the atmosphere, it tends to enhance the peak temperature by not accounting for mixing of hot discharged water with cooler ambient pond water. The SwRI model treats the segments as a series of well-mixed tanks, accounting for mixing of the hot water with cooler ambient pond water. We believe this to be a more realistic approach that accounts for dispersion processes encountered in real water bodies.

SwRI staff's analysis of the licensee's performance results was conducted in the following steps:

- Determine the adequacy of using a one-dimensional cooling pond model to evaluate a complex pond. Also, evaluate correction factors for surface area and volume that the licensee used to account for non-ideal flow in a real water body in order to use a one-dimensional model.
- Determine the adequacy of using meteorological data collected at the site and from distant weather stations.
- Determine the maximum return temperature using the available meteorological record with SwRI's models and formulas.
- Determine the sensitivity of calculated maximum return temperature to model and data assumptions.

4.4.3 Adequacy of Licensee's Use of a One-Dimensional Cooling Pond Model

4.4.3.1 Evaluation of UHS Pond Circulation

Flow of discharged water in the pond can be divided into near- and far-field effects:

Near-Field Release From the Discharge and Its Effect On Pond Circulation and Performance. There is substantial uncertainty about the hydraulics of the Braidwood UHS pond, in particular, the degree of mixing of discharged water in the near field and its potential effect on pond stratification. The licensee did not provide an adequate analysis of the potential mixing that would occur around the discharge structure. In the absence of support data or model analysis from the licensee on the discharge structure on the UHS pond, SwRI staff has drawn some conclusions based on its experience and knowledge of jet mixing:

- Upon failure of the main cooling reservoir, the discharge from the above-ground pipes would fall to the water surface at about 24 ft per second, likely resulting in considerable local mixing. However, the mixing would not be as great as was seen in the CFD model for the LaSalle UHS (SwRI, 2015, Appendix A). In the LaSalle case, the jet was horizontal from the pond bottom into a large expanse of open water, resulting in efficient mixing and the generation of large gyres in the pond. In the Braidwood case, the jet is vertical into a relatively shallow pond, with a concrete pad about 10 ft below the water surface. Depth of the surrounding pond is 10 ft, gradually sloping up to about 5.5 ft. Jet mixing is likely to be reduced by the shallowness of the pond and the dissipation of energy as the jet sharply changes direction when it strikes the concrete pad.
- The discharge is relatively close to the pond's bank, restricting growth of a jet plume on the south side.
- The jet would be deflected mostly parallel to shore and toward the intake. This is likely to set up gyres that would increase circulation and mixing, but not as efficiently as with the LaSalle case. Furthermore, the component of the jet toward the intake could reduce travel time.

Without additional computation or knowledge of similar circumstances, it is difficult to estimate the actual flow patterns in the pond caused by the jet discharge, and its effect on stratification.

The SwRI staff performed sensitivity analyses to estimate the effect of assumptions about the presence or lack of stratification and mixing in the near field (see Section 4.4.5.1).

Far-Field Transport Through the UHS Pond. Mixing of discharged water in the near field would be highly dependent on transfer of mass and momentum by turbulence. Further away from the discharge structure, flow would be less affected by turbulence. SwRI staff estimated the probable travel time distribution of water in the UHS pond using a simplified model of pond hydraulics. This model assumes that the flow patterns in the pond are strictly two dimensional (i.e., vertically mixed), and that outside of the region of jet discharge, flows are irrotational and steady state. These are both reasonable assumptions because velocities in the pond resulting from pumping are very small once away from the discharge area, and flow patterns should be conformal to the pond boundaries. With two pumps operating, the average velocity in the pond between the discharge and intake controlled by pumping alone would be only about 0.012 ft/sec. Furthermore, flow disturbances travel quickly across the pond, moving at the velocity (celerity) of shallow water waves. For a 5.5 ft average depth, this celerity would be about 14 ft/second, which would reach the other end of the pond about 3,000 ft away in less than 4 minutes.

The SwRI staff used a finite difference model derived from the Poisson equation for steady state irrotational flow in two dimensions, often used for groundwater modeling. The velocities calculated in the model were then used to generate a large number of released particles, each representing a parcel of water following a streamline between the discharge and intake. The travel time distribution of the parcels was then used to address the question of the adequacy of using a one-dimensional model for calculating pond performance, and the correction factors (pond efficiency) for area and volume applied in the one-dimensional model calculations.

The SwRI model calculated pond efficiency using the following assumptions:

- The parcel would cool as it traveled between the discharge and intake at a rate determined by the difference between temperature and a fixed “equilibrium” temperature and a fixed heat transfer coefficient;
- Heat input, and therefore the increase of temperature of the water entering the pond, is constant;
- The flow rate of the parcel path would be inversely proportional to its travel time.

With these assumptions, the pond efficiency would be determined by how much each released particle contributed to the average temperature of all parcels collected at the intake. The average temperature from all parcels is then equated to the travel time of a single parcel that has the same temperature as the average, and represents a one-dimensional transport between the discharge and intake. The pond efficiency can then be calculated by the ratio of the single travel time to the average of all flow-weighted parcel travel times.

The results of the model showed that the pond efficiency depends only on the equilibrium heat transfer coefficient, and is independent of temperature rise and equilibrium temperature. For typical values of the equilibrium coefficient, pond efficiency was calculated to be greater than 90 percent. SwRI used a conservatively small value of 80 percent in all its pond performance calculations. The licensee used an efficiency of 83.2 percent derived from its MES-11.1 procedure (Sargent and Lundy, 2014). The SwRI staff therefore concludes that the thermal efficiency values used in subsequent calculations with either the licensee or SwRI staff's one dimensional model are conservative.

Other uncertainties of the hydraulics of the UHS pond were evaluated in the SwRI confirmatory analyses by altering the size of the first segment to account for mixing in the near field of the discharge structure. More mixing in the near field would tend to reduce atmospheric heat transfer somewhat, but also diminish sharp rises in temperature at the pond intake.

4.4.3.2 Effects of Stratification

SwRI staff reviewed the licensee's calculations to determine whether the pond would become stratified. Although the pond number approach used by the licensee has been shown to be useful in the analysis of cooling reservoirs, SwRI staff felt it may not give an accurate portrayal of actual UHS pond performance, mainly because the latter is highly transient, the model does not account for interfacial transport between the upper and the lower water layers, and there is no accurate accounting of near-field mixing from a surface discharge.

None of these reasons is necessarily nonconservative and empirical evidence on shallow ponds shows they are frequently vertically well mixed. The discharge to the Braidwood UHS pond should lead to considerable vertical and horizontal mixing in at least the near field. Furthermore, stratification, if it were present, would have the beneficial effect of maintaining a high surface temperature with correspondingly higher heat transfer to the atmosphere, and also promote circulation of hot water into any dead-end spaces in the pond.

SwRI staff has made several sensitivity calculations postulating stratification existed in the pond and concluded stratification would not result in a return water temperature greater than that calculated by the nonstratified assumption. The analysis assumed that there was a stratified water layer floating on the top of a cooler stagnant layer. Travel time from the discharge to the intake would be half as long, and water entering the intake structure and sumps would mix with the cooler underlying water in equal proportions. Results are presented in Section 4.4.5.1, Table 4 of this TER, and indicate that stratification should not lead to degraded UHS cooling performance.

4.4.3.3 Adequacy of the Licensee's Use of Meteorological Data Collected From Distant Weather Stations

The SwRI staff compared meteorological data from the Braidwood site tower to data collected at Peoria to determine the adequacy of using the offsite data in the performance calculations. Note that most of the meteorological data between 1990 and 2012 was collected onsite, except for cloud cover, and cloud ceiling (used for solar radiation estimates), and periods of missing data from the onsite tower, which were furnished from the Peoria station. Results showed that the worst-cases of peak temperature all occurred between 2009 and 2012, within the time period where predominantly on-site meteorological data were used.

SwRI staff compared meteorological data on wind speed, dry bulb temperature and dew point from the Braidwood site tower to those data from Peoria for the year 2010. Differences in the respective measurements between Peoria and the site were not great. Visual plots of peak wind speeds and temperatures looked quite similar. The mean of the daily peak dry bulb temperature was slightly lower at the Braidwood site, which is nonconservative. However, the mean of the daily peak dew point temperatures at the Braidwood site were on average slightly higher and wind speeds were slightly lower, both of which are conservative. The SwRI staff conclude that the small differences would not have led to a higher peak had Peoria data been used during the 1990 to 2012 period instead of mainly onsite data, nor would offsite data prior to 1990.

4.4.4 SwRI Staff Evaluation of Maximum Return Temperature

SwRI Staff calculated the peak return water temperature using the BRPLUG model with the licensee's primary inputs for meteorology, heat load, and flow rates. The SwRI staff evaluations consider the base case, and a number of sensitivity experiments that consider more conservative factors for cooling and circulation.

The base case refers to the benchmark run using SwRI staff's best estimate of physical pond parameters and heat transfer relationships[1]. The calculations assumed two SX pumps in operation, initial pond temperature was 102 °F, the pond efficiency factors for surface area and volume were 80 percent, wind speed adjustment factor from 10 m AGL to 2 m was 80 percent, and the cooling efficiency factor for the Ryan-Harleman heat transfer relationship was 100 percent. SwRI staff believes that the pond efficiency relative to a plug-flow case is higher than 95 percent, based on its model of circulation in the Braidwood pond. SwRI staff also believes that the factor for evaporative cooling efficiency for the Ryan-Harleman heat transfer formula would be between 75 and 107 percent. An unweighted average thermal efficiency of the Ryan-Harleman formula based on evaluations of actual cooling at heated reservoirs greater than 28 acres in surface area is about 89 percent (EPRI, 1987). Peak return temperature for the base case run was 104.03 °F, and occurred 8.2 hours after the DBA. Results of the base case and sensitivity cases are presented in Table 4. These peak temperatures do not account for the small 0.1 °F assumed measurement error, which can be added to the peak temperature results. In addition, the SwRI staff's analysis also did not account for the small amount of sediment assumed by the licensee to be in the pond.

Calculations started on 3-hour intervals from May through September (the hottest months) from 1948 through 2012, tabulating the peak return temperature for each run, and the time to peak temperature after the start of the DBA.

4.4.5 Evaluation of Sensitivity of Calculated Maximum Return Water Temperature to Model and Data Assumptions

4.4.5.1 Sensitivity Cases

Given there is uncertainty in the models, data, and heat-transfer relationships used, SwRI staff executed a number of runs to test the sensitivity of peak return water temperature to various assumptions about data, heat-exchange relationships, and model parameters. The following sensitivity runs (i.e., what-if analyses) were made:

- Adjustments to Ryan-Harleman heat transfer formula—All runs of the BRPLUG model used only the Ryan-Harleman heat transfer relationships. However, an adjustment factor (0.75) was also used to reduce the evaporative cooling efficiency by 25 percent in

[1] Although the licensee uses three SX pumps in their base case and we use two SX pumps, other sensitivity runs cover the three-pump scenario.

some runs to conservatively take into account reduced cooling measured at a range of actual artificially heated ponds.

- Operation of 2, 3, or 4 SX pumps.
- Effects of stratification—SwRI staff assumed that there is a thermal layer half the total depth on top of ambient pond water to determine if stratification would lead to a more adverse condition. The stratified layer mixes with 102 °F undisturbed water at pond intake.
- Size of first segment—SwRI staff assume the first pond segment contained 20 percent of the pond volume and area to determine the importance of near-field mixing.
- The effect of a higher starting temperature of 103 or 104 °F at the beginning of the run to account for uncertainty in temperature measurements or delays in commencing plant shut down.
- More adverse meteorology from global climate change (GCC) during plant lifetime—Add 2 or 5 °F to dry bulb temperature and 1.6 or 4 °F, to dew point temperature based on an approximation of climate projections over the remaining lifetime of the plants {Great Lakes Integrated Sciences + Assessments (GLISA), 2015, 2014}. These were the same values added for the LaSalle UHS analysis (SwRI, 2015).
- Combine worst GCC scenario with 75 percent Ryan-Harleman evaporative cooling efficiency, for 2 or 3 SX pumps.

Results from these sensitivity runs and the base case are given in Table 4. The numbers in red exceed the 105.2 °F temperature limit specified by the licensee.

Table 4. Results of Base Case and Sensitivity Runs - Deviations From Base-Case as Stated

Description	Peak T, °F	Elapsed Time, Hr
Base case, Ryan wind function, 30 equal segments, wind speed reduction 0.8, 100 percent Ryan evaporative thermal efficiency (Ryan Efficiency), 2 SX pumps	104.03	8.2
3 SX pumps	104.03	8.2
4 SX pumps	104.03	8.2
Stratified layer – 3 SX pumps and half depth of pond*	103.82	7.2
First segment with 20 percent of total pond volume and surface area	104.03	8.2
Wind speed reduction factor of 0.617	104.22	8.2
75 percent Ryan efficiency	104.74	8.2
75 percent Ryan efficiency, 3 SX pumps	104.74	8.2
Wind speed reduction factor of 0.617 and 75 percent Ryan efficiency†	104.90	8.2
Starting temperature 103 °F	104.82	8.2
Starting temperature 103 °F, 75 percent Ryan efficiency	105.57	8.2
Starting temperature 104 °F (100 percent Ryan efficiency)	105.60	7.2

Table 4. Results of Base Case and Sensitivity Runs - Deviations From Base-Case as Stated		
Description	**Peak T, °F**	**Elapsed Time, Hr**
Global Climate Change (GCC), + 2 °F to dry bulb, +1.6 °F to dew point	104.29	8.2
GCC2, +5 °F to dry bulb, +4 °F to dew point	104.69	8.2
GCC2, combined with 75 percent Ryan efficiency	105.40	60.0
GCC2, 75 percent Ryan efficiency, 3 pumps	106.00	56.0
GCC2, 75 percent Ryan efficiency, 3 pumps, 20 percent Volume and Area in 1st segment	106.12	81.2
*Average of stratified and underlying water †SwRI staff does not consider this to be a fair juxtaposition in general, and does not use the combination in other sensitivity cases.		

4.4.5.2 Discussion of Sensitivity Results

For most runs, peak return temperature occurred at either 7.2 or 8.2 hours after the DBA, well before the arrival of the heated water from the plant discharge. This result shows for these cases that the peak does not depend on the introduction of heated water from the plant, but is purely a result of heat transfer into the pond from the environment, especially solar radiation. Since pond temperature calculations are assumed to always start at 102 °F, most runs show that temperature decreases immediately after the DBA. Only a minority of the runs has meteorological conditions severe enough for temperatures to climb after the DBA, and these are the subset of runs leading to highest temperatures reported in Table 4.

Allowing a higher starting temperature of 103 or 104 °F can allow peak return temperature to exceed 105.2 °F, particularly for degraded heat transfer scenarios (reduced Ryan evaporative efficiency or reduced 2-m wind speeds).

The only runs that showed an effect of added heat on peak return temperature were for severe cases of projected GCC meteorology, along with degraded pond cooling performance.

SwRI staff believes there are two primary reasons for the difference between SwRI and licensee results:

- The licensee's use of "natural temperature" in its model to switch between two wind functions—the "Ryan" and "Lake Hefner" (Ryan and Harleman, 1973)—considerably reduces heat transfer to the atmosphere under certain conditions.

- The licensee used a strict plug flow approach for movement of hot water through the pond. We believe this approach does not properly account for mixing, dispersion, and multiple paths in the balance of the pond.

SwRI staff believes the use of natural temperature and strict plug flow, while conservative, is not realistic.

In addition, the SwRI staff's model is more rigorous in the way worst-case cooling is determined, since it uses the full model with numerous starting times to directly determine pond performance. The licensee's analysis for peak return temperature relies on pre-screened periods of meteorological data that do not use the full complexity of the heat transfer and flow phenomena in determining peak temperature.

4.4.6 SwRI Conclusions about Braidwood UHS Performance

SwRI staff has carefully examined the licensee's analyses of the peak return water temperature from the UHS pond at the Braidwood site, and performed an independent confirmatory analysis based on its best understanding of the data and phenomena involved. We conclude the licensee's calculations of peak return water temperature are conservative, and the 102 °F pond starting temperature in the revised Technical Specification is acceptable when based on meteorological conditions characterized by historic data collected at the site and at regional locations offsite. We base this conclusion on the following factors:

- We evaluated the meteorological data used by the licensee and determined it was appropriate for use in the pond performance models.
- We examined the licensee's performance models and determined they were appropriate and conservative for the worst conditions of pond operation and adverse meteorology determined from the historic record.
- We performed our own confirmatory analyses that include sensitivity of peak return water temperatures to alternative assumptions about data, models, and parameters. Since our peak temperature results were uniformly more favorable (i.e., lower) than the licensee's for meteorological conditions characterized from existing data, we conclude the licensee's results are conservative.

The results of sensitivity calculations indicate that meteorological conditions more adverse than those characterized by the historic record, (i.e., GCC), could result in future peak temperatures that exceed the licensee's 105.2 °F estimate by as much as 1.0 °F.

Allowing measured temperatures of circulating water in the main cooling reservoir to significantly exceed 102 °F could lead to peak return temperatures from the UHS pond that exceed 105.2 °F, particularly when using model parameters chosen for degraded pond cooling performance.

5 SwRI EVALUATION OF LICENSEE'S LAR ANALYSES – UHS-COOLED-EQUIPMENT PERFORMANCE

5.1 Background

The Braidwood UHS consists of an excavated cooling pond that is integral within the main cooling pond. SX pumps take suction from this cooling pond and transfer plant-safety-related heat loads to the pond. Two units, each having two SX pumps, are associated with the cooling pond. The maximum heat load on the UHS is based on a scenario in which both units are initially at full power when one unit experiences a DBA with a LOCA concurrent with a LOOP in one unit while the other unit starts a non-accident shutdown. The contents of the main cooling pond are assumed to be unavailable at the beginning of the accident.

This section reviews the licensee's evaluation of critical safety related equipment in the plant for a higher starting temperature of 102 °F, leading to a calculated peak return water temperature of up to 105.2 °F.

5.2 Containment Performance

The Braidwood plants containment structure is designed such that for all accident types the maximum pressure and temperatures reached will be less than the design pressures and temperatures. Based on the licensee's review of the associated accident analyses for containment, only two analyses were impacted by the increased UHS temperature.

Both of these analyses address containment integrity and are impacted by the increased UHS temperature water that provides cooling of the RCFCs. The analyses the licensee identified as affected are: (i) LOCA Long-/Short-Term Mass and Energy (Containment Integrity) and (ii) MSLB Inside Containment/Outside Containment Mass and Energy – Dose Steam Release (Containment Integrity). In item (i) above only the long-term portion of the analyses is affected as the short pressure pulse analyzed is effectively over within about 3 seconds, which is too short a time for a significant effect from the RCFCs.

Most of the accident analysis performed by the licensee in the LAR used a peak UHS temperature of 105.2 °F, but the revised containment analysis used a maximum UHS temperature of 104 °F. Although the licensee projected that peak UHS temperature would be reached 36 hours after the accident, confirmatory analysis by SwRI indicates that UHS temperatures greater than 104 °F would be reached approximately 7.2 to 8.2 hours after the onset of the accident due to the effects of solar heating.

The peak load on the RCFCs is encountered during the initial pressurization of containment following the break of either the RCS or the steam generator shell side. In both of the associated accident analyses the peak containment pressure is encountered well within the first half hour of the accident, well before the water returning from the pond would reach 104 °F. In both cases containment pressures and RCFC heat loads are greatly reduced within the first hour. Because of this the use of 104°F UHS temperature was determined to be conservative.

5.4 Evaluation of Instrumentation

As previously described the Braidwood UHS consists of an excavated pond, which is integral with the cooling lake and the associated pumps, piping, and valves that connect the pond to the plants safeguard cooling systems.

Each plant has SX pump discharge instrumentation that is available to the control room operator. The associated operator records the SX temperature once per shift on each unit. The average of the two units is calculated and compared to the temperature requirements of TS 3.7.9, SR 3.7.9.2. In the event that a SX high temperature alarm setpoint of 96 °F is reached the temperature will be monitored on an hourly basis. If SR 3.7.9.2 limits are reached, both units will enter the requirements of TS 3.7.9.

In order to eliminate some of the factors associated with instrument uncertainty in the installed instrumentation, the licensee has proposed to use precision temperature indication at temperatures exceeding 97 °F. These instruments have a maximum uncertainty of .07 °F and surveillance procedures developed by the licensee direct the operator to obtain pump discharge temperature by inserting the tip of the instrument into spare thermowell locations on the SX pump discharge header. Due to the associated instrument uncertainty of .07 °F a limit of 101.9 °F will be applicable to ensure that the limit of 102 °F is not exceeded.

SwRI staff finds that the use of highly accurate local readings to eliminate instrument uncertainty is an acceptable practice. Similar methods have been utilized in the industry to eliminate or reduce instrument uncertainty in such areas as lake level detection systems through manual measurement. The proposed solution does not burden Operations staff excessively and will provide highly accurate readings.

5.5 Evaluation of Equipment

5.5.1 Evaluation of pump room cubicle coolers

All safety-related pump room cubicle coolers were evaluated by the licensee as part of the LAR to ensure that adequate margins existed with an increased UHS temperature of 105.2 °F. The evaluation determined that all associated cubicle coolers had adequate margin (10–50 percent) with the exception of the charging and containment spray (CS) pumps. In the case of their cubicle coolers adequate margin was obtained by lowering the tube plugging limits. This change provided adequate margin.

Subsequent to this evaluation, which was performed utilizing “simplified models”, the licensee performed a second set of calculations using design calculations in response to a request by NRC staff. A conservative temperature limit of 106 °F was used as the UHS temperature for these calculations and Section 3.5 of the LAR was revised. Based on this revision, CS pumps and SFP pumps cubicle coolers were the only components with less than 10 percent margin. These components were evaluated to maximize the tube plugging limits while still providing for margin.

SwRI staff reviewed the original LAR and the revised Section 3.5 and concludes that the licensee has taken the necessary steps to ensure adequate margin exists and have evaluated the coolers using a conservative UHS temperature. The peak temperature of water returned from the pond will be reached during the DBA LOCA accident as previously discussed. This accident will also typically result in the highest heat load on the cubicle coolers due to the excess heat load while the plant recirculates the hot water from the containment sump.

5.5.2 Evaluation of Oil Coolers and Engine Coolers

All safety-related pump oil coolers were evaluated by the licensee to ensure that adequate margins existed with an increased UHS temperature of 105.2 °F. The licensee initially concluded that based on simplified models developed for the LAR that approximately 10 °F margin existed between the highest expected temperature and the “limiting” oil temperature. Based on the licensee analysis, SwRI staff asked for the licensee to provide a “simplified model” for the most limiting equipment and for the licensee to define the term “limiting oil temperature.” NRC staff issued three RAI’s connected with these issues:

- NRC sought a clarification of the meaning of the term “limiting oil temperature,” which was used in the LAR in reference to the analysis performed on oil coolers. The response provided by Exelon states that the term refers to limits above, which continued operation of the equipment would not be recommended. SwRI staff finds that this is a conservative position, as the concern that generated this RAI was that the “limiting oil temperature” was based on the threshold beyond which immediate equipment breakdown could be expected to commence.

- The LAR submitted described a formal engineering evaluation that was completed using “simplified models.” The NRC staff requested that the licensee complete their application based on actual design calculations. In response, the licensee performed design calculations for all equipment addressed in Section 3.5 of the LAR and submitted a revised Section 3.5. All equipment analyses in the revised Section 3.5 were performed at a bounding UHS temperature of 106 °F. All the analyses performed indicated that adequate margin existed on both oil coolers and engine coolers. Tube plugging limits were maximized while ensuring margin exists at the minimum expected flow rates. SwRI staff concludes that the licensee has adequately addressed concerns regarding the use of “simplified models.” The revised calculations are largely consistent with the initial calculations provided and the tube plugging limits display a conservative bias.

- NRC staff requested that the licensee provide significantly more information in regards to the EDG heat exchangers in the following specific areas:

    - design fouling factor
    - as tested fouling factor
    - frequency of testing
    - tube plugging allowance
    - actual number of plugged tubes
    - design heat load
    - actual SX flow rate
    - calculated heat removal capability with design fouling factor at 105.2 °F

Based on a review of the licensee’s response, SwRI staff concludes that they provided the needed information. The licensee was unable to provide an as-tested fouling factor as they do not conduct performance testing on these heat exchangers. Design calculations were performed and the licensee determined that the heat exchangers are capable of removing their design heat load with a total of 54 tubes plugged per bundle. The maximum number of tubes plugged on any bundle is currently 30 tubes.

Based on the information provided by the licensee, SwRI staff concludes that it is reasonable that the EDG lube oil and jacket water heat exchangers will be able to remove all design heat loads at minimum expected SX flowrates. SwRI further concludes that the calculations have an additional conservatism based on the use of an UHS temperature of 106 °F. As previously discussed, SwRI staff has calculated that UHS temperatures greater than 104 °F would be reached approximately 7.2 to 8.2 hours after the onset of the accident due to the effects of solar heating. EDG loading (and thus heat loads) will be highest during the injection phase of the accident. EDG loading will lower with containment pressure reduction due to reduced RCFC electrical loading and containment spray flow reduction steps, and lower further with the transition to sump recirculation.

5.5.3 Main Control Room Chiller

The Braidwood LAR evaluated the MCR chiller condenser and concluded that it has 25 percent margin at a temperature of 105.2 °F. The evaluation performed was described as using a reduced fouling factor "based on the as-found fouling factors of other heat exchangers in the NRC Generic Letter (GL) 89-13 program." NRC staff questioned the use of this reasoning due to the fact that other heat exchangers may not have SX flow aligned to them as regularly and issued RAI–11 described below. The LAR proposed that the MCR chiller had 25 percent margin at 105.2 °F if a reduced fouling factor was utilized in the calculations. The LAR considered it reasonable to utilize a reduced fouling factor based on the fact that other heat exchangers had as-found reduced fouling factors.

NRC staff questioned the use of the licensee's reasoning due to the fact that other heat exchangers may not have SX flow aligned to them as regularly. In addition, some of the other heat exchangers referenced in the GL 89-13 program may operate less frequently than the MCR chiller condenser. This reduced frequency of operation may not make a comparison between the heat exchangers applicable.

The licensee response provided a modified evaluation with an increased level of detail. The new model allowed for variation of the refrigerant pressure in the chiller condenser, thus, altering the driving temperature difference across the heat exchanger surface (with higher chiller condenser pressures a higher saturation temperature will exist resulting in increased differential temperature). This altered calculation demonstrated that at the worst tube plugging level the MCR chiller has 18 percent margin. SwRI staff conclude that the newer thermodynamic model used has enhanced realism to actual equipment operation and that the licensee has adequately addressed NRC concerns.

5.5.4 Safety Analyses Considered

An area of the proposed UHS temperature increase that must be considered during the review is the impact on accident analyses. Braidwood staff performed an initial review of the accident analyses that is discussed in Attachment 1 of the LAR. Based on this review, licensee staff determined that only 2 of the 13 analyses reviewed were impacted by the proposed change to UHS temperature. Impacted analyses were identified as those wherein energy is removed from containment via the RCFS. These analyses were re-performed using a UHS temperature of 104 °F.

NRC staff requested additional information from the licensee in regards to five of the analyses that were determined by licensee staff to not be affected. An RAI (NRC, 2015a) was provided to Exelon Generating Company, LLC, in regards to this matter via a teleconference with the

NRC on February 18, 2015. The NRC requested that the licensee provide the rationale used in reaching the determination that the proposed UHS temperature change would not affect several specific analyses listed in Attachment 1 of the subject LAR. The question is summarized as NRC RAI–1 in the March 31, 2015, letter from David Gullot to NRC (EGC, 2015a), in which the licensee staff provides their rationale.

A review of the accident analyses information contained in the original LAR and in the response to the associated RAI was performed by SwRI staff. This review concludes that the licensee has correctly identified the analyses that are impacted by the increased UHS temperature. Many of the analyses under question are not directly impacted by the increased UHS temperature but rather by the CC temperature, which has been evaluated separately under the CC function.

6 SWRI'S CONCLUSIONS

SwRI has evaluated the licensee's LAR for a change in the TS for maximum return water temperature and noted several deficiencies in the initial information provided.

The licensee's setup of the model that estimates the peak UHS pond temperature is not entirely clear. The SwRI staff's preliminary evaluation of the LAR concluded that there could be major omissions in the following areas:

- Their analyses did not take into account the complicated hydraulics in the pond adequately, especially how circulation in the pond would be affected by release of water from the vertical discharge structure. Such a circulation could not be directly included in their plug-flow model. The licensee did not adequately justify their bases for adjusting the pond area and volume by a factor of 82.3 percent.

- Mixing induced by this jet discharge could either increase or decrease the peak return water temperature taken at the plant intake, but what occurs cannot be resolved without further analysis, including sensitivity studies on the efficiency factors for surface area and volume.

- The meteorological data from distant weather stations at Peoria and Springfield was not clearly compared to onsite data to determine if they were sufficiently similar or conservative for the purposes of determining maximum return temperature.

SwRI staff concluded that in order to make a solid case in the TER, it was necessary to perform independent confirmatory analyses to determine the adequacy of the temperature calculations and the meteorological data used in the licensee's analyses. Results from the SwRI confirmatory analysis concluded that the peak return pond temperature would remain below 105.2 °F, specified in the LAR for conditions characterized by the historic meteorological record.

Sensitivity analyses that used conditions beyond the design basis, (i.e., GCC), predicted return water temperatures that could be up to 1.0 °F higher than the 105.2 °F limit. Allowing measured temperatures of circulating water in the main cooling reservoir to significantly exceed 102 °F just prior to the DBA could lead to peak return temperatures from the UHS pond that exceed 105.2 °F, particularly for model parameters chosen for degraded pond cooling performance.

SwRI staff feels that the licensee's analysis of maximum 30-day water loss is adequate and that we do not need to perform further analysis on this part of the review.

Based on a review of the original LAR coupled with the licensees most recent responses to RAI's generated by SwRI and NRC staff, SwRI staff conclude that the licensee has demonstrated that there is adequate margin which exists in the event of a DBA accident coincident with a loss of the main cooling pond at an initial temperature of 102 °F UHS temperature. Based on this, there is reasonable assurance that all equipment will function in such a manner to remove necessary design heat loads and maintain plant structures, systems and components in a functional capacity, thus, protecting the health and safety of the public.

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