Enclosure 4

MFN 09-525

Transmittal of ESBWR CRHA Heatup Calculation, including Applicable Input and Output Data Files

Document No. 092-134-F-M-05011, Issue 1, Control Building Environmental Equipment Qualification Temperature Sensitivity Analysis

Public Version

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1	26A6642AT	4	DCD Tier 2. Chapter 6	- Table 6.4-1: Maximum allowable temperature inside the CRHA for the first 72 h: 93°F -Subsection 6.4.3: The CRHA passive heat sink is designed to limit the temperature rise during the 72-hour period	V
2	26A6642AY	4	DCD Tier 2, Chapter 9 Auxiliary Systems. Section 9.4	- Table 9.4-1. Summer. Limiting value for outside: 47.2°C (117°F) dry bulb, coincident: 26.7°C (80°F) wet bulb - Table 9.4-1.Maximum Initial Relative Humidity: CRHA: 60 %	V
3	092-134-C-A-05011	1	Control Building Environmental Temperature Sensitivity Calculations	Heatup calculations results.	V
4	26A6642AN	4	DCD Tier. Chapter 3, Appendices 3G to 3L	Subsection 3G.1.5. Structural Analysis and Design Reinforced concrete: 23.5 kN/m3 (150 lbf/ft^3)	V
5	105E3908	3	ESBWR Nuclear Island. General Arrangement	CB layout and equipment locations	V
6	092-134-C-M-05011	1	Control Building. Environmental Equipment Qualification. Temperature Sensitivity Analysis Input Data And Assumptions	Assumptions traceability	V
7	Unused				
8	092-134-F-M-05001	5	Control Building. Environmental Equipment Qualification. Temperature Analysis	CRHA EFU flow: 240 L/s 11 persons will be considered inside CRHA CRHA heat load split	V

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1. BACKGROUND

This document continues with the job initiated in Doc. No. 092-134-F-M-05000-Issue 1 and continued in Doc. No. 092-134-F-M-05001-Issue 1 to 5 regarding the maximum temperature reached in CB rooms housing safety-related equipment under an SBO event. Case S1 in Doc. No. 092-134-F-M-05001-Issue 5 is taken as the base case to perform the sensitivity analysis described in this report. See Section 4.3 herein.

2. PURPOSE AND SCOPE

During emergency operation, the Control Room Habitability Area (CRHA) emergency habitability system passive heat sink is designed to limit the temperature rise inside the CRHA to allowable values.

The sensitivity analysis reported in this document provide compliance with the Control Room Habitability Area (CRHA) emergency habitability system passive heat sink limits when accident conditions (LOCA and Loss of offsite power) occurs after a transient of 8 hours, which considers a malfunction of the CRHA normal operation ventilation system and additional internal heat load inside the CRHA of 2000 W during the72h period that accounts some nonsafety heat loads. Reduced initial air temperature is considered in the CRHA and CRHA surrounding areas with respect to case S1 in 092-134-FM-05001 Rev. 5. See Section 3.1.

Calculations consider moist air and latent heat inside the CRHA.

This document includes all references used and assumptions made to obtain the temperature values per room. Therefore, this document includes the inputs, hypotheses, and results of heatup calculations performed to evaluate the maximum room air temperature. The main purpose of this document is to evaluate the temperature in the CRHA, but the maximum temperature in CB rooms that house safety-related equipment is also evaluated.

3. INPUT DATA AND ASSUMPTIONS FROM HEATUP CALCULATIONS

NOTE: Clarification on Assumptions.

Any information used to define the assumptions herein that is not referenced in a document in Section 6 is discussed in Document No. 092-134-C-M-05011 (Ref. 6.5). Some assumptions (e.g., equipment heat load per room) are based on estimates because the individual equipment heat loads are not yet defined. Since the heat loads per room are included in DCD Tier 2 Appendix 3H, if the actual heat loads were to turn out greater than the estimates, the calculations would be updated or modifications carried out (e.g., relocating equipment, increasing the heat absorption capacity of the structures by placing steel fills, or some other viable solution) to ensure habitability in the CRHA and that the equipment qualification temperature is not exceeded.

3.1 ACCIDENT SCENARIO

A Station Black Out (SBO) condition is considered during the 72-hour period after an accident. Moreover, prior to SBO, the CRHA average heat sink temperature is considered to have been at a higher temperature than the maximum normal operating temperature for 8 hours.

The accident scenario considered has been divided into three steps:

- Step 1 represents 'normal operation' and is a long enough period of time to cause a steady state inside the CB. This means that non-appreciable changes in temperature are expected during this time in structures in the CRHA heat sink. This period assumes normal operation of the CB HVAC system. It is during this period that the CRHA heat sink sets up
- Step 2 represents an 'abnormal function' of the CB HVAC subsystem and is a period of time in which the CRHA internal air temperature exceeds the limit stated in Table B 3.7.2-1 of Ref. 6.4. During this period it will be assumed that the temperature inside the CRHA is kept constant at 29.4°C (85°F) for 8h , that is 6.1 °C (11 °F) over the 23.3°C (74°F) temperature in normal operation. This scenario could occur if there is a malfunction of the Control Room Habitability Area HVAC Subsystem (CRHAVS) leading to an increase in the CRHA air temperature. The 29.4°C (85°F) could be maintained by de-energizing selected Nonsafety-related Distributed Control and Information System (N-DCIS) equipment located in the CRHA

- Step 3 represents the SBO itself, and it is in this step that all the assumptions stated herein apply and the heatup analysis is performed

The accident (SBO) is considered to last 72h, during which time no credit has been given for the operation of non-safety cooling systems to mitigate non-safety heat loads, nor has any operation or action been credited to the N-DCIS equipment during this period.

In particular, inside the CRHA during the first 72 h (step 3), when alternating current (AC) power is unavailable or if high radioactivity is detected by the Process Radiation Monitoring Subsystem (PRMS) in the CRHA outside air supply duct, the CRHA normal air supply is automatically isolated and the habitability requirements are then met only by the operation of an Emergency Filter Unit (EFU) and the CRHA emergency habitability system passive heat sink (Ref. 6.1). Regarding electrical equipment, in an SBO event the nonsafety-related electronic and electrical loads, powered from the 2 h nonsafety-related batteries, are active for 2 h while the safety-related electronic and electrical loads are powered for 72 h. Therefore, the heat rejection load interval is as follows (Ref. 6.1).

	Time interval, after SBO starts	
	0-2 h	2-72 h
Loads from Electric & Electronic nonsafety–related equipment	Active*	Inactive*
Loads from Electric & Electronic safety–related equipment	Active	Active
Non-safety cooling systems	Inactive	Inactive
CRHA normal air supply	Inactive (Isolated)	Inactive (Isolated)
Emergency Filter Unit (EFU)	Active	Active

* Select nonsafety-related equipment inside the CRHA is considered inactive in the calculation during the period of interest. Some nonsafety-related equipment is assumed active in the calculation. See Subsection 3.5.1.1

3.2 CONTROL BUILDING ROOM MAXIMUM TEMPERATURE

3.2.1 Safety-Related Equipment Qualification Temperatures

The maximum (target) temperature considered for the equipment environmental qualification is shown in Appendix A, Table A-1, second column.

The maximum room air temperature must not exceed the temperature for which the safety-related equipment located inside the room is designed or qualified.

3.2.2 Control Room Habitability Area

The maximum (target) temperature considered inside the CRHA is 93° (33.9°C). See Table A-1 in Appendix A.

3.3 SAFETY-RELATED EQUIPMENT LOCATION

The safety-related equipment location and its heat load considered in this heatup sensitivity analysis calculation are included in Table B-2 of Appendix B.

3.4 HEAT SINK CAPACITY

The passive heat sink capacity of the CRHA and other areas of the CB depends on the temperature of the building structures, and on its thermal conductivity, density and specific heat. These characteristics define the heat sink capacity of the CRHA and other areas of the CB and, by extension, the model. The thermal conductivity of the different materials and the heat transfer coefficient govern the heat interchange among them. All these properties must be defined or calculated at the outset and during the steps stated in Section 3.1.

The properties of structures are explained in Section 3.7 and remain uniform in all the analyses performed.

3.4.1 Heat Sink Thermal Conditions in Step 1

As explained in Section 3.1, in step 1 all room air temperatures are kept steady for a long time until all temperatures across the structures reach a steady state. In this step, all the temperatures of the nodes in the structures, i.e., the surface and interior temperatures of the structure nodalization, reach their temperature in normal operation simulating full operation of the CB HVAC system. This is accomplished by forcing a steady temperature in the CB-Heatup model for a long time. The initial heat sink conditions considered at the beginning of the step 1 transient are not of concern, since what is being looked for are the conditions at the end. The bigger the difference is between the heat sink thermal conditions considered at the outset of the transient and the steady state conditions, the more the computational time used to reach the desired steady state conditions will be.

The air temperatures kept steady during step 1 are shown in Table B-1 in Appendix B.

The thermal conditions of structures (wall, floors, ceiling etc) reached at the end of the transient are taken as initial conditions for step 2.

3.4.2 Heat Sink Thermal Conditions in Step 2

During step 2 all room air temperatures are kept the same as in step 1 during 8h with the exception of the CRHA air temperature, which is maintained at 29.4°C (85°F). During this period the concrete temperatures on the surface and inside the CRHA structures increase slightly because they are in contact with air at a higher temperature.

The air temperatures kept uniform during this 8h transient in step 1 are shown in Table B-1 in Appendix B.

The thermal conditions of the structures (wall, floors, ceiling etc) reached at the end of the transient are taken as initial conditions for step 3.

3.4.3 Step 3 Evaluation

During step 3 the event of an SBO is considered. This stage is when the heatup due to SBO takes place in the CB model.

This transient calculates the room air heatup curve inside the CRHA and rooms housing safety-related equipment in an SBO during 72h when the CB starts from an assumed malfunction of the CRHAVS for 8h (step 2) which caused an increase of 11°F (85°F-74°F) in the CRHA air temperature.

3.4.4 Heat Sink Temperatures for Walls in Contact with the Ground

The sensitivity analysis performed link steps 1, 2 and 3 as explained in subsections 3.4.1, 3.4.2, and 3.4.3. Thus, the thermal conditions (air, concrete and steel temperature) calculated at the end of each step are used as initial conditions at the beginning of the following step.

For walls in contact with the ground, a surface temperature of 30°C (86°F) has been considered on the soil side, assuming that the ground, far from the CB walls, will be at a constant temperature of 30°C (86°F). This fully conservative value has been obtained as follows:

- According to Chapter 29 of the ASHRAE Fundamentals (Ref. 6.12), the mean ground temperature may be estimated roughly as a function (Equation 29.36, Ref. 6.12) of annual average air temperature. Very conservatively, the summer average air temperature is used instead, i.e., 39.7°C (103.5°F), [47.2°C(117°F)-DR/2, where DR is the daily range in summer(15°C)]
- A representative value is obtained for the "ground surface temperature amplitude" based on Fig-29.2 of Ref. 6.12: 10°C (18°F)
- According to Eq-29.36 of Ref. 6.12, a mean ground surface temperature is obtained by subtracting 10°C (18°F) from 39.7°C (103.5°F), obtaining 29.7°C (85.5°F). A typical "apparent" thermal conductivity value of 4 $W/m^{2}{}^{o}C$ has been considered for the soil, according to Table 5 and Table 6 of Chapter 25 in Ref. 6.12

3.5 INTERNAL HEAT LOADS

3.5.1 Sensible Heat Load

The internal heat loads considered in the heatup calculation (step 3) are included in Table B-2 of Appendix B. In steps 1 and 2, internal heat loads are of no concern because room air temperatures are intentionally forced to remain constant during the simulation, reproducing correct operation of the CB HVAC system.

3.5.1.1 Control Room Habitability Area (CRHA)

Heat rejection loads in the CRHA are due to safety-related and nonsafety-related equipment as well as to the people inside the CRHA.

According to DCD Subsection 9.4.1 (Ref. 6.2), a nonsafety-related cooling system is provided to remove the heat loads due to nonsafety-related equipment during the 0-2 h period. The nonsafety-related cooling system is designed for the nonsafety-related plus the safety-related heat loads. If this cooling system fails, nonsafety-related equipment is disconnected. Therefore, there are two possible scenarios:

1) The nonsafety-related cooling works during the first 2 h after the accident. In this case, the safety-related load needs to be absorbed by the surrounding structures during the 2 to 72 h period
2) The nonsafety-related cooling fails. In this case, the safety-related load needs to be absorbed by the surrounding structures during the 0-72 h period. Calculations have been performed for this case

Therefore, only safety-related loads and non-disconnectable nonsafety-related loads have been considered. A maximum internal heat load of 7630 W plus an additional 2000 W more is considered during the 0-72h interval. The heat load distribution in this case (Case T) among equipment, emergency lighting, people and others is included in Tables B-2 and B-3 in Appendix B.

It is considered that heat dissipation due to the EFU fan is 1 hp (746 W) (Ref. 6.10) plus a 15% margin. This value is added as one more internal load inside the CRHA.

3.5.2 Latent Heat Load

The latent load in the CRHA due to people has been considered at a rate of 55W per person. This is a typical value stated for “Standing, light work; walking” in Chapter 30 Table 1 of Ref. 6.12.

11 persons have been considered inside the CRHA; see Table B-3 (Appendix B) for general data.

Latent load in the rest of the CB rooms has not been considered.

3.6 EXTERNAL HEAT LOADS. BOUNDARY CONDITIONS

3.6.1 External Loads

Whenever a conditioned space is adjacent to a space with a different temperature during the heatup transient, heat transfer through the separating physical structure is considered in the calculation.

In mechanical rooms #3406 and #3407 and their adjacent rooms, solar heat transmission through the exterior walls and roof has been considered. The method used accounts for solar radiation and the effect on the irradiated surface structure, and is called Radiant Time Series (RTS) described in Chapters 30 and 31 of Ref. 6.12.

The external heat loads are of concern in step 1, step 2 and step 3 because, in the walls and ceilings connecting the room to the exterior, the temperature profile across the structure is calculated by the Contain model. In step 3, the external heat loads can be transmitted to a room through walls, floors and ceilings or partitions that separate it from another room or from the exterior.

The RTS method calculates the sol-air temperature in rooms situated above grade. This temperature is the outdoor air temperature that, in the absence of all radiation changes, gives the same rate of heat entry into the surface as would the combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with outdoor air.

The method will calculate a temperature profile (sol-air temperature) throughout the day based on:

a) Maximum dry bulb temperature at 3 pm: 47.2 °C (117°F). (Ref. 6.2)

b) Daily range. 15 °C (27°F)

c) Date of simulation. (21st of July)

d) Surface azimuth (orientation). (South for vertical surface)

e) Surface tilt from the horizontal. (0° for roof and 90° for walls)

f) Latitude & Longitude. (112.37° & 33.55°)

g) Absorptance (α) of surface (structure) for solar radiation (surface color) and coefficient of heat transfer (ho) for long-wave radiation and convection at outer surface. α/ho=0.052 (Ref. 6.12)

h) Hemispherical emittance of surface (ε) and the difference between long-wave radiation incident on the surface from the sky and surroundings, and radiation emitted by blackbody at outdoor air temperature (ΔR), where $\varepsilon \cdot \Delta R = 0$ K (°F) (Ref. 6.12) for vertical surfaces and 4 K (7.2°F) (Ref. 6.12) for horizontal

i) Clearness number, multiplier for clear/dry or hazy/humid locations. CN=1 (Ref. 6.12)

The latitude of 33.55° and longitude 112.37° correspond to locations in the United States where the maximum dry bulb reached is near the limiting value for outside air stated in Ref. 6.2, i.e. 47.2°C (117°F).

On the 21st of July, solar altitude along the day reaches values greater than 72° (see the figure, left), enough to irradiate the vertical surface. Obviously, a southern orientation produces the highest radiation and subsequently higher sol-air temperatures and heat transmission.

[[ ]]

Figure 3.6-1.- CB Solar Radiation

The sol-air temperature profile for vertical and horizontal structures obtained is shown in Figure 3.6-2.

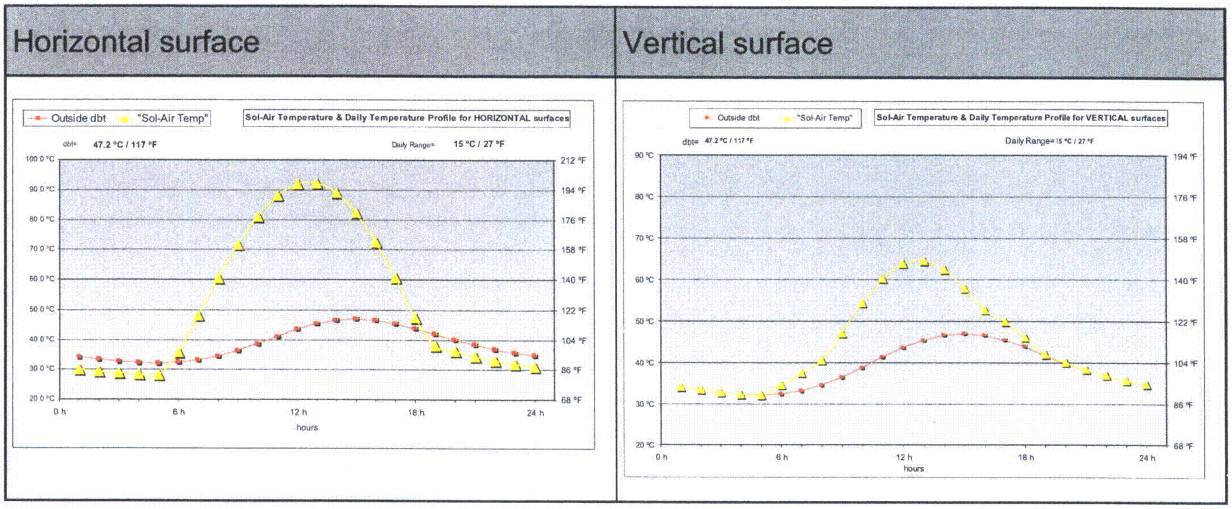

Figure 3.6-2.- The sol-air temperature profile for vertical and horizontal structures

In step 3 the N-DCIS rooms located above the CRHA are simulated with a maximum temperature of 60°C (140°F) 2 h after the accident. After that 2-hour period, the temperature is kept constant for the remaining 70h.

3.6.2 Ventilation Loads

The heat load due to the outside air intake is taken into account only in step 3 and inside the CRHA.

Outside air conditions considered in step 3 are the 0% exceedance values (Ref. 6.2), e.g., 47.2°C (117°F) dry bulb and 26.7°C (80°F)wet bulb coincident are considered.

The daily profile has been calculated as per the ASHRAE-Fundamentals method in Chapter 28 (Ref. 6.12). The accident (step 3) starts at 3 pm (maximum day temperature).

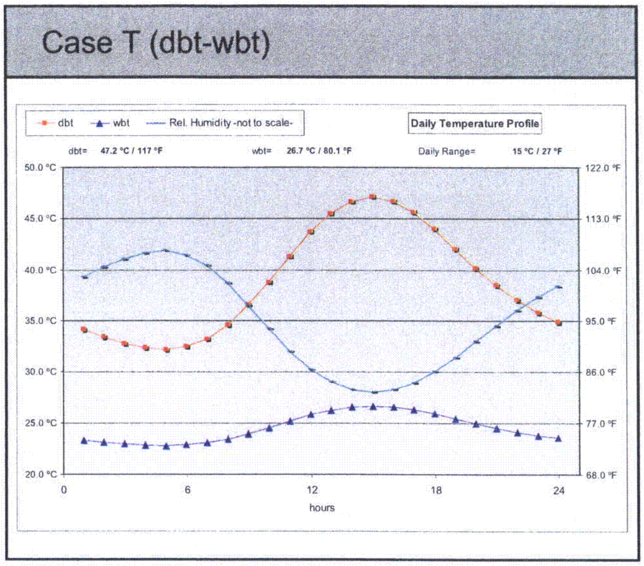

Figure 3.6-3.- Case T daily profile

The outside air flow is drawn into the CRHA through the EFU. The resultant temperatures have been evaluated inside the CRHA considering that the EFU draws 240 l/s (Ref. 6.15) into the CRHA.

3.7 CONCRETE CHARACTERISTICS

The CB concrete characteristics are not defined yet. The value of Po=23.5 kN/m³ (150 lb/ft^3) included in DCD Appendix 3G (Ref. 6.11) is considered to be a conservative value for structure weight evaluation.

The material properties of the concrete used for calculation are conservative, and were obtained from Ref. 6.7 (Type-1 concrete): K=0.8654 W/m·°C (6.0 Btu·in/h·ft^2·°F); Po=1922.2 kg/m³ (120.00 lb/ft^3); Cp=653.12 J/kg·°C (0.156 Btu/lb°F).

A relationship between suggested practical thermal conductivity design values and concrete density is given in Table 2.4 of Ref. 6.3. The conductivity assumed (6.0 Btu·in/h·ft^2·°F) for the density 120 lb/ft^3 is below 6.4 Btu·in/h·ft^2·°F, the lowest value stated in said Table 2.4 for structural concrete for a density of 120 lb/ft^3.

3.7.1 Thermal Properties of Reinforced Concrete

The steel structural structures and rebars defined in Ref. 6.11 have been considered as applicable in accordance with Ref. 6.11.

Thermal properties (heat capacity, density and conductivity) are evaluated for each structure based on its reinforcement layers (rebars). The properties, evaluated following the method described below, are the 'representative' thermal properties for the material used in the code for the heatup calculations.

- Conductivity

Conductivity has been evaluated following the methodology in Ref. 6.13. Figure 3.7-1 shows a section of one square meter on an example wall. The dark colored drawings represent the rebar. The round ones represent the vertical bars and the thin rectangles the horizontal ones.

[[ ]]

Figure 3.7-1.- Location of Rebars

To calculate the representative thermal conductivity of a material formed by scattered particles in a matrix of a different constituent, we have considered, firstly, that heat flux flows only in the Y direction, which is perpendicular to the structure surface. Assuming this, the heat flow encounters four different paths based on their different thermal conductivities (see Figure 3.7-1).

D1. The path corresponding to the layers of concrete - vertical and horizontal rebars – concrete - vertical and horizontal rebars - concrete.

D2. The path corresponding to the layers of concrete - horizontal rebar - concrete – horizontal rebar – concrete. The parameter ‘n’ in the formula below will be the number of rebars in one meter along the Z axis.

D3. The path corresponding to the layers of concrete - vertical rebar - concrete – vertical rebar – concrete in one meter along the X axis.

D4. The path corresponding to the constituent material (concrete, in this case).

Before the conductivity of the resultant material can be evaluated, the conductivity of each of the aforementioned paths must be evaluated first, for instance, for D3:

$$\frac{1}{k_3} = \frac{n \cdot \theta}{1000} \times \frac{1}{e} \times \frac{1}{k_s} + \left(1 - \frac{n \cdot \theta}{1000} \times \frac{1}{e}\right) \times \frac{1}{k_m}$$

Where:

- k_3, k_s, k_m: is the conductivity of path D3, of steel and of concrete respectively. $\left(\frac{W}{m \cdot K}\right)$
- n: is the number of bars on the Y axis (two, in the example)
- Φ: is the diameter of the bar (mm)
- e: is the thickness of the facing (m)

The rest of the conductivities are calculated in the same way.

The conductivity of the resulting material is evaluated by adding the areas of each of the paths weighted by the conductivity calculated above, k_j:

$k_r = \sum_{j=1}^{j=4} A_j \times k_j$, where Aj is the sum of the surfaces in axes Z, X that meet with the condition of ‘j’ flux direction, [in the above example, $1 \times 20 \times \frac{\phi}{1000} - \frac{\pi}{4} \times \left(\frac{\phi}{1000}\right)^2 \times N$; where N(180) is the number of crosses in 1 square meter]. Sum Aj equals one.

- Density and heat capacity

Weighted mean has been applied.

The material used in the calculation is a homogenous concrete with the characteristics calculated above.

The following properties used in calculations are obtained:

Representative Concrete	Description	Density kg/m³ (lb/ft³)	Specific heat J/kg·°C (Btu/lb°F)	Conductivity W/m°C (Btu in/h ft²°F)
C1	Plain Concrete	1922.2 (120.00)	653.12 (0.1560)	0.8653 (6.00)
C2	Reinforced Conc. Ceiling	1950.5 (121.77)	652.39 (0.1558)	0.9010 (6.25)
C3	Reinforced Conc. Floor	1950.5 (121.77)	652.39 (0.1558)	0.9180 (6.36)
C4	Reinforced Conc. Walls	1978.8 (123.53)	651.65 (0.1556)	0.9250 (6.41)
S1	Steel	7830.0 (488.81)	500.00 (0.1194)	45.30 (314.1)

The concrete properties (representative properties) used for the calculations are considered very conservative because, considering the density from DCD Appendix 3G, which is 150 lb/ft^3 (23.5 kN/m^3), the lowest concrete conductivity stated in Table 2.4 of Ref. 6.3 (see Section 2.7 above) for the structural group is 13.8 Btu·in/h·ft^2·°F (1.99 W/m·°C), higher than all 'representative concrete' properties considered in the calculations.

3.8 ROOM, FLOOR, AND WALL DIMENSIONS

Room internal dimensions for the heatup calculations are taken from the NI General Arrangement AutoCAD drawings (Ref. 6.6).

Floor and wall thicknesses are taken from Ref. 6.6.

4. CALCULATION METHOD AND ASSUMPTIONS

4.1 MODELING OF BUILDING ROOMS

Rooms are modeled using CONTAIN 2.0 Code. The CB is a single model that has the rooms subdivided and takes into account interactions between rooms during heatup.

4.2 MODELING ASSUMPTIONS

The following assumptions are considered:

- The program considers rooms as nodes with no input for shape or height, so the favorable effect of stratification is not considered
- Radiant heat transmission is not taken into account either as a fraction of heat load generated inside the room or as a radiant heat transfer coefficient. The effect of radiant heat flow is negligible considering that the heat flow in most cases is from ambient air to a concrete structure. Not considering a radiant heat transfer coefficient is more conservative in this case
- It is assumed that there are no temperature differences inside the room
- It is assumed that the CRHA room raised floors and suspended ceilings have large openings and thus the CRHA is modeled as a single room and the CRHA false ceiling and raised floor are modeled as a part of a unique CRHA volume. This means that all rooms belonging to the CRHA, false ceilings and raised floors are modeled into a single room. The temperature obtained in the CRHA calculations is the temperature of this single room

4.3 METHODOLOGY

The following approach is used to evaluate the maximum environmental conditions in the different rooms with safety-related equipment.

The CONTAIN model has undergone slight modifications which do not greatly affect the results, respecting the previous model on case S1 in Ref. 6.16:

- The model of N-DCIS rooms at EL +4650 has been improved. The modifications have no effect on the results because a heatup curve is considered in N-DCIS rooms
- Ground soil has not been assumed adiabatic, and a very conservative apparent conductivity has been assumed instead. See Section 3.6

The maximum temperatures are obtained in step 3:

a) Modeling of the CB using the CONTAIN program. Compartments are interconnected by appropriate heat flow paths (walls, floors, ceilings, doors, hatches, etc) taking into account the impact of inertia in each path (mass, conductivity, specific heat, surface exposed arrangement and the heat transfer coefficient)

b) No occupancy rate is considered when estimating the free volume of each compartment because the heat capacity of furniture is higher than that of the air space occupied by it

c) Considering wall and ceiling structures as heat sinks, the concrete characteristics and initial temperature must be taken into account to achieve accurate results. Type-1 concrete considering rebars is used in all structures

d) Identification of the room air temperatures under normal operation in accordance with Appendix B, Table B-1 for step 1. The aforementioned temperatures are artificially maintained in CB rooms until there is no further change in the temperatures of the structures.

e) The structure temperature profile in structures calculated previously (by CONTAIN) is considered as initial temperatures, and the model is run for 8h., but considering that the CRHA air temperature rises very quickly up to 29.4°C (85°F) in the first moments of the 8h transient and is then maintained during the entire 8h transient. The remaining CB room air temperatures are maintained. In this step CONTAIN calculates the yielded concrete temperatures of all structures involved in the model after keeping the air temperature of the CRHA at 29.4°C (85°F) and the other CB room according to Table B-1 in Appendix B for 8 h

f) The concrete temperatures obtained are considered at TIME=0 of the accident (SBO)

g) Identification of quantity and quality of electronic, electrical and/or mechanical heat loads located inside each room according to Appendix B, Table B-2

h) After the 72 h transient, the temperature in the CRHA is reported.

4.4 CODE DESCRIPTION

The analytical tool selected and used to perform the resulting short-term response in summer is CONTAIN 2.0 Code (Ref. 6.9).

The CONTAIN code is an analysis tool for predicting the physical, chemical, and radiological conditions inside the containment and connected buildings of a nuclear reactor in the event of an accident. CONTAIN was developed at Sandia National Laboratories under the sponsorship of the US Nuclear Regulatory Commission (USNRC) for analyzing containment phenomena under severe accident and design basis accident conditions. It is designed to predict the thermal hydraulic response inside containment in the event of an accident. Heat transfer is one of the physical phenomena involved, and this tool is used to evaluate temperature profiles inside the CB. A more detailed code description is included in Appendix D.

4.5 MODELING OF HEAT STRUCTURES

4.5.1 Types of Structures

Walls, floors and roofs are the structures and heat sinks considered for each room modeled. Specific models for wall, roof and floor structure type are invoked in the CONTAIN model.

The 'inner surface' of the structure is considered fully exposed to the room environment. Such exposure invokes the modeling of convective heat transfer, coolant film formation, transport, etc. The outer face of the structure can be divided into three groups:

a) The outer face is connected to the outer face of another structure to, eventually, connect to another cell (room ambient)

b) The outer face temperature is fixed, e.g. at boundary conditions

c) The outer face is treated as adiabatic

Regarding the relative location in the rooms, three general kinds can be taken into consideration:

1) The structure is fully inside the room

2) The structure is between two rooms

3) The structure is a boundary of the model (for instance adiabatic conditions and walls in contact with the ground)

In type 1 structures the surface considered is the total surface exposed to the environment, and the thickness is half of the total. For type 2 structures, half of the wall thickness is considered for each room, and the surface is in accordance with the real area exposed for each room. For type 3 structures, the total wall thickness is accounted for and the surface area is in accordance with the real area exposed for the pertinent room.

For example, inside the CRHA types 1 and 2 have been considered. Type 1 has been used for interior walls separating rooms e.g. #3272 and #3271, columns and beams, while type 2 has been applied for walls separating two modeled rooms such as the CRHA and corridor #3200.

4.5.2 Nodalization of Structures

Thermal diffusion length is considered in this case to determine how finely the structure should be nodalized, that is, the number of layers the program accounts for. The surface nodes that are in contact with the room environment should be a small fraction of this length. This is especially significant if there is a big heat flux across the structure.

In order to have good accuracy, heat sinks in contact with the CRHA have been nodalized taking into account the thermal diffusion length, which is defined as (according to Chapter 10.5.1.1 Heat Transfer Structures of CONTAIN Manual; Ref. 6.9):

$$\delta = \left(\frac{4 \cdot K \cdot \Delta t}{\rho \cdot c_p} \right)^{\frac{1}{2}}$$

Where:

- δ; thermal diffusion [m]
- K; conductivity [W/m·K]

- Δt; shortest time scale of interest [s]
- ρ; density [kg/m^3]
- c_p; specific heat [J/kg·K]

When calculating conduction heat transfer inside the structures in contact with the CRHA, the following general mesh points (slabs) for nodal location (thickness direction) are considered (in millimeters): 0, 0.01, 0.03, 0.07, 0.15, 0.31, 0.63, 1.27, 2.55, 5.11, 10.23, 20.47, 40.95, 81.91, 163.83, 327.67, 655.35, etc. This means that the thickness of the slab increases in the direction of the heat flux.

The initial temperature considered on structure nodes (thickness direction) is the same when the room temperatures are the same on both sides of the wall, floor or ceiling. When the room temperature (or surface temperatures) in operation is not the same in several rooms, a linear temperature distribution across the wall, roof or floor is considered. The convective coefficient and surface temperatures are calculated previously in each surface of the wall, taking into account the gas temperature in each room and the wall material properties. These temperatures are used to perform the linear temperature distribution across the wall.

The CRHA ceiling initial temperature profile has been calculated by performing a simple model in Contain because a steel plate is located in the ceiling facing the CRHA. There is a small air gap (1 mm of thickness) between the steel plate and the concrete. This simple model consists of two rooms separated by the same structure which separates the CRHA and N-DCIS rooms. The model is run maintaining the initial temperatures in these additional rooms to evaluate the initial temperatures of the slabs to be considered in the main Contain model.

The CRHA ceiling initial temperature profile has been calculated considering a metal deck, 75mm (3 inch) thick (Ref. 6.3), placed just below the concrete ceiling, by performing another model where only this heat sink and its boundary conditions are simulated. This is because a steel plate is located in the ceiling facing the CRHA and there is a small air gap (1 mm of thickness) between the steel plate and the concrete.

Thus, the ceiling is modeled using a heat structure with several slabs of different materials. The first 75 mm (from the CRHA to the N-DCIS) is made of steel, the next 1 mm is nitrogen, and the rest of the structure (500 mm) is made of reinforced concrete. Nitrogen is used instead of air for practical purposes; the thermal characteristics of air can be considered the same as the thermal characteristics of nitrogen (Thermal properties according to Chapter 2.3 Material Properties of Ref. 6.9). Once the heat structure is modeled, the temperature profile along the thickness of the structure is calculated keeping the temperature inside each room (CRHA and N-DCIS) constant and equal to its initial value.

Finally, the initial temperature of the heat structure that is used in the analysis will be the temperature profile through the thickness of the ceiling once the surface temperature on both sides of the ceiling is constant.

5. CALCULATIONS, RESULTS AND CONCLUSIONS

The following calculations result and conclusions are only reported for step 3 of the case performed. Some results regarding the temperature of structures after step 1 and step 3 have been displayed.

5.1 HEATUP CALCULATIONS PERFORMED (0-72 H)

The temperature profile of the heatup calculation results (step 3) for each room is included in Appendix C.

Following an SBO, the heat generated in the rooms is absorbed by the surrounding walls, floor and ceiling. Since the heat absorption capacity of air is very low, the room air temperature rises quickly before the walls and ceilings start to warm. Because the CRHA temperature is affected by the outside air temperature (the EFU draws outside air into the CRHA) the CRHA temperature rise profile follows the temperature variations of the outside air.

The initial conditions and input data considered in the case performed have been set out in Appendix B, Table B-1, Table B-2 and Table B-3.

The maximum temperature calculated in step 3 in rooms housing safety-related equipment in the CB, including the CRHA, is shown in Appendix A, Table A.1, and the temperature profile (heatup graphical results) in Appendix C.

5.2 RESULTS OF THE HEATUP CALCULATIONS

Appendix A Table A-1 shows the maximum allowable temperature (target), in accident conditions up to 72h in rooms and the temperature obtained in calculations. The volume of condensation, where applicable, is also included. Appendix C shows all the heatup profiles obtained in calculations. The relevant results are the following:

a) The maximum room air temperature obtained in the calculations is below the maximum allowable values

b) The effect of moisture on the results is negligible. Nevertheless moisture has been considered in the CRHA heatup calculations

c) No condensation occurs inside the CRHA

5.3 CONCLUSIONS

The main conclusions are:

- The maximum allowable temperature in the CRHA, i.e., 93°F (33.9°C), is not exceeded when 0% exceedance 47.2°C (117°F) dry bulb and coincident 31.1°C (80°F) wet bulb are considered
- The maximum allowable temperature is not exceeded in any room with safety related equipment in the CB
- No condensation occurs in any structure

5.3.1 Condensation Concerns

Condensation occurs when the dew point of air in the CRHA reaches the temperature of any surface structure inside the CRHA. Outside air humidity and latent load inside the CRHA will help condensation. Both issues have been taken into account:

  - Outside conditions consider design wet bulb temperature
  - Moisture due to 11 people breathing is also considered (latent load)

- Condensation in cabinets

  As discussed above, condensation occurs when the dew point of air in the CRHA reaches the surface temperature of any structure or component. Therefore, condensation occurs on the surfaces with the lowest temperature.

  Heat is transferred to the structures because the air temperature is higher than the temperature on the surface of the structures

  - The internal temperature of the cabinets is higher than the temperature of the surrounding air in the CRHA (typically 10°C (18°F) higher)
  - It may be concluded that the cabinet internal temperature is clearly higher than the temperature on the surface of the structures and therefore, no condensation can occur inside the cabinets

- The effect of condensation on heat transfer

  The CONTAIN program takes into account the effect of the condensation in the heat transfer coefficient and the surfaces; therefore, the effect of condensation on the heat transfer coefficient is taken into account in the calculations if condensation occurs.

- The effect of the coating of the structures on heat transfer

  Calculations performed show that the coating effect on the heat transfer is negligible. With the thermal conductivity of typical coating systems included in Table A-1 of ANSI N 101.2 and a typical coating thickness of 200 microns (8 mil), it is demonstrated that the thermal resistance of the coating is the same as 0.34 mm to 1.2 mm (13 mil to 47 mil) of concrete with the conductivity considered in the report.

5.4 MARGINS

The CB heatup calculations have the following margins and conservative assumptions:

- A margin of 15% is considered in the internal heat load (see Appendix B, Table B-3) of the CRHA
- The concrete density, conductivity, and heat capacity considered in the calculations are conservative; the concrete density included in DCD Appendix 3G.1.5.2.1.1 (Ref. 6.11) leads to a concrete conductivity much higher than 0.8653 W/m•°C (6.0 Btu•in/h•ft2•°F), value used in calculation. See Section 3.7 of the report for further information
- The assumed initial soil temperature at below-grade CB elevations is 30°C

6. REFERENCES

1) 26A6642AT (Rev-5). DCD Tier 2. Chapter 6, Engineered Safety Features. Section 6.4, Control Room Habitability System

2) 26A6642AY (Rev-5). DCD Tier 2, Chapter 9; Auxiliary System. Subsection 9.4.1 Control Building HVAC System

3) ACI 122R-02. Guide to Thermal Properties of Concrete and Masonry Systems

4) 26A6642BT (Rev-5). DCD Tier 2, Chapter 16B; Bases

5) 092-134-C-M-05011 (Rev-1). Control Building. Environmental Equipment Qualification. Temperature Sensitivity Analysis Input Data And Assumptions

6) 105E3908 (Rev-3). ESBWR Nuclear Island. General Arrangement

7) Yilmaz T. P. & Paschal W. B. article: "An analytical approach to transient room temperature analysis"

8) 092-134-C-A-05011 (Rev-1). Control Building Environmental Temperature Sensitivity Calculations

9) CONTAIN 2.O Code: A Computer Code for Nuclear Reactor Containment Analysis. NUREG/CR-6533. SAND97-1735

10) SR3-1-ECA-00011 (Rev-1). EBAS Elimination. CRHVS Redesign

11) 26A6642AN (Rev-5). DCD Tier. Chapter 3, Design of Structures, Components, Equipment and Systems. Appendices 3G – 3L

12) ASHRAE Fundamentals 2005

13) Thermal Conductivity Of A Dispersed Porous Material. A. Denis, A. Soba. Dto. Combustibles Nucleares, Centro Atómico Constituyentes, CNEA

14) Unused

15) 092-158-C-EA-GE-0810333. Heat-up calculation - Sensitivity analysis. Scope and planning confirmation

16) 092-134-C-A-05001 (Rev-4). Control Building Environmental Temperature Calculation

17) 092-134-F-M-05001 Issue 3. Control Building Environmental Temperature Calculation (Basis for GOTHIC Control Building Heat Up Analysis Summary, Addendum 1.0 GEH-0000-0084-3844R5)

APPENDIX A

RESULTS. MAXIMUM TEMPERATURES

Table A-1. Thermodynamic Environment Conditions inside Control Building for Accident Conditions

Rooms & Equipment	Max. Allowable Temp Up to 72h Target	Max. Temp. obtained in calculations Up to 72 h (Step 3)**
Division I, II, III and IV electrical rooms Q-DCIS panels Rooms No 3110, 3120, 3130 and 3140	45°C (113°F)	36.0°C (96.8°F)
Control Room Habitability Area. Main control room panels Rooms No 3270, 3272, 3271, 3201, 3202, 3273, 3206, 3205, 3204, 3275, 3207, 3208	33.9°C (93°F)*	33.36°C (92.0°F)
Electrical chases Rooms 3250, 3261	110°C (230°F)	36.2°C (97.2°F)
Safety Portions of CHRAVS Rooms 3406, 3407	50°C (122°F)	45.2°C (113°F)

*. Maximum allowable temperature 93°F (33.9°C)
**. Results Case T (Step 3) (Ref. 6.8)
***. Condensation inside CRHA: None

APPENDIX B

INPUT DATA

Table B-1. Initial room air temperature in the different steps of case T

Rooms & Equipment	Step 1 Uniform	Step 2 Uniform	Step 3 Variable (heatup)
Division I, II, III and IV electrical rooms Q-DCIS panels Rooms No 3110, 3120, 3130 and 3140	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 2
Corridors Rooms No 3100, 3101	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 2
Control Room Habitability Area. Main control room panels Rooms No 3270, 3272, 3271, 3201, 3202, 3273, 3206, 3205, 3204, 3275, 3207, 3208	23.3°C (74.0°F)	29.4°C (85.0°F)[1]	Note 2
Corridor Rooms 3200,3203, 3277, 3274	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 2
Electrical chases Rooms 3250, 3261	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 2
HVAC chases Rooms 3251, 3260	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 2
N-DCIS Rooms 3301, 3302, 3303, 3300	25.6°C (78.0°F)	25.6°C (78.0°F)	Note 3
HVAC equipment Rooms 3401, 3402, 3403, 3404	40°C (104°F)	40°C (104°F)	Note 2
Safety Portions of CRHAVS Rooms 3406, 3407	40°C (104°F)	40°C (104°F)	Note 2

1. It is considered that the CRHA air temperature rises very fast from 74 °F (the temperature in step 1) to 85°F in the first instants of step 2 and them it is maintained uniform
2. The room air temperatures for step-2 are considered the initial conditions for step-3 (accident). Room air temperatures heat up during this step 3 depends on the internal heat loads and the heat sink capacity of each room.
3. Inside these rooms it will be forced a conservative air heatup curve during the 72h. During the first 2h the room air increases until 60°C(140°F) to remain constant until the end of the accident.

Table B-2. Internal Heat Loads and safety-related equipment location

Floor El.	Rooms	Equipment and Description	Safety-related Eq.	Heat Load 0h-2h	Heat Load 2h-24h	Heat Load 24h-72h
-7400	3110, 3120, 3130, 3140	Div I, II, III and IV Q-DCIS	Yes	5720 W (0h-2h) (19517 Btu/h)	4675 W (2h-24h) (15952 Btu/h)	3080 W (24h-72h) (10509 Btu/h)
	3100, 3101	Corridors [1]	No	--	--	--
-2000	3270, 3272, 3271, 3201, 3202, 3273, 3206, 3205, 3204, 3275, 3207, 3208	Main Control Room (MCR) and associated support areas (CRHA)	Yes	7630 W [3]+2000 W [5] (32859 Btu/h)	7630 W [3]+2000 W [5] (32859 Btu/h)	7630 W [3]+2000 W [5] (32859 Btu/h)
	3200,3203, 3277, 3274	Corridor [1]	No	--	--	--
	3250, 3261	Electrical chases	Yes	500 W (1706 Btu/h)	500 W (1706 Btu/h)	500 W (1706 Btu/h)
	3251, 3260	HVAC chases [1]	No	--	--	--
+4650	3301, 3302, 3303, 3300	N-DCIS	No	Note 4	Note 4	Note 4
+9060	3401, 3402, 3403, 3404	HVAC equipment [1]	No	--	--	--
	3406, 3407	Safety Portions of CRHAVS subsystem. [2]	Yes	500 W (1706 Btu/h)	500 W (1706 Btu/h)	500 W (1706 Btu/h)

1. No heat loads during a 0 - 72 h period (heat sink)
2. The CRHAVS EFU for SBO operation are located in these rooms
3. Ref. 6.11
4. Conservative heatup curve has been considered. During the first 2h the room air increases from 25.6°C (78.0°F) until 60°C (140°F) to remain constant until the end of the accident
5. Additional nonsafety heat load

Table B-3. CRHA Heatup sensitivity case (Step-3)

CASE 1	0-72h			
OUTSIDE AIR CONDITIONS	Maximum at 3 pm		Minimum at 5 am	
Dry bulb temp	47.2 ºC [2]	117 ºF	32.2 ºC	90.0 ºF
Coincident wet bulb temp.	26.7 ºC [2]	80.1 ºF	22.8 ºC	73.0 ºF
Coincident relative humidity	20 %		45 %	
Humidity ratio	0.0136 kg_w/kg_{da}		0.0136 kg_w/kg_{da}	
DAILY RANGE	15.0 ºC		27 ºF	
Total (Sensible) internal heat load	7630 W+2000W [6]			
a. Equipment	4600 W+1739 W			
b. Emergency lighting	400 W			
c. Additional lighting or equipment	64 W			
d. EFU fan	746 W [4]			
e. People. 11 p	11x75 [1] = 825 W			
f. Margin 15%	995 W+261 W			
Total (Latent) internal heat load	605 W			
a. People. 11 p	11x55 [1] = 605 W			
HVAC Air	--			
Ventilation Air. (EFU flow)	240 l/s [3]			

1 – Table 1, chapter 30. Ref. 6.12
2 – 0% exceedance values. Ref. 6.2
3 – Flow on Ref. 6.1 increased a 20%
4 – Ref. 6.10
5 – The initial relative humidity considered is 60%
6 – Additional nonsafety heat load

APPENDIX C

RESULTS. HEATUP FIGURES. (REF. 6.8)

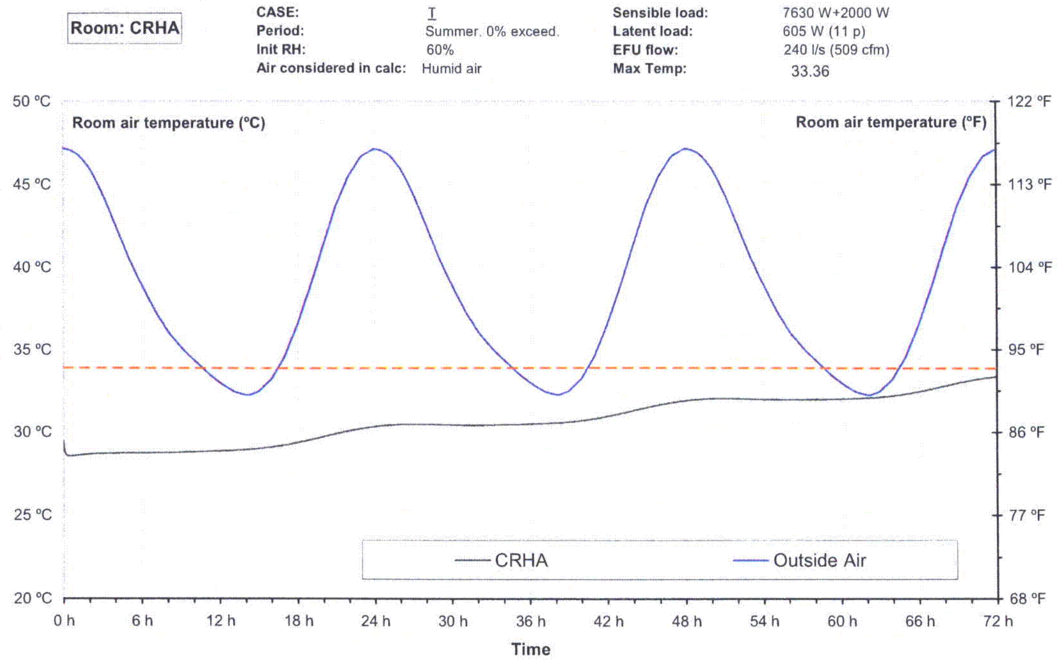

Figure 1

[[ ]]

Figure 2

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Figure 3

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Figure 4

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Figure 5

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Figure 6

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Figure 7

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Figure 8

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Figure 9

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Figure 10

APPENDIX D

CONTAIN. CODE DESCRIPTION

CONTAIN is a highly flexible and modular code that can solve problems that range from the quite simple to the highly complex. The main features of the code are:

1) Atmospheric models for steam/air thermodynamics
2) Intercell flow (Gas/pool flow path gravitational heads)
3) Condensation/evaporation on structures and aerosols
4) Aerosol behavior
5) Gas combustion
6) Heat conduction in structures
7) Reactor cavity phenomena such as core-concrete interactions and coolant pool boiling
8) Engineered safety features (fan cooler, containment sprays, ice condenser, etc.)

Some of the different features included in the mathematical model developed for the code are:

a) Atmosphere Thermal-Hydraulic Conservation Equations

   - The basic equations that govern the thermo-hydraulic behavior in the code are the conservation equations of momentum, mass and energy. In addition, the code uses the ideal gas law equation of state, which specifies the relationships between pressure, temperature, and mass within a control volume. These four equations are solved simultaneously

b) Thermodynamics and Intercell Flow

   - This refers to the way in which the flow of different materials between cells through paths is modeled and handled in the code. All movement of hydrodynamic gases, and other materials that do not participate in the thermodynamic atmosphere (such as aerosols, gaseous fission products, and condensed phase atmospheric material other than water) is done at the global level of the calculations
   - CONTAIN currently has two types of mathematical flow modeling for paths, the regular flow path and the engineered vent. The engineered vent allows

the user to model more than one flow path between cells and provides additional flexibility in modeling the flow through a flow path

- Thermodynamic material flow through paths is calculated under various user specified options: inertial flow (taking into account differential pressure between cells, friction losses and material inertia), quasi-steady (only differential pressure and irreversible flow losses are considered) and critical flow (choking model which depends on the cell-upstream pressure)

c) Heat and mass transfer

- This section gives a general description of the most important physical effects related to heat and mass transfer between the cell atmosphere, sink structures, lower pool, etc. modeled by the code
- The heat transfer model includes radiation, convection, conduction, and condensation features. The most acceptable heat transfer correlations are used by the code depending on the specific problem to be solved
- Mass transfer governing vapor condensation and liquid evaporation at the heat sink structure surface is driven by the partial pressure difference of the condensable vapor (diffusion model). If a condensate film layer exists on the structure surface, the partial pressure of the non-condensable gas at this film layer will be higher than that of the bulk mixture. This condition occurs because the non-condensable gas is carried with the vapor towards the interface where it accumulates. The increase in the partial pressure of the non-condensable gas produces a driving force for diffusion of non condensable gas away from the surface. This force opposes the motion of the bulk mixture (sum of non-condensable gas and vapor) towards the surface. If the total pressure of the bulk mixture remains constant, the partial vapor pressure at the interface is lower than that in the bulk mixtures when the process is condensation. The partial vapor pressure at the interface is higher than that in the bulk mixture when the process is evaporation

d) Engineering Safety features

- There are three basic models: fan cooler, ice condenser and containment spray. Associated with these models is a framework construction of a liquid transport system that can provide surges and drops of coolant levels for the engineered safety features. Typical and well-known heat transfer equations are implemented in these models

e) Algorithm solutions

- The most important overall process is the intercell flow of gases. For an arbitrary system of cells and interconnection, an accurate calculation of the flow rate through each flow path must be self-consistent: that is to say, the flow through any one must reflect changes in pressure in the upstream and downstream cells to arise from flows through all other paths

- The integration method employed for flow paths is either a first-order implicit method or an explicit fourth-order Runge-Kutta method. The implicit method will typically be the preferred one for multicell problems that cover the long term characteristics of severe accidents. The Runge-Kutta method should be reserved for special calculations of transient behavior such as those undertaken to assess integration errors. In either method, the integration timescale is selected automatically. The time scale in the implicit method is selected to ensure that inventory in a cell does not change (through flow sources) by more than 20% in total mass during the time scale

- A variety of features is available only in conjunction with the implicit method. They are:

  - Gravity-driven gas flow

  - The instantaneous liquid DROPOUT model (to remove all suspended liquid models from the atmosphere and deposit them in the appropriate pool), for water condensing in the bulk gas

  - Critical or choked flow

  - Aerosol transport between cells through settling

An implicit model for pool boiling is solved simultaneously with the flow equations.

f) Validation

The Code Manual for CONTAIN 2.0 is NUREG/CR-6533, SAND97. This NUREG in Table C-4 includes validations for heat and mass modeling.

APPENDIX E

NODALIZATION DIAGRAMS

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