Attachment 6
to RBS-47668

Engineering Report No. RBS-ME-15-00036, Main Control Room (MCR) Operator Habitability under Beyond Design Basis Loss of HVAC Conditions

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MPR

Main Control Room (MCR) Operator Habitability under Beyond-Design Basis Loss of HVAC Condition

RBS-ME-15-00036
Revision 0

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Executive Summary

This report evaluates the habitability of the main control room (MCR) at River Bend Station (RBS) during the first 24-hours of a beyond-design basis loss of control building ventilation event caused by a control building chilled water (HVK) system malfunction that could not be corrected within 24 hours. The postulated event is for a plausible worst case set of conditions with respect to MCR habitability regarding heat stress. This postulated event is evaluated for the period between January 2014 and March 2015 with procedures in effect during that period. The purpose of this evaluation is to determine:

- The severity of the heat stress conditions inside the MCR;
- Actions the operators would have taken to mitigate the effects of heat stress conditions;
- Whether operators would have been able to safely and effectively perform their required control room functions during the postulated event.

Entergy reviewed the MCR heat loads and available backup ventilation options associated with all plausible plant events which could occur in conjunction with a loss of control building ventilation and determined the limiting plant event for maximizing temperatures in the MCR would be either (1) a loss of offsite power (LOOP) with reduced heat loads but limited ability to power ventilation equipment, or (2) normal operating heat loads and with power available to operate ventilation. Entergy then calculated the temperature and humidity in the MCR using the foregoing heat load conditions with a range of initial conditions and operator actions. These calculations are in References 18 and 30.

This report uses the temperature and humidity results of the Entergy calculations as inputs to determine the MCR habitability with respect to heat stress. This report:

- Calculates the wet bulb globe temperature (WBGT) to evaluate the severity of the heat stress condition on operator habitability.
- Evaluates the effect of added moisture generated by operators in the MCR;
- Evaluates the effect of heat stress on operator cognitive abilities;
- Calculates the allowable stay times and recovery times for personnel rotation in the MCR.

Entergy performed a heat load measurement test in the RBS MCR which showed that the design heat loads initially used in the analytical models of the RBS MCR were significantly higher (about 2 times) than the actual heat loads. Consequently, the calculations of MCR habitability based on these design heat loads are very conservative. For this report, design heat loads are used for most cases and one of the limiting cases is also performed using realistic heat loads.

Heat Stress Evaluation Methodology

The wet bulb globe temperature (WBGT) includes the effects of dry bulb air temperature, humidity (wet bulb temperature), air velocity, and radiant heat transfer. The WBGT includes all of the environmental factors that affect heat stress of individuals and is the industry standard for measuring the severity of a heat stress environment. The WBGT weighs the effect of humidity as

a much stronger effect than dry bulb air temperature alone on heat stress. Entergy/RBS procedure EN-IS-108 (Reference 4) uses WBGT, worker activity level, and the type of clothing worn to provide guidance for safely conducting work that requires entering an elevated temperature zone.

A key mitigating action to protect workers from heat stress is to institute stay time limits and associated recovery times for operator rotation if the limits of EN-IS-108 (see Table 2-1) are exceeded. The stay times and recovery times defined by EN-IS-108 are consistent with a conservative application of industrial and military guidelines (see Appendix B for details). The recovery time guidance states that workers can return to the hot environment after 60 minutes in a cool recovery area if they used the full allowable stay time in the hot environment. The recovery time is reduced proportionally for times in the hot environment that are less than the full allowable stay time. A review of records showed that all MCR operators received training on the use of EN-IS-108, and interviews with RBS senior reactor operators indicated that they would refer to EN-IS-108 for guidance on stay times if rising temperatures inside the MCR became uncomfortable.

Stay times for MCR reactor operators are based on the fact that they wear normal work clothing and perform low demand activity level work. In the postulated events analyzed, there are a limited number of moderate activity tasks which would be performed. These activities include removing ceiling tiles, opening doors, and placing fans. These tasks would be performed by readily available personnel other than MCR operators (see discussion of available personnel in next section). Consequently, these tasks would have no impact on operator stay times.

Since cognitive functions are important to MCR operators performing safely, this report also evaluates the effects of the MCR heat stress environment on operator cognitive abilities for the postulated event.

MCR Staffing and Relief Availability

A normal MCR operator crew consists of three senior reactor operators (SROs) and three reactor operators (ROs). A minimum of two SROs and two ROs are required to staff the MCR. For stay times 2 hours or greater and a 1 hour recovery time, one MCR crew can staff the MCR indefinitely by rotating two of the six operators for recovery while maintaining the minimum four operators in the MCR. In addition, relief personnel would be brought in to provide an additional margin for safe operation.

The duty manager would be notified when the loss of ventilation occurs and the abnormal operating procedure utilized. The duty manager would call in a range of personnel to provide assistance. Based interviews with RBS SROs, when the MCR operators began to feel uncomfortably hot they would ask the duty manager to call in relief operators. Two SROs are on call and required to be onsite within 90 minutes of an emergency call. These two relief SROs, in addition to the MCR crew on shift, would be able to staff the MCR indefinitely with six operators for stay times 3 hours or greater. During the weekday day shifts, a full backup team of operators is available on site doing training. Those individuals would be available to support MCR operator relief and rotation.

Based on an interview of an RBS SRO and Figure 13.1-5 from the SAR (Reference 31), there are other personnel available to perform moderate activity tasks such as removing ceiling tiles. The personnel expected to be available include: two maintenance technicians, one nuclear chemistry technician, and two radiation protection technicians. In the event none of these personnel were available, security could also provide personnel to perform these tasks.

Summary of Results

Four cases were analyzed for a loss of control building ventilation. Table 5-1 provides a summary of results. All cases have conservative assumptions. All cases considered in this report assume that the initial MCR conditions are at the design maximum temperature (75°F) and relative humidity (70%) (Reference 21) for normal operations, and the ambient outdoor conditions at the design maximum temperature (96°F) and relative humidity of 53%.

The first case discussed below is that the loss of control building ventilation occurs during normal plant operation. Realistic MCR equipment heat loads are assumed which are based on an MCR heat load test (Reference 27).

- Normal operation, realistic heat loads, smoke removal fan used.

  Restart of an MCR air handling unit is assumed not available. Actions taken to reduce the temperature of the MCR include opening stairway doors and installing temporary fans at 1 hour, initiating the smoke removal system at 2 hours, and removing selected ceiling tiles starting at 2.5 hours. For the conditions predicted in this case, discussed in Appendix H, Procedure EN-IS-108 would recommend:

  - No limit on operator stay times for the entire 24 hours.

  The moisture added by perspiration of people inside MCR would not significantly impact the humidity in the MCR since the entire volume of the MCR air is turned over several times per hour once the smoke removal fan is started. Cooling and humidity values are therefore determined by the flow of outside air.

Discussed below are the other three cases performed, which assume MCR design heat loads:

- Normal operation, design heat loads, smoke removal fans used.

  This case assumes the same normal operating initial conditions as in the first case discussed above. Actions taken to reduce the MCR temperature include opening stairway doors and installing temporary fans at 1 hour, initiating the smoke removal system at 2 hours, and removing ceiling tiles starting at 2.5 hours. For the conditions predicted in this case, discussed in the body of the report, Procedure EN-IS-108 would recommend:

  - No limit on operator stay times for the first hour.
  - Operator stay times 3.25 hours or greater for the remaining 24 hours.

  The moisture added by perspiration of people inside MCR would not significantly impact the humidity in the MCR since the entire volume of the MCR air is turned over several

times per hour once the smoke removal fan is started. Cooling and humidity values are therefore determined by the flow of outside air.

- Normal operation, design heat loads, service water cross connect cooling the MCR air handling unit.

  Action taken to reduce the MCR temperature is to start the MCR air handling unit at 1 hour with cooling provided by service water (conservatively assumed to be at the maximum post-accident temperature). For the conditions predicted in this case, discussed in Appendix F, Procedure EN-IS-108 would recommend:

  - No limit on operator stay times for the first four hours.
  - Operator stay times 3.8 hours or greater for the remaining 24 hours.

  The moisture added by perspiration of people inside MCR would not significantly impact the humidity in the MCR since the entire volume of the MCR air is turned over about once per hour once the air handling unit is initiated.

- Loss of MCR ventilation in conjunction with a loss of offsite power (LOOP) event - design heat loads for equipment that would operate during a LOOP.

  No ventilation is assumed to be available. Action taken to reduce MCR temperature is removal of ceiling tiles, initiated when MCR reaches 104°F (approximately 1 hour). For the conditions predicted in this case, discussed in Appendices G and I, Procedure EN-IS-108 would recommend:

  - No limit on operator stay times for the first 13 hours.
  - Operator stay times 2.75 hours or greater for the remaining hours (13 – 24 hours).

  The moisture added by perspiration of operators inside the MCR of 0.5 pounds of water vapor per hour per person is based on the metabolic cooling needs and is a significant contributor to the WBGT by the second half of the 24-hour period of the event.

For the above three cases assuming design heat loads, the most limiting stay times for low demand activity work are greater than 2 hours. Therefore, as discussed in the previous section, all cases could be adequately staffed indefinitely by one MCR crew by rotating two of the six operators for recovery while maintaining the minimum four operators in the MCR at all times. In addition, two relief operators could be brought in within 90 minutes of a call to provide an additional margin for safe operation. For the LOOP case, no stay times would be imposed until 13 hours after the start of the event which would be ample time to plan for rotation of operators.

The analysis, described in the body of this report, also shows that several short-term moderate work demand tasks to mitigate the heat stress conditions (portable fans, ceiling tile removal, etc.) could be performed by individuals other than MCR operators without approaching the stay times recommended for moderate activity tasks for all cases evaluated.

The potential impact of heat stress on operator cognitive abilities was considered separately from the typical industry stay time guidance based on physiological considerations. A review of the literature, discussed in Appendix C, concludes that the heat stress conditions associated with this

postulated event would not be expected to affect an operator's cognitive abilities. Operator training and teamwork and the types of tasks performed would mitigate the effects of heat stress on cognitive abilities, particularly while observing the stay times established based on physiological considerations.

As previously discussed, the MCR design heat loads for the normal operating cases were shown to be 76% higher than the realistic heat loads by an MCR test (Reference 27). As shown by a comparison of the first two normal operation cases presented above, when the realistic heat loads are used, the resulting temperature rise in the MCR is substantially reduced and no stay times are required. A similar reduction in temperatures would occur for the realistic heat loads in the case of the MCR being cooled by a service-water-cooled air handling unit for the MCR for both normal operations and for the case where a LOOP was occurring. (Testing was not performed to determine realistic LOOP loads; however, the LOOP heat loads are lower than the normal operation heat loads.) In both of these cases there would be no recommended stay times, as discussed in more detail in Appendices F and G.

Conclusions

During the postulated event for normal operation design heat loads using heat stress mitigating actions based on interviews, one MCR operator crew could adequately staff the MCR indefinitely by rotating two of the six operators for recovery while maintaining the minimum four operators in the MCR. Two SROs would be available within 1.5 hours of a call to provide additional support and this would allow six operators to remain in the MCR at all times during the early hours of the event.

If realistic heat loads for the MCR are used, no stay times would be necessary for MCR operators for the two normal operation scenarios modeled in this report, or for the LOOP scenario with MCR ventilation by the MCR air handling unit, ACU1A(B), using service water cooling of the chilled water loops.

During the postulated event in conjunction with a loss of offsite power, stay times are not needed for the first 13 hours. Therefore ample time would be available for watchstanders to conduct planned rotations with the MCR fully manned.

Individuals brought into the MCR to perform expected short-term physical activities requiring moderate work demand to mitigate the temperature would have been able to perform those activities without heat stress impacting their performance.

Recommendations

Section 7 of this report provides recommendations to improve RBS procedures and training with respect to mitigating heat stress in the MCR when ventilation is lost.

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Main Control Room (MCR) Operator Habitability under Beyond-Design Basis Loss of HVAC Condition

1.0 Scope and Objective

This report evaluates the habitability of the main control room (MCR) at River Bend Station (RBS) during the first 24-hours of a beyond-design basis loss of control building ventilation event that has been postulated to occur if the control building chilled water (HVK) system malfunctioned and could not be returned to service. The postulated event is evaluated for the period between January 2014 and March 2015 with procedures in effect during that period.

This evaluation starts with normal plant operation as the initial condition for the evaluation. It is applicable for the postulated loss of control building event occurring in conjunction with any other plausible plant event because the environment in the MCR with normal operation heat loads produces the bounding heat stress conditions in the MCR. (See Section 1.1 for additional discussion.)

The purpose of this evaluation is to determine:

- The severity of the heat stress habitability conditions inside the MCR during predicted temperature and humidity transients associated with the postulated event;
- What actions the operators would take to mitigate the effects of heat stress conditions;
- Whether operators would be able to perform the required control room functions.

1.1. Background

On March 9, 2015, a loss of control building ventilation occurred during an outage at RBS. After a period of less than four hours the problem was identified and resolved and a chiller was restarted. During this event, the dry bulb temperature in the MCR remained below 73°F (Reference 22) and people reported that the conditions in the control building were not uncomfortable due to temperature (Reference 34). A discussion paper developed by Entergy of the temperature data available for the MCR during the event is included as Appendix D of this report. A discussion of actions taken which prepared MCR personnel for a potential increase in MCR temperature is included as Appendix E of this report.

Due to the March 2015 event, questions were raised regarding the temperature which could have occurred in the MCR during a loss of control building ventilation on the highest design temperature day (Reference 18) in conjunction with any other plausible plant event. For this postulated event, it is assumed that a chiller would not successfully restart. Entergy developed Calculation ENTR-078-CALC-004 (Reference 18) to calculate the bounding temperature in the MCR during the postulated event to provide input to evaluate the impact on the MCR equipment and MCR personnel. Entergy reviewed the MCR heat loads associated with all plausible plant events which could occur in conjunction with a loss of control building ventilation and determined the limiting condition was either (1) a loss of offsite power (LOOP) with reduced

heat loads but limited ability to power ventilation equipment, or (2) normal operating heat loads with power available to operate ventilation.

Entergy (Reference 18 and Reference 30) evaluated several cases with these heat load conditions and mitigating actions taken by operators based on procedures and interviews. This report evaluates the impact on operators of the MCR temperature and humidity conditions for several cases. The body of this report evaluates the scenario with the worst case heat stress condition during the initial portion of the event. Appendices F, G, H, and I provide evaluations of additional cases. Table 1-1 provides a summary of the cases which are evaluated in this report for habitability.

Table 1-1. Summary of Cases Evaluated

Location of Case in this Report	Gothic Calculation Reference Case	Heat Loads Applied	Ventilation Sources
Body	Reference 18, Case 2 (temperature) / Attachment 2 (relative humidity)	Normal Operation Design Loads	Open MCR doors with staged fans. Smoke removal fan started at 2 hours.
Appendix F	Reference 18, Attachment 1 (with relative humidity adjusted)	Normal Operation Design Loads	Service water cross connect cooling the MCR air handling unit started at 1 hour.
Appendix G	Reference 30, Attachment 14	Loss of Offsite Power Design Loads	No ventilation.
Appendix H	Reference 30, Attachment 5, Case B	Normal Operation Realistic Loads	Open MCR doors with staged fans. Smoke removal fan started at 2 hours.
Appendix I	All Cases Above Evaluated	Evaluation of Additional Humidity due to Operator Perspiration for All Previously Evaluated Cases	

On February 16, 2016, NRC issued a special inspection report (NRC Letter EA-15-140) which summarized their preliminary findings on this issue. On February 23, 2016, MPR provided comments on the habitability assessment provided in the NRC special inspection report (Reference 36).

1.2. Method of Presentation

Section 2.0 identifies the inputs used for this evaluation report.

Section 3.0 provides the assumptions that were made to model the postulated event for the habitability evaluation.

Section 4.1 uses the air temperature and relative humidity from Entergy's GOTHIC analysis (Reference 18) to calculate the wet bulb globe temperature (WBGT).

Section 4.2 evaluates the potential for physiological effects due to the WBGT thermal transients on personnel performing tasks inside the MCR during the postulated event.

Section 4.3 evaluates the possible impacts of the calculated WBGT transient on human cognitive behavior.

Section 4.4 discusses the expected habitability management response for heat stress that would have been performed by RBS personnel during the postulated event. This response is based on interviews with reactor operators about habitability management in the MCR with rising temperature conditions and a review of operator training. Additional details are provided in Appendix A.

Section 5.0 provides a summary table of all the habitability results of the different cases tested.

Section 6.0 identifies the key conclusions of the evaluation of the different cases.

Section 7.0 provides recommendations for the next revision to the loss of control building ventilation procedure and for heat stress training.

Appendix A discusses the readiness of the RBS reactor operators to respond to a loss of MCR ventilation. It is based on:

- Review of operator actions during a prior loss of control building ventilation at RBS on March 9, 2015.
- Review of RBS thermal habitability training for control room operators.
- Interviews of RBS personnel on habitability actions inside the MCR during a postulated extended loss of main control building ventilation.

Appendix B compares industry and military guidelines on worker habitability in hot environments with the Entergy guidelines in place at RBS.

Appendix C provides a discussion of the heat effects on cognitive performance of workers and if this consideration might affect the MCR operators in the performance of their plant control functions during the postulated event.

Appendix D provides a paper developed by Entergy of the timeline of events for the March 9, 2015 loss of control building ventilation, with a goal being to identify the actual temperature inside the MCR during this event.

Appendix E provides a paper developed by Entergy summarizing habitability-related actions that were taken at RBS during the March 9, 2015 loss of control building ventilation.

Appendix F provides a habitability assessment of the Reference 18, Attachment 1 case (MCR ventilation is restarted after one hour using cross-connected service water). As discussed in Reference 18, the relative humidity values calculated by Reference 18 do not represent expected humidity in the MCR but they were conservative for determining maximum air temperatures. In order to properly determine habitability, this Appendix also develops appropriately conservative relative humidity values to be used by the evaluation.

Appendix G provides a habitability assessment of the Reference 30 Attachment 14 case (loss of control building ventilation in conjunction with a loss of offsite power (LOOP) in which no ventilation is provided for the MCR during the event).

Appendix H provides a habitability assessment of Reference 30, Attachment 5, Case B (similar to the baseline worst case Reference 18, Case 2/Attachment 2 except that realistic heat loads inside the MCR are applied based on MCR testing reported by Reference 27).

Appendix I provides a habitability assessment of each of the cases evaluated in the main body of the report and in Appendices F, G and H when the contribution to the humidity in the MCR of the perspiration from the people who are inside the MCR during the event is accounted for.

2.0 Evaluation Inputs

This section provides the evaluation inputs used in the body of this calculation. Additional inputs are provided in Appendices F, G, H, and I for the cases documented therein.

1. The temperatures used to evaluate the heat stress on personnel in the MCR are from the results of Case 2 from ENTR-078-CALC-004 (Reference 18). The calculation provides average and peak MCR temperatures results. The peak temperatures are not located in the horseshoe area of the MCR, where operators typically spend most of their time. Operators who are not in the horseshoe area would be moving throughout the MCR. Therefore, the average MCR temperature is used to evaluate the heat stress on operators. The dry bulb temperatures for the postulated event are shown in Figure 4-1.

2. The relative humidity in the horseshoe area is taken from ENTR-078-CALC-004 (Reference 18) Attachment 2 for Case 2 with the maximum allowable initial MCR relative humidity (70%) (Reference 21). The relative humidity during the postulated transient is shown in Figure 4-2.

3. Work demand levels are an indication of how much metabolic heat an individual generates due to the work that the individual performs. The definitions of the different levels of work demand used by Entergy/RBS (Reference 4) are shown in Table 2-1, below.

   General reactor operator duties inside the MCR are consistent with the low work demand category. The additional physical actions taken during the postulated event listed in Table 3-2 are consistent with the moderate work demand category. No high work demand tasks are performed in the MCR during the postulated events; accordingly, heat stress effects for high work demand tasks is not considered in this evaluation.

4. Clothing impacts the body's ability to cool itself in a heat stress condition. Normal work clothes are typical of those worn in the MCR.

5. Based on interviews with RBS operators and Figure 13.1-5 from the RBS SAR (Reference 29), a MCR operator crew is made up of three senior reactor operators (SROs) and three reactor operators (ROs). A minimum of two SROs and two ROs are required to be in the MCR. SROs can substitute for ROs if needed.

Table 2-1. Work Demand Levels Used for Stay Times (Ref. 4)

WORK DEMAND	ACTIVITY*
L LOW 180 Kcal/hr.	Sitting/walking Monitoring/Inspecting Calibrating instruments/equipment Equipment operation (e.g., crane operations)
M MODERATE 300 Kcal/hr.	Sorting materials (e.g., clothing) Intermittent stair or ladder climbing Moderate or intermittent manual materials handling Installing insulation Manual valve alignment - easy Mopping/Sweeping
H HIGH 415 Kcal/hr.	Manual valve alignment - difficult Heavy or continuous manual material handling Manual decontamination Manual hoisting Scrubbing/brushing/scraping/Hand Sawing Shoveling/Digging Using tight fitting respirator

*The listed activities are for example only. This list is not all-inclusive.

3.0 Assumptions

This section provides the evaluation assumptions used in the body of this calculation. Additional assumptions are provided in Appendices F, G, H, and I for the cases documented therein. This analysis uses the MCR temperature and humidity results from Reference 18 Case 2 (normal plant operation is the initial condition) and Attachment 2 (maximum allowable relative humidity is the initial condition), respectively, as inputs for the evaluation of the habitability of the MCR. Therefore, the assumptions used by Reference 18 also apply to this evaluation. Key assumptions from Reference 18 which are important to the habitability evaluation are repeated as follows:

1. Per Reference 18 Assumption 4.1, for the calculation of heat loads, ten people are assumed to be in the MCR during the event. This is conservative as AOP-0060 (Reference 1, Section 5.1.6) directs non-essential personnel to leave the control room during a Loss of HVAC. The heat loads are placed in the control room as follows:

    a. The heat load from five operators is distributed in the central horseshoe area of the MCR.

    b. The remaining five people are assumed to be moving around the MCR and their heat load is evenly distributed across the MCR.

    The total heat load from each person is 475 BTU/hr. This heat load includes both the sensible heat and the latent heat produced by operators in the MCR. This is conservative with respect to dry bulb temperature but neglects the moisture due to perspiration. The impact of moisture due to perspiration is evaluated in Appendix I of this report.

2. Case 2/Attachment 2 of Reference 18 applies the following assumptions:

   a. Reference 18 Assumption 4.3, Table 5 (shown in this calculation as Table 3-1) shows the mitigating operator actions taken based on the referenced procedural guidance, operator interviews and operator action taken during the March 9, 2015 loss of control building ventilation event.

   b. Per Reference 18, Input 3.1 and Attachment 2, the air inside the MCR at the start of the loss of ventilation event is at the maximum of the normal ranges of temperature (75°F) and of humidity (70%) (Reference 21). These initial values maximize the potential impact to habitability conditions during a loss of ventilation.

   c. Per Reference 18, Assumptions 4.5 and 4.12, ambient outdoor air conditions are at 96°F and 53% relative humidity during the day with a normal diurnal temperature cycle for the region. The ambient absolute humidity (pounds of water vapor per pound of air) remains constant through the temperature cycle.

   d. The expected duration for the mitigating actions which would be considered moderate work demand (as defined in Section 2) are listed in Table 3-2 below based on Reference 18, Table 5.

3. Based on an interview of an RBS SRO (Reference 28), there are two SROs on call for Emergency Response at all times. These SROs are required to be onsite within 90 minutes of a call in the case of an emergency. While the loss of ventilation would not classify as an emergency, it is reasonable to assume that these SROs could be onsite within 90 minutes of a call.

4. Per OSP-0046 (Reference 32), the duty manager would be notified when AOP-0060 was entered. Therefore, it is expected that there would be personnel available to make calls for reliefs within approximate one hour after the loss of ventilation.

5. Based on an interview of an RBS SRO (Reference 28) and Figure 13.1-5 from the SAR (Reference 31), there are other personnel available for the MCR operators to direct to remove ceiling tiles or perform other moderately demanding physical activities in the MCR. The personnel expected to be available include: 2 maintenance technicians, 1 nuclear chemistry technician, and 2 radiation protection technicians. In the event none of these personnel were available, security could also provide personnel to perform these tasks.

6. Based on an interview of an RBS SRO (Reference 33), if MCR personnel began to show signs of heat stress, SROs would call for reliefs and rotate out one SRO and one RO at a time for periods of recovery while maintaining the minimum of four operators in the MCR.

Table 3-1. Mitigating Actions Taken (Reference 18, Table 5)

Time	Action	Basis
0	Loss of Control Building cooling (failure of HVC-ACU1A(B) to run due to chiller failure) Offsite Power available. Toilet and Exhaust Fans remain running.	
<30 min	Operators attempt to restart chillers or manually start HVC-ACU1A(B). ***These actions are assumed to fail.***	AOP-0060 (Reference 8.6) Step 5.1.1 and Operator Interviews.
30 min	Complete actions to open back panel doors in Control Room.	AOP-0060 (Reference 8.6)
	Operators would normally initiate steps to align SWP to provide cooling to HVC-ACU's Operators would start this action at some MCR temperature below the TS limit (e.g., 100F). ***This action is not credited (See Attachment 1).***	AOP-0060 step 5.1.2. (Reference 8.6) and Operator Interviews
1 hour	Operations open Main Control Room door CB136-9 to SW stairway (near elevator) and open door from stairwell to the outside	Operator Interviews
1 hour 30 minutes	A portable electric fan staged in door CB136-9 to exhaust from Main Control Room.	Operator Interviews
2 hours	Smoke Removal fan (HVC-FN9) started to provide Main Control Room Ventilation.	SOP-0058 (Reference 8.30) Section 5.5 and Operator Interviews
2 hours 30 minutes	Initiate actions to remove ceiling tiles.	AOP-0050 (Reference 8.14)

Note: Table was taken directly from Reference 18, therefore, references cited are from that document.

Table 3-2. Task Duration for Moderate Work Demand Tasks

Task	Task Initiation Time (See Table 3-1)	Task Duration (min.)
Open electrical panel back doors	Within first 0.5 hours	Completed within first 30 minutes
Open MCR door to stairway and stairway door to outside	1.0 hr	Estimated 15 min or less
Stage portable electric fan in MCR door	1.5 hrs	Estimated 15 min or less
Remove selected ceiling tiles	2.5 hrs	80 min to remove 80 tiles - in eight 10-minute groups (Reference 2)

4.0 Detailed Discussion

As discussed in Section 1.1, the body of this report evaluates the most limiting postulated case for a loss of ventilation of the MCR for habitability. Additional cases are evaluated in Appendices F, G, H, and I. This section provides details of the methodology used by all cases and the details of the most limiting case.

Section 4.1 incorporates the temperature and humidity data from Entergy's MCR thermal heatup model and converts these data into wet bulb globe temperatures (WBGT). In Sections 4.2 and 4.3, the WBGT is used to evaluate the heat stress on the physiological and cognitive performances of the reactor operators. Section 4.4 provides the actions that would be taken by the RBS operators during the postulated event to mitigate any adverse heat stress effects on the MCR operators. Section 4.5 summarizes the overall impact of the thermal transient on the operators.

4.1. Postulated Event Transient Conditions – Limiting Case

Section 4.1.1 evaluates the transient behavior of the temperature and humidity inside the MCR during the postulated worst case loss of control building ventilation event. Section 4.1.2 identifies how these transients affect the wet bulb globe temperature (WBGT) which is the thermal factor that correlates with heat stress habitability. Additional information on how WBGT is calculated is in Appendix B.

4.1.1. MCR Temperature and Humidity during the Limiting Postulated Event

As discussed in Sections 2.0 and 3.0, dry bulb temperatures and relative humidities in the MCR during the event were calculated in Reference 18, Case 2 and Attachment 2, respectively.

MCR dry bulb temperature variation with time from this calculation is shown in Figure 4-1, below. The blocks and arrows in Figure 4-1 provide a timeline for the actions that were assumed to be taken (see Table 3-1) during the postulated event by Reference 18, Case 2.

In Figure 4-1, the temperature is seen to rise sharply as the heat inputs to the MCR heat the air which is not being circulated or cooled. Significant circulation of outside air to the MCR begins to occur when the smoke removal fan is started at 120 minutes. That is when the air temperature begins to decrease. Since the outside air is at 96°F, the equilibrium temperature is still relatively high at 100°F to 105°F.

The variation in relative humidity of the air in the MCR is shown in Figure 4-2. The humidity is initially the maximum design humidity (70%) allowed in the MCR (see Section 3.0, Assumption 2). As the MCR air heats up, the amount of moisture in the air stays the same so the relative humidity drops. Then, as fresh outside air having high relative humidity (53%) replaces the original air, the relative humidity inside the MCR levels off between 35% and 45%.

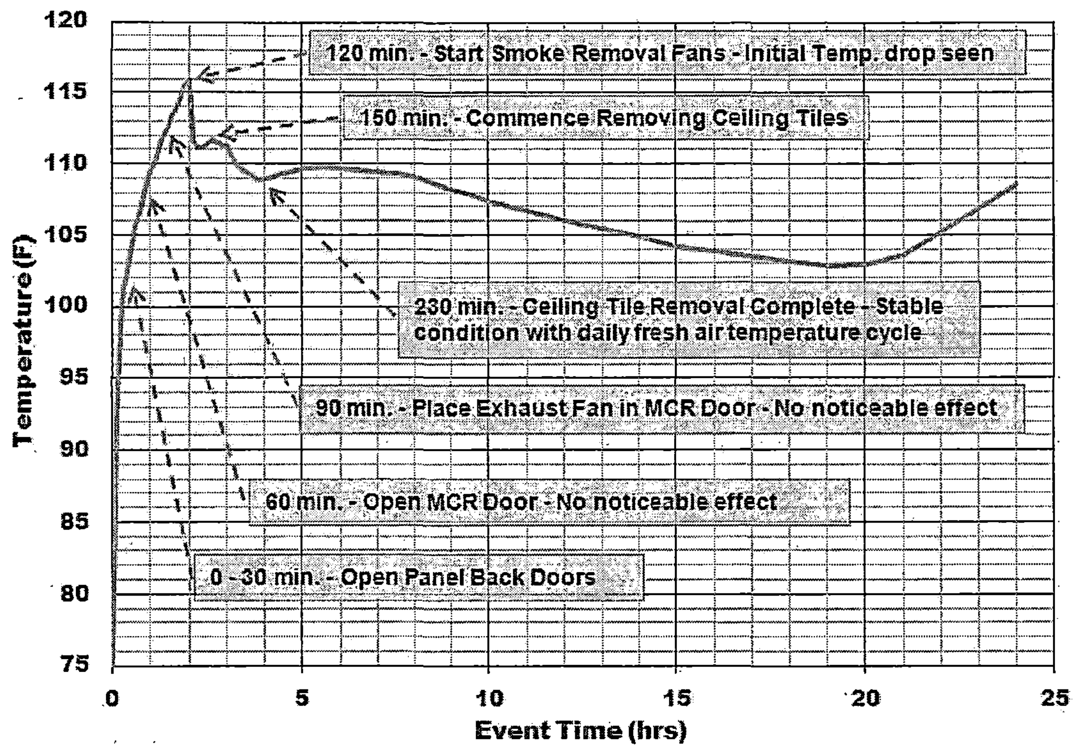

Figure 4-1. MCR Temperature for Postulated Loss of HVAC Event with Design Heat Loads

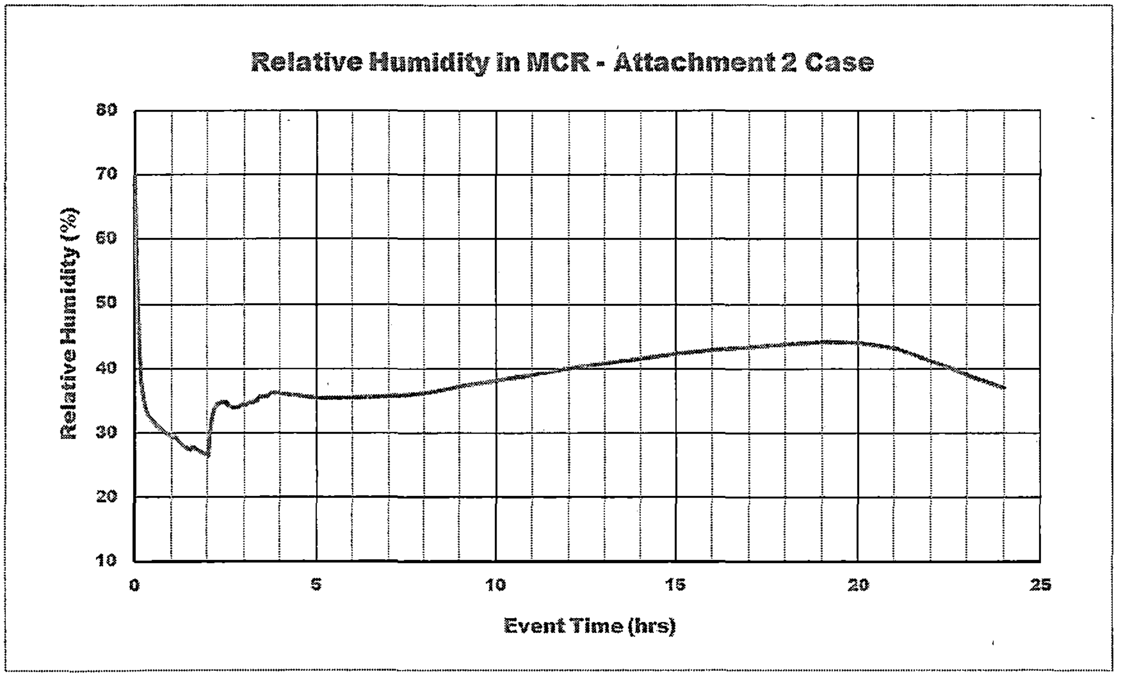

Figure 4-2. Humidity of Air in MCR during the Postulated Event with Design Heat Loads

4.1.2. Wet Bulb Globe Temperatures

Heat stress is correlated with ambient temperature, radiation effects, air velocity, and relative humidity. These effects are represented by the use of the WBGT. The use of WBGT for the management of personnel habitability in a heat stress environments is well accepted by industry and military standards nationally and internationally (Refs. 7, 8, 9, 10, 11, 12, 15). Consistent with industry practice, WBGT is used at RBS to establish stay times for entries into areas that are subject to heat stress (Reference 4).

WBGT is calculated based on the wet bulb temperature and the black globe temperature. Black globe temperature measures the effect of radiant heat transfer and wind convection and is equal to the dry bulb temperature in the absence of radiant heat sources or sinks and air velocities. The wet bulb temperature is a strong function of the relative humidity. The WBGT is more heavily weighted by wet bulb temperature than by the dry bulb temperature, as can be seen in the equation for calculating the WBGT for indoor environments:

$$WBGT = 0.7 \times T_{wet\ bulb} + 0.3 \times T_{dry\ bulb}$$

The calculations of the WBGT are explained in more detail in Appendix B of this report. The resulting WBGT transient for the postulated event is plotted in Figure 4-3, together with the dry bulb and wet bulb temperatures.

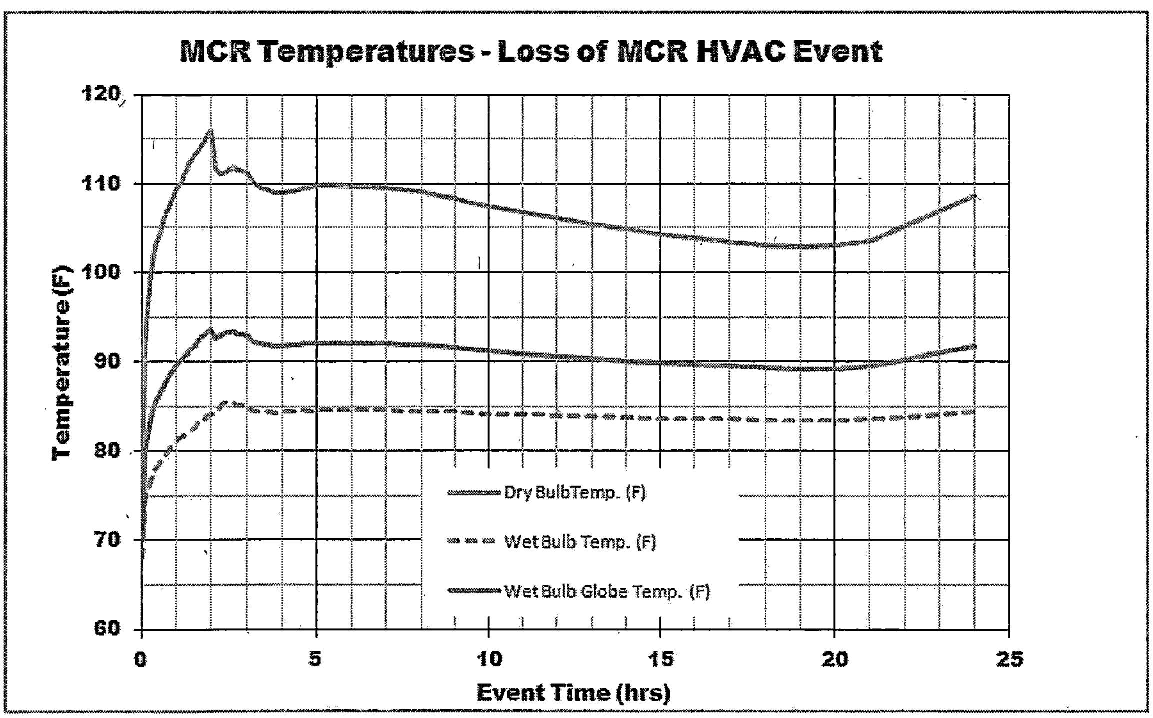

Figure 4-3. MCR Temperatures for Case 2/Attachment 2 with Design Heat Loads

4.2. *Evaluation of Potential Physiological Effects for Postulated Transient*

This section evaluates if industry standards would recommend time limits for personnel exposed to the MCR conditions identified in Section 4.1 to prevent adverse physiological effects as a result of the temperature and humidity.

4.2.1. Stay Time Limits

Consistent with industry practices, Entergy/RBS procedures provide guidance to check the conditions of zones which may have elevated temperatures prior to assigning work in these areas. Mitigating actions are taken to provide for the safety and effectiveness of the workers for work zones determined to have the potential to cause heat stress based on the WBGT, worker activity level, and clothing worn. A key mitigating action is to institute stay time limits.

Table 4-1. Stay Times (minutes) Allowed by Entergy/RBS for Workers in Normal Work Clothes

	Work Demand		
WBGT	LOW	MOD	HIGH
120°F	20		
118°F	20		
116°F	25		
114°F	25	15	
112°F	30	20	
110°F	35	20	
108°F	45	25	
106°F	50	25	
104°F	60	30	15
102°F	75	35	20
100°F	90	40	20
98°F	105	45	25
96°F	130	50	35
94°F	165	55	40
92°F	195	70	45
90°F	230	85	55
88°F	NL	110	70
86°F	NL	170	85
84°F	NL	240	115
82°F	NL	NL	180
80°F	NL	NL	NL
78°F	NL	NL	NL
76°F	NL	NL	NL
74°F	NL	NL	NL
72°F	NL	NL	NL
70°F	NL	NL	NL
68°F	NL	NL	NL
66°F	NL	NL	NL

Table Legend: NL= No limit on stay time

Entergy/RBS has stay time guidance which is used for preparing to enter hot conditions for work, EN-IS-108 (Reference 4) for typical heat stress conditions. A review of industry standards (provided in Appendix B) indicates that the stay time values used by Entergy/RBS from Reference 4 are consistent with guidelines used in other standards and more conservative than the most limiting allowable range of stay times proposed by EPRI in Heat Stress Management

Program NP-4453, Rev. 0 (Reference 7). In Heat Stress Management Program NP-4453, Rev. 1, Reference 8, EPRI proposes a new methodology using a software program to establish check times at which workers should start checking each other for signs of heat stress and notes that these times could be exceeded as long as there are no adverse signs of heat stress. The new revision defines an action time, which is closely corresponds to the shorter exposure time of the range of stay times that were previously used in NP-4453 Rev. 0, and notes that the worker who is observing check times should generally not stay beyond two times the action time, which corresponds to the high end of the allowed stay times in NP-4453 Rev. 0. The emphasis on checking each other for signs of heat stress in Rev. 1 corresponds closely to the standard training in EN-IS-108 and with the general training of SROs for self-monitoring each other when on watch in the MCR. The factor of two times the minimum stay time, promoted by NP-4453 Rev. 1 substantiates that the minimum stay times defined by EN-IS-108 should not be considered to be challenging for expected heat stress performance of operators..

Table 4-1 provides stay time limits for workers dressed in normal work clothes for low, moderate and high work demand used in the Entergy/RBS procedure (Reference 4). Section 2.0 and Table 2-1 provide the definition of work demand.

4.2.2. Stay Time Limits for Postulated Event Conditions

The postulated event in the MCR is a transient condition in a continuously occupied work zone that initiates with mild thermal conditions. Entergy Procedure EN-IS-108 (Reference 4), on the other hand, provides guidance to workers entering a known hot work zone. Nevertheless, the stay time limits used by this procedure provide a useful indication of the severity of the postulated event conditions in the MCR.

For the determination of stay times in this report, the WBGT value used as the reference temperature for determining stay times is selected to the nearest tenth of a degree, similar to the readouts of industrial WBGT meters. The stay time that is imposed for each temperature step is applied when that temperature step is reached. For example, a stay time of 195 minutes is imposed for Low work demand tasks when the WBGT reaches 92°F (see Table 4-1). Entergy agrees that this is consistent with the EN-IS-108 procedure. It should be noted, however, based on discussions with the Industrial Safety Coordinator at RBS who routinely uses stay times when entering a known hot area for performing work, that conservatism is typically used in using the table to determine stay times before entering a hot room. RBS industrial safety personnel stated that for reactor operators already inside the MCR with a rising heat stress environment such as the postulated event, identifying the status of stay times as each temperature step is reached is a reasonable approach to deciding cumulative stay times, as discussed below in the discussion on Table 4-3.

The stay time limits for the conditions at several points throughout the transient were evaluated using the Entergy/RBS guidelines shown in Table 4-1. As discussed in Section 2.0, Input 3, general reactor operator duties are low work demand and manual operator actions to mitigate temperature (i.e., removal of ceiling panels, installation of portable fans, etc) are moderate work demand. As discussed in Section 2.0, Input 4, MCR operators are clad in normal work clothes.

Data points evaluating the conditions throughout the postulated event are shown in Table 4-2. The last two columns of the table provide the stay time limits for low demand and moderate demand work at the MCR conditions throughout the transient. Figure 4-4 shows how the maximum stay time requirements change over the duration of the postulated event. The gap between 14 and 22 hours in Figure 4-2 corresponds to the time when the WBGT drops below 90°F (see Table 4-2) and there are no specified stay time limits for Low work demand tasks.

Table 4-2. Stay Times for Conditions during Postulated Event with Design Heat Loads

Event Time (hr)	Dry Bulb Temp (F)	Relative Humidity (%)	Wet Bulb Temp. (F)	Wet Bulb Globe Temp. (F)	LOW Demand Work Stay Time* (min)	MODERATE Demand Work Stay Time* (min)
0.0	75.0	70	68	70.1	NL	NL
0.3	101.2	33	77	84.4	NL	240
0.6	105.7	31	79	87.2	NL	170
0.9	108.7	30	81	89.2	NL	110
1.1	110.1	29	82	90.1	230	85
1.6	113.5	28	83	92.2	195	70
2.0	115.9	26	84	93.6	195	70
2.5	111.4	34	85	93.2	195	70
3.0	111.2	34	85	93.0	195	70
5.0	109.7	35	85	92.1	195	70
6.0	109.7	35	85	92.1	195	70
8.0	109.1	36	84	91.9	230	85
10.0	107.4	38	84	91.2	230	85
12.0	106.0	40	84	90.6	230	85
14.0	104.8	41	84	90.1	230	85
16.0	103.8	43	84	89.6	NL	110
18.0	103.1	44	83	89.3	NL	110
20.0	103.0	44	83	89.3	NL	110
22.0	105.2	41	84	90.2	230	85
24.0	108.6	37	85	91.7	230	85

Note: NL = No limit on stay times

* = More restrictive stay times are imposed when rising WBGT reaches each temperature step in EN-IS-108 stay time table (Table 4-1 of this report). Less restrictive stay times are allowed when WBGT falls below each temperature step.

Low Work Demand Tasks

For low work demand duties such as normal watchstanding duties of the reactor operators, as discussed in Section 2.0, maximum stay times of either 230 minutes or 195 minutes would be warranted after the first hour. As a conceptual example of how these stay times could be used, if the initial reactor operators on watch only performed normal watchstanding duties (i.e., Low work demand tasks), they would have a little over four hours before rotation with backup watchstanders would be needed. This is shown in Table 4-3 by time spent in MCR using up about 0.88 of the allowed cumulative stay time after 4 hours. Similarly, operators coming on watch at the 4th hour would use up 0.90 of their allowable stay times after 3 hours, etc.

According to EN-IS-108 (Reference 4), the watchstanders could return to the MCR after 60 minutes in a cool recovery area after they use their full allowable stay time limits or they could return after 30 minutes of recovery time if they only use up half the allowable stay time limits. Thus a reactor operator could work for 4 hours and take an hour off before returning or could work for a fraction of each hour and take a shorter time in the recovery area. This is shown in Table 4-4 where operators can rotate from the MCR to a recovery area based on full stay time or hourly rotation as a function of the allowed stay times. Using the rotation times of Table 4-4, a six operator crew (3 SROs and 3 ROs) could provide indefinite watchstanding, with the minimum of 4 operators inside the MCR at all times, by rotating 2 people at a time to a cool recovery area based on a 3:1 or 2:1 on/off time rotation (i.e., ≥ 2-hour stay times) whether by using full stay times followed by 1 hour recovery or by using fractions of an hour each hour. With two additional relief operators, a minimum of 6 operators could be maintained inside the MCR for stay times permitting at least a 3:1 on/off time rotation (≥ 3-hour stay times).

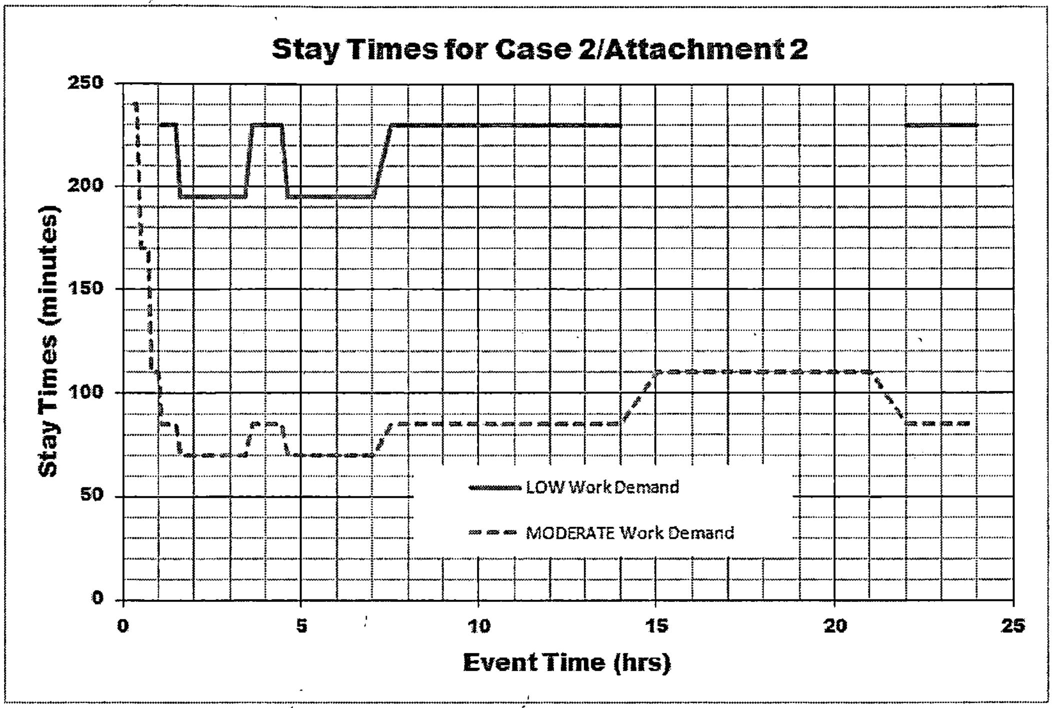

Figure 4-4. Stay Times for Case 2/Attachment 2 with Design Heat Loads

Table 4-3. Conceptual Watch Stander Stay Times for Design Heat Load Event

Event Time (hr)	LOW Work Demand Stay Time in MCR		Time Increment in MCR	Fraction of Stay Time Used in Increment	Cumul. Stay Time Fraction Used	Cumul. Time in MCR
	(min)	(hr)	(hr)			
0 to 1.0	No Limit	No Limit	1.0	0.00	0.00	
1.0 to 1.5	230	3.8	0.5	0.13	0.13	
1.5 to 3.5	195	3.3	2.0	0.62	0.75	
3.5 to 4.0	230	3.8	0.5	0.13	0.88	4.0 hrs
4 to 4.5	230	3.8	0.5	0.13	0.13	
4.5 to 7.0	195	3.3	2.5	0.77	0.90	3 hrs
7.0 to 10.5	230	3.8	3.5	0.91	0.91	3.5 hrs
10.5 to 14.0	230	3.8	3.5	0.91	0.91	3.5 hrs

Table 4-4. Alternate Ways of Using Recovery Times for a Watch Rotation

Low Work Demand	Full Stay Time Rotation			Hourly Rotation Times		
WBGT (°F)	Stay Time (min)	Recovery Time (min)	Total Cycle (min)	Stay Time (min)	Recovery Time (min)	Simplified Rotation Time On/Off (min)
90≤ T<92	230	60	290	47	13	45/15 [3:1]
92≤ T<94	195	60	255	45	15	45/15 [3:1]
94≤ T<96	165	60	225	44	16	40/20 [2:1]
96≤ T<98	130	60	190	41	19	40/20 [2:1]
98≤ T<100	105	60	165	38	22	

The Entergy procedure EN-IS-108 (Reference 4) has very conservative stay times for low work demand, commencing with 230 minutes when WBGT reaches 90°F. The EPRI guidelines for work in power plants (EPRI NP-4453 Rev. 0, Reference 7) would initiate stay times only after WBGT reaches 93°F and then permit stay times from 3 hours (180 min) to 8 hours (480 min) until the WBGT reaches 97°F, with the actual time spent within this range being decided by self determination for signs of heat stress and the use of mitigating measures such as fans and drinks of cold water. Therefore, some operators would be expected to be able to perform effectively for stay times beyond those recommended by EN-IS-108 as long as they were watching for signs of heat stress in themselves and others. These other standards are discussed in Appendix B (Section 2.2).

Moderate Work Demand Tasks

For moderate work demand duties, as discussed in Section 2.0 and listed in Table 3-2, minimum stay times would be no shorter than 70 minutes during the event. Most of the tasks, such as installing portable fans and opening stairway doors would take no more than 30 minutes so these stay times should not be unduly restrictive to workers who will perform these tasks. In the case of ceiling tile removal, Reference 2 notes removal could take 80 minutes overall but tiles are divided into 8 groups each taking about 10 minutes. The installation of the stairway fans are done in part in the stairway air environments which would be cooler than the MCR. Management of tasks is further discussed in Section 4.4.

There are no tasks inside the MCR during the postulated event that involve High work demand, as defined in Section 2.0.

4.3. Potential for Cognitive Effects on MCR Personnel due to MCR Conditions

This section evaluates the potential for the MCR conditions during the postulated event to impact the cognitive performance of the MCR operators during the transient.

Current literature regarding the cognitive impact of heat stress is reviewed in Appendix C. The heat stress environment identified in Section 4.2.2 for the postulated event is relatively mild for the normal work performed by the MCR personnel to maintain the plant in a safe condition. The

WBGT values did not exceed 94°F. These conditions are at the edge of the highly conservative "no-effects curve" in Figure C-1. In addition, research reviewed indicates that the following factors present in MCR operator teams would mitigate the impact of heat stress on cognitive performance:

- Highly trained and motivated,
- Perform in a team environment,
- Have close and experienced supervision by senior coworkers trained to recognize degradations in performance, and
- Perform tasks in a setting where they have repeatedly performed the same work for many months or years.

Therefore, there is no expected cognitive impact on the MCR operators due to the thermal conditions during the postulated transient.

4.4. RBS Habitability Management Review

This section summarizes the mitigating actions that operators and other personnel at RBS would have taken during the postulated event to monitor MCR thermal conditions, monitor workers exposed to conditions, and assist operators to avoid heat stress, as needed. Actions taken during the March 9, 2015 loss of ventilation event as documented in Reference 23 are also discussed. Additional details of the review of training and procedures are provided in Appendix A. Recommendations for improvements to training and procedures are included in Section 7.0.

4.4.1. Self-Monitoring and Supervisor Observation Training

MCR operators and supervisors are trained to observe conditions in themselves, their co-workers, and the operators under their supervision for signs that they are not fit to perform work. This includes observation for heat stress symptoms and conditions. As discussed in Appendix A, through frequent training and briefings operators are made aware of the dangers of heat stress and the early symptoms to watch for in themselves and others.

As noted in EPRI-NP-4453, Revision 1 guidelines (Reference 8) for heat stress management of personnel in nuclear plants, the foremost protection for personnel is self-determination – the personal awareness of the warning signs that the heat stress environment may be affecting their physical or mental health. Self-determination takes precedence over stay time concepts in that supervisors or other observers seek explicit confirmation from individuals that each is doing all right and can continue work.

4.4.2. Monitoring of MCR Temperatures

If the postulated loss of control building ventilation were to occur and could not be immediately restored, personnel would work to identify a solution to restore control building ventilation and cooling. In parallel, plant personnel would monitor and trend the MCR conditions to ensure the continued capability of the MCR personnel and equipment.

The monitoring of conditions in the MCR during the loss of ventilation event on March 9, 2015 is described in two papers developed by Entergy (References 22 and 23) which are included as

Appendix D and Appendix E of this report. The installed MCR temperature monitoring sensors are located in the inlet and outlet ventilation ducts. As describe in Reference 22, these sensors do not provide an accurate measurement of the temperature in the MCR when the ventilation fans are not in operation. These sensors were monitored during the March 9, 2015 event and provided valid temperature information during the periods that the fans were in operation. As discussed in Reference 22, the MCR temperature remained below 73 °F throughout the March 9th transient and WBGT monitoring was not needed. (The revision to the AOP-0060 procedure for loss of control building ventilation issued in August 2015 (Reference 6) specified that an appropriate temperature device should be used for monitoring the air temperature inside the MCR during a loss of MCR ventilation.)

As discussed in Reference 23, operators interviewed indicated that if the temperature in the MCR was rapidly increasing, they would reference EN-IS-108 and obtain appropriate temperature measurements in the MCR to determine necessary mitigating actions. Per Reference 23, measurement devices for dry bulb and WBGT are located in the cold tool room and could be obtained in less than 10 minutes. Per Reference 23, the industrial safety coordinator stated that several people are qualified to perform WBGT calculations. He estimated it would take onsite personnel trained in performing heat stress calculations 20 minutes to report to the MCR, measure WBGT, and perform a stay time limit calculation.

4.4.3. Relief Support for the MCR Personnel

Per Reference 23, during the loss of Control Building ventilation on March 9, 2015, support and oversight was provided to assist the MCR operators. During the event the management team discussed heat stress and the potential need for relief personnel. However, relief operators were not required because the temperature was not increasing rapidly and the ventilation system was restored before the temperature in the MCR increased significantly.

Based on Assumptions 3 and 4, approximately 2.5 hours after the postulated loss of ventilation, two additional SROs would be on site to further assist with providing reliefs to operators. During the weekday day shifts, a full backup team of operators is available on site doing training. Those individuals would be available to support MCR operator relief and rotation.

As discussed in Assumption 5, individuals other than reactor operators could be brought in to perform the few moderate work demand tasks each of which were either of short duration (e.g., installation of a portable fan) or could be divided into segments of short duration (e.g., 80 minutes to remove 80 ceiling tiles is normally performed as eight groups of 10 tiles each (Reference 2).

4.5. Impact of Heat Stress in the MCR on Operators for Limiting Case

As discussed in the sections above, RBS MCR operators understand heat stress risk and would take mitigating actions to protect against heat stress. While the dry bulb temperature in the MCR is predicted to increase rapidly for the postulated event, the heat stress condition throughout the event is mild. The stay times remain above three hours for the duration of this event.

During this event, one crew of six MCR operators would be able to staff the MCR continuously with a minimum of four operators inside the MCR at all times, by rotating recovery breaks in a

cool area outside the MCR to observe the recommended stay times. It is expected that approximately 2.5 hours after the start of the postulated loss of ventilation event, two additional SROs would be on site to further assist with providing reliefs to operators.

Therefore, the evaluation of this most limiting case concludes that the operators would be able to perform their duties safely and effectively throughout the 24 hour period of the postulated event.

5.0 Summary of Results of Cases

As discussed in Section 1.1, this report evaluates the impact on operators of the MCR temperature and humidity conditions for several cases. The body of this report evaluates the scenario with the worst case heat stress condition during the initial portion of the event and Appendices F, G, H, and I provide evaluations of additional cases. Table 5-1 below provides a summary of the results from each case for low demand activities which will be performed by MCR operators.

Moderate work demand duties will be performed by non-operators who are brought into the MCR to perform these tasks. Moderate work demand minimum stay times for the cases documented in the body and Appendices F, G, H and I would be no shorter than 55 minutes during the event. Most of the tasks, such as installing portable fans and opening stairway doors would take no more than 30 minutes so these stay times should not be unduly restrictive to workers who will perform these tasks.

Table 5-1. Summary of Results

Location of Case in Report	Case Description	Stay Times for Operators (Low Demand Activities)	Ability of Operators to Staff MCR during Stay Times
Body	• Normal operation • Design heat loads • MCR door opened and fan staged by 1.5 hrs • Smoke removal fan started at 2 hrs • Ceiling tile removal at 2.5 hrs	Stay times start at 1.0 hour. Stay times always > 3 hours	6 operators can maintain watch indefinitely with at least 4 operators always in MCR 8 operators can maintain watch continuously with 6 operators always in MCR
Appendix F	• Normal operation • Design heat loads • Service water cross connect cooling the MCR air handling unit started at 1 hr	Stay times start at 4.0 hours Stay times always > 3.8 hours	6 operators can maintain watch indefinitely with at least 4 operators always in MCR 8 operators can maintain watch continuously with 6 operators always in MCR
Appendix G	• Loss of offsite power (LOOP) • Design heat loads • No ventilation[1] • Ceiling tile removal at 1 hr	No stay times	No stay time effects
Appendix H	• Normal operation • Realistic heat loads • MCR door opened and fan staged by 1.5 hrs • Smoke removal fan started at 2 hrs • Ceiling tile removal at 2.5 hrs	No stay times	No stay time effects
Appendix I (Adjusts results provided in Appendix H)	• Loss of offsite power (LOOP) • Design heat loads • Added moisture generated by six to ten operators • No ventilation[1] • Ceiling tile removal at 1 hr	Stay times start at 13 hours Stay times always ≥ 2.75 hours	6 operators can maintain watch indefinitely with 4 operators always in MCR However, by 13 hours extra operators will be available to maintain 6 operators in MCR at all times
Appendix I (Applicable to Body, Appendix F and Appendix G)	• Normal operation • Design heat loads • Added moisture generated by six to ten operators • Ventilation available within 2 hours	The amount of water vapor added due to sweat is a small effect per hour and, therefore, the effect during the first five hours is negligible. For the cases above which have ventilation available within the first five hours, the impact of humidity due to operators is negligible.	

Note 1: No credit given for actions by operators to open doors and use portable gas or battery powered fans to reduce humidity and provide additional cooling.

6.0 Conclusions

6.1. Conservative Case Using Realistic Heat Loads

The following conclusions are drawn from the evaluation of the most limiting case (see Section 6.2), applying realistic MCR heat loads based on a test of the MCR during normal operations (Reference 27). Design heat loads were found to be 76% higher than the actual heat loads inside the MCR during normal operations. Appendix H provides a habitability assessment of Reference 30, Attachment 5, Case B (similar to the baseline worst case Reference 18, Case 2/Attachment 2 except that realistic heat loads are applied). This case assumes the chilled water and service water systems for the MCR air handling unit are not available. The following mitigating actions are taken: opening stairway doors, installing portable stairway fans, starting the smoke removal system and removing selected MCR ceiling tiles.

When realistic heat loads inside the MCR are used rather than the design heat loads (see comparison in Figure H-2) the maximum dry bulb temperature is 102°F and the WBGT does not reach 90°F, so no stay times are predicted to be needed during the postulated event.

6.2. Most Limiting Case

The following conclusions are drawn from the evaluation of the most limiting case which is discussed in the body of this report. This case is based on design heat loads, non-availability of chilled water and service water systems for the MCR air handling unit, opening stairway doors, installing portable fans, starting the smoke removal system and removing selected MCR ceiling tiles.

1. While the dry bulb air temperatures in the MCR during the postulated event would have reached 116°F, the WBGT in the MCR would not have reached 94°F. The WBGT values account for the humidity in the MCR and are the measure used to determine heat stress and habitability management.
2. Operators would have continued to perform their duties safely and effectively in the MCR during the postulated transient by following Entergy Procedure EN-IS-108 (Reference 4) for working in heat stress environments. All reactor operators were trained on this Procedure.
    a. As discussed in Section 4.3, exposure to WBGT values above 90°F for duties in the MCR that involve Low work demand, such as normal watch standing for reactor operators, would have warranted the use of stay time controls as a mitigating action. Stay time restrictions for operators during the postulated event would have resulted in rotating watchstanders out of the MCR after stays of about 3 to 3.5 hours starting after the first hour of the postulated event. Other mitigating actions would have included drinking cold water, use of fans, self monitoring for possible signs or heat stress, and monitoring of each other for signs that individuals might be affected by the heat environment.

b. Exposure to WBGT over 84°F for tasks involving Moderate work demand would have warranted the use of stay time controls as a mitigating action. For the postulated event, the few tasks that were judged to be of Moderate work demand (e.g., staging portable fans) were either of short duration (less than a half hour) or could have been divided into partial tasks of short duration (e.g., eight sections of ceiling tile removal) and would be completed in the first four hours of the event. As discussed in Assumption 5, someone other than reactor operators would have been available to perform the Moderate work tasks.

c. As discussed in Section 4.4, there would have been no expected cognitive impact on the MCR operators due to the thermal conditions during the postulated transient. This is based on the relatively mild WBGT values and the nature of the cognitive work.

3. Operators and other staff would have been prepared to take additional mitigating actions to allow operators to perform safety and effectively, when needed.

    a. As discussed in Section 4.4.1, MCR operators and supervisors were trained to observe conditions in themselves, their co-workers, and the operators under their supervision for signs that they are not fit to perform work. In addition, operators received annual training and frequent briefings on recognizing and avoiding heat stress.

    b. As discussed in Section 4.4.2 and 4.4.3, it is expected that operators and supporting plant personnel would have monitored temperatures and habitability conditions in the MCR using guidance from Entergy Procedure EN-IS-108 (Reference 4). Based on the guidance from this procedure, it is expected that plant personnel would have established stay times when they were needed and brought in operator reliefs when needed.

    c. The Entergy/RBS instruction for working in hot environments EN-IS-108 (Reference 4) provided a satisfactory basis, consistent with or conservative compared to other commercial and military standards and guidelines (see recommendations below).

6.3. *Other Cases Evaluated*

The following conclusions are drawn from Appendices F, G, H, and I. The focus of these conclusions is on the impact on allowable stay time limits that affect the reactor operators on watch inside the MCR. Reactor operator duties inside the MCR are low work demand tasks as they relate to habitability limitations. The few support tasks that are of a higher, moderate work demand inside the MCR during the postulated event are of short duration compared to the allowed stay times for moderate work demand tasks and are therefore not detailed in these conclusions.

1. Appendix F provides a habitability assessment of the Reference 18, Attachment 1 case (MCR ventilation is restarted after one hour using cross-connected service water). Figure F-3 and Figure F-4 provide a habitability comparison between this case and the most limiting Case 2/Attachment 2 in the main body of the report. Because the air handling unit begins to replace the MCR air volume sooner than for Case 2,

the adverse effect on habitability due to rising WBGT is delayed from 1 hour for Case 2 to 4 hours for the Attachment 1 case, and the maximum impact of stay times is slightly less than Case 2. However, because of the lower flow of fresh air (2000 cfm) in the air handling unit compared to the smoke removal fan (10,000 cfm) for Case 2, the Attachment 1 case is slightly more limiting between 14 and 22 hours when it continues to have stay times of 3.8 hours while the Case 2 requires no stay time during these hours. Since the stay time during this interval is no different than the stay time for Case 2 just before and after this interval, Case 2 is judged to be more limiting overall.

Realistic Heat Load Evaluation - A comparison of the results of the two cases discussed above from Appendix H and from the body of the report showed that using realistic heat loads substantially lowered the maximum temperature during the 24 hour period and eliminated the recommendation for stay times. If the realistic heat loads were applied to the normal operation case which uses the air handling unit cooled by service water, a similar reduction in temperature would occur and no stay time limits would be recommended for operators.

Furthermore, if the LOOP condition existed and was mitigated by the use of the air handling unit supplied by service water cooling, with realistic heat loads, no stay time limits would be recommended for operators,, since the heat loads in the MCR are lower during a LOOP than for normal operations.

2. Appendix G provides a habitability assessment of the Attachment 14 case of Reference 30 (loss of control building ventilation in conjunction with a loss of offsite power (LOOP) in which no ventilation is provided for the MCR during the event). When the starting RH is the only source of moisture in the MCR, the RH values drop rapidly and the dropping RH has a stronger effect on the WBGT than the rising dry bulb temperatures due to MCR heat loads, until the falling RH trend flattens out (see Figure G-2). No stay times are recommended for this case for the duration of the postulated event. As discussed below, Appendix I evaluates the impact of additional moisture due to operator perspiration on this case.

3. Appendix I provides a habitability assessment of each of the cases evaluated in the main body of the report and in Appendices F, G and H when the contribution of the perspiration from the people who are inside the MCR during the event are taken into account.

    a. The water vapor that enters the MCR from human perspiration is about 0.5 lbs/hr/person based on the work demand of the operators inside the MCR. This affect from a crew of six inside the MCR for example, has a small impact on humidity over the period of one or two hours (less than one percentage point) but can have a significant impact if the vapor is allowed to accumulate over a 24 hour period (more than 10 percentage points added).

    b. For the LOOP case, no ventilation is available. The increasing humidity in the MCR causes WBGT values that require stay times after about 13 hours. In this case, at the end of 24 hours the stay time is 165 minutes. Because these stay times do not occur for several shifts, there would be time to plan for

watchstander relief to assure the full 6-person watch crew inside the MCR at all times.

c. For the cases where the forced air replacement of the MCR occurs at one to two hours, the effect of humidity accumulation for more than 2 hours is eliminated within the first few hours of the event, so that there is no significant effect of perspiration on stay times.

7.0 Recommendations for Improvements to Procedures and Training

1. AOP-0060, Loss of Control Building Ventilation (Reference 6) was revised in August 2015. In addition to steps associated with alternate means of restoring ventilation, this revision included a step to initiate air temperature monitoring in the MCR and provided a data logging sheet for monitoring all temperatures to be tracked in the MCR and the control building during a loss of ventilation. Based on the lessons learned from this evaluation, the following recommendations are made for the next revision to this procedure:

   a. The temperature monitoring forms in AOP-0060-10 (Reference 6) should be modified to track the WBGT for the MCR in addition to dry bulb temperature. WBGT trends would be needed for managing thermal habitability inside the MCR if the recovery of the MCR HVAC is delayed. Calculating the WBGT in the MCR requires the use of special instruments beside a standard air temperature (dry bulb) detector. The procedure should reference the RBS procedure for measuring WBGT or describe how the WBGT should be measured or calculated and what instrument is needed for the measurement.

   b. In the Temperature Log of Attachment 1 of the revised AOP-0060 procedure (Reference 6), the footnote for monitoring MCR temperature in each of four areas states that temperatures should be monitored approximately 5 feet above the floor using a hand held pyrometer or other suitable temperature measuring instrument. However, the intent of this table is to measure MCR air temperature. The use of a hand held pyrometer can tell the temperature of components, but not of air directly. During a loss of MCR ventilation, component temperatures would not be a reliable measure of a changing air temperature. Therefore, it is recommend that this statement be replaced with a statement such as the following:

      "Temperatures should be monitored approximately 5 feet above the floor using a suitable device or devices for monitoring ambient air temperatures (dry bulb temperature) for identifying equipment compatibility concerns as well as for monitoring the wet bulb globe temperature (WBGT) to determine the need for habitability measures inside the MCR per EN-IS-108."

   c. Guidance should be added to the procedure to begin trending dry bulb temperature and WBGT measurement as early as possible in the event of a loss of MCR ventilation. As shown in Figure 4-1 and Table 4-1, the MCR dry bulb air

temperature could exceed 100°F within 30 minutes after failure to restart the MCR air handling unit in a worst case scenario. In Step 5.1.4 of Reference 6, which directs the commencement of temperature monitoring, it should note that the normally logged MCR air temperature is in the recirculation ducts and will not be representative of the MCR atmosphere during a loss of control room ventilation. Consequently, it is important to utilize manual instruments early to commence measurements of the MCR air temperature to confirm the habitability environment.

2. Heat Stress Training - EN-IS-108, "Working in Hot Environments" (Reference 4). Based on review of the heat stress training materials and the results of the crew interviews on habitability, the following recommendations are made:

    a. Training materials that discuss the use of the WBGT as the measure for determining habitability stay times in a hot environment can be improved by adding discussion of the specific instruments that will be available at RBS. This is to ensure that personnel understand that habitability is determined by WBGT and this requires special instruments other than normal dry bulb air or equipment contact temperature sensors.

    b. Training materials should clarify that while the dry bulb temperature of air is sufficient for identifying equipment cooling concerns, personnel habitability assessment requires the consideration of relative humidity, radiant heat sources and air velocity in the working area, all of which are included in the WBGT temperature value.

3. Simulator training scenarios for MCR personnel should be enhanced to include training on habitability issues resulting from a significant increase in MCR temperature for events where this might occur if procedural corrective actions for the tested scenario are delayed (e.g., loss of MCR ventilation).

8.0 References

1. Abnormal Operating Procedure AOP-0060, "Loss of Control Building Ventilation," Rev. 9, June 2014.
2. Abnormal Operating Procedure AOP-0050, "Station Blackout," Rev. 53, September 2015.
3. Abnormal Operating Procedure AOP-0052, Fire Outside the Main Control Room.
4. Entergy Procedure EN-IS-108, "Working in Hot Environments." Rev. 10, October 2011.
5. Entergy Procedure EN-IS-124, "Job Safety Hazards Analysis," March 2009.
6. Abnormal Operating Procedure AOP-0060, "Loss of Control Building Ventilation," Rev. 10, August 2015.
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19. National Oceanic and Atmospheric Administration (NOAA) web; Dew Point and Wet Bulb Calculator, at URL: http://www.srh.noaa.gov/epz/?n=wxcalc_rh, accessed on November 2, 2015.

20. OPNAVINST 5100.19E, "Safety and Occupational Health (SOH) Program Manual for Forces Afloat," dated May 2007.

21. System Design Criteria SDC-402/410, "Control Bldg. HVAC System, Control Bldg. Chilled Water System, Ventilation Chilled Water System Design Criteria System Numbers 402, 410 & 410," Rev. 03, November 25, 2011, which references RBS Specification 215.150, "Environmental Design Criteria."

22. Entergy Discussion Paper presenting the Timeline of Events and Temperature Data Recorded during the March 9, 2015 Loss of Control Building Ventilation, documented under item WT-WTRBS-2014-0171-046 in Entergy's PCRS system (Paperless Condition Report System) and included as Appendix D for reference.

23. Entergy Summary of Habitability Related Actions taken during March 9, 2015 Loss of Control Building Ventilation, documented under item WT-WTRBS-2014-0171-047 in Entergy's PCRS system and included as Appendix E for reference.

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35. RBS USAR, Table 9.2-2, "Reactor Plant Component Cooling Water System Component Description," and Paragraph 9.2.5.2 "System Description."

36. "MCR Operator Habitability – NRC Letter EA-15-140 Attachment A-3, dated February 16, 2016," MPR Comments on Habitability, MPR Memorandum MEMO-2062-1502-04-02 R0, dated February 23, 2016.

A Review of Procedures, Training and Interviews Regarding Heat Stress in MCR

The following documents are reviewed and summarized in this section:

1. AOP-0060 RBS Procedure for Responding to a Loss of Control Building Ventilation, Rev. 9, June 2014 (Reference 1).
2. RBS Thermal Habitability Training for Control Room Operators (Reference 25).
3. Results of Interviews of RBS Personnel on Habitability Actions inside the MCR during a Postulated Extended Loss of Main Control Building Ventilation (Reference 26).

A.1 RBS Procedure for Responding to a Loss of Control Building Ventilation

In the event that the control building ventilation is lost, a temperature rise would occur inside the main control room (MCR) due to heat generation from the electrical components and from personnel inside the MCR. Procedural actions for loss of control building ventilation in effect in March 2015 (AOP-0060 Rev. 9, Reference 1) were primarily focused on restoring HVAC to the MCR as quickly as possible. The first action would be to attempt restarting the chilled water system (HVK/HVC) and the MCR air conditioning unit (ACU1A(B)). If the chilled water did not function, the next step in the procedure was, with the concurrence of the OSM/CRS, to cross connect the service water to cool the chilled water loops to the ACU (per SOP-066, Plant and Control Building HVAC Chilled - Section 5.5). This procedure required manually starting the MCR air handling unit (ACU1A(B)). Habitability guidance in Reference 1 is predominantly to have unnecessary people exit the MCR. Revision 10 of this procedure (Reference 6) added guidance for monitoring temperatures. Recommendations for further improving this procedure are provided in Section 7.0 of the body of this report.

A.2 Review of RBS Thermal Habitability Training for Control Room Operators

As part of this evaluation, MPR conducted a review of the habitability training requirements for reactor operators (Reference 25). MPR found that, as of March 2015, all licensed reactor operators were required to receive training on the effects of heat stress when working in hot environments. A review of qualification documents showed that this training was done.

The basic document used for heat stress training for MCR personnel was the Entergy/RBS procedure for "Working in Hot Environments" EN-IS-108 (Reference 4). While this document is focused more for preparations to enter into a known hot environment to perform work, the same key principles of heat stress apply to work in an evolving (rising temperature) hot work environment.

A review of the training materials showed that training included understanding the risks and signs of heat stress illnesses, the factors affecting susceptibility to heat stress illness in general and individual risk factors, the concept of stay times and recovery times, the necessity of individual self determination and co-worker observations, mitigating actions such as drinking

cold water and responsibilities of individuals and supervisors. In addition, the RBS safety department conducts one annual refresher session for plant personnel on habitability precautions for working in high temperature environments and the signs to be observed for heat stress-related illnesses

A review of simulator training scenarios for MCR personnel found that some events were simulated which could result in a rising temperature inside the MCR (e.g., station blackout), and the focus of these simulator training sessions was to quickly take actions needed to correct the plant conditions and recover MCR temperature control. Future training could be enhanced to provide ancillary training to consider habitability issues with a protracted increase in MCR temperatures if the corrective actions were not successful (see Section 7.0 recommendations).

A.3 Results of Interviews of RBS Personnel on Habitability Actions inside the MCR during a Postulated Extended Loss of Main Control Building Ventilation

MPR prepared a questionnaire used to interview MCR personnel as to their understanding of actions that should be taken to manage heat stress effects on personnel inside the MCR during an evolving heat stress condition. Results of these interviews were provided in Reference 26.

Senior Reactor Operators (SROs) interviewed indicated that their reactions to postulated rising temperatures inside the MCR would include:

- Frequently discuss and check operator personnel for signs of adverse effects of heat stress,
- Take actions to correct the rising temperatures if possible,
- Mitigate the effects of rising temperatures on people by determining stay times and recovery times when needed,
- Bring in fans or other local cooling devices, and to
- Brief personnel about the need for hydration and self-determination.

The majority of SROs and reactor operators (ROs) identified that there was an RBS guidance document on heat stress work that identified stay times and recovery times. The ROs interviewed noted that the supervisor would be identifying corrective actions for the rising temperatures, watching for signs of discomfort, getting help from outside the MCR, implementing ways to keep people in the MCR cool including use of fans and local coolers, and identifying stay times if needed.

While operators identified the need to monitor the rising temperatures inside the MCR, there was a general weakness in knowing what specific temperature and humidity measurements would be needed to establish habitability stay times and what instruments that would be used to make these measurements. This was also a weakness in the training materials which discussed the use of the WBGT values but not the instruments needed to obtain these values. These heat stress measurements are typically performed by the Industrial Safety group and they would likely be called in to support the MCR operators. However, additional familiarity on the part of the operators would be beneficial and an update to the training material is recommended in Section 7.0.

B Comparison of RBS Guidelines for Allowable Stay Time in Heat Stress Environments with Industry Guidance

The purpose of this appendix is to summarize guidelines and standards which discuss how to manage the work of personnel in a heat stress environment. These standards and guidelines allow for work to be safely performed by establishing allowable stay times for working in the hot environment.

The review documented in this section concludes that these standards and guidelines are consistent with the guidelines provided by Entergy in EN-IS-108 (Reference 4). As a measure of this similarity, examples will be provided below that focus on the establishment of allowable stay times as done in the Entergy guideline.

Note that each of the standards use Wet Bulb Globe Temperature (WBGT) as a parameter in defining heat stress impacts and stay times. Therefore, this appendix (Section B.1) includes a brief discussion of how WBGT is determined generally and in this evaluation.

B.1 Determination of WBGT

WBGT accounts for the following effects:

- The dry bulb temperature of the air (Tdb) and the natural wet bulb temperature (Twb) of the air. The Twb is used to determine the relative humidity (RH) of the air, which is the ratio of the water vapor pressure that is actually in the air and the vapor pressure that could be present in saturated air at the same Tdb. The RH affects how readily a human can be cooled by sweat being evaporated from the skin. At higher RHs, sweat will not readily evaporate from the skin which would add to the severity of the heat stress.
- Radiant sources of heat that can either add to heat stress (such as radiant heat from the sun or from hot steam pipes) or subtract from heat stress (radiant absorption by a cold body such as cold walls of a freezer or the night sky).
- Convective cooling or heating effects of air velocity that can cool more rapidly by assisting in evaporation, and can cool or heat by convection.

The radiant heat and air velocity effects are measured by using a globe thermometer and the natural wet bulb temperature (rather than the forced air wet bulb temperature). The globe temperature (Tgt) is measured using a thermometer which is placed inside a blackened copper sphere (globe) so that the internal temperature of the globe can sense the radiant and convective air effects on the exterior of the globe (similar to the manner in which the human body reacts). In the absence of any significant radiant heat sources or air velocities, the globe temperature would be the same as the dry bulb temperature.

The WBGT is calculated by a formula which weights the humidity effect as determined by the Twb more strongly than the effects of ambient temperature, radiant sources and air velocity:

WBGT = 0.7 * Twb + 0.3 * Tgt (Reference 7)

As a demonstration of the WBGT, if an environment has a globe temperature of 120°F and a relative humidity of 5%, it would have a Twb of about 70°F and a WBGT of 85°F. The

habitability is determined by the WBGT value of 85°F, which is less than the globe temperature because of the low humidity.

For purposes of this report, the Tdb for the inside of the MCR will be used as the equivalent of the Tgt. This is an acceptable assumption for the inside of the MCR because there will no strong radiant sources or sinks inside the MCR and no significant air velocities during the loss of the ventilation system event. It is assumed that any air velocities in the vicinity of the operators will be negligible even when exhausting air from the MCR out a stairwell door or out the smoke-removal fan exhaust ducts which are remotely located. Therefore,

$$\mathbf{WBGT = 0.7 * Twb + 0.3 * Tdb}$$

This assumption that Tdb can be used or Tgt for inside environments with no thermal radiation or air flow is used by other researchers (Reference 16).

B.2 Use of WBGT and Other Factors to Establish Stay Times

Allowable stay times can vary based on WBGT, type of clothing, and metabolic levels of the work being performed. Actual times that an individual spends in a heat stress environment are also dependent on the individual's response to the heat stress condition and shorter times in the environment can be assigned by the supervisor or by the individual based on personal observations while in the environment. An individual's susceptibility to heat stress varies with factors such as age, weight, medications, illnesses, prior heat exposure, acclimatization, physical conditioning, and other factors. These general and individual factors affecting the response to heat stress are discussed in most of the guidelines summarized below on how to use allowable stay times in a heat stress environment. Mitigating factors such as drinking cold water, use of fans, medical monitoring (particularly for high heat stress conditions), personal determination (self monitoring), and monitoring co-workers are intended to be used in conjunction with allowable time limits (Reference 4).

Stay times from some of the available guidelines and standards are summarized briefly below.

B.2.1 Entergy Procedure EN-IS-108, "Working in Hot Environments."

The stay time limits used by Entergy Procedure EN-IS-108, "Working in Hot Environments" (Reference 4) are shown in Table B-1, below. Stay times are based on the activity demand of the work, the clothing worn, and the WBGT. The following instructions are provided by the procedure.

Worker stay times are determined as follows:

1. Find WBGT temperature of the Heat Stress Area in the left hand column of the Stay Time Chart
2. Follow this line to the right to the appropriate columns for clothing ensemble
3. Determine the Work Demand (low, medium or high) from within the clothing ensemble column. Refer to attachment 9.2 for guidance.
4. The number within that box is the worker's maximum stay time in minutes.
5. Recovery Time = Time Spent in Heat Stress Area divided by assigned Stay Time multiplied by 60 minutes

Table B-1. Entergy Procedure EN-IS-108 Stay Times

	WORK CLOTHES			SINGLE PCS			DOUBLE PCS			PLASTICS		
	Work Demand			Work Demand			Work Demand			Work Demand		
WBGT	LOW	MOD	HIGH	LOW	MOD	HIGH	LOW	MOD	HIGH	LOW	MOD	HIGH
120°F	20											
118°F	20											
116°F	25											
114°F	25	15		15								
112°F	30	20		20								
110°F	35	20		25			20					
108°F	45	25		25	15		20					
106°F	50	25		30	20		25	15				
104°F	60	30	15	35	20		25	20		15		
102°F	75	35	20	45	25		30	20		20		
100°F	90	40	20	50	25		40	20		25	15	
98°F	105	45	25	60	30	15	45	25		30	15	
96°F	130	50	35	75	35	20	55	30		30	20	
94°F	165	55	40	90	40	20	70	30	20	40	20	
92°F	195	70	45	105	45	25	80	35	20	45	25	
90°F	230	85	55	130	50	35	100	40	25	55	30	
88°F	NL	110	70	165	55	40	120	45	30	65	30	15
86°F	NL	170	85	195	70	45	150	50	35	80	35	20
84°F	NL	240	115	230	85	55	180	60	40	100	40	25
82°F	NL	NL	180	NL	110	70	210	75	45	120	45	30
80°F	NL	NL	NL	NL	180	90	NL	95	65	150	50	35
78°F	NL	NL	NL	NL	NL	120	NL	150	80	180	60	40
76°F	NL	NL	NL	NL	NL	NL	NL	210	100	210	75	45
74°F	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	100	60
72°F	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	150	75
70°F	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	210	100
68°F	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	140
66°F	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	240

B.2.2 EPRI - NP-4453-Heat Stress Management Program for Power Plants

The EPRI NP-4453 stay time guidelines from 1986 (Reference 7) are listed below. In Table B-2, it can be seen that no stay time limits are placed on low work demand operators in normal working clothes for WBGT values below 93°F WBGT. This is less conservative than the Entergy guideline (Reference 4) for normal low demand work such as watch standing at a typical control room. Likewise the EPRI stay times for moderate work demand is unlimited below 86°F WBGT whereas the Entergy stay times are unlimited for moderate work demand only below 84°F WBGT.

In 1991, the EPRI NP-4453 guidelines (Reference 8) were revised to use a software program with many individual inputs instead of the stay time table used in 1986. The new management guidelines emphasized the establishment of self-determination and frequent checking of personnel by coworkers rather than too much reliance on stay times by themselves. The 1991 terminology changes from the term "stay times" to "check times" (for checking with personnel). The use of a software program to determine recommended times that self-monitoring checks should begin is redundant with reactor operator practice to continually monitor reactor operator conditions.

Table B-2. EPRI Stay Times Identified in NP-4453 Rev. 0 dated 1986

Table 7-2

Ranges of stay times in minutes (or "h" for hours) for different WBGTs (and Botsball readings) in °C and °F by combinations of clothing ensemble and metabolism

WBGT (Botsball)		Work Clothes Metabolism			Cotton Coveralls Metabolism			Double Cottons Metabolism			Cottons plus Plastics Metabolism		
°C	°F	Low	Mod	High	Low	Mod	High	Low	Mod	High	Low	Mod	High
50 (47)	122 (116)	15-30	0-10		5-15	0-5		5-15					
48 (45)	118 (112)	20-45	5-15		15-30	5-10		10-20			5-15		
46 (43)	115 (109)	20-45	5-20		20-45	5-15		15-30	0-10		15-20		
44 (41)	111 (105)	30-60	10-25		20-45	5-20		20-45	5-15		15-30	0-10	
42 (39)	108 (102)	45-90	15-30	5-10	30-60	10-25		20-45	5-20		20-45	5-15	
40 (37)	104 (99)	60-90	15-45	10-20	45-90	15-40	5-10	30-60	10-25		20-45	5-20	
38 (35)	100 (95)	90-120	20-45	15-30	60-90	15-45	10-25	45-90	15-30	5-10	30-60	10-25	
36 (33)	97 (92)	2h-4h	30-60	15-40	90-120	25-45	15-30	60-90	15-45	10-20	45-90	15-30	5-10
34 (31)	93 (88)	3h-8h	45-90	20-45	2h-4h	30-60	15-45	90-120	20-45	15-30	60-90	15-45	10-20
32 (29)	90 (85)	NL	90-120	30-60	3h-8h	60-100	25-50	2h-4h	30-60	15-40	90-120	20-45	15-30
30 (27)	86 (81)	NL	2h-4h	60-120	NL	1h-2h	30-90	3h-8h	45-90	20-45	2h-4h	30-60	15-40
28 (26)	82 (78)	NL	NL	2h-4h	NL	1h-4h	1h-3h	NL	90-120	30-60	3h-8h	45-90	20-45
26 (24)	79 (75)	NL	NL	4h-8h	NL	NL	3h-8h	NL	2h-4h	60-120	NL	90-120	30-60
24 (22)	75 (71)	NL	NL	NL	NL	NL	NL	NL	NL	2h-4h	NL	2h-4h	60-120
22 (20)	72 (68)	NL	NL	NL	NL	NL	NL	NL	NL	4h-8h	NL	NL	2h-4h
20 (18)	68 (64)	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	4h-8h
<20	<68	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL

The 1991 revision also defines "action times" so that the permission to exceed check times if no heat stress signs are observed will not exceed more than two times the action times. The check times and action times are calculated by a software program that must be obtained from EPRI, but in the absence of the software program, the action times can be obtained from a look up graph (see Figure B-2) that is nearly identical to the low end of the range of stay times defined by NP-4453 Rev. 0 (Reference 7), except that it includes WBGTs as low as 90°F. The factor of two times the action times would seem to correspond to the upper end of the range of stay times defined in NP-4453 Rev. 0. Thus, the allowed stay times of EN-IS-108 (Table B-1) are still conservative since current EPRI guidance indicates that they can be exceeded by a factor of 2 if personnel self-monitoring permits.

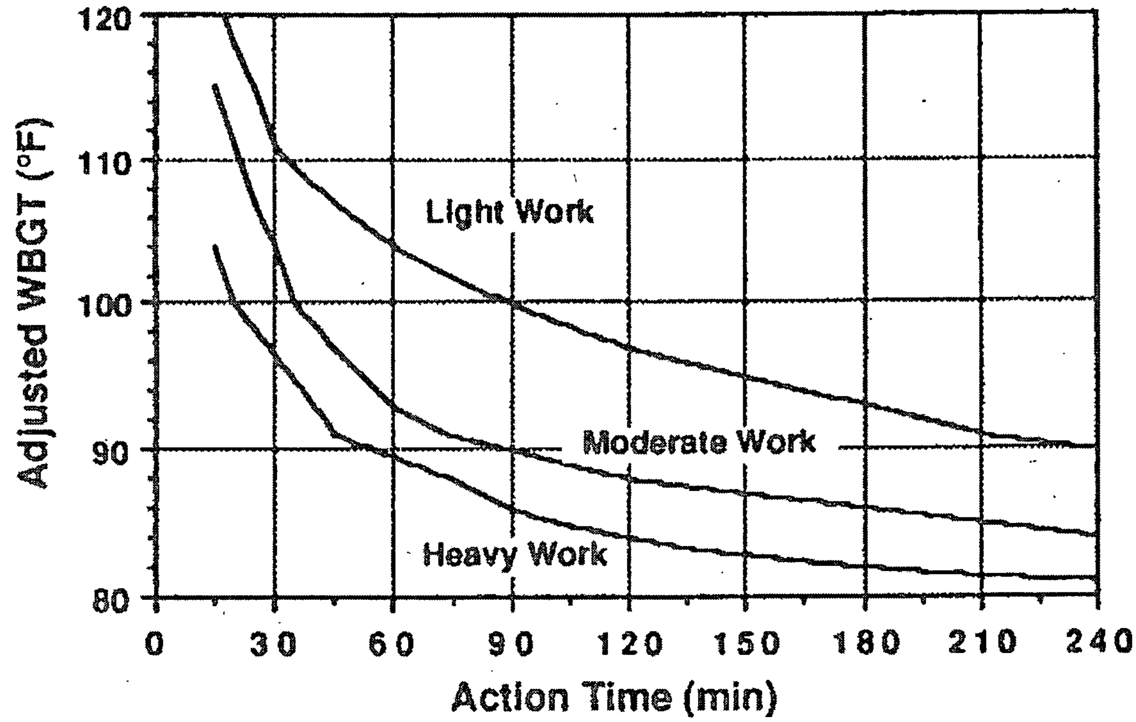


Figure B-1. Action Time Selector for EPRI NP-4453 Rev. 1 for Normal Working Clothes

B.3 NUREG/CR-5680 - "The Impact of Environmental Conditions on Human Performance" (Ref. 15)

Figure B-2, below is excerpted from this standard. The figure illustrates how stay time limits can be used to determine the amount of time each hour that watchstanders could be on station rather than simply presenting the total allowable stay time in one stretch. The figure also shows how much time each watchstander could be resting (recovering) in a benign environment given a suggested hourly rest break.

This approach of watchstanding on a regular rotating basis for a fraction of each hour could be used for heat stress conditions in lieu of using total allowed stay time for each rotation of the watch. For a single task, such as some of the moderate work demand tasks for the postulated event, if the task is shorter than the allowed stay times, the fractional hour approach would not be needed.

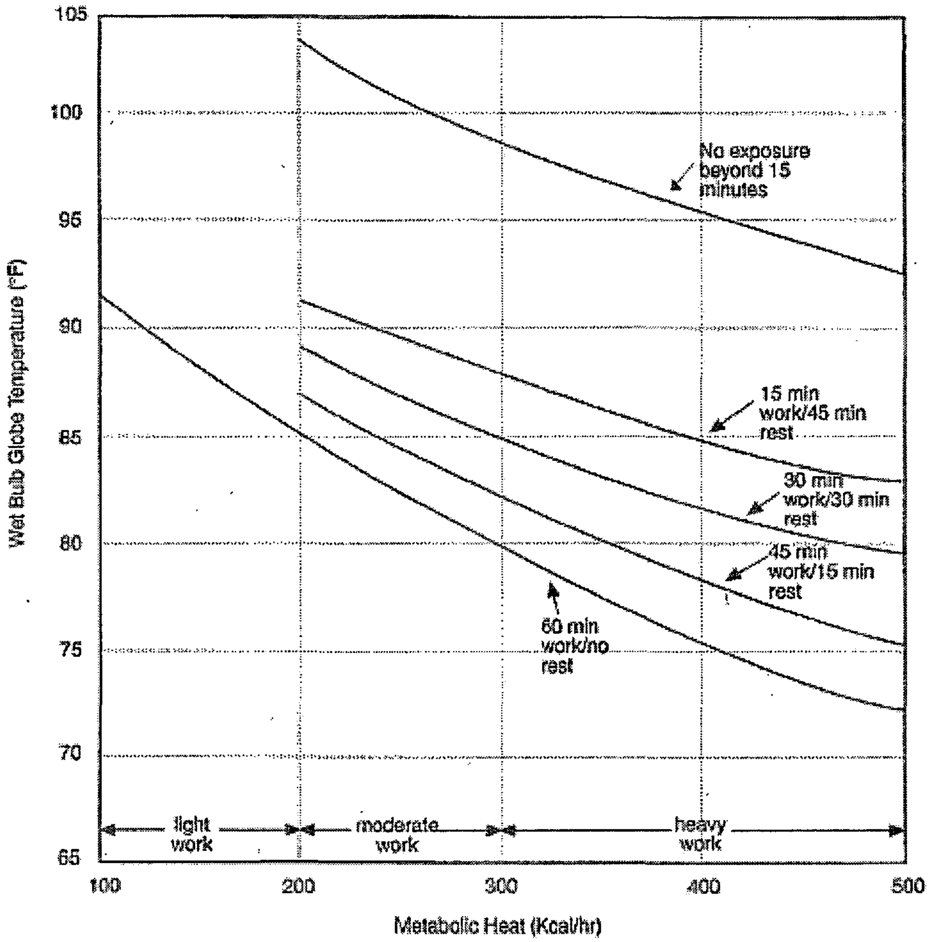


Figure B-2. Stay Time Values for NUREG/CR-5680 – 1994

B.4 NIOSH – 1986 "Criteria for a Recommended Standard – Occupational Exposure to Hot Environments – Revised Criteria 1986 "(Ref. 9)

The U.S. Department of Health and Human Services, under its National Institute for Occupational Safety and health (NIOSH), provides many guidelines for managing personnel health in hot environments and has a similar approach to allowable stay times, proposing a recovery period each hour of ongoing watchstanding, rather than a stay time applied to a single task. Basically, this is similar to the guidance in NUREG/CR-5680 (see Figure B-3).

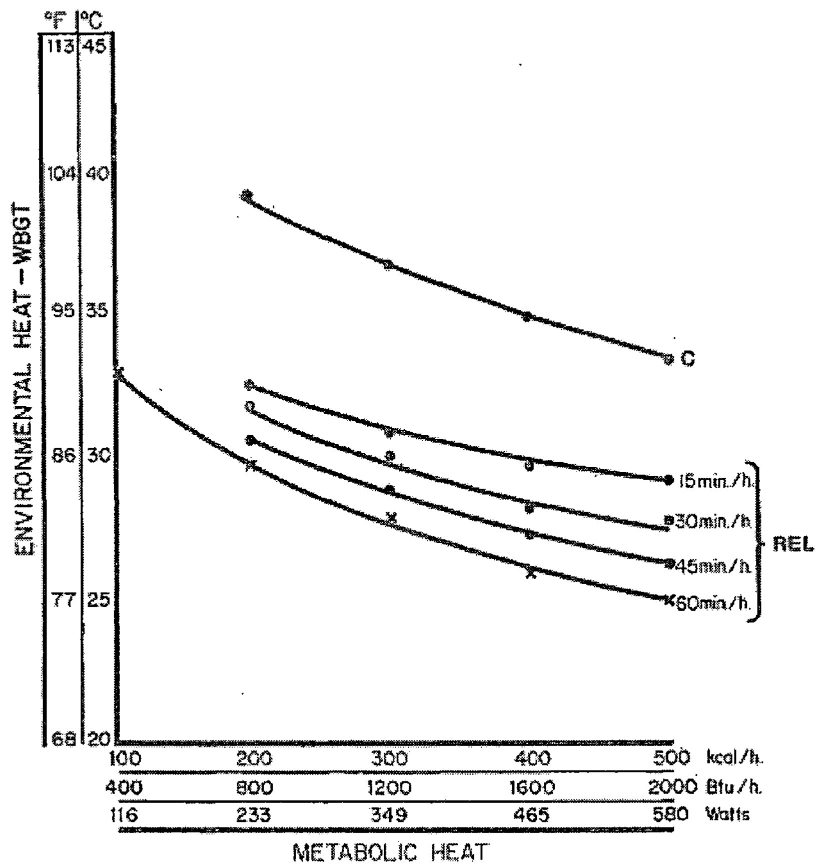


Figure B-3. NIOSH Stay Times and Hourly Recovery Times for Ongoing Watchstanding

B.5 Navy Physiological Heat Exposure Limit (PHEL) Curves and Table (Ref. 11)

The Navy and also the Army and the Air Force all have documents providing guidance on how to manage personnel in a heat stress environment, using the WBGT as the principle factor. The Navy version is provided here as an example. The stay time guidance in Reference 11 is also contained in a higher tier Navy standard, OPNAVINST 5100.19E (Reference 20), which designates that control room reactor operators are classified as a Level I (low work demand) application. Levels II through VI correspond to increasing work demand and the Navy actually assigns different work demand levels to specific watchstanding duties for different classes of ships. (Reference 20).

Stay times for RBS (Reference 4) for WBGTs above 90°F are more conservative than Navy guidelines (Table B-3) for low demand, moderate demand and high demand work categories. For the less restrictive WBGT values below 90°F, the Navy defines allowable stay time limits that are between 6 hours to 8 hours, rather than jumping to a "no-limit" value below 90°F. This is slightly more conservative than RBS at the low work demand and mild WBGTs.

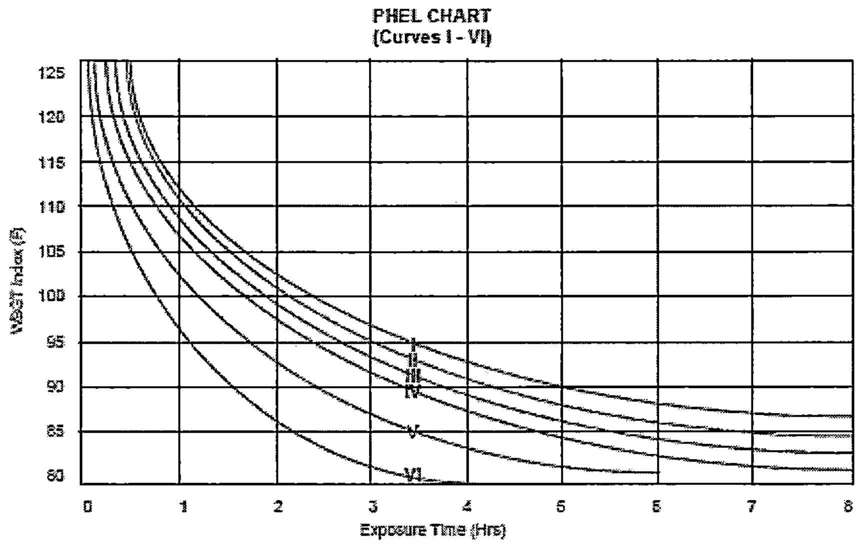


Figure B-4. Navy Curves of WBGT vs. Stay Time for Different Work Demands

Table B-3. Finding the Allowable Exposure Time for Navy Work in a Hot Environment

WBGT Index (F)	PHEL Curves Total Exposure Time in Hours:Minutes											
	Without the presence of fuel vapors or combustion gases						With the presence of fuel vapors or combustion gases					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
80.0	>8:00	>8:00	>8:00	8:00	6:35	4:30	4:50	4:15	3:30	2:55	2:15	1:30
81.0	>8:00	>8:00	>8:00	7:45	6:00	4:05	4:25	3:50	3:10	2:40	2:00	1:20
82.0	>8:00	>8:00	8:00	7:05	5:25	3:40	4:00	3:30	2:55	2:25	1:50	1:15
83.0	>8:00	8:00	7:45	6:25	4:55	3:20	3:40	3:10	2:40	2:10	1:40	1:10
84.0	>8:00	8:00	7:05	5:55	4:30	3:05	3:20	2:55	2:25	2:00	1:30	1:00
85.0	8:00	7:45	6:30	5:20	4:05	2:50	3:00	2:40	2:10	1:50	1:25	0:55
86.0	8:00	7:05	5:55	4:55	3:45	2:35	2:45	2:25	2:00	1:40	1:15	0:50
87.0	7:25	6:30	5:25	4:30	3:25	2:20	2:30	2:10	1:50	1:30	1:10	0:45
88.0	6:45	5:55	4:55	4:05	3:10	2:10	2:20	2:00	1:40	1:25	1:05	0:40
89.0	6:10	5:25	4:30	3:45	2:50	2:00	2:05	1:50	1:30	1:15	1:00	0:40
90.0	5:40	5:00	4:10	3:25	2:40	1:50	1:55	1:40	1:25	1:10	0:55	0:35
91.0	5:15	4:35	3:50	3:10	2:25	1:40	1:45	1:30	1:15	1:05	0:50	0:30
92.0	4:50	4:10	3:30	2:55	2:15	1:30	1:35	1:25	1:10	1:00	0:45	0:30
93.0	4:25	3:50	3:15	2:40	2:00	1:25	1:30	1:20	1:05	0:55	0:40	0:25
94.0	4:05	3:35	3:00	2:25	1:50	1:15	1:20	1:10	1:00	0:50	0:35	0:25

This is continued on the next partial table.

WBGT Index (F)	PHEL Curves Total Exposure Time in Hours:Minutes											
	Without the presence of fuel vapors or combustion gases						With the presence of fuel vapors or combustion gases					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
95.0	3:45	3:15	2:45	2:15	1:45	1:10	1:15	1:05	0:55	0:45	0:35	0:20
96.0	3:25	3:00	2:30	2:05	1:35	1:05	1:10	1:00	0:50	0:40	0:30	0:20
97.0	3:10	2:45	2:20	1:55	1:25	1:00	1:10	0:55	0:45	0:40	0:30	0:20
98.0	2:55	2:35	2:10	1:45	1:20	0:55	1:05	0:50	0:40	0:35	0:25	0:15
99.0	2:40	2:20	2:00	1:40	1:15	0:50	0:55	0:45	0:40	0:30	0:25	0:15
100.0	2:30	2:10	1:50	1:30	1:10	0:45	0:50	0:45	0:35	0:30	0:20	0:15
101.0	2:20	2:00	1:40	1:25	1:05	0:45	0:45	0:40	0:35	0:25	0:20	0:15
102.0	2:10	1:50	1:35	1:15	1:00	0:40	0:40	0:35	0:30	0:25	0:20	0:10
103.0	2:00	1:45	1:25	1:10	0:55	0:35	0:40	0:35	0:30	0:25	0:15	0:10
104.0	1:50	1:35	1:20	1:05	0:50	0:35	0:35	0:30	0:25	0:20	0:15	0:10
105.0	1:40	1:30	1:15	1:00	0:45	0:30	0:35	0:30	0:25	0:20	0:15	0:10
106.0	1:35	1:25	1:10	0:55	0:45	0:30	0:30	0:25	0:20	0:20	0:15	0:10
107.0	1:30	1:15	1:05	0:50	0:40	0:35	0:30	0:25	0:20	0:15	0:10	0:10
108.0	1:20	1:10	1:00	0:50	0:35	0:25	0:25	0:25	0:20	0:15	0:10	0:05
109.0	1:15	1:05	0:55	0:45	0:35	0:25	0:25	0:20	0:15	0:15	0:10	0:05
110.0	1:10	1:00	0:50	0:40	0:30	0:30	0:25	0:20	0:15	0:15	0:10	0:05
111.0	1:05	1:00	0:50	0:40	0:30	0:20	0:20	0:20	0:15	0:10	0:10	0:05
112.0	1:00	0:55	0:45	0:35	0:25	0:20	0:20	0:15	0:15	0:10	0:10	0:05
113.0	0:55	0:50	0:40	0:35	0:25	0:15	0:20	0:15	0:15	0:10	0:05	0:05
114.0	0:55	0:45	0:40	0:30	0:25	0:15	0:15	0:15	0:10	0:10	0:05	0:05
115.0	0:50	0:45	0:35	0:30	0:20	0:15	0:15	0:15	0:10	0:10	0:05	0:05
116.0	0:45	0:40	0:35	0:25	0:20	0:15	0:15	0:10	0:10	0:10	0:05	0:05
117.0	0:45	0:40	0:30	0:25	0:20	0:10	0:15	0:10	0:10	0:05	0:05	0:05
118.0	0:40	0:35	0:30	0:25	0:15	0:10						
119.0	0:35	0:35	0:25	0:20	0:15	0:10						
120.0	0:35	0:30	0:25	0:20	0:15	0:10						
121.0	0:35	0:30	0:25	0:20	0:15	0:10						
122.0	0:30	0:25	0:20	0:15	0:15	0:10						
123.0	0:30	0:25	0:20	0:15	0:10	0:10						
124.0	0:25	0:25	0:20	0:15	0:10	0:05						
125.0	0.25	0.20	0.20	0.15	0.10	0.05						

B.6 International Standard ISO 7243, "Hot Environments – Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature) (Ref. 12)

The international standard is an attempt to unify standards commonly used in different countries. The stay time guidance is similar to that cited in other U.S. standards discussed herein but it does not fully address all factors and personal variations for the individual susceptibility to heat stress. Nevertheless, the stay times are similar to those used by the RBS guidelines (see Table 4-1). Note in Figure B-4 and Figure B-5, for example that for low demand work, continuous work (i.e., unlimited stay time) may be performed for WBGT up to 32°C (90°F).

Table B-4. ISO 7243 Determination of Work Load Demand

Table of reference values of the *WBGT* heat stress index

Table A.1 — Reference values corresponding to a given situation

Metabolic rate class	Metabolic rate, *M*		Reference value of *WBGT*			
	Related to a unit skin surface area W/m²	Total (for a mean skin surface area of 1,8 m²) W	Person acclimatized to heat °C		Person not acclimatized to heat °C	
0 (resting)	$M < 65$	$M < 117$	33		32	
1	$65 < M < 130$	$117 < M < 234$	30		29	
2	$130 < M < 200$	$234 < M < 360$	28		26	
3	$200 < M < 260$	$360 < M < 468$	No sensible air movement 25	Sensible air movement 26	No sensible air movement 22	Sensible air movement 23
4	$M > 260$	$M > 468$	23	25	18	20

NOTE — The values given have been established allowing for a maximum rectal temperature of 38 °C for the persons concerned.

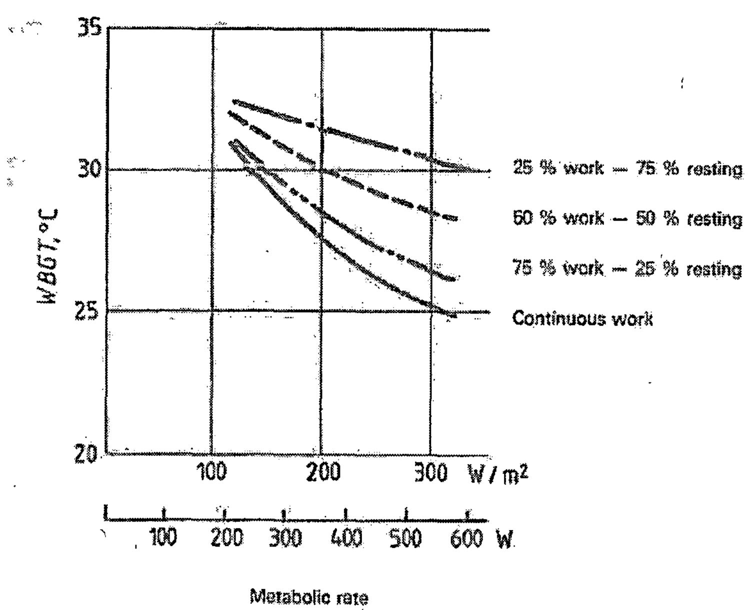


Figure B-5. ISO 7243 Stay Time Guidance

B.7 Conclusion

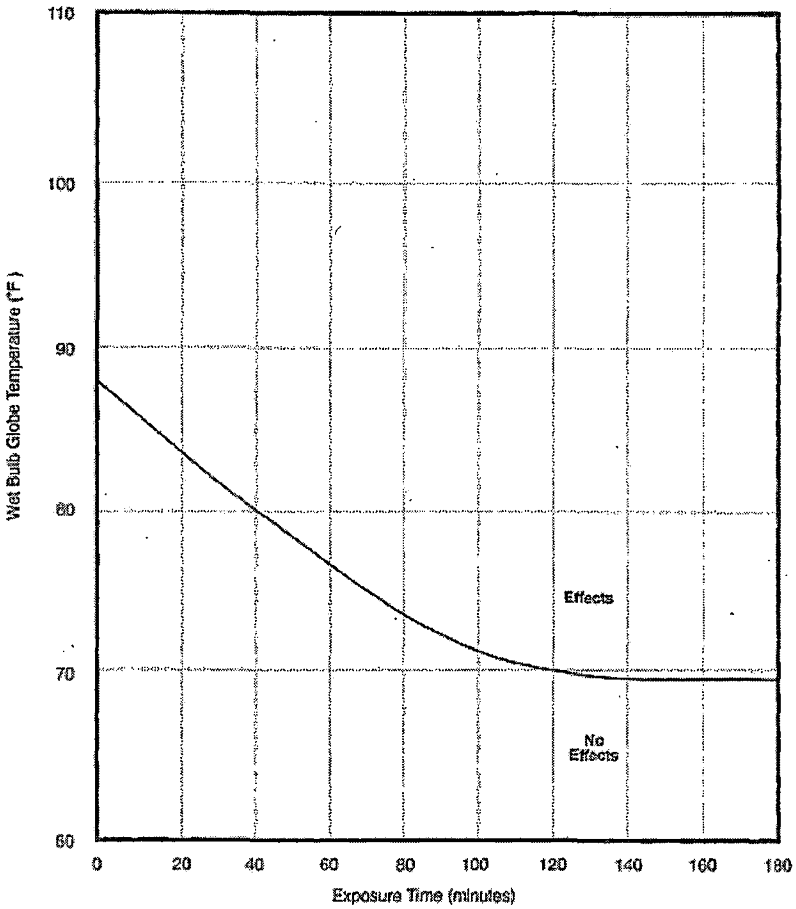
This evaluation concludes that the stay times implemented by Entergy Procedure EN-IS-108 are consistent with industry and military standards although they are much more conservative than the most limiting allowable range proposed by EPRI in Heat Stress Management Program NP-4453, Rev. 0 (Reference 7). Reference 7 imposes no stay time requirement for low work demand

tasks below a WBGT of 93°F (see Table B-2) versus at 90°F for Entergy/RBS (see Table B-1) and allows up to 8 hour-stay times up to WBGT of 97°F versus a maximum of 1.75 hours for Entergy/RBS when WBGT reaches 96°F. This comparison serves to emphasize that the heat stress effects of the postulated worst case loss of control building HVAC are very mild heat stress conditions.

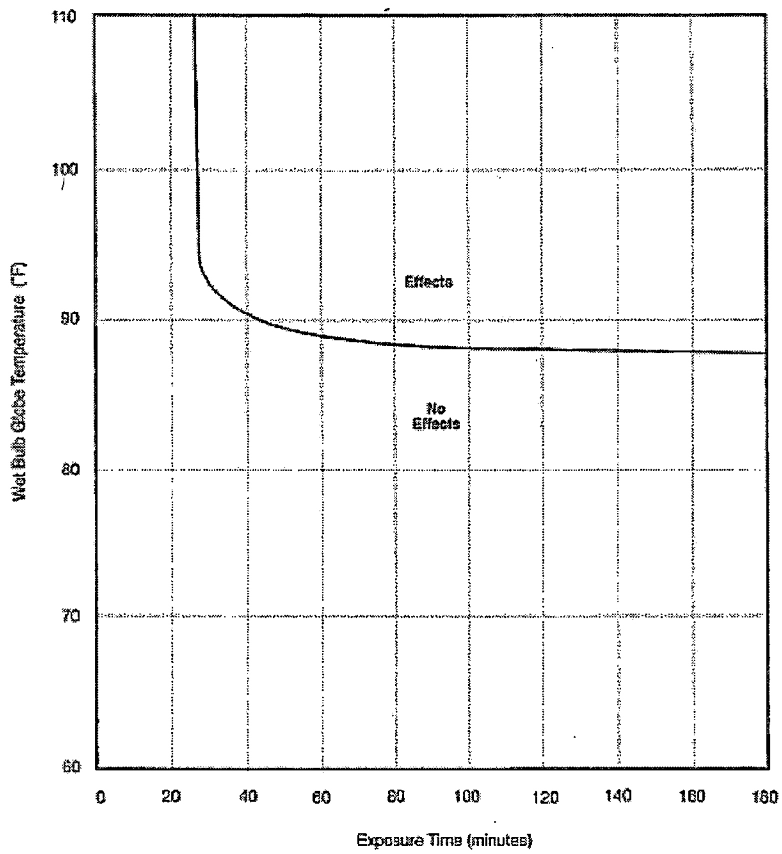
C Heat Stress and Cognitive Performance

C.1 Impact of Heat Stress on Cognitive Performance

NUREG/CR-5680 (Reference 15) indicates that heat stress can have an adverse effect on cognitive performance. This NUREG document presents the following simplistic curves showing the combinations of exposure times and WBGT values which have been found to affect cognitive performance. The curves encompass all studies reviewed in such a way that no effects of heat stress were observed below the curves.



Graph A: Tasks that Require Perception and Motor Skills



Graph B: Tasks that Require Simple Mental Tasks

Figure C-1. No Adverse Effects of Heat Exposure Below the WBGT Curves (Ref. 15)

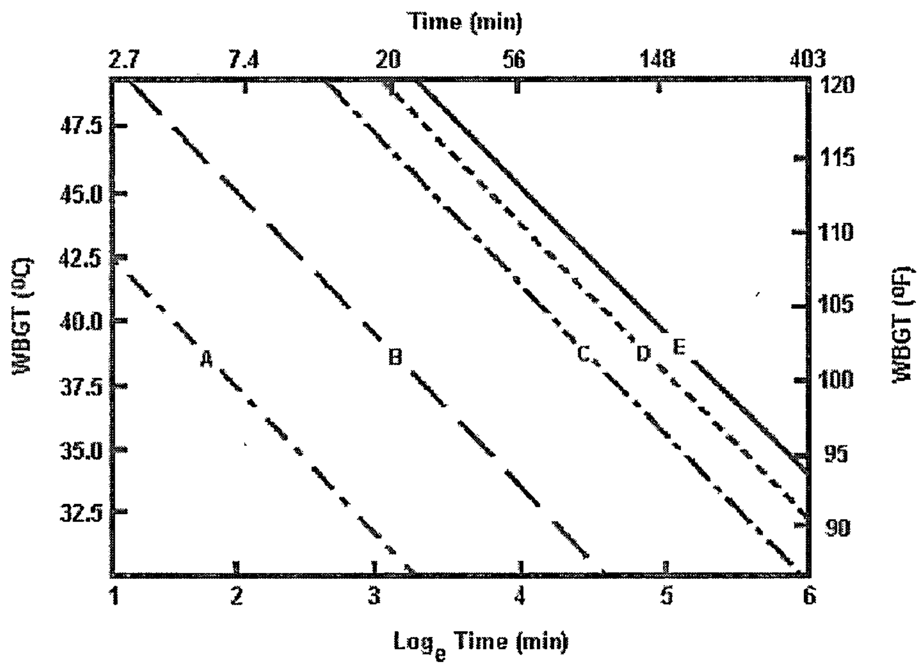
In Figure C-1, Graph A represents tasks that require perception/motor skills and Graph B represents simple mental tasks (see Table C-1 for typical definitions of terms). The NUREG report notes that the curves are very conservative because they bound all data that was surveyed in the literature. One weakness of the summary curves above is that there are many successes above the curves.

NUREG/CR-5680 concludes that cognitive performance above the no-effects curves would have a greater chance of having an adverse effect due to heat stress than performance below the curves; and, therefore, conditions (combinations of exposure times and WBGT) above the curves should be avoided.

Hancock, in Reference 17, notes that the authors (Ramsey and Kwon) of the studies from which these graphs in NUREG/CR-5680 are taken did not advocate using these graphs as standards for two reasons: first, significant decrement in a laboratory setting does not necessarily imply loss of the ability to perform a cognitively demanding task in practical situations; and second, there are a large number of confounding variables that can affect task performance and, therefore, interact with the effects of heat stress. Hancock further points out many weaknesses in the curves of Figure C-1 including:

1. Most of the tests did not use WBGT as a control (so air temperatures used in many experiments had to be converted to WBGT without a reliable basis);
2. There were many more subdivisions in types of work for which independent relationships could have been made besides the two categories shown by these two graphs;
3. The students who were used for most of the academic studies were not necessarily typical of all workers;
4. The tasks were not based on people doing a repetitive type of job over a long period.

Hancock evaluates the data in detail and points out that simple mental tasks, reaction times and tracking tasks all tend to be little affected by heat stress beyond the physiological limits previously defined; whereas, more complex tasks such as "dual tasks" which are already demanding for competing cognitive concentration, and tasks based on vigilance were more likely to be affected by heat stress (see Figure C-2 and see Table C-1 for definitions).



LINE A - vigilance tasks; LINE B - dual-tasking; LINE C - tracking tasks; LINE D - simple mental tasks; Line E - represents the physiological tolerance limit.

Figure C-2. Demonstration that Certain Types of Tasks are Less Likely to Have Heat Effects

Pilcher (Reference 16) used analytical methods for studies where sufficient data from experiments allowed statistical analyses. He concluded that there were several studies indicating that, in tests up to 92°F WBGT, there were no adverse effects on mental/cognitive tasks or on simple perceptual/motor tasks, although there were some effects on complex perceptual/motor tasks.

Table C-1 provides definitions which were used by NUREG/CR-5680, in the approximate order (top to bottom) of increasing likelihood of heat stress effects on performance. These are presented here to provide a sense of the terminology used by those studying cognitive effects. Different authors may use variations of these definitions depending on the experiments being evaluated.

Table C-1. Definition of Types of Tasks Considered in Studies of Effects of Heat Stress (Ref. 15)

Type of Task	Definition
Mental tasks	Tasks that primarily require cognitive activity (thinking) to perform, such as decision making, judgments, and problem-solving
Reaction time	The amount of time required for an individual to respond to a stimulus (e.g., to push a button in response to a light or sound stimulus).
Tracking tasks	Tasks where the goal is to visually or manually follow an object that is changing position
Perceptual/motor task	Tasks that call upon both perceptual and motor capabilities.
Dual tasking	Perform two cognitively demanding tasks simultaneously
Vigilance	The ability to maintain attention over a long period of time in order to detect a change in a stimulus. A vigilance task typically requires an individual to respond to infrequent and random changes

Hancock (Reference 17) importantly noted that the lack of a systematic approach across many experiments makes it difficult to generalize from the results. He further notes that variables such as skill levels, prior training and experience in performing the task, highly incentivized workers, working with team members, and the ability to self-determine when breaks are needed from the environment all are factors that tended to offset the effects of the heat stress environment.

Benefit of Trained Nuclear Power Plant Control Room Operators

For reactor operators, most of the mitigating factors cited by Hancock (Reference 17) that minimize the effects of heat stress on cognitive functions are present in the MCR. The MCR operators are generally performing mental tasks and monitoring and tracking data. Under the leadership of the Control Room Supervisor (CRS) and the Operations Shift Manager (OSM), the MCR operators are highly trained and motivated, perform in a team environment, have close and experienced supervision by senior coworkers trained to recognize degradations in performance, and are performing tasks in a setting where they have repeatedly performed the same work for many months or years. All of these practical aspects have been shown to minimize the effects of heat stress beyond the limits normally used for physiological heat stress considerations (i.e., stay times based on core temperature considerations).

No Additional Limits for Performance Effects during Postulated Event

The heat stress environment identified in Section 4.2.2 for the postulated event is relatively mild for the normal work performed by the MCR personnel to maintain the plant in a safe condition. The WBGT did not reach 94°F. These conditions are at the edge of the highly conservative "no-effects curve" and the mitigating factors which diminish the heat stress effects on cognitive performance are very strong for an MCR team of operators. Therefore, limits on heat exposure more stringent than the physiological stay-time limits are considered unnecessary.

D Reference 22 - Entergy Discussion Paper presenting the Timeline of Events and Temperature Data Recorded during the March 9, 2015 Loss of Control Building Ventilation

Evaluation of March 9, 2015 Loss of MCR HVAC Event and Analysis of MCR Temperature Over the Course of the Event

Executive Summary:

A discussion is presented herein on what occurred during the AOP-0060 entry (Loss of Control Building HVAC) in the Main Control Room (MCR) on March 9, 2015. This event is documented in CR-RBS-2015-1829 and CR-RBS-2015-1830.

- The initial temperature rise indicated by HVCTA01 on 3/9/2015 was due to backflow from the Control Room Fresh Air (CRFA) system which was started at the time of test initiation on the LOP/ LOCA signal. This is heated backflow due to the 23KW heater in the CRFA filter train and is much lower flow rate (4,000 CFM vs. 38,200 CFM for the air handling units).

- The temperature sensor (HVC-RTD140) for Plant Data System (PDS) computer point, HVCTA01, for MCR temperature indication is located in the MCR HVC return air duct outside of the MCR. When there is no circulating air flow due to HVC-ACU1A (B) not in operation, this indication is not representative of actual MCR temperature.

- Manual start of HVC-ACU1A at about 52 minutes into the event provided effective MCR temperature control by mixing MCR air with air in the duct work through the air handling unit, with no chiller running, and restored proper indication of HVCTA01 to measure accurate MCR temperatures.

- Review of the sequence of events and actual temperature changes during this event concludes that the actual MCR temperature increase was about 7.7 degrees F, which is less than 1/3 of the calculated temperature rise, based on the conservative design information for MCR equipment heat loads assuming no cooling in the MCR.

Purpose and Event Summary:

The purpose of this paper is to explain the sequence of the pertinent events during the loss of HVC/HVK which occurred during the Division I LOP/LOCA test of STP-309-0601 ("Division I ECCS Test") on 3/9/15, and to describe the reasons for the response of the available temperature indicators including the PDS computer point data for HVCTA01, Control Room Exhaust Temperature. A detailed timeline is included at the end of the discussion.

Before the event started, PDS computer point HVCTA01, Control Room Exhaust Temperature, indicated 64.5 degrees. Initiation of the Division I LOP/LOCA test of STP-309-0601 started CRFA and cycled the MCR cooling to isolate the Kitchen Exhaust Fan and Toilet Exhaust Fan as part of simulating a LOCA and Loss of Power (LOP) event. However, HVK-CHL1C failed to restart. HVC-ACU1A sequenced on properly, however it tripped at about 10:52 due to its interlocks with the chiller. At the time the chiller tripped, MCR temperature indicated on HVCTA01 was about 65.1 degrees. Subsequent failures in HVC/HVK caused entry into AOP-0060, Loss of Control Room Cooling. After HVC-ACU1A was manually started and temperature stabilized at about 11:44, indicated temperature on HVCTA01 was 70.0 degrees. This is only a 4.9 degree rise in about 52 minutes. Subsequently HVCTA01 temperature slowly rose from 69.4 degrees at 11:46 to 72.2 degrees at 14:29 when the chiller started. This is indicative of a slow temperature rise in the MCR of 2.8 degrees over a period of 2 hours and 43 minutes. During this time some heat gain from CRFA running and some heat loss through the airflow in the ductwork is anticipated but this change in temperature is indicative of the realistic magnitude of the MCR temperature rise from the heat load with HVC-ACU1A running with no chilled water supply. This small temperature rise is indicative of the actual temperature increase in the MCR over the course of the event as also recalled by Operators who were in the MCR during the event. This is also indicative of the actual lower heat loads in the MCR compared to the conservative design basis calculation values.

Detailed Discussion and Analysis:

All times given are from the RBS Plant Data System (PDS) computer times unless noted otherwise. The LOP/LOCA test of STP-309-0601 was initiated at 10:47 on 3/9/15. By 10:48, the isolation valve for Control Room Fresh Air (CRFA), HVC-MOV1A, (as confirmed by review of sign-offs in the STP 309-0601 procedure copy in use at the time of the event) had closed as part of its initiation from the LOCA signal. Closing HVC-MOV1A isolates the normal HVC suction path and is designed to prevent HVC-ACU1A/B from pulling outside air directly. In addition to the isolation of normal supply air, the CRFA fan (HVC-FN1A for Division 1) starts and dampers realign to force MCR intake suction through the filter trains where it is filtered and heated via the 23KW heater in each filter train. Note that HVC-FN1A/B, also known as the Filter Train Booster Fans or Charcoal Filter Train Fans, are relatively small compared to the HVC-ACU1A/B fans. HVC-FN1A/B are rated for 4,000 CFM compared to 38,200 CFM for the HVC-ACU1A/B fans or about 10.5% of the Air Handling Unit flow rates. CRFA continued to run in this mode and was not secured until approximately 15:01 based on MCR logs. HVC-ACU1A and HVK chiller C also tripped on the load shed signal from the test at the same time and attempted to load sequence back on. HVC-ACU1A started at 10:48, but tripped again at 10:51 because of its interlock with the HVK-CHL1C chiller which failed to start.

Note that initiation of the LOP/LOCA test of STP-309-0601 isolates three other smaller flow paths from the MCR. These are HVC-AOD51A, CR TOILET DN STREAM ISOL,

HVC-AOD52A, CR KITCHEN DN STREAM ISOL, and HVC-AOD108, SMOKE REMOVAL FAN SUCTION. These were verified to have occurred properly in Attachment 8 of STP-309-0601 on the day of the event.

Operations attempted to swap to Div. 2 HVK/HVC, but HVC-ACU1B failed to start. They then attempted to start Div. 1 again. HVC-ACU1A started at 11:04 and ran for approximately 3 minutes, but tripped off again when the chiller failed to start. At 11:39, HVC-ACU1A was started manually by Operations at the MCR control boards, without a chiller running and it ran for the duration of the event. Note that manually starting the air handling unit with the pushbuttons from the MCR panel bypasses the chiller interlocks and allows the air handling unit to run without the chiller. The chiller, HVK-CHL1C, was returned to service at 14:29. During this time, the air handling unit was recirculating the air in the MCR without any cooling until the chiller was started.

During the majority of the first approximately 52 minute period of this event (e.g. other than the 3-4 minutes the HVC-ACU1A ran during attempts to restart a chiller), CRFA (e.g. HVC-FN1A, Filter Train Booster Fan) was running with no forced ventilation flow for the MCR. Review of the system logic and P&IDs, allows an evaluation of what would happen in this scenario. CRFA is designed to work in conjunction with HVC-ACU1A/B. The CRFA system, when in operation, takes approximately 2000 cfm of outside air, mixes it with 2000 cfm of recirculating air returning from the MCR, then heats it, filters it, and discharges it into the common suction duct for HVC-ACU1A/B. (Reference PID-22-9A and PID-22-9B) If HVC-ACU1A/B are both off then their suction dampers (HVC-AOD8A/B) are closed, isolating the flow path to the MCR. If the CRFA isolation damper HVC-MOV1A is also closed, which it was, then the only flow-path for the air is through HVC-AOD106/148 and to attempt to go through the normal exhaust line in a reverse flow path into the MCR or into the mechanical equipment room. This is also the same line where, during normal line-up, the system would be drawing 2000CFM from the MCR return via HVC-AOD171/ 172 for recirculation. Therefore, the system would be attempting to discharge 4000 cfm up the Control Room Exhaust line while also attempting to draw 2000 cfm from the same line, resulting in recirculation of its discharge back to its suction. Flow could also try to go through the Smoke Removal Fan discharge flow path, but recall that this path was also isolated by closure of HVC-AOD108 as part of the test. Some leakage would be expected through each of the closed dampers since these are not leak tight devices, however, there is no way to quantify this. Also, it is not possible to quantify the exact resultant flow rates in each path, but due to isolation of the other flow paths, it would most likely result in some heated air going in the reverse path up the Control Room Exhaust line (e.g. back-flowing to the Main Control Room through the HVAC return ducting). The fact that the Main Control Room was isolated further reduced the backflow of this heated air through the return duct since only MCR equivalent envelope leakage flow could go into the MCR.

As noted previously, the sensing RTD for computer point HVCTA01, HVC-RTD140, is physically located in the Control Room Exhaust line immediately upstream of the HVC-AOD106/148 dampers. The RTD is located in the Return Air duct several feet below

the Main Control Room floor, in the HVAC Equipment Room. In this scenario with CRFA running and HVC-ACU1A/B off, any flow past HVC-RTD140 would be outside air heated by the CRFA charcoal filter train heaters. It could not be flow from the MCR and could not be representative of MCR air temperatures. However, when HVC-ACU1A is running it will pull MCR air through the MCR HVC Exhaust line, reversing the flow to the normal flow path, past HVC-RTD140, and mix it with the discharge from CRFA, and discharge it back into the MCR through the normal Supply Line. When the chiller is running it will cool the air before returning it to the MCR. If the chiller is not running it will recirculate air across whatever cool water is still in the air handling unit heat exchanger, which would likely provide some amount of cooling for a short time period.

Note that the operations crew had been briefed and was prepared to go to the Control Building chiller room to align Service Water to provide cooling to HVC-ACU1A when Operations management stopped this action since MCR temperature control had been successfully established, thus this cross-tie was no longer needed for MCR cooling and contamination of the HVK Chilled Water system chemistry could be avoided.

Once HVC-ACU1A was off with CRFA on, HVCTA01 indicated temperature rose very quickly. (Refer to the first attached PDS trace below). Indicated temperature went from 64.5 degrees before the test to 91.4 degrees, at 11:23, an increase of 26.9 degree in approximately 36 minutes. But note that during this same time window, from 11:04 to 11:07 when HVC-ACU1A was running briefly during the attempted Div 1 start, HVCTA01 indicated temperature dropped from 85 to 73 degrees in less than three minutes. These indications are not indicative of real temperature changes in the MCR, but represents the decrease seen in the return duct temperature as cooler air from the MCR entered the duct and mixed with and cooled the hot air in the duct. 85 degrees was not indicative of the MCR temperature, but once flow was established, the temperature indicated by HVCTA01 would trend down toward a temperature representative of the temperature in the MCR. Twelve degrees of MCR temperature drop in three minutes without a chiller running, is not reasonable, and therefore this data is not representative of MCR temperatures. For comparison refer to the second PDS trace at 14:30 when Chiller C was started. At that time it took 30 minutes for the temperature to drop 2.8 degrees, from 72.2 to 69.4 degrees. This is representative of cooling down the entire Main Control Room with a chiller, and is reasonable. Note that start of a HVC-ACU unit even without a chiller running would provide some cooling for the MCR as MCR air is mixed and air flow through the duct work and the HVC-ACU coils would be cooled somewhat by the quiescent chilled water in the HVC-ACU unit.

It should also be noted from the first attached PDS trace, that the temperature dropped from the peak indicated temperature of 91.4 degrees at 11:23 to 76.5 degrees, at 11:39, a difference of 14.9 degrees in 16 minutes without HVC-ACU1A running. HVC-ACU1A was started at 11:39. There was no forced air to the MCR except perhaps some hotter CRFA back-flow, during this temperature drop. This is not indicative of MCR temperature, but is indicative of what may have been occurring in the HVAC duct in this situation. This temperature drop is likely due to the CRFA internal heater cycling off and is not indicative of actual MCR temperature. The CRFA heater, HVC-FLT3AH, can

cycle automatically on the air temperature at the heater as sensed by temperature switch HVC-TS30A, as long as there is flow through the unit. The nominal setpoint is 200 degrees F per SPDS HVC*TS30A. When the temperature switch trips it turns the heater elements off, and when it resets it turns the heater elements back on. (Reference schematic drawing 0225.220-115-021 and VTD N431-0101). The CRFA discharge air temperature was measured at 96 degrees F when it was running for testing on February 3, 2016. The outside air temperature at the time of this measurement was approximately 72 degrees. On March 9, 2015, the outside air temperature was about 66 degrees. Since approximately 50% of the total CRFA flow is drawn from outside and the rest is recirculated from the MCR, this 6 degree difference would not be expected to make more than a few degrees difference in the outlet temperature of the filter train. This temperature supports the conclusion that the value indicated by computer point HVCTA01 of 91.4 degrees was indicative of backflow from the heater train and not indicative of actual MCR temperature.

Note that temperature data from HVCTA01 is used for this analysis because it is the only MCR temperature indicator which is recorded and available for use after the event. During the event, Operations made attempts to monitor MCR temperature using HVC-TIS141 located in the rear of the MCR. The RTD feeding this indicator is located in the supply duct to the MCR and, similar to HVCTA01, is not indicative of actual MCR temperature when there is no forced air flow through the duct. This temperature indicator does not feed a computer point and values were not recorded by the MCR crew and the crew did not recognize this limitation at the time. Again, these readings would not have been indicative of actual MCR temperature and based on discussions with several operators on shift at the time of the event and others in the MCR (including the Engineer who was the Test Director for the ECCS test and developed this evaluation), all noted that the actual change in MCR temperature seemed fairly low and conditions were not uncomfortable. This was consistent with Operator reports from other parts of the Control Building which was also impacted by the loss of the HVK chiller.

The total Main Control Room volume in the GOTHIC heat up calculations (e.g., ENTR-078-CALC-003) is 170,566 ft3, consisting of 87417 ft3 in the lower volume below the false ceiling and 83,149 ft3 above the false ceiling. At the 37000 CFM design air flow rate of HVC-ACU1A (B), the time to turnover this total volume is 4.6 minutes. This indicates that the HVC-ACU1A (B) units would be capable of quickly establishing an equilibrium temperature in the MCR when they are started after a loss of ventilation heat up transient.

The calculated temperature above the MCR ceiling is calculated to be less than below the ceiling, where most of the heat loads are located. Using an in process version of the heat up calculation, bulk temperature above the ceiling at 30 minutes into a loss of HVC/HVK event was 87.6F compared to a bulk temperature below the ceiling of 104.8oF. When HVC-ACU1A (B) are started, the initially cooler air would be seen at the temperature sensor before air drawn from the MCR lower volume would be seen at the instrument.

Under a loss of MCR ventilation scenario as of 3/9/2015, operator actions to provide Main Control Room cooling by aligning Service Water (SWP) to the Control Building Chilled Water system (HVK) piping, per AOP-0060, would have been accomplished if needed and would have been highly effective.

During the March 9, 2015, loss of control building cooling event during Refueling Outage 18, Operations briefed aligning Service Water (SWP) to Control Building Chilled Water (HVK) system piping to provide cooling for the Control Building HVAC (HVC) system in accordance with procedure AOP-0060, "Loss of Control Building Ventilation." This was done shortly after Operations had manually initiated operation of a Main Control Room (MCR) Air Conditioning Unit, which resulted in successful MCR temperature control. The operations crew had been briefed and were ready to go to the Control Room chiller room to perform the realignment when Operations Management stopped this action since MCR temperature control had already been successfully established, thus this cross-tie was no longer needed for MCR cooling and contamination of Chilled Water system chemistry would be avoided.

AOP-0060 revision 9, effective June 17, 2014, contained instructions for mitigating a Loss of MCR cooling. Step 5.1.1 provides instructions for restoring the HVC and HVK systems. Step 5.1.2, the second step in the procedure, called for consideration of the SWP-HVK cross-tie.

Conclusion:

In conclusion, the HVCTA01 indicated temperatures from HVC-RTD140 when HVC-ACU1A was not running, are not indicative of actual MCR temperature. They are duct temperatures affected primarily by back flow from CRFA heated air, as well as temperature loss or cooling from the duct itself, or perhaps other factors such as leakage by closed dampers, but not indicative of MCR temperature. This would be indicative of backflow which is being directed to what is the normal return path for MCR air, via the upper plenum of the main control room, above the false ceiling. However, when HVC-ACU1A is running, the HVCTA01 indicated temperature from HVC-RTD140 will stabilize quickly (within a few minutes) and be representative of the average MCR temperature which is the physical sum of the mixture of all the air being pulled from the MCR.

Before the event, HVCTA01 indicated 64.5 degrees. HVC-ACU1A started and ran for three minutes and tripped. Indicated temperature after the trip was 65.1 degrees and began to rise at 10:52 After HVC-ACU1A was re-started with no chiller, and temperature stabilized, HVCTA01 indicated 70.0 degrees at 11:44. This is only a 4.9 degree F rise in about 52 minutes. From the second PDS trace HVCTA01 temperature slowly rose from 69.4 degrees at 11:46 to 72.2 degrees at 14:29 when the chiller started. This is indicative of the slow temperature rise in the MCR of 2.8 degrees over the approximately 2 hours and 43 minutes when the air handling unit was running with no

chiller running or approximately 1 degree per hour. During this time some heat gain would be expected due to main control room heat loads and due to CRFA running and some heat loss through the airflow in the ductwork.

The temperature rise demonstrated by review of 3/9/2015 data is significantly less than the temperature increase predicted by using design heat loads and the GOTHIC room heat up models and is representative of the realistic magnitude of the temperature rise in the MCR with HVC-ACU1A running without a chilled water supply over the course of the event, and indicative of the much lower values of actual heat load in the MCR compared to the conservative design values.

Timeline:

10:47 LOP/LOCA test of STP-309-0601 was initiated. HVCTA01 from HVC-RTD140 indicating 64.5 degrees before the test

10:47 HVC-ACU1A and HVK chiller C load shed off from the LOP signal

10:47 Control Room Fresh Air (CRFA) initiation from the LOCA signal

10:48 HVC-MOV1A, isolation valve for CRFA closed as part of initiation

10:48-10:51 HVC-ACU1A load sequences on, but tripped off again due to an interlock when the chiller failed to start.

10:52 Indicated temperature at HVCTA01 from HVC-RTD140 begins to rise rapidly. CRFA was running with no forced CR ventilation flow path. CRFA is taking outside air, heating it, filtering it, and discharging it into the common suction duct for HVC-ACU1A/B. With HVC-ACU1A/B off, their suction dampers closed, and HVC-MOV1A closed, then the air is forced through HVC-AOD106/148 and attempts to go in a reverse flow path into the MCR or mechanical equipment room. This passes through the duct by HVC-RTD140, so HVCTA01 rises accordingly.

10:55-10:57 Operations attempted to swap to Div. 2 HVK/HVC, but HVC-ACU1B failed to start.

11:04-11:07 Operations attempted to start Div. 1 HVK/HVC again. HVC-ACU1A started, but tripped off again on interlock when the chiller failed to start.

11:05-11:08 While HVC-ACU1A was running, it reversed the air flow past HVC-RTD140 to the normal flow path from the MCR, so that HVCTA01 temperature indication drops sharply back toward the actual MCR temperature.

11:08 HVC-ACU1A is off, so the CRFA flow is again forced backwards through the duct past HVC-RTD140, so HVCTA01 rises again accordingly.

11:23 Indicated temperature at HVCTA01 reaches a peak of 91.4 degrees and begins to drop rapidly. There is still no forced CR ventilation flow path and no cooling. Temperature drop was likely due to the CRFA internal heater cycling off. There is no computer point or recorded indication of heater cycles.

11:39 Indicated temperature at HVCTA01 has dropped to 76.5 degrees. Indicated temperature dropped 14.9 degrees in 16 minutes with no cooling. Not indicative of real MCR temperature.

11:39 Operations started HVC-ACU1A without a chiller and it ran for the duration of the event, but it ran with no chiller until 14:29.

11:40 Indicated temperature at HVCTA01 has dropped to 74.9 degrees.

11:41 Indicated temperature at HVCTA01 has dropped to 72.2 degrees.

11:44 Indicated temperature at HVCTA01 has dropped to 70.0 degrees.

11:46 Indicated temperature at HVCTA01 has stabilized at 69.4 degrees due to the forward flow of MCR exhaust air through the duct.

11:46-14:29 Indicated temperature at HVCTA01 slowly trends up from 69.4 degrees to 72.2 degrees due to a combination of MCR heat load, heat added by CRFA, and heat losses to the environment. HVC-ACU1A continues to run with no chiller. This is a rise of 2.8 degrees in approx. 2 hours and 43 minutes.

14:29 Chiller HVK-CHL1C is started to provide cooling to the MCR.

14:29-15:01 Indicated temperature at HVCTA01 drops from 72.2 degrees to 69.4 degrees with proper cooling of the MCR. This is 2.8 degrees in 32 minutes.

15:01 CRFA is secured after the completion of the LOP/LOCA test of STP-309-0601

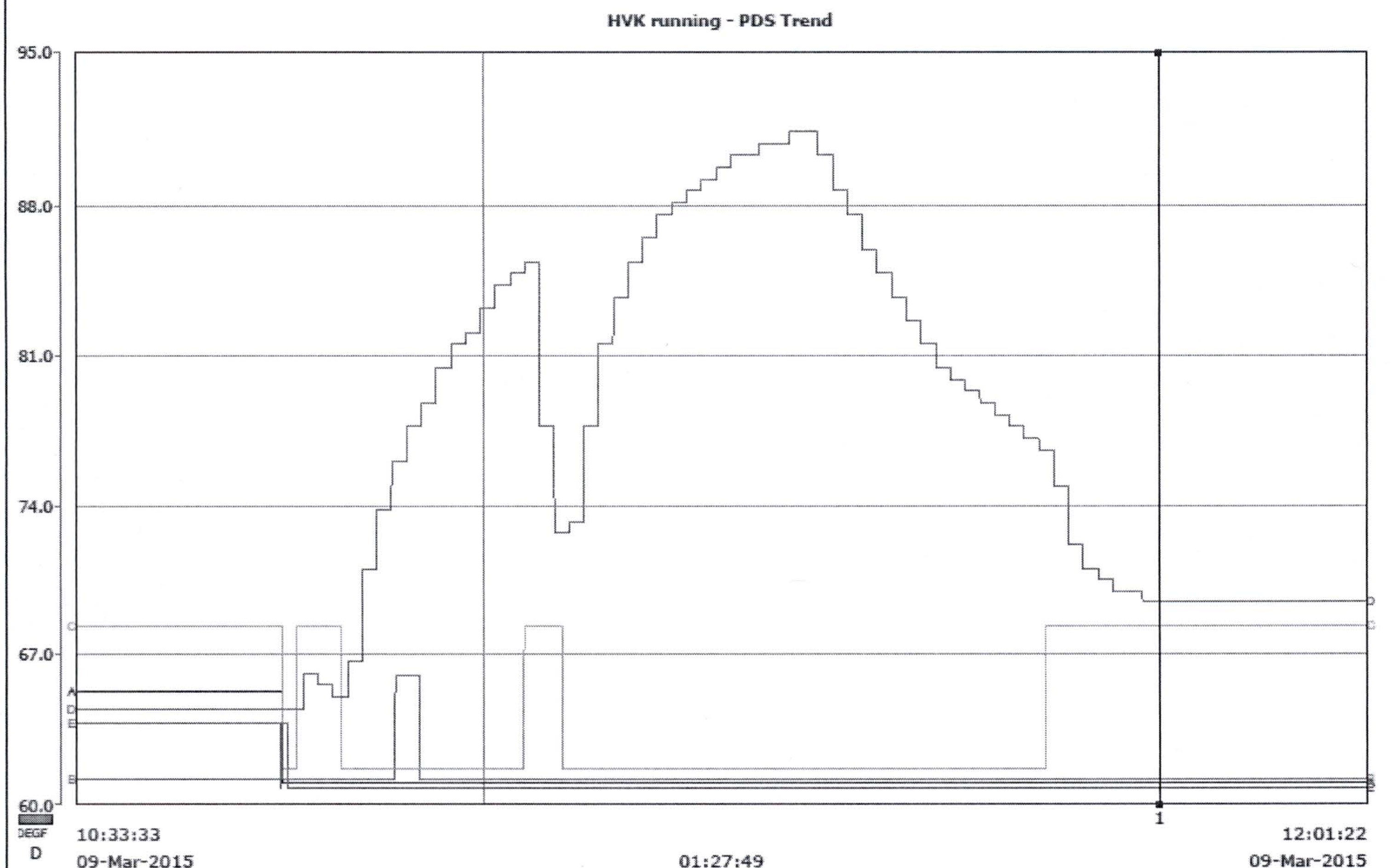
16:20 Indicated temperature at HVCTA01 continues to drop slowly and reaches 66.7 degrees.

18:45 Indicated temperature at HVCTA01 continues to drop slowly and reaches 65.6 degrees.

PDS Trend Data, Control Room Exhaust Temp (3/9/2015)
(from Masterpact Breaker Risk Summary provided to NRC, March 2015; WT-WTRBS-2015-0171)

Date/Time HVCTA01		
3/9/2015 7:30 64.5	3/9/2015 11:11 83.7	3/9/2015 11:36 78.2
3/9/2015 10:49 64.5	3/9/2015 11:11 85.4	3/9/2015 11:37 78.2
3/9/2015 10:49 66.2	3/9/2015 11:12 85.4	3/9/2015 11:37 77.7
3/9/2015 10:50 66.2	3/9/2015 11:12 86.5	3/9/2015 11:38 77.7
3/9/2015 10:50 65.6	3/9/2015 11:13 86.5	3/9/2015 11:38 77.1
3/9/2015 10:51 65.6	3/9/2015 11:13 87.6	3/9/2015 11:39 77.1
3/9/2015 10:51 65.1	3/9/2015 11:14 87.6	3/9/2015 11:39 76.6
3/9/2015 10:52 65.1	3/9/2015 11:14 88.1	3/9/2015 11:40 76.6
3/9/2015 10:52 66.7	3/9/2015 11:15 88.1	3/9/2015 11:40 74.9
3/9/2015 10:53 66.7	3/9/2015 11:15 88.7	3/9/2015 11:41 74.9
3/9/2015 10:53 71.1	3/9/2015 11:16 88.7	3/9/2015 11:41 72.2
3/9/2015 10:54 71.1	3/9/2015 11:16 89.2	3/9/2015 11:42 72.2
3/9/2015 10:54 73.8	3/9/2015 11:17 89.2	3/9/2015 11:42 71.1
3/9/2015 10:55 73.8	3/9/2015 11:17 89.8	3/9/2015 11:43 71.1
3/9/2015 10:55 76	3/9/2015 11:18 89.8	3/9/2015 11:43 70.5
3/9/2015 10:56 76	3/9/2015 11:18 90.3	3/9/2015 11:44 70.5
3/9/2015 10:56 77.7	3/9/2015 11:20 90.3	3/9/2015 11:44 70
3/9/2015 10:57 77.7	3/9/2015 11:20 90.9	3/9/2015 11:46 70
3/9/2015 10:57 78.8	3/9/2015 11:22 90.9	3/9/2015 11:46 69.4
3/9/2015 10:58 78.8	3/9/2015 11:22 91.4	3/9/2015 12:19 69.4
3/9/2015 10:58 80.4	3/9/2015 11:24 91.4	3/9/2015 12:19 70
3/9/2015 10:59 80.4	3/9/2015 11:24 90.3	3/9/2015 12:40 70

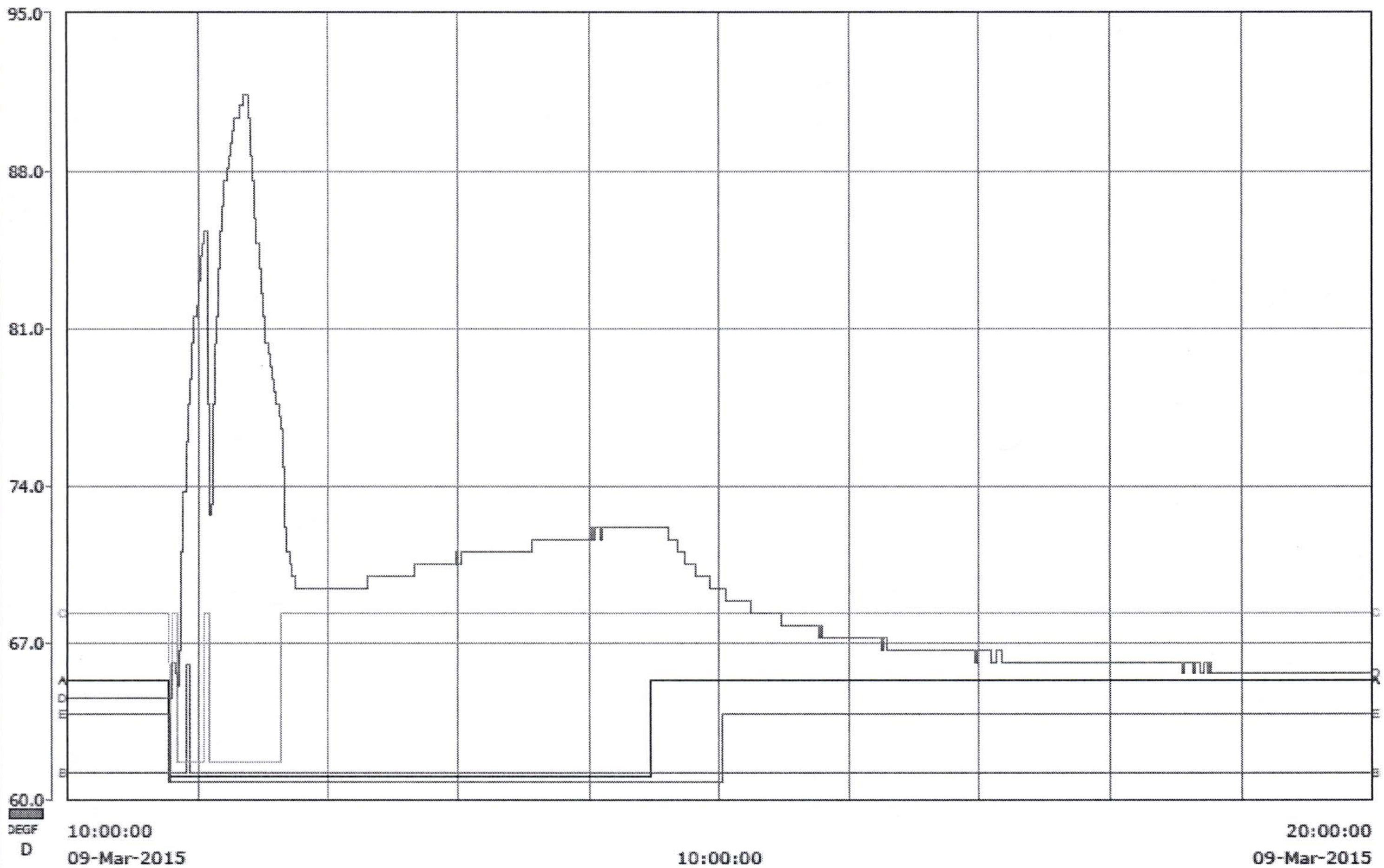
3/9/2015 10:59 81.5	3/9/2015 11:25 90.3	3/9/2015 12:40 70.5
3/9/2015 11:00 81.5	3/9/2015 11:25 88.7	3/9/2015 12:59 70.5
3/9/2015 11:00 82.1	3/9/2015 11:26 88.7	3/9/2015 12:59 71.1
3/9/2015 11:01 82.1	3/9/2015 11:26 87.6	3/9/2015 13:00 71.1
3/9/2015 11:01 83.2	3/9/2015 11:27 87.6	3/9/2015 13:00 70.5
3/9/2015 11:02 83.2	3/9/2015 11:27 85.9	3/9/2015 13:02 70.5
3/9/2015 11:02 84.3	3/9/2015 11:28 85.9	3/9/2015 13:02 71.1
3/9/2015 11:03 84.3	3/9/2015 11:28 84.8	3/9/2015 13:34 71.1
3/9/2015 11:03 84.8	3/9/2015 11:29 84.8	3/9/2015 13:34 71.6
3/9/2015 11:04 84.8	3/9/2015 11:29 83.7	3/9/2015 14:01 71.6
3/9/2015 11:04 85.4	3/9/2015 11:30 83.7	3/9/2015 14:01 72.2
3/9/2015 11:05 85.4	3/9/2015 11:30 82.6	3/9/2015 14:02 72.2
3/9/2015 11:05 77.7	3/9/2015 11:31 82.6	3/9/2015 14:02 71.6
3/9/2015 11:06 77.7	3/9/2015 11:31 81.5	3/9/2015 14:03 71.6
3/9/2015 11:06 72.7	3/9/2015 11:32 81.5	3/9/2015 14:03 72.2
3/9/2015 11:07 72.7	3/9/2015 11:32 80.4	3/9/2015 14:05 72.2
3/9/2015 11:07 73.3	3/9/2015 11:33 80.4	3/9/2015 14:05 71.6
3/9/2015 11:08 73.3	3/9/2015 11:33 79.9	3/9/2015 14:06 71.6
3/9/2015 11:08 77.7	3/9/2015 11:34 79.9	3/9/2015 14:06 72.2
3/9/2015 11:09 77.7	3/9/2015 11:34 79.3	3/9/2015 14:37 72.2
3/9/2015 11:09 81.5	3/9/2015 11:35 79.3	3/9/2015 14:37 71.6
3/9/2015 11:10 81.5	3/9/2015 11:35 78.8	
3/9/2015 11:10 83.7	3/9/2015 11:36 78.8	



Printed by: RBS-DDXS2ZV1\jparke9 Historical Printed: 11-Nov-2015 14:14:08

	Point ID	Description	E Units	Cursor 1 09-Mar-2015 11:47:16.386		09-Mar-2015 11:47:19.276	Retrieval Method
A	HVKBC07	CHILL WTR CPRSR 1C		0.00	0.00	QNA	LTA Event
B	HVKBC08	CHILL WTR CPRSR 1D		0.00	0.00	QNA	LTA Event
C	HVCBC13	CONT RM ACU 1A		0.00	0.00	QNA	LTA Event
D	HVCTA01	CONT RM EXHAUST	DEGF	69.4	69.4	QNA	LTA Event
E	HVCBX003	CONTROL RM AC UNIT ISOL M0V-1A		0.00	0.00	QNA	LTA Event

HVK running - PDS Trend



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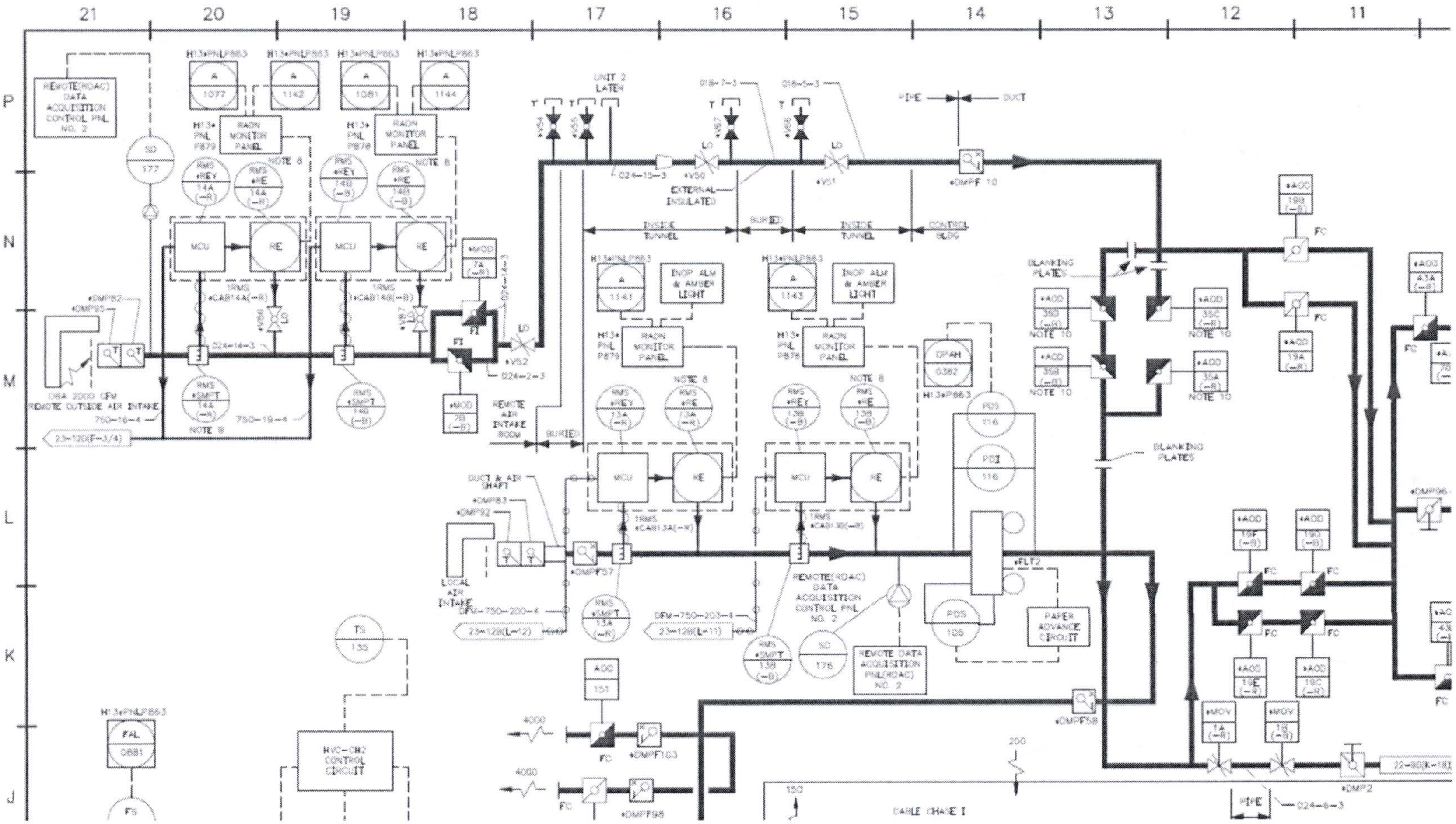
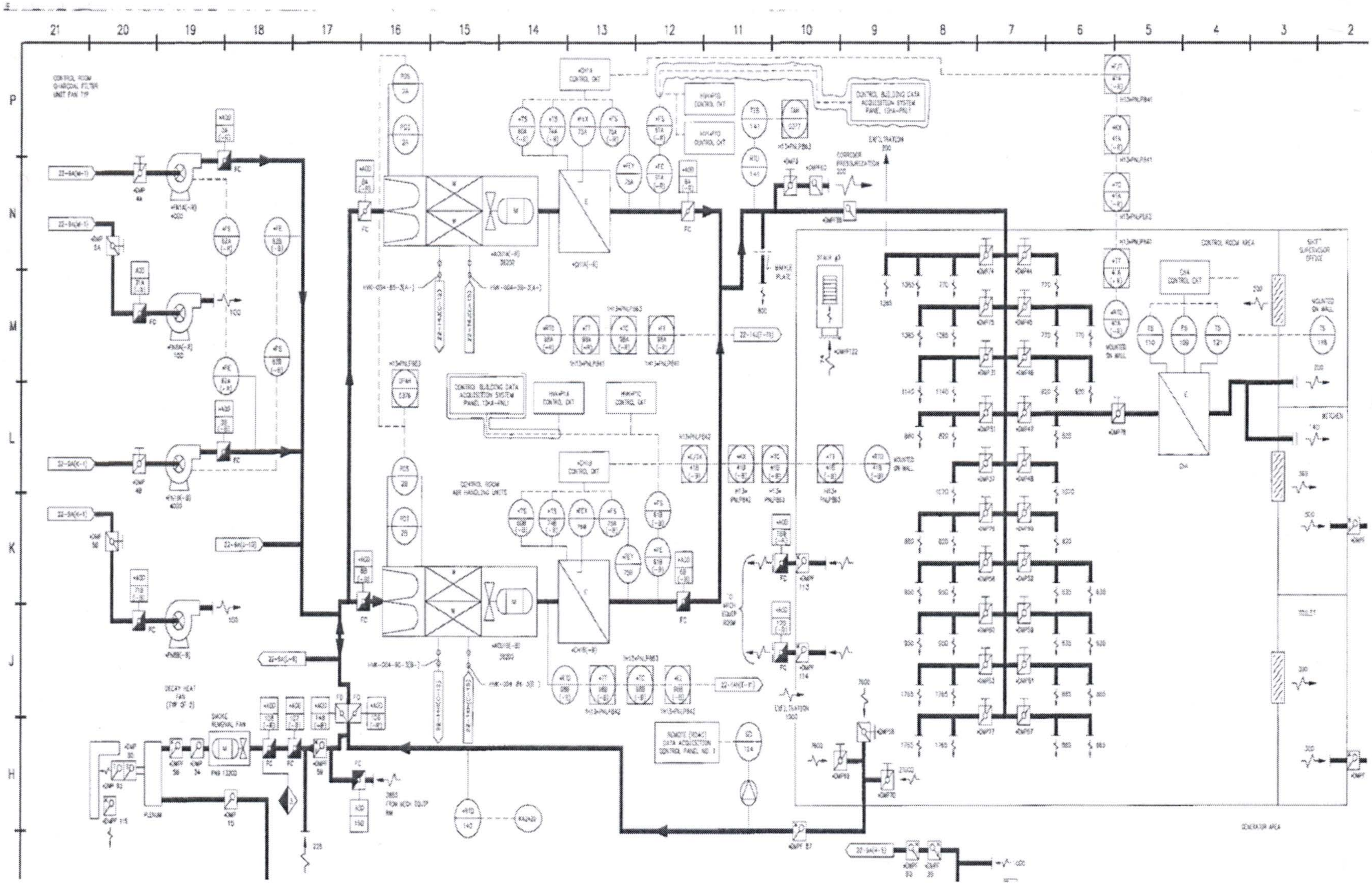
Historical Printed: 11-Nov-2015 14:15:52

	Point ID	Description	Y Min	Y Max	E Units	Val Min	Val Max	Val Avg
A	HVKBC07	CHILL WTR CPRSR 1C	-0.25	8.00		0.00	0.00	0.00
B	HVKBC08	CHILL WTR CPRSR 1D	-0.25	7.00		0.00	0.00	0.00
C	HVCBC13	CONT RM ACU 1A	-0.25	5.00		0.00	0.00	0.00
D	HVCTA01	CONT RM EXHAUST	60.0	95.0	DEGF	64.5	91.4	75.0
E	HVCBX003	CONTROL RM AC UNIT ISOL MOV-1A	-0.25	11.25		0.00	0.00	0.00

Excerpt from PID-22-09A showing Control Room Fresh Air (filtration) trains:



Excerpt from PID-22-09B showing Control Room Fresh Air (filtration) trains:



E Reference 23 - Entergy Summary of Habitability Related Actions Taken during March 9, 2015 Loss of Control Building Ventilation

The purpose of this white paper is to document further information regarding operator actions on March 9 for reference in the MCR habitability report. The intent is to answer questions supplied in an email from Erin Tindall concerning (1) habitability actions taken on March 9 and (2) actions which would have been taken on March 9 if MCR temperature had increased much faster (as shown by the GOTHIC model). Most of the information is taken from statements and interviews of operators who were present on March 9, along with some explanatory or technical comments.

(1) habitability actions taken on March 9

Procedure AOP-0060, Loss of Control Building Ventilation, would be entered when all Control Building ventilation is lost to provide guidance to the operators to minimize Control Room heatup and the loss of control functions. This could be due to loss of all HVK Chillers or loss of the associated HVC air handling units.

On 3/9/15 the plant entered AOP-0060, Loss of Control Building Ventilation, during Division 1 ECCS testing. The entry was driven by failure of HVK-CHL1C, Control Building Chiller C, to restart during the test and the inability to start a Division 2 Chiller due to HVC-ACU1B not starting. Engineering and Maintenance resources were requested for assistance through the Outage Control Center. Clearly the MCR personnel were aware that the MCR cooling had been lost and that the MCR temperature would be increasing due to the loss of the chillers.

AOP-0060 rev 10 (current revision) now includes section 5.1.4. "Monitor and trend local temperatures using Attachment 1, Main Control Room and Control Building Temperature Monitoring, to verify ambient room temperatures are less than 104 degrees Fahrenheit." The table in Attachment 1 is marked for 30 minute time intervals or shorter and indicates to record the MCR temperature in four areas using a hand held temperature measuring device. However AOP-0060 rev 9 (the revision on 3/9/15) did not include these directions.

During the event the Main Control Room team was directing the efforts to restore the chillers with the CRS providing Command and Control. The OSM was providing oversight, with the AOM-shift also present in the MCR. A primary focus of the management team was restoring a Control Building Chiller to service and completion of AOP-0060 actions. The Main Control Room team was also concerned with and was also addressing MCR and Control Building temperatures. Several reports were received from the field that there was no significant changes in Control Building temperatures during the time the chillers were out of service. There are no installed temperature indicators which monitor MCR ambient temperature while the HVC air handling units are not in service. Several operators and personnel who were in the MCR during all or part of the event stated, separately and independently, (and without prompting) that it really was not very hot in the MCR that day with the HVC/HVK off. A review of the recorded temperature data available during the March 9 event indicates that the temperature in the MCR remained below 73 degrees F throughout the entire 3 hours and 42 minutes of the event.

The OSM stated that the management team was aware of and continuously evaluating the effects of the elevated temperatures on the crew during the event. Heat stress and reliefs were discussed but actions were not required by the time HVK was restored. While the MCR temperature was elevated the crew did not exhibit any symptoms from the temperature.

The Main Control Room team was attempting to monitor the MCR temperatures with a five minute report to the management team. One of the on shift MCR Reactor Operators was directed to get and report temperature readings from a particular HVC indicator located on the North wall of the MCR. He could not remember the temperature values that he reported, but he did remember that the temperature was rising slowly and that no one was concerned about the value of the temperatures he was reporting. The

indicator was HVC-TIS141, which has its HVC-RTD141 located in the common duct for cold air leaving the discharge of HVC-ACU1A(B) going to the MCR. Its only purpose is to bring in an alarm at 68 degrees for high discharge temperature. But it is also only a valid number when either HVC-ACU1A or HVC-ACU1B is running to provide flow by the RTD in the ductwork. During the first 59 minutes of the event, the CRFA was running and HVC-ACU1A(B) were both off, therefore, the inlet and outlet dampers for HVC-ACU1A(B), dampers HVC-AOD8A(B) and HVC-AOD6A(B), would all be closed. Any flow past HVC-RTD141 would be air leaking past these closed dampers; on March 9, 2015, it would have been outside air heated by the CRFA charcoal filter train heaters, and leaking by the closed HVC-ACU1A(B) inlet and outlet dampers. If there was any leakage past these dampers, the amount of leakage is not known. Therefore, indicator HVC-TIS141 monitored during the transient was not representative of MCR air temperatures. Due to leakage of heated air past the closed dampers, it is expected that the indicated temperature was conservatively higher than the MCR temperature and that any actions taken based on this indicated temperature would be taken conservatively early.

Based on the HVC-TIS141indications, the OSM stated that Main Control temperature was slowly rising but not rapidly enough to cause immediate concern for exceeding tech spec allowed limits. The management team discussed options to maintain building and MCR temperatures below tech spec limits. The options discussed were temporary ventilation (fans and duct work including FLEX equipment), and the use of service water in the HVC Air Handling Units. The OCC was contacted and directed to stage temporary fans, duct work and extension cords in the Control building and were authorized by the OSM to use FLEX equipment to establish outside air flow into the MCR. A trigger point of 100 degrees was established for aligning Service Water into the HVK system to provide cooling to HVC-ACU1A. The operations crew had been briefed and was ready to go to the Control Building chiller room to align Service Water to HVC-ACU1A, but this action was not necessary.

(2) actions which would have been taken on March 9 if MCR temperature had increased much faster (as shown by the GOTHIC model)

It is difficult to quantify timing of actions which would have been performed if temperature in the MCR had increased to approximately 120 degrees F within 2 hours (calculations based on vendor / design heat load information indicate MCR temperature could increase 75 degrees to approximately 115 degrees over two hours), since they only increased about 4.9 degrees in the first 59 minutes (from 64.5 degrees at 10:47 to 69.4 degrees at 11:46), and then 2.8 degrees in the next 2 hours and 43 minutes (from 69.4 degrees at 11:46 to 72.2 degrees at 14:29). The postulated scenario is extremely conservative compared to the actual observed temperature transient. EN-IS-108, Working in Hot Environments, is the procedure which covers heat stress and stay times. It is normally used when sending personnel into areas that are not normally occupied for work, and which could be hot. In that case Industrial Safety, or some other personnel, obtains the wet bulb globe temperature (WBGT), performs the heat stress calc, and determines required work conditions. In this postulated case the OSM, CRS, and all the operators are standing in the subject room. Based on interviews, it is expected that operators would reference EN-IS-108, at some point if temperature continued to rise, probably when they began to feel uncomfortably warm. In the case of 3-9-15, several operators and personnel who were in the MCR stated, separately and independently, that it really was not very hot in the MCR that day with the HVC/HVK off. So it would not be expected that EN-IS-108 would have been referenced during the March 9, 2015 event. But they would all clearly feel hot long before MCR temperature neared 120 degrees. As personnel began to feel hot, they would probably start thinking about obtaining M&TE for normal dry bulb temperature and then WBGT for heat stress calcs and stay times.

As far as what is considered hot in the MCR, or who decides, the Control Room Supervisor (CRS) is the SRO in charge in the MCR. He decides based on the conditions to enter AOP-0060, Loss of Control

Building Ventilation. He also would be the one to make official decisions such as entering EN-IS-108, Working in Hot Environments, or calling Industrial Safety for determination of WBGT, stay times, etc. If this event happened the Shift Manager (SM), the SRO in charge of the CRS, would also be there as well as Duty plant people and anyone else the CRS called for help. Although the CRS is in charge, anyone can make a suggestion or point out the people are hot or in stress, which would drive toward the heat stress procedure and actions.

Most, if not all, the operators that were interviewed mentioned the EN-IS-108 procedure when asked questions about people and the heat level. The procedure has a Heat Stress Threshold Value (attachment 9.2) for normal work clothes and light to moderate work at 90 degrees dry bulb. It also has a Stay Time chart for different clothes and different work demands based on WBGT. Although Industrial Safety normally performs the heat stress calcs and makes recommendations, the procedure does not require that and other personnel can be allowed to perform checks. Obtaining the M&TE hand held temperature device for dry bulb temperatures or the WBGT instrumentation for the MCR from the cold tool room should only take a few minutes (5-10) in a situation like this, since it is very close to the MCR and anyone can be sent to obtain it.

Discussions with the Industrial Safety Coordinator about WBGT instruments, and how long it would take them to do a heat stress calc if needed, revealed the following: Industrial Safety has their own instrumentation and the instrumentation is also located in the cold and the hot tool rooms. He stated that many people are qualified to use them. The modern ones are apparently pretty simple. He stated that if he was on site and got a call to do heat stress evaluations in the MCR, he should be able to get there and perform it in about 20 minutes. He also said there is normally someone from their department on call, and if he got the call after hours he should be able to get to the plant and do the heat stress calc in less than an hour.

F Normal Operation, Design Heat Loads, Air Handling Unit Cooled by Service Water - "Attachment 1" Scenario with More Realistic (Hybrid) Relative Humidity Assumptions

The worst case transient selected for the principal evaluation of habitability in the MCR during the postulated loss of control room ventilation was that of Reference 18, Case 2 with an assumed starting condition of 70% relative humidity (RH) (Reference 18, Attachment 2) and design heat loads. Design heat loads were found to be 76% higher than the actual heat loads inside the MCR during normal operations, based on an actual test of the MCR during normal operations (Reference 27). Case 2 assumes normal plant operation as the initial condition and initiates smoke removal fans for ventilation 2 hours into the event, after the MCR air handling units (ACU1A(B)) failed to restart. Case 2 was selected because it resulted in the highest air temperature in the MCR. The starting high humidity of 70% (which is the highest allowed RH for the MCR under normal operating conditions – Reference 21) was added to the Case 2 scenario in order to produce the worst case habitability conditions for Case 2.

The procedure for loss of control building ventilation that was in effect at the time of the postulated event (Reference 1) included actions to, with the concurrence of the Shift Manager / Control Room Supervisor, use Service Water to cool the Control Building chilled water loops per the System Operating Procedure for the Control Building Chilled Water System. This case was simulated by Reference 18, Attachment 1, and it did not result in higher maximum MCR air temperature than Case 2. However, to determine the worst case habitability effects of the Attachment 1 case it is necessary to re-evaluate this case with a starting RH of 70% (as done by Reference 18, Attachment 2 for Case 2) and with a realistic, worst case RH after the ventilation with the ACU1A(B) restarts. This Appendix uses the temperature transient results of Reference 18, Attachment 1 with the hybrid RH conditions identified in this appendix, to calculate the worst case habitability effects of ventilating the MCR with the air handling unit cross connected to service water.

F.1 Assumptions for the Attachment 1 Scenario

F.1.1 General Procedural Steps

The Reference 1 procedure for loss of control building ventilation first requires an attempt to restart an MCR ventilation system air conditioning unit (ACU1A(B)) using the chilled water system. If that fails, the service water system can be cross-connected and the air conditioning unit restarted. For the Attachment 1 scenario of Reference 18, only one of the two available service water pumps is assumed to start (would normally use both pumps) and the service water temperature during the event is conservatively assumed to be the post-accident maximum temperature of 95°F (USAR Chapter 9, Reference 35), rather than the maximum technical specification surveillance requirement of the ultimate heat sink of 88°F (per SR 3.7.1.2). The restart of ventilation is assumed to be done at one hour after the start of the loss of ventilation.

F.1.2 Assumptions Made about Relative Humidity

The Reference 18, Attachment 1 analysis was performed assuming an initial RH value inside the MCR at the bottom of its allowed range (20%) (Reference 21). In addition, simplifying assumptions were made which resulted in RH values inside the MCR being kept unrealistically high. As discussed in Reference 18 Attachment 1, these assumptions allowed reasonable, slightly conservative temperature predictions.

F.1.3 Sensitivity Study for 70% Starting Relative Humidity in the MCR

Although the starting RH values in the MCR for most of the thermal modeling in Reference 18 used a starting RH of 20%, to maximize dry bulb temperature, a sensitivity study using a starting RH of 70% was modeled for Case 2 to make habitability evaluations more conservative. This resulted in an increase in heat stress conditions, as measured by the wet bulb globe temperatures (WBGT). As a result, the worst case air temperature model (Case 2) with a high RH starting value (Reference 18, Attachment 2) was used as the limiting habitability Case for this report.

F.2 More Realistic Assumptions about Relative Humidity

F.2.1 Use of Attachment 2 Relative Humidity Values for the First Hour

The trend for the relative humidity during the first hour of the postulated event will be assumed to be the same as for Reference 18, Attachment 2 used in the Case 2 sensitivity study. This is reasonable because for both scenarios, the heat generation and lack of ventilation inside the MCR will be the same during this time. After one hour, the Attachment 1 case commences ventilation using the MCR air handling unit cross-connected to the service water system.

F.2.2 Relative Humidity after Air Handling Unit is Restarted Using Service Water

After the MCR air handling unit restarts using service water for cooling, the MCR will gain humidity from the insertion of 2000 cfm of outside air with the recirculation flow of MCR air (in addition to 800 cfm from the MCR kitchen and toilet exhaust fans) (Reference 21). This additional humidity from outside will be based on the outside air being at 96°F and having 53% RH, the assumed outside air parameters used in Reference 18. The outside air at 96°F and 53% RH will have a humidity of 2.00 pounds of water per 100 pounds of dry air, based on air psychrometric tables (e.g., Reference 24).

No lag time will be assumed between the initiation of 2000 cfm of outside air into the recirculation air path for the MCR and the equilibration of the outside humidity with the MCR air volume (approximately 87,000 cubic feet prior to removal of the ceiling tiles - as noted in Reference 18). This is acceptable because the turnover time is only about one hour and no immediate heat stress condition requiring limits on stay time occurs during this time in the event (see Table F-1). Therefore, all of the air in the MCR will be assumed to have the same absolute humidity (2.00 pounds of water per 100 pounds of dry air) as the outside air after the first hour, when the air handling unit restarts. The resulting RH inside the MCR would be below the outside RH of 53% due to the additional heat up of the air inside the MCR. These values are shown in Table F-1.

F.3 Calculation of the WBGT and Heat Stress Related Stay Times

The WBGT values are calculated using the dry bulb air temperatures from the Reference 18 calculations for the Attachment 1 case (shown in Table F-2) and the hybrid RH values discussed in Section F.2. The RH values are shown in the third column of Table F-1. For the first hour, the RH values are taken from Reference 18, Attachment 2 (initial condition of 70% RH), similar to those shown in Table 4-2. After the first hour the RH values are those associated with the absolute humidity of the outside air, adjusted for the dry bulb temperature.

Table F-1. WBGT and Stay Times for Reference 18, Attachment 1 with Design Heat Loads and Hybrid Relative Humidity

From Att 1 Model Event Time (hr)	From Att 1 Model Temp (F)	1st hour use Att 2 RH% After 1st hour, use RH% calculated from outside air humidity	Wet Bulb Temp. (F)	WBGT (F)	LOW Demand Work Stay Time* (min)	MODERATE Demand Work Stay Time* (min)
0.0	75.0	70	68	70.1	No Limit	No Limit
0.2	98.5	36	76	82.9	No Limit	No Limit
0.4	103.2	32	78	85.6	No Limit	240
0.6	106.0	31	80	87.5	No Limit	170
0.8	108.1	30	79	87.6	No Limit	170
1.0	109.2	29	81	89.4	No Limit	110
1.2	104.1	41	83	89.3	No Limit	110
1.4	104.4	41	83	89.4	No Limit	110
1.6	104.6	40	83	89.5	No Limit	110
1.8	104.8	40	83	89.6	No Limit	110
2.0	105.0	40	83	89.6	No Limit	110
3.0	105.6	39	83	89.9	No Limit	110
4.0	106.1	38	83	90.1	230	85
5.0	106.3	38	83	90.2	230	85
10.0	107.1	37	83	90.5	230	85
15.0	107.4	37	84	90.7	230	85
20.0	107.6	37	84	90.8	230	85
24.0	107.8	36	84	90.9	230	85

Notes: NL = No limit on stay times

* = More restrictive stay times are imposed when rising WBGT reaches each temperature step in EN-IS-108 stay time table (Table 4-1 of this report). Less restrictive stay times are allowed when WBGT falls below each temperature step.

The stay times that are listed in Table F-1 are those that correspond to the stay time tables in EN-IS-108 (Reference 4) for Low work demand, and Moderate work demand, for workers wearing regular work clothes. See additional description on using WBGT values to determine stay times in the discussion in Section 4.2.2 regarding the use of Table 4-2.

Table F-2. Determining the RH Values for Heatup of Outside Air to MCR $T_{dry\ bulb}$

$T_{dry\ bulb}$ (°F)	Saturated moisture at Dry bulb temperature ($lb\ H_2O/100\ lb$ dry air)	Absolute moisture in air ($lb\ H_2O/100\ lb$ dry air)	RH%	WBGT (°F) at the Tdb
96	3.783	2.005	53%	85.7
100	4.305	2.005	47%	87.5
103	4.741	2.005	42%	88.8
104	4.895	2.005	41%	89.2
105	5.050	2.005	40%	89.7
106	5.220	2.005	38%	90.1
107	5.390	2.005	37%	90.5
108	5.560	2.005	36%	90.9
109	5.740	2.005	35%	91.4
110	5.930	2.005	34%	91.8
111	6.120	2.005	33%	92.4

Figure F-1 shows the behavior of the dry bulb temperatures and the WBGT over the time period of the postulated event, under the scenario of Reference 18, Attachment 1 with the hybrid RH values. Figure F-2 shows how the maximum stay time values associated with the calculated WBGT values change during the period of the postulated event under the Attachment 1/ Hybrid RH case and the corresponding WBGT values. It can be seen that there would be no stay times for heated outside air provided the Tdb inside the MCR was less than or equal to 105°F and no other sources of moisture inside the MCR were allowed to build up.

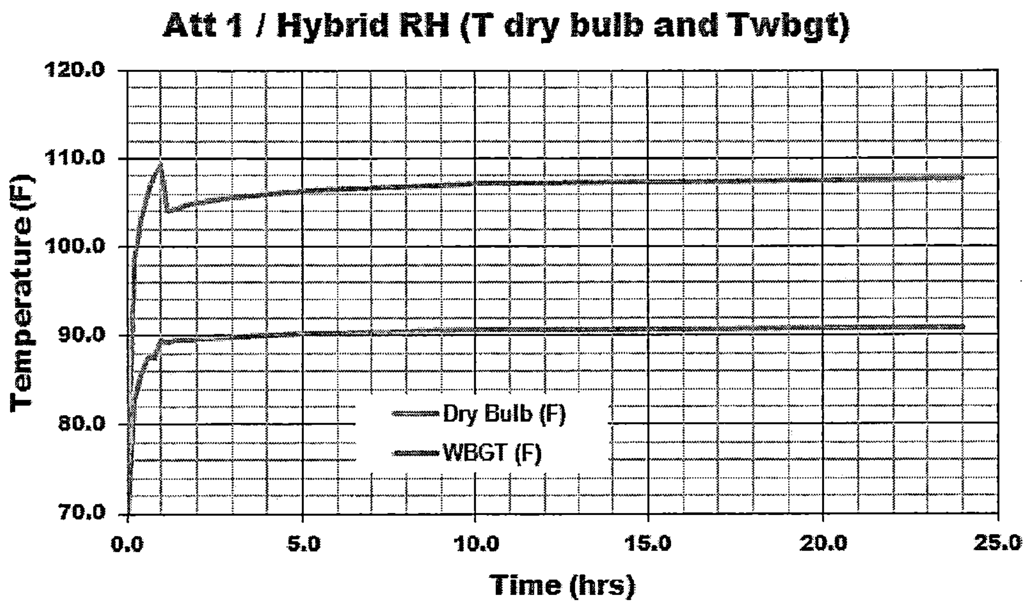


Figure F-1. MCR Temperatures for Attachment 1/ Hybrid RH with Design Heat Loads

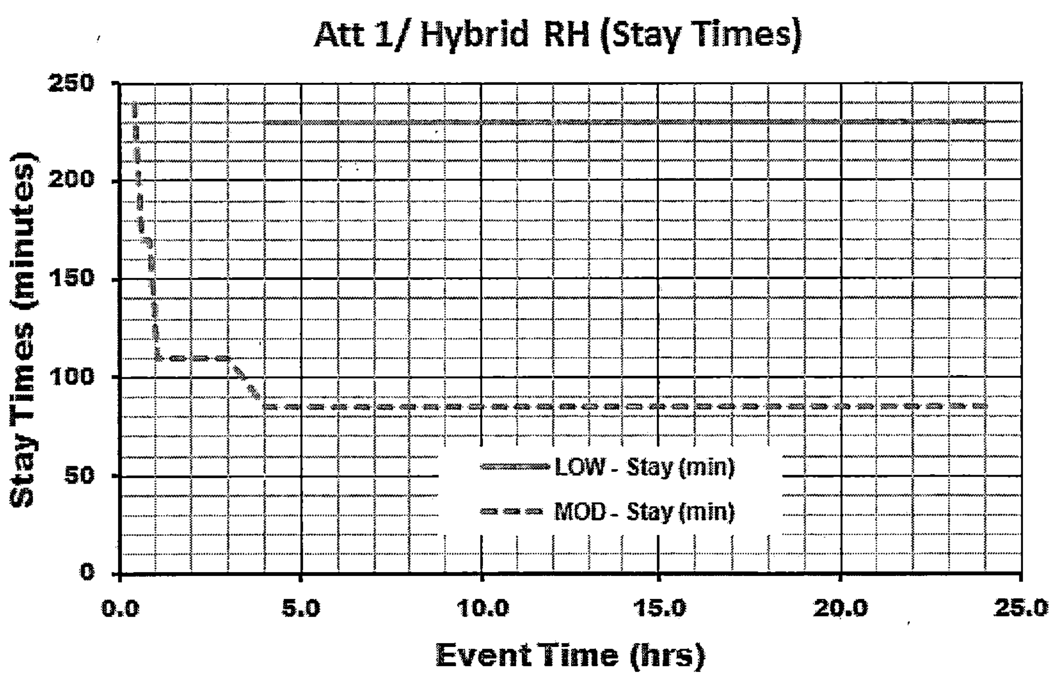


Figure F-2. Stay Times for Reference 18, Attachment 1 Case with Design Heat Loads and Hybrid Relative Humidity for Low and Moderate Work Demand Tasks

F.4 Evaluation of Realistic Heat Loads Applied

Appendix H evaluates realistic heat loads for the limiting case evaluated in the body of this report. A comparison of the results of these two cases shows that the realistic heat loads improve the habitability results significantly. When realistic heat loads inside the MCR (which are about 56% of the design heat loads - see Reference 27) are used for the most limiting Case 2 rather than the design heat loads, maximum average dry bulb air temperatures decrease from 110°F to 102°F at 5 hours (see comparison in Figure H-2) and no stay times are predicted to be needed during the postulated event. A similar reduction in dry bulb temperature would be judged to occur for the Attachment 1 case evaluated in this section if realistic heat loads were applied. Unlike the most limiting case which is cooled by direct MCR air replacement by the smoke removal system, the cooling method for the Appendix F case is by circulation of MCR air through the heat exchanger in the ACU1A(B) air handling unit which was cooled by service water at 95°F (Reference 35). For a reduction to 56% of the design heat load, it is expected that the maximum dry bulb temperature of 107.8°F would be reduced to below 105°F, at which point no stay times would be needed as discussed in the section above and shown in Table F-2.

F.5 Comparison of Attachment 1/Hybrid RH with Case 2/Attachment 2

Figure F-3 makes a comparison of the thermal conditions associated with the Reference 18, Case 2 with Attachment 2 RH and the thermal conditions of Reference 18, Attachment 1 with Hybrid RH. There is a period after 11 hours where the dry bulb air temperature inside the MCR is hotter for the Attachment 1 case. After 11 hours, the Case 2/Attachment 2 model allows for the temperature of the outside air to decrease because the diurnal variation in outside temperature goes down at night and the Case 2 scenario is bringing its entire supply of cooling air from outside air, via the smoke removal fans in the MCR. By comparison, more than 90% of the air flow into the MCR in the Attachment 1 case is recirculated warm air from inside the MCR and only 2000 cfm of the recirculation flow is from the outside air. In addition, the outside air in the Attachment 1 case is brought in over the LOCA filtration system which adds additional heat to the outside air. Therefore, the MCR temperature for the Attachment 1 case is not expected to benefit as much from the diurnal cooling of the outside air as is Case 2, which is consistent with the temperature trend shown in Figure F-3.

The WBGT temperatures are more limiting for Case 2/Attachment 2 for the first 14 hours, although there are times when the Attachment 1/Hybrid RH case is equally limiting. However, from the 14th to the 22nd hour, the Attachment 1 case becomes limiting, at about the same time that the dry bulb temperature for this case becomes higher than Case 2.

Figure F-4 shows a side by side comparison of the stay time requirements. Case 2 is more limiting or equally limiting overall except between the 14th and the 22nd hours. However, the stay time for the Attachment 1 case is at the least severe stay time limit (230 minutes) and no more limiting than the stay time values controlled by Case 2 just before and just after this period. Therefore, there is no noticeable change in watchstanders stay times or in the adverse effects of heat stress in this period where Attachment 1 is slightly more limiting.

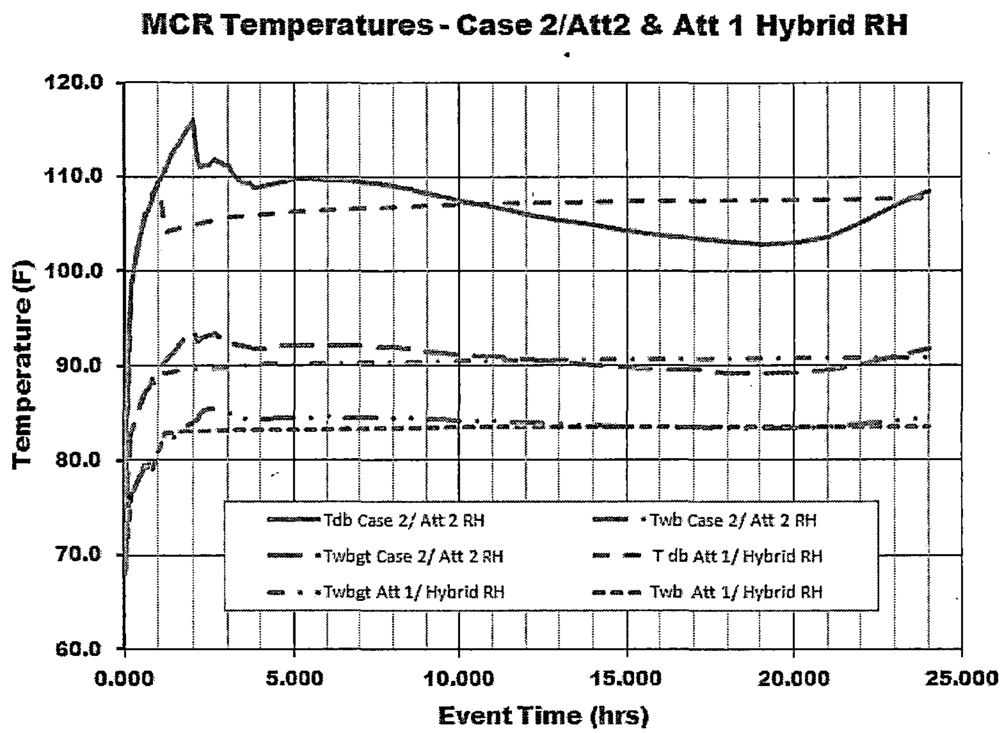


Figure F-3. Case 2/Attachment 2 vs. Attachment 1/Hybrid RH both with Design Heat Loads

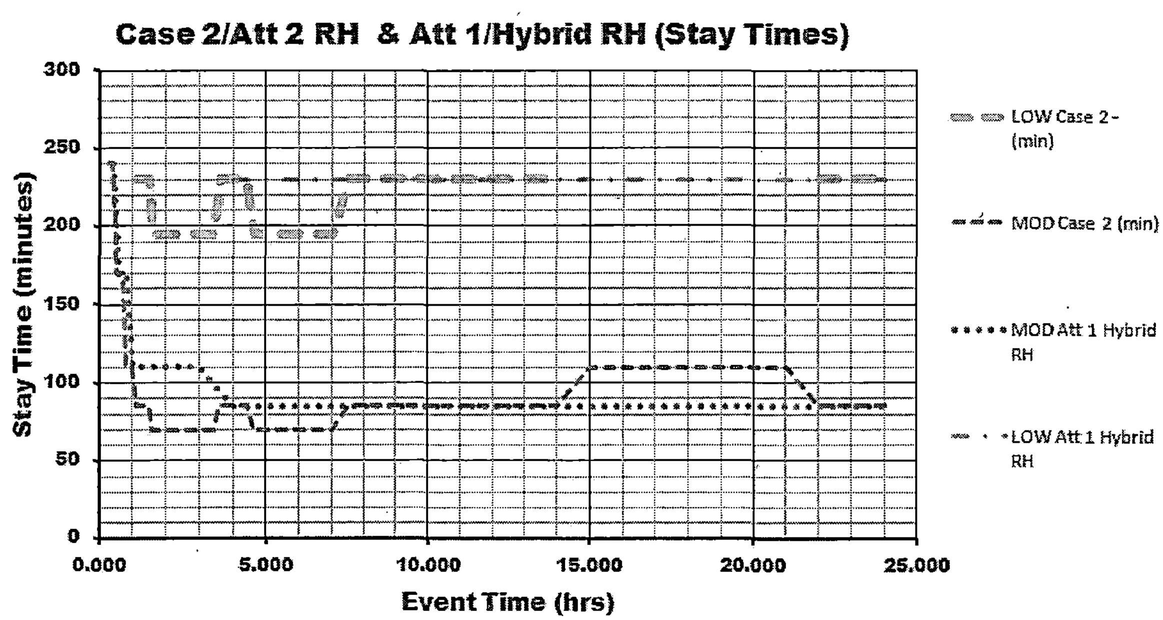


Figure F-4. Case 2/Attachment 2 vs. Attachment 1/Hybrid RH both with Design Heat loads

Table F-3 demonstrates a way that stay times can be used to determine a cumulative stay time allowance for MCR operators during the Attachment 1/Hybrid RH case. These allowances would be used to determine a basis for rotating each operator outside the MCR to a cool area for a recovery period, as explained in Section 4.2.2. These could involve each operator spending a

fraction of each hour (e.g., 15 minutes) in a recovery area or for spending 1 hour in a recovery area after each 3 hour period inside the MCR. a watch rotation for the period in which heat stress requirements might be imposed on the MCR operators. The manner in which this table is used is explained in the Section 4.2.2 discussion of Table 4-2.

Table F-3. Conceptual Stay Time Usage for Establishing Watch Rotations for Attachment 1/ Hybrid RH with Design Heat Loads

Event Time (hr)	LOW Work Demand Stay Time		Time in MCR (hr)	Stay Time Fraction Used	Cumul. Usage Fraction	Continuous Shift Length
	Time (min)	Time (hr)				
0 to 4	No Limit	No Limit	4	0.00	0.00	7.5 hrs
4.0 to 7.5	230	3.83	3.5	0.91	0.91	
7.5 to 11.0	230	3.83	3.5	0.91	0.91	3.5 hrs
11.0 to 14.5	230	3.83	3.5	0.91	0.91	3.5 hrs
14.5 to 18.0	230	3.83	3.5	0.91	0.91	3.5 hrs
18.0 to 21.5	230	3.83	3.5	0.91	0.91	3.5 hrs
21.5 to 25.0	230	3.83	3.5	0.91	0.91	3.5 hrs

F.6 Conclusions

1. Comparing to the stay time requirements of Attachment 1/Hybrid RH, the Case 2/Attachment 2 scenario is more limiting overall, except between hours 14 and 22 when the Case 2/Attachment 2 would change from 230 minutes stay time to No Limits on stay time, while the Attachment 1/Hybrid RH case would continue to require 230 minute stay times.
2. Since the acceptability of maintaining 230 minute stay times has been established for Case 2/Attachment 2, the Attachment 1/ Hybrid RH case is also acceptable.
3. A comparison of the results of the two cases discussed above shows that using realistic heat loads substantially lowered the maximum temperature during the 24 hour period. If the realistic heat loads are applied to the normal operation case which uses the air handling unit cooled by service water, a similar reduction in temperature would occur and no stay time limits would be recommended for operators.

G Loss of Offsite Power (LOOP) with Design Heat Loads

This appendix evaluates the habitability of the main control room (MCR) for the case in Attachment 14 of Reference 30, in which a loss of control building ventilation occurs in conjunction with a loss of offsite power (LOOP) and the humidity in the MCR starts at the maximum design value.

G.1 Assumptions for LOOP with Design Heat Loads Case

This analysis uses the MCR temperature and humidity results from Reference 30, Attachment 14 as inputs for the evaluation of the habitability of the MCR. Reference 30 uses the model which was developed in Reference 18. Therefore, the assumptions used by those calculations also apply to this evaluation. Key assumptions from Reference 18 are discussed in Section 1.1 of this report.

Table G-1. Mitigating Actions Assumed for LOOP with Design Heat Loads

Time	Action	Basis
0	Loss of Control Building cooling(failure of HVC-ACU1A(B) to run due to chiller failure) Loss of Offsite Power: Div.1 and/or Div.2 Standby DG's respond successfully.	
< 30 min	Operators attempt to restart chillers or manually start HVC-ACU1A(B). ***These actions are assumed to fail.***	AOP-0060 (Reference 8.6) Step 5.1.1 and Operator Interviews.
30 min	Complete actions to open back panel doors in Control Room.	AOP-0060 (Reference 8.6)
	Operators would normally initiate steps to align SWP to provide cooling to HVC-ACU's Operators would start this action at some MCR temperature below the TS limit (e.g., 100F). ***This action is not credited.***	AOP-0060 step 5.1.2 (Reference 8.6). and Operator Interviews
104°F	Initiate actions to remove ceiling tiles.	AOP-0050 (Reference 8.14) and Operator Interviews

Key inputs and assumptions include initial conditions inside the MCR are at the maximum design conditions for temperature (75°F dry bulb) and relative humidity (RH) (70%) for normal operations, and outside temperatures and humidity are at 96°F and 53% RH. In general, for the cases evaluated in Reference 18 and Reference 30, the only sources of moisture in the MCR during the event other than the initial humidity are those that originate from air drawn in from outside the MCR.

The mitigating actions taken for this case in Reference 18 and 30 are shown in Table G-1. It can be seen that no actions are taken in this case to provide other sources of outside ventilation so that the thermal and humidity transients will be based on the heatup of the enclosed MCR volume. When the ceiling tiles inside the MCR are removed (which commences when the dry bulb temperature reaches 104°F), the volume above the ceiling tiles is combined with the volume below which increases the volume of air from about 87,000 ft^3 to 170,000 ft^3 (Reference 18). The increase in volume benefits the rise in temperature in two ways: 1) the air trapped above the tiles is cooler (80°F) and there is a short term drop in temperature as a result, and 2) the volume

of air increases by about a factor of two which results in slower and less severe temperature changes for a given heat load.

G.2 Thermal and Humidity Transients Predicted for LOOP with Design Heat Loads

The dry bulb temperature and relative humidity transient for Attachment 14 of Reference 30 are shown in Table G-2. The temperatures are taken from the average MCR temperature values in the calculation since the average temperature is most representative of the area where the operators are stationed inside the MCR (explained in Section 2.0, Input 1 of this report). Using the dry bulb temperature (Tdb) and the RH values from the calculation, the wet bulb temperature (Twb) and the wet bulb globe temperature (WBGT) are determined for each condition. This methodology is explained in Section 4.1.2 of this report. Then using the WBGT values and the stay time table of the Entergy Procedure EN-IS-108 (Reference 4), the stay times are determined, and these are listed in Table G-2.

The dry bulb temperature is observed to rise steadily (see Figure G-1) until the ceiling tiles are removed after about one hour into the event. Then after the cooling effect of the air volume in the upper MCR stabilizes, the continued heat input to the MCR begins to heat up the larger air mass at a slower rate. The relative humidity initially plummets rapidly (see Figure G-2) because the rising temperatures have a much larger saturation capacity for water vapor and therefore reduce the "relative" humidity values since there are no sources of moisture for this case. Without further inputs of moisture, the RH values decrease as the air heats up.

The rising temperatures eventually result in WBGT values (≥ 84°F) that are high enough to affect stay times for moderate work demand tasks, but do not reach the point (≥90°F) at which operators (having low work demand duties) inside the MCR would have their stay times affected by the end of the 24 hour period of the event. As noted in the report (Section 4.4.1), the operators would nevertheless be making self-determined assessments for heat stress, observing fellow operators, and taking mitigative actions such as drinking water.

The rising WBGT values are shown in Figure G-1. Moderate work demand tasks reach stay time conditions when the WBGT reaches 84°F and there are some of these tasks that occur such as the removal of ceiling tiles. Low work demand tasks do not require stay time limitations until the WBGT reaches 90°F which does not occur for this event.

Table G-2. LOOP with Design Heat Loads and 70% Initial Relative Humidity – Stay Time Evaluation

					Stay Times (min)	
t (hr)	Tdb (F)	RH%	Twb (F)	WBGT (F)	LOW	MOD
0.0	75	70	68.0	70.1	no limit	no limit
0.2	95	40	75.0	80.8	no limit	no limit
0.4	99	36	76.5	83.2	no limit	no limit
0.6	101	35	77.6	84.6	no limit	240
0.8	103	34	78.3	85.6	no limit	240
1.0	104	32	78.9	86.5	no limit	170
1.2	105	33	79.6	87.1	no limit	170
1.4	105	34	80.0	87.3	no limit	170
1.6	104	34	79.5	86.9	no limit	170
1.8	103	34	79.2	86.5	no limit	170
2.0	103	34	79.2	86.4	no limit	170
2.5	104	34	79.1	86.5	no limit	170
3.0	105	33	79.4	87.0	no limit	170
3.5	106	32	79.7	87.4	no limit	170
4.0	106	31	79.7	87.5	no limit	170
4.5	103	34	78.5	85.8	no limit	240
5.0	103	34	78.5	85.8	no limit	240
6.0	103	34	78.6	85.9	no limit	240
7.0	104	33	78.8	86.2	no limit	170
8.0	104	32	78.9	86.5	no limit	170
9.0	105	32	79.0	86.7	no limit	170
10.0	105	31	79.1	86.9	no limit	170
15.0	108	29	79.8	88.2	no limit	110
20.0	110	27	80.3	89.2	no limit	110
24.0	111	26	80.7	89.9	no limit	110

G.3 Accounting for the Humidity Additions due to People

Although not included in the Reference 18 and 30 calculations, the presence of people inside the MCR will contribute to the relative humidity inside the MCR. While the rate of perspiration that the body requires is relatively low each hour (see Appendix I), the fact that there is no removal of this moisture for the loss of offsite power case (because of the conservative assumption that the MCR air handling unit cannot be restarted) results in a significant effect over the 24 hours of the event. The rising humidity due to moisture emitted by people in a heat stress environment with no ventilation is discussed in Appendix I.

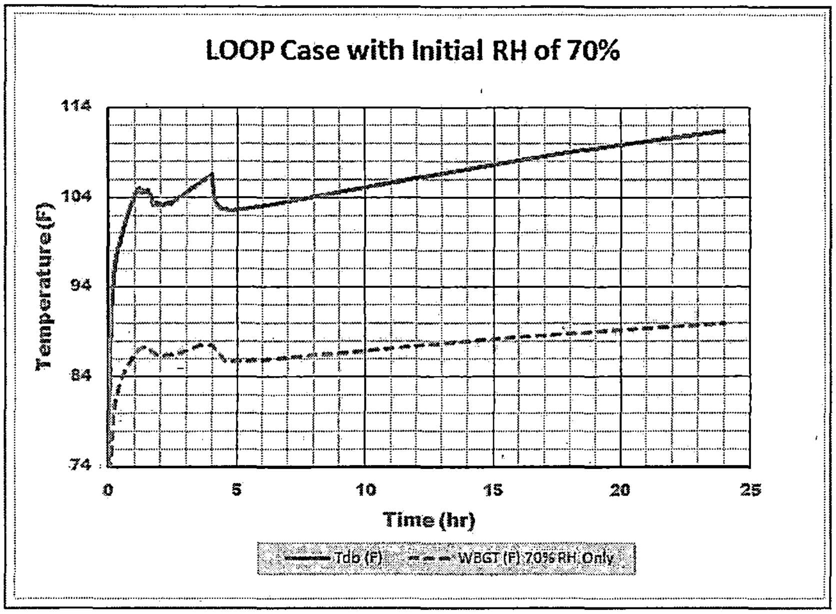


Figure G-1. Temperature Transients due to Lost HVAC during Loss of Offsite Power (LOOP) and no Ventilation Availability with Design Heat Loads

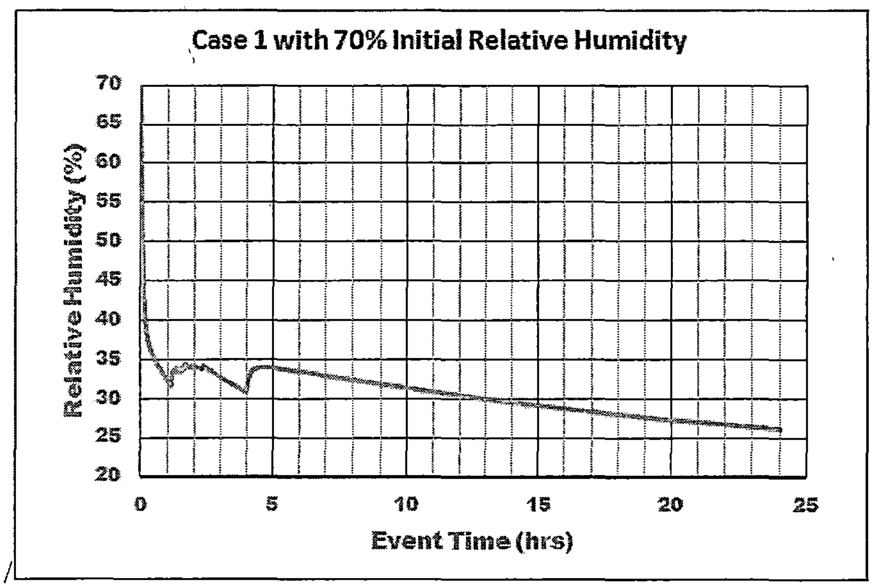


Figure G-2. Relative Humidity Transient, LOOP with Design Heat Loads

G.4 If LOOP Condition Included Restarted MCR Air Handling Unit with Service Water

This section evaluates the impact of the MCR air handling unit cooled by service water on a loss of ventilation in conjunction with a LOOP. If this ventilation system was restarted at about 104°F or at 1 hour as was postulated for normal operation in Appendix F with a 70% RH and

75°F starting condition, the moisture level after the start of the air handling system would soon be the same as outdoor air heated to the MCR temperature as discussed in Appendix F (see Table F-2). The reduced heat loads would be based on the energized components in the MCR (assuming design heat load conditions) which still were operated under the LOOP condition, which would be less than for the case evaluated in Appendix F which retains full offsite power.

The LOOP case would be similar to Appendix F except that the LOOP heat loads are lower and the fresh air makeup rate would be 2000 cfm for LOOP rather than 2800 cfm for Appendix F because the 800 cfm for the MCR kitchen and toilet exhaust fans would not be operational during a LOOP. However, the cooling of the MCR would be dependent on the flow of recirculated plus fresh air (37,200 cfm – Reference 21) over the heat exchangers in the ACU1A(B) air handling unit. This air would be cooled by the service water cross-connected to the chilled water loops, as permitted by the AOP-0060 procedure (Reference 1).

Because this condition is essentially the same as that of Appendix F Attachment 1 except with a lower fraction of the design heat loads, the expected WBGTs would be less and the stay times would be greater for this scenario than the Appendix F case. As discussed in Appendix F, that case assumes that only one service water pump is in operation and the cooling water temperature is 95°F. If the additional service water pump was operated and the water temperature was the more realistic 88°F rather than the assumed 95°F, the WBGTs would be more favorable and the effect of stay times less restricting. More would have to be understood about the heat exchanger to conclude whether this would be sufficient benefit to conclude there would be no need for stay times.

Since Appendix F notes that there would be no stay times for the normal operation case if realistic heat loads were assumed, the same would be true for LOOP with the mitigating actions discussed in Appendix F and realistic heat loads.

H Realistic Heat Loads

Reference 18 Case 2/Attachment 2 (normal plant operation and maximum allowable relative humidity as the initial condition) exhibited the worst case postulated loss of MCR ventilation event based on resulting in the highest air temperatures and highest WBGTs, as discussed in Section 1.1 and Section 4.0 of the report. However, the results of the assumptions used in the calculational model appear to be highly conservative compared to two known instances. The first is the relatively low heatup rate inside the MCR observed during the March 9, 2015 loss of control building ventilation (Reference 22), in which the actual heatup rates were less than 1/3 of the rates predicted by the model. The second is the result of a heat balance test in February 2016 (Reference 27) which determined that the MCR design heat loads assumed for the calculation were about 76% higher than the actual heat loads measured by the heat balance..

The purpose of this appendix is to evaluate the results of the using the more realistic heat loads inside the MCR under the same conditions for Case 2/Attachment 2 that were evaluated in the report (see Section 4.0) with70% initial RH and 75°F initial MCR temperature and the other assumptions for mitigating actions (principally the use of smoke removal fans for cooling of the MCR). All of the assumption and inputs provided in Sections 2 and 3 of this report apply to the case evaluated in this appendix. The temperature and relative humidity calculation for this case is contained in Attachment 5 of Reference 30.

H.1 Case 2 Scenario with Realistic Heat Loads

The predicted dry bulb air temperatures (Tdb), and relative humidities for this Reference 30, Attachment 5 case are shown in Table H-1, below. These were used to determine the wet bulb temperature (Twb) and the WBGTs. The WBGTs were used to determine the stay time requirements, if any, from the Entergy EN-IS-108 Procedure (Reference 4).

Figure H-1 shows the transients for Attachment 5 for the dry bulb and wet bulb temperatures and the WBGTs. Figure H-2 compares the dry bulb temperatures and WBGT's for the high heat load and realistic heat load cases. The following conclusions can be drawn from this comparison:

- The peak temperature reached is around 102°F for the realistic heat loads compared to 116°F for the more conservative prediction with design heat loads.
- The WBGTs never reach 90°F by the end of the assumed 24-hour period so there are no stay times for low work demand tasks such as the reactor operators on watch. Therefore, for the postulated event but using realistic heat loads, no stay times would have needed to be observed during the entire event.
- Stay Times for moderate work demand tasks have very mild restrictions and would be longer than necessary (no less than 110 minutes) for performance of individual mitigative actions inside the MCR that might require moderate work demand (e.g., moving fans, or ceiling tiles, etc.).

- Under realistic heat loads, the entire worst case postulated event could have occurred without having any restrictions on actual time to perform mitigating actions and normal watchstanding.

Table H-1. Case 2/Attachment 5 with Realistic Heat Loads

t (hrs)	Tdb (°F)	Twb (°F)	RH%	WBGT (°F)	Stay Time Low Demand (min)	Stay Time Moderate Demand (min)
0.0	75.0	68.0	70.0	70.1	No Limit	No Limit
0.2	87.8	73.2	49.7	77.6	No Limit	No Limit
0.4	90.6	74.5	46.9	79.4	No Limit	No Limit
0.6	92.4	75.6	45.9	80.7	No Limit	No Limit
0.8	93.9	76.6	45.2	81.8	No Limit	No Limit
1.0	95.2	77.4	44.5	82.7	No Limit	No Limit
1.5	98.0	78.7	42.3	84.5	No Limit	240
2.0	100.3	80.4	42.1	86.4	No Limit	170
2.5	100.5	83.3	48.5	88.4	No Limit	110
3.0	101.5	83.3	46.5	88.7	No Limit	110
3.5	101.1	82.8	46.2	88.3	No Limit	110
4.0	101.1	82.7	45.9	88.2	No Limit	110
4.5	101.6	82.9	45.3	88.5	No Limit	110
5.0	101.9	82.8	44.7	88.6	No Limit	110
6.0	101.9	82.8	44.6	88.5	No Limit	110
7.0	101.7	82.7	44.7	88.4	No Limit	110
8.0	101.2	82.5	45.3	88.1	No Limit	110
9.0	100.2	82.2	46.6	87.6	No Limit	170
10.0	99.3	82.1	47.9	87.2	No Limit	170
15.0	95.5	81.1	53.8	85.4	No Limit	240
20.0	93.8	80.6	56.5	84.6	No Limit	240
24.0	99.7	82.1	47.3	87.4	No Limit	170

H.2 Realistic Heat Loads for Other Cases

As shown in the previous section, the realistic heat loads substantially lowered the rate and maximum level of temperature rise during the 24 hour period so that the forced air circulation was better able to cool the MCR. If the realistic heat loads are applied to the less limiting normal operation case with forced circulation reviewed in Appendix F, the same reduction in temperature would occur and it is expected that no stay times would be required.

If heat loads for the LOOP scenario discussed in Appendix G were reduced by the same ratio the normal operation loads were decreased, the temperature rise would be less than for the design

heat loads, but the buildup of moisture over the 24 hour period would probably still be a concern for reaching WBGT values requiring stay times in the second half of the 24 hour period.

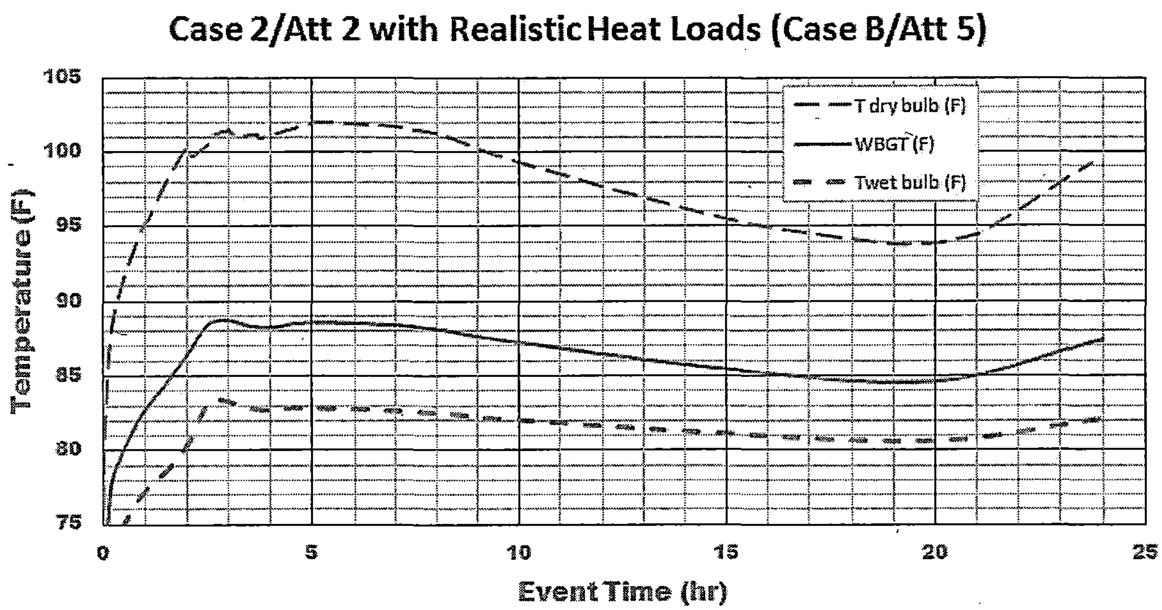


Figure H-1. Case 2/Attachment 2 with Realistic (Attachment 5) Heat Loads

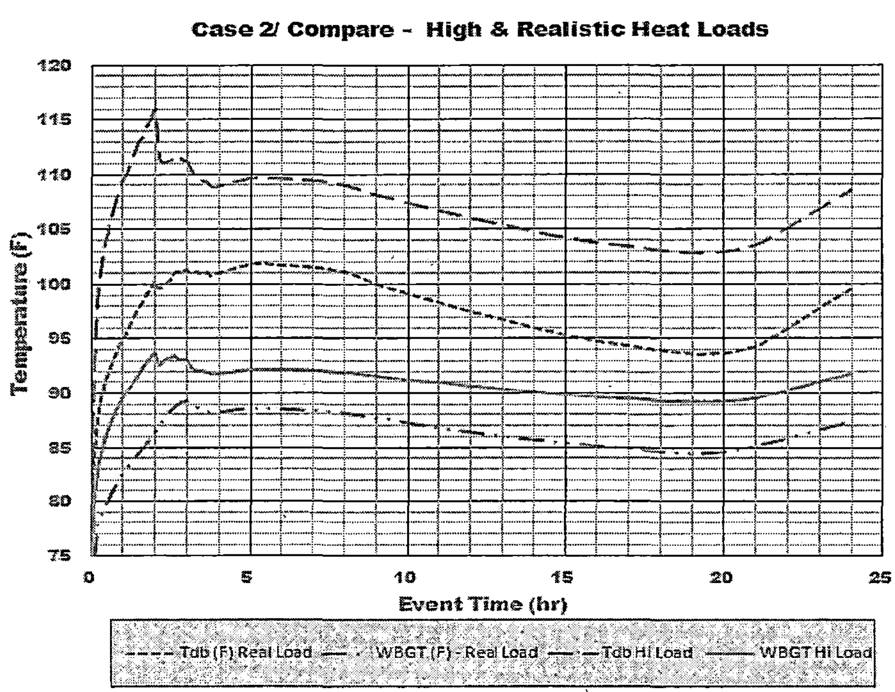


Figure H-2. Comparison of Design (High) Heat Loads and Realistic Heat Loads

I Accounting for Moisture from People in the MCR

Although not included in the Reference 18 and 30 calculations, moisture resulting from the presence of people inside the MCR will contribute to the relative humidity inside the MCR. Ignoring this moisture is acceptable for evaluations of the effects of the dry bulb temperatures on the electrical equipment because it results in more conservative (higher) dry bulb temperatures to minimize humidity; however, for habitability assessments, higher relative humidity is more limiting. This appendix will assess the habitability effects of moisture from people in the MCR for the postulated loss of MCR ventilation.

I.1 Key Details and Assumptions

The following key details and assumptions are stated elsewhere in this report, but are repeated and detailed here because they are important to the evaluation of moisture buildup in the MCR:

1. The amount of heat being generated by each person in the MCR is assumed to be 475 Btu/hr by References 18 and 30. Each person will emit this much energy either by convection, conduction, radiation or evaporation (whether by perspiration or respiration).
2. The loss of offsite power (LOOP) in conjunction with the postulated loss of MCR ventilation case assumes that no forced air replenishment occurs during the 24 hours of the event. Removal of selected ceiling tiles in the MCR commences at one hour (when air temperature reaches 104°F) in order to permit the air volume in the MCR above the ceiling tiles (assumed to be at 81°F) to mix with the warmer air below the tiles. This case is discussed further in Appendix G.
3. Case 2 of Reference 18 opens a door in the MCR after one hour, installs a ventilation fan in the door after 1.5 hours, and activates the smoke removal fans after 2 hours. Removal of selected ceiling tiles in the MCR commences at 2.5 hours in order to permit the air volume in the MCR above the ceiling tiles (assumed to be at 81°F) to mix with the warmer air below the tiles. This case is discussed further in the body of this report and in Appendix H.
4. The Attachment 1 case of Reference 18 starts up the MCR air handling unit after one hour to circulate MCR air using the air handling unit (ACU 1A(B)) with service water cross connected in place of the normal chilled water system. This case is discussed further in the Appendix F of this report.

The following two assumptions are used for the evaluation of the additional humidity due to people in the MCR:

1. References 18 and 30 assumed that there were 10 people inside the MCR at all times and they contributed all of their emitted heat to the MCR without any evaporative moisture emissions. However, during the loss of control building ventilation, all unnecessary personnel are required to exit the MCR by procedure (Reference 1), which would leave 6 operators full time (24 hours) inside the MCR during the postulated event. Although the heat emitted by the 10 people is inherent in the air temperatures predicted by the

Reference 18 and 30 calculations, the baseline moisture being emitted for the calculations of this section will be based on 6 people.

2. Because the temperature in the MCR rises above the body temperature in the first half hour of the postulated event, we will assume that all heat dissipation from the body occurs by evaporation. (For realistic heat loads, this happens within the first two hours, based on Figure H-1.)

I.2 Moisture due to Perspiration

All heat loss by evaporation from the body, whether by respiration or perspiration, will be referred to as perspiration. The amount of heat lost by the person perspiring can be calculated from the change in enthalpy necessary to convert moisture in the body at 99°F to water vapor in the air at ambient conditions. This difference in enthalpy varies only slightly as the ambient temperature increases from 100°F to 112°F, the ambient air temperature range for the LOOP case in the MCR during the event as shown in Table I-1. The primary heat removal is by the large latent heat of vaporization.

Vapor at 112°F has enthalpy of 1110 Btu/lb and from this is subtracted the enthalpy of body liquid at 99°F which is 67 Btu/lb, which yields a removal of 1043 Btu/lb of perspiration.

Table I-1. Range of Enthalpy for Water Vapor at Ambient Conditions

$T_{dry\ bulb}$ (F)	Enthalpy of Vapor at 1 ATM	Heat Removed from Body
112°F	1110 Btu/lb	1043 Btu/lb
108°F	1108 Btu/lb	1041 Btu/lb
104°F	1107 Btu/lb	1040 Btu/lb
100°F	1105 Btu/lb	1038 Btu/lb

Using 1043 Btu/lb, it would take 0.455 lb of water (475 Btu/hr / 1043 Btu/lb) given off as perspiration per hour to keep a person generating 475 Btu/hr at a stable body temperatures. If we round off to 0.5 lbs of water per hour per person, in 24 hours, each person would contribute about 12 lbs water vapor to the MCR atmosphere, 6 operators would contribute 72 lbs, and 10 operators would contribute 120 lbs.

The air volume of the MCR with the ceiling tiles removed is about 170,600 cubic feet and the density of dry air at 112°F is 0.07 lbs/cu ft so the weight of dry air is about 11,900 lbs. The added weight of moisture would be 72 lbs water/11,900 lbs dry air or 0.0061 lb water/lb dry air. At 112°F, the amount of moisture in air at saturation is 0.0631 lbs water/lb dry air. The ratio of 0.0061/0.0631 or about 10 percentage points are approximately the additional amount of RH that would be added to the RH in the MCR at 112°F after 24 hours. (For 10 people it would be about 16 percentage points added to the RH).

I.3 Moisture Transients inside the MCR

I.3.1 Impact of Initial Humidity inside the MCR

The initial humidity inside the MCR has an effect on habitability up to the time that significant changeover of the air inside the MCR occurs. When the air is stagnated by the loss of ventilation, the room heats up and the absolute humidity (pounds of water per pound of dry air) stays the same as the initial condition. As the room temperature rises with the same absolute humidity, the RH values drop because the higher temperature air has a much larger capacity for water vapor so that the relative % of its saturated capability drops accordingly (see Figure I-1). As soon as the ventilation brings in fresh air, the initial humidity is removed and no longer an effect (see Figure I-2).

For Reference 18, Case 2, evaluated in the body of this report, the air is replaced by outside air at about 800 cfm for the first two hours due to small exhaust fans in the MCR until flow is increased by 10,000 cfm starting at 2 hours due to the smoke removal fan. For the Attachment 1 Case evaluated in Appendix H (restarting MCR air handling units using service water cross connected to the chilled water piping) MCR air is replaced by fresh air at 800 cfm for the first hour due to small exhaust fans in the MCR until it is increased by 2000 cfm due to the restart of the MCR air handling unit. Once the fresh air replaces the initial air volume (usually within about one hour of initiating the high flow rates) the effect of the initial humidity is gone. Likewise, since the turnover of the MCR air occurs very frequently, the buildup of perspiration in the MCR will not extend beyond a couple hours of buildup which is negligible.

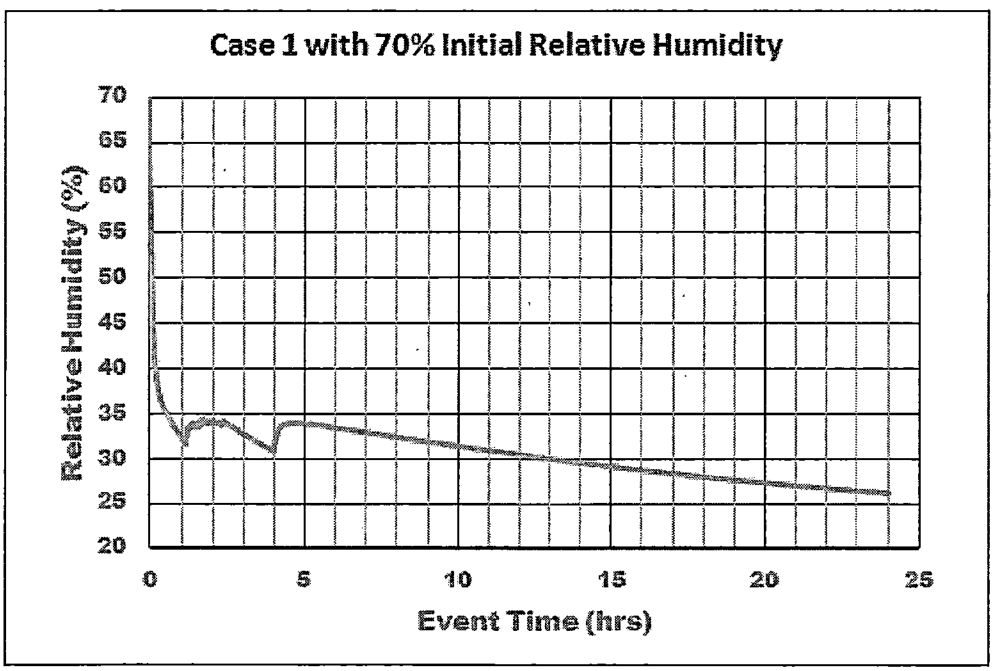


Figure I-1. Strong Effect of Heatup on RH for No Ventilation and Design Heat Loads

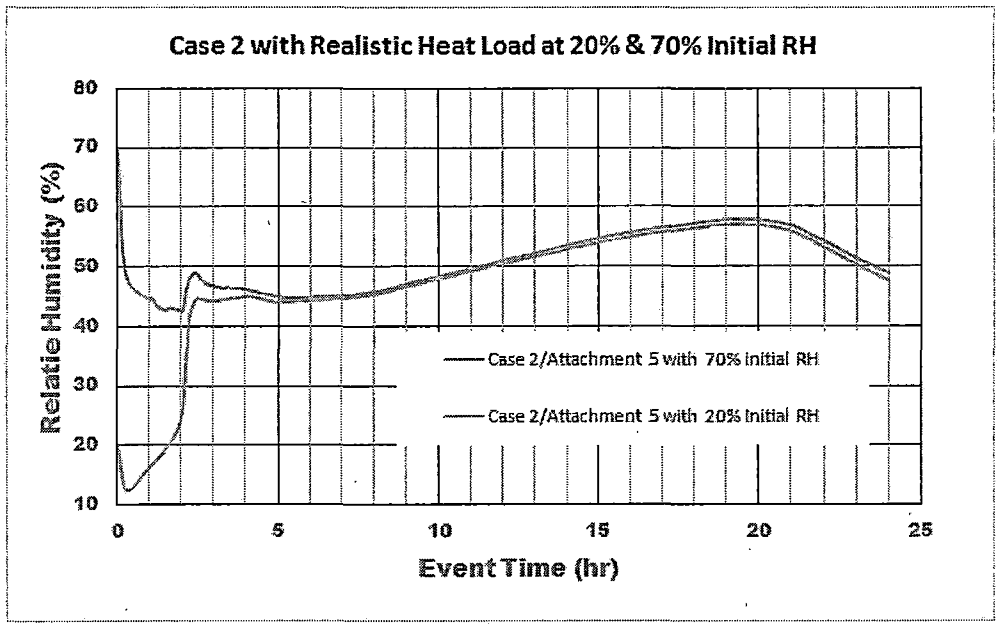


Figure I-2. Effect of High Initial Moisture Disappears Once Forced Air Circulation Begins

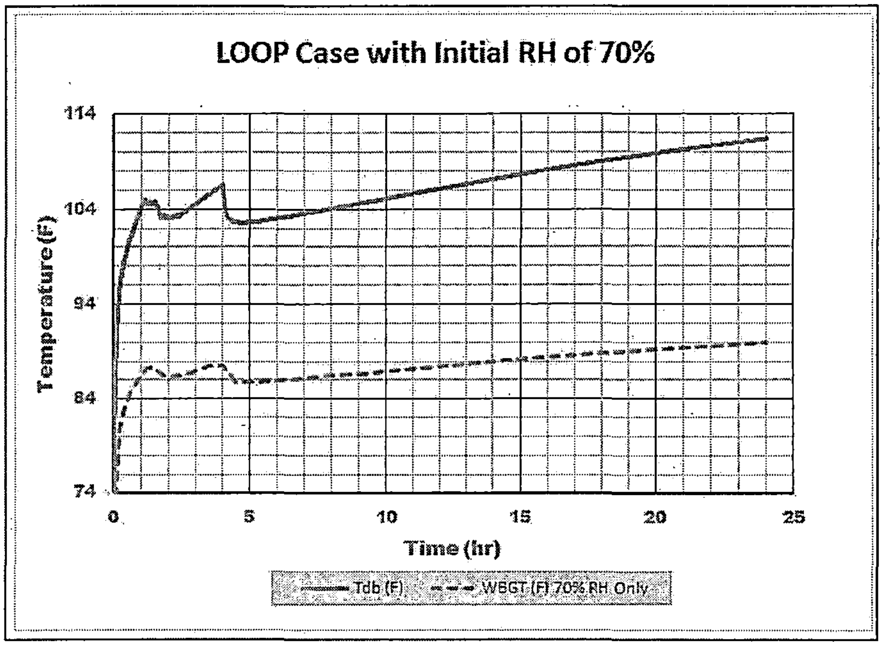


Figure I-3. WBGT Values Creep Up Despite Low RH Values (Figure I-1) for Rising Dry Bulb Temperatures with Design heat Loads

However, for the LOOP case, the assumptions include high starting humidity and no removal or turnover of air inside the MCR for the entire 24 hour event. In this case, even though the RH values continue to decrease as the room heats up (see Figure I-1), the rising of the dry bulb temperature eventually causes the WBGT values to reach the point where stay time actions could be warranted (see Figure I-3). This case is discussed in Appendix G.

I.3.2 Impact of Additional Moisture due to Perspiration on LOOP Case

As shown in Section I.2 above, with no removal of moisture six people would increase the relative humidity would by about 10 percentage points after 24 hours. (For 10 people it would be about 16 percentage points added to the RH). The effect on humidity is depicted in Figure I-4, below.

Table I-2 shows how the added moisture from six people integrated up to each time and temperature can be used as done in the above paragraph, to evaluate the effect of this water vapor on humidity (Figure I-4), on WBGT (Figure I-5) and on stay times (Figure I-6). As shown in Table I-2 the calculation accounts for the MCR volume changes after one hour for the LOOP Case when the ceiling tiles are removed and the upper MCR volume is combined with the lower MCR volume.

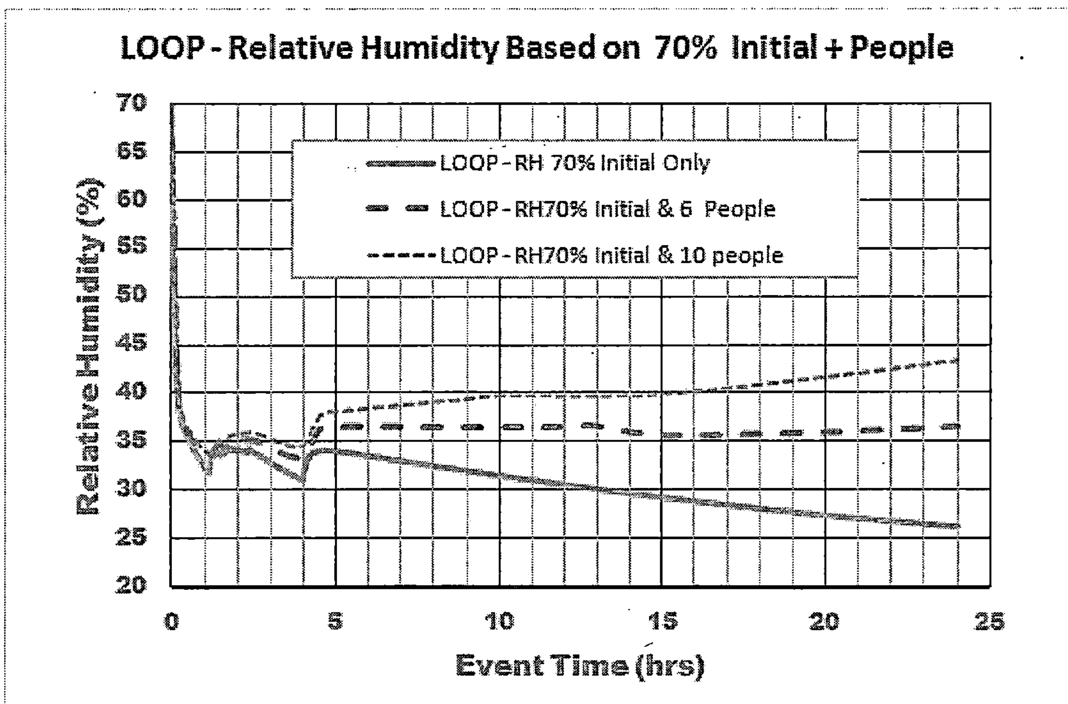


Figure I-4. LOOP Case Assuming Perspiration due to 0, 6 and 10 people and Rising Dry Bulb Temperatures (Figure I-3) with Design Heat Loads

Because the water vapor due to cumulative perspiration does not get removed in the postulated event in conjunction with the LOOP, the increasing effect on RH results in higher WBGTs, as shown in Figure I-5. It can be seen that there is not much of an effect in the first five hours.

As discussed in Appendix G, without the additional water vapor from people, the WBGT for the lost MCR ventilation event with a LOOP condition starting at 70% initial RH never exceeds 90°F and there are no stay time limits for operators. But with the accumulation of the moisture from 6 operators' perspiration, WBGT of 90°F is exceeded at about 13 hours (Figure I-5) and stay times would go from 230 minutes at 90°F to 195 minutes at 92°F to 165 minutes at 94°F. These are not very severe conditions for stay times and could be handled indefinitely by rotating the operators for recovery time as discussed in Section 4.2.2, without the need for additional operators beyond the normal crew of 6.

The assumptions for Attachment 14 of Reference 30 did not include actions to provide air circulation in the MCR during the LOOP condition. In a realistic case, the MCR ventilation would be available with either the chill water system or with the service water system as a backup. Even if these are assumed to be inoperable, actions that would bring cooler outside air to the MCR would likely be pursued if heat stress conditions progressed as shown in Figure I-4, and these would lessen the heat stress in the MCR.

I.3.3 Impact of Additional Moisture due to Perspiration on Cases with Ventilation Available

Because the amount of water vapor from sweat is a relatively small effect per hour but a significant effect cumulatively over 12 or more hours, it can be seen in Figure I-5 that the effect during the first 5 hours is negligible. Based on this, the effect of sweat adding moisture to the MCR atmosphere would be insignificant for Case 2 and Attachment 1 scenarios because the forced circulations of MCR air would remove the cumulative effect of the perspiration from the people by refreshing the MCR air volume with outside air one to four times per hour. (This turnover is based on outside air replacement flows of about 10,000 cfm for the smoke removal fan and about 2000 cfm for the MCR air handling unit – Reference 21).

If the LOOP case discussed in Section I.3.2 above was modified by the restart of the MCR air handling unit with service water cooling cross connected, similar to Appendix F Attachment 1, there would be no buildup of moisture from perspiration in the MCR. The replacement of MCR air at 2000 cfm via the air handling unit HVAC system would keep moisture from perspiration from building up, but moisture from the outside air would enter the MCR as observed for the normal operation case in Appendix F. A case evaluating the LOOP condition in conjunction with the assumptions discussed in Appendix F is addressed in Appendix G.

Table I-2. LOOP Case with Design Heat Loads and No Ventilation, Effect of Perspiration on Stay Times

Accounting for 0.50 lb/hr/person Water Vapor from 6 People - CumulativeMoisture									
Event Time (hr)	Tdb (F)	RH% without People	MCR Air Volume (10^3 ft^3)	Water Vapor (lbs)	Revised RH%	Twb (F)	WBGT (F)	Stay Times (min)	
								Low Demand	Mod Demand
0.0	75.0	70.0	87.5	0.0	70.0	68.0	70.1	no limit	no limit
0.2	94.6	39.7	87.5	0.6	40.0	75.1	80.9	no limit	no limit
0.4	98.6	36.2	87.5	1.2	36.6	76.7	83.3	no limit	no limit
0.6	100.9	34.7	87.5	1.8	35.4	77.9	84.8	no limit	240
0.8	102.6	33.6	87.5	2.4	34.4	78.7	85.9	no limit	240
1.0	104.1	32.5	87.5	3.0	33.5	79.4	86.8	no limit	170
1.2	104.7	33.0	170.6	3.6	33.6	79.9	87.4	no limit	170
1.4	104.5	34.0	170.6	4.2	34.7	80.3	87.6	no limit	170
1.6	104.1	33.7	170.6	4.8	34.5	79.7	87.0	no limit	170
1.8	103.4	34.2	170.6	5.4	35.1	79.7	86.8	no limit	170
2.0	103.3	34.2	170.6	6.0	35.2	79.6	86.7	no limit	170
2.5	103.5	33.9	170.6	7.5	35.1	79.7	86.9	no limit	170
3.0	104.6	32.8	170.6	9.0	34.3	80.2	87.5	no limit	170
3.5	105.6	31.8	170.6	10.5	33.6	80.6	88.1	no limit	110
4.0	105.8	31.5	170.6	12.0	33.5	80.7	88.2	no limit	110
4.5	102.6	34.0	170.6	13.6	36.3	79.6	86.5	no limit	170
5.0	102.6	34.0	170.6	15.1	36.5	79.7	86.6	no limit	170
6.0	103.0	33.5	170.6	18.0	36.5	80.0	86.9	no limit	170
7.0	103.6	33.0	170.6	21.0	36.5	80.5	87.4	no limit	170
8.0	104.1	32.5	170.6	24.1	36.5	80.9	87.8	no limit	170
9.0	104.6	32.0	170.6	27.0	36.5	81.3	88.3	no limit	110
10.0	105.1	31.4	170.6	30.0	36.5	81.6	88.7	no limit	110
12.0	106.2	30.5	170.6	36.0	36.5	82.5	89.6	no limit	110
13.0	106.7	30.0	170.6	39.0	36.5	82.9	90.0	230	85
15.0	107.7	29.2	170.6	45.1	35.6	83.2	90.5	230	85
20.0	109.9	27.3	170.6	60.1	36.0	85.1	92.5	195	70
24.0	111.4	26.2	170.6	72.0	36.5	86.5	94.0	165	55

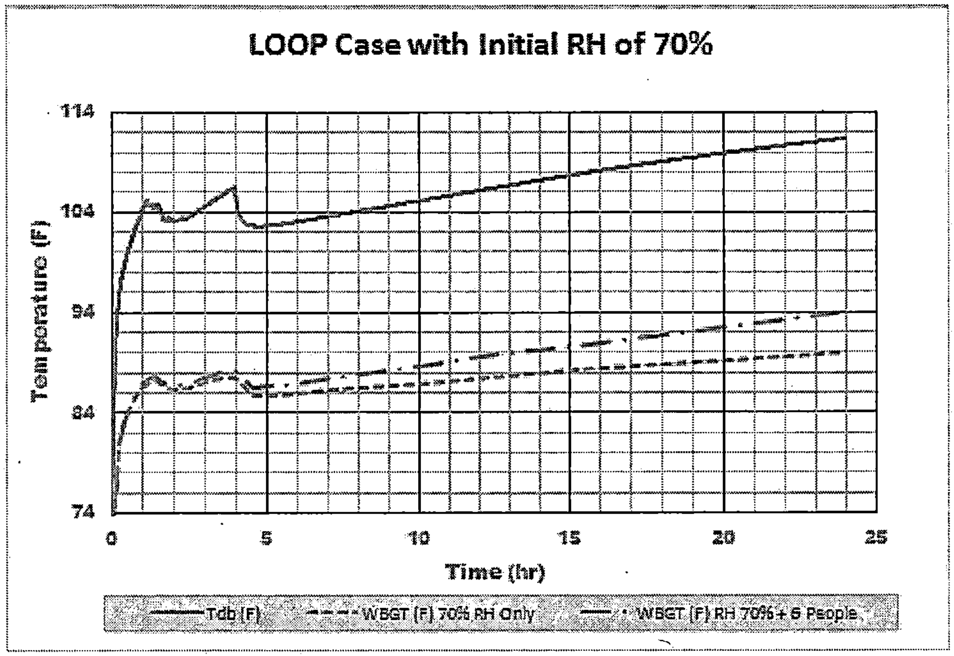


Figure I-5. LOOP Case with Design Heat Loads, Effect of 6 People on Increasing the WBGT - Exceeds 90°F after 13 Hours

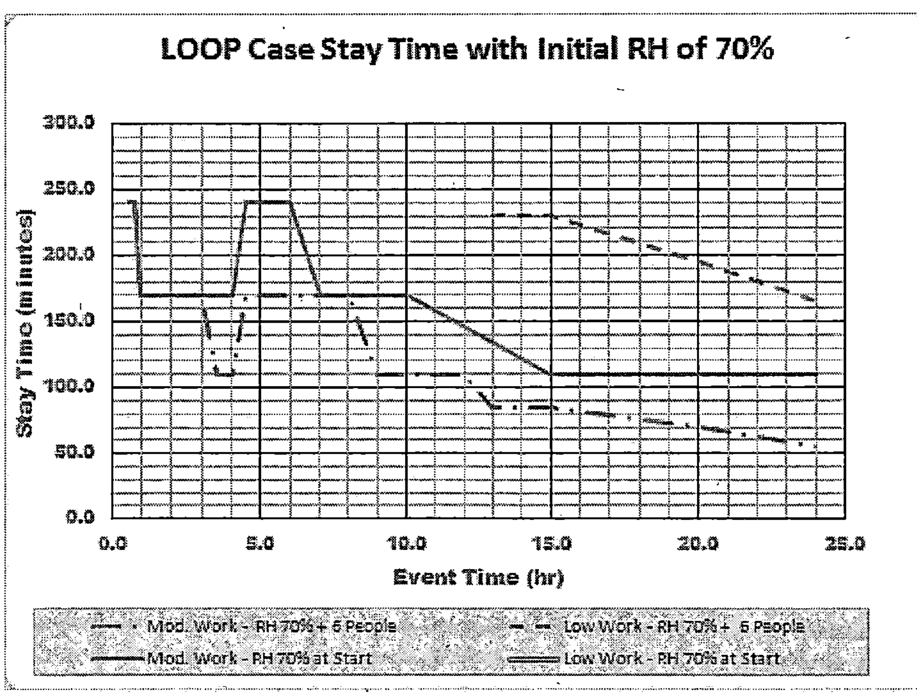


Figure I-6. LOOP Case with Design Heat Loads, Stay Times with and without Accounting for Perspiration of 6 People