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Vogtle Project

October 20, 1986

Director of Nuclear Reactor Regulation
Attention: Mr. B. J. Youngblood
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U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

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NRC DOCKET NUMBERS 50-424 AND 50-425
CONSTRUCTION PERMIT NUMBERS CPPR-108 AND CPPR-109
VOGTLE ELECTRIC GENERATING PLANT - UNITS 1 AND 2
SER CONFIRMATORY ITEM 9: MAIN STEAM LINE BREAK OUTSIDE CONTAINMENT

Dear Mr. Denton:

As discussed with your staff on August 27 and 28, 1986, the following changes are made to the referenced submittal:

Attachment 1 - VEGP Evaluation of Main Steam Line Break with Superheat Blowdown Outside Containment.

Attachment 2 - Thermal Analysis of Safety Related Valves Exposed to VEGP Control and Auxiliary Building Steam Line Breaks.

Attachments 1 and 2 are a complete replacement to the corresponding attachments of the referenced letter. Change bars indicate the portions revised.

If your staff requires any additional information, please do not hesitate to contact me.

Sincerely,

J. A. Bailey

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Project Licensing Manager

JAB/sm
Attachment

3001
1/5

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ATTACHMENT 1

VEGP EVALUATION OF MAIN STEAM LINE BREAK WITH SUPERHEATED BLOWDOWN OUTSIDE CONTAINMENT

REVISION 1
OCTOBER 1986

BACKGROUND

In December 1984, the Nuclear Regulatory Commission (NRC) issued Inspection and Enforcement (IE) Information Notice 84-90 (Main Steam Line Break Effect on Environmental Qualification of Equipment) requesting all licensees to review their main steam line break (MSLB) analyses with regard to steam superheating during steam generator tube bundle uncovery as a result of postulated main steam line breaks and subsequent release to compartments. Superheated steam being expelled from a MSLB would result in higher temperature conditions for the area of the plant containing and communicating with the break. This could possibly preclude safety-related components in the area from performing their intended safety function.

The Vogtle Electric Generating Plant (VEGP) Units 1 and 2 have four main steam lines for each unit. Two of the main steam lines (loops 2 and 3) are routed in the control building main steam isolation valve (MSIV) compartment directly north of the containment and the other two (loops 1 and 4) are routed in the auxiliary building MSIV compartment directly south of the containment. (See figure 1.) The MSIV compartments are physically separate from other areas of the power block, and all penetrations (e.g., piping, instrumentation, and electrical conduit) into other areas are physically sealed to prevent pressurization of these areas. The main steam piping in the MSIV compartments consists of straight piping runs extending from the containment penetrations to the five-way restraints mounted in the auxiliary building and control building walls through which these lines enter the main steam tunnel. There is a partial wall between the two main steam lines in each MSIV compartment that provides additional separation in each MSIV compartment. Some of the components located in these compartments are the MSIVs, MSIV bypass valves, main feedwater isolation valves, main feedwater bypass isolation valves, main feedwater control valves, main feedwater control bypass valves, main steam safety valves, atmospheric relief valves, and auxiliary feedwater discharge valves. The VEGP design has separated the essential equipment such that the valves associated with steam generators 2 and 3 are in the control building MSIV compartment and the valves associated with steam generators 1 and 4 are in the auxiliary building MSIV compartment. Because a MSLB in one MSIV compartment does not impact the equipment in the other MSIV compartment, there are two unaffected loops available to achieve safe shutdown.

In addition, the main steam piping in the MSIV compartments is designed to the break exclusion (superpipe) criteria of Branch Technical Position MEB 3-1 item B.1.b for the portions of piping passing through the primary containment and extending to the first five-way restraint past the MSIVs.

The superpipe design meets the following conditions:

- The superpipe design maintains low stress and fatigue usage factors which are attributable in part to the use of good geometry;
- The superpipe design uses seamless pipe to minimize circumferential and longitudinal welds;

- The superpipe design avoids attachment welds to the superpipe surface except where detailed stress analyses or tests are performed to demonstrate that the maximum stresses do not exceed the limits defined in Branch Technical Position MEB 3-1 B.1.b(1)

- The superpipe nominal wall thickness is 2 1/16 inches and 2 13/16 inches for the 28-inch and 29.5-inch forgings, respectively.

- The superpipe is examined through 100 percent volumetric inspection of all welds during each inspection interval.

The superpipe design reduces the probability of a MSLB in this portion of piping, so a single active failure is not considered concurrent with a MSLB in the superpipe.

SCENARIOS EVALUATED

The environmental effects of superheated steam exiting from a MSLB in the MSIV compartment have been evaluated for the following scenarios:

- In the superpipe region, MSLBs up to one square foot were evaluated without a single active failure;

- Downstream of the superpipe region, the largest MSLB that resulted in superheated steam being released in the compartment prior to the MSIVs isolating the blowdown was considered with a single active failure; and

- The largest main steam branch line break was considered with a single active failure.

DEVELOPMENT OF MASS AND ENERGY RELEASE DATA

As active members in the Westinghouse Owners Group (WOG), VEGP participated in the WOG Subgroup for High Energy Line Break/Superheated Blowdowns Outside Containment (HELB/SBOC). The purpose of the program was to provide members with steamline break mass and energy releases necessary to address equipment qualification outside containment (WCAP-10961-P).

The generic analyses were performed to include all member plants. VEGP was grouped with other WOG members categorized by the following criteria: the number of loops, power rating, and the type of steamline break protection logic. The mass and energy releases of the original WOG analyses were evaluated to determine the temperature profiles in the MSIV compartments outside containment for VEGP. Several cases were reanalyzed as described in this report using a VEGP specific model and input.

Analysis

The assumptions used in the WOG analyses were utilized in the VEGP analysis with the exceptions below:

A. A VEGP specific NSSS model was used. This included piping volumes, RCS loop pressure drops, and steam generator type (Model F).

B. The initial conditions representative of VEGP were also used. This included initial temperature, pressure, steam generator mass, power rating, RCS flow, and fuel data.

C. The VEGP protection system was modeled with allowances for system errors. Plant specific setpoints for over temperature delta T (OTDT), over power delta T (OPDT), low-low level steam generator water level, high neutron flux, low pressurizer pressure, and low steamline pressure were used with nominal errors since none of the sensors experience the adverse environment.

D The VEGP auxiliary feedwater system was modeled. This was reflected primarily in the flowrates assumed in the analysis.

Methods

The LOFTRAN code used to model the superheated steamline break mass and energy releases is identical to the code used in the WOG analyses. LOFTRAN is a digital computer code that simulates transient behavior in a multi-loop, pressurized water reactor system. The code simulates the neutron kinetics, thermal-hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection system operation.

Input

The purpose of this analysis is to generate a more detailed evaluation incorporating the VEGP specific aspects of the NSSS design. The difference between initial steam generator level and the low level setpoint was reduced for VEGP (the difference primarily being the relatively higher low level setpoint for VEGP and a different steam generator model). This impacts the relative mass and energy released before the low steam generator level setpoint is reached. The low steamline pressure safety injection setpoint was increased since no adverse environmental error was required. VEGP steamline pressure transmitters are not located in the compartments that would experience or communicate with the break. Consequently, a low steamline pressure setpoint for similar conditions was reached earlier in the transient than the WOG subgroup study. The low pressurizer pressure safety injection setpoint was increased which actuated SI sooner. Two trains of safety injection pumps were also used.

Auxiliary feedwater

For breaks in superpipe, a single failure does not have to be taken into account. This impacts the amount of auxiliary feedwater available. Normally, for a given single failure, the turbine-driven AFW pump is assumed to fail since it possesses the largest single flowrate. However, for the superpipe break cases in this analysis, it was assumed to be available. The mass and energy blowdown data was calculated both with and without the turbine-driven pump operating to address breaks that do not occur in the superpipe.

The modeling of the auxiliary feedwater system is complex. The conditions under which the water is pumped to the steam generators varies significantly with pressure. Prior to steamline isolation, all four steam generators depressurize equally. Once steamline isolation occurs, the intact steam generators begin to repressurize rapidly to a steady-state pressure (this steady-state pressure varies with power level). The faulted steam generator quickly blows down to atmospheric pressure. When the assumption of turbine-driven pump availability is changed, it also impacts the flow. For the cases analyzed, auxiliary feed flow was modeled as a function of pressure.

The logic for AFW pump actuation is consistent with the WOG subgroup study and VEGP. Any one steam generator low-low level signal will start the motor-driven pumps. Low-low level signals are needed in two steam generators to start the turbine-driven pump.

VEGP specific cases

Two power levels were assumed: 102% and 70%

Four break sizes were assumed: 1.0, 0.7, 0.5, and 0.4 ft^2

These break sizes represent the following:

1. 1.0 ft^2 is the largest postulated break in superpipe,
2. 0.7 ft^2 is the largest break downstream of the MSIV where the temperature envelope is exceeded prior to protection actuation.
3. 0.5 ft^2 is the largest branchline break,
4. 0.4 ft^2 is the smallest break that occurs with the resulting compartment temperature exceeding 320°F (the current specified qualification temperature).

DEVELOPMENT OF MSIV COMPARTMENT TEMPERATURE PROFILES

The analyses of the environmental response of each MSIV compartment to MSLBs with superheated steam blowdown is consistent with the requirements of NUREG-0588. These analyses were completed using the Bechtel computer code "FLUD". FLUD is a multi-node, one-dimensional, thermal-hydraulic code which takes credit for heat transfer to the surrounding concrete structures. The FLUD code provides a calculation of the long-term subcompartment pressures and temperatures as a function of time following the pipe break.

The auxiliary building and control building MSIV compartments are modelled into various control volumes with interconnecting flow paths. The nodal boundaries are taken at significant restrictions such as at walls, gratings or major pipes. The auxiliary building MSIV compartment is modeled into 12 nodes (see figure 2), and the control building MSIV compartment is modelled into 8 nodes (see figure 3).

The centerline of the superpipe portion of the main steam lines is at elevation 229'-6" and forms the boundary between nodes 1 and 2 and between nodes 5 and 8 in the auxiliary building, and between nodes 1 and 2 and between nodes 4 and 5 in the control building. The portion of the main steam line (nonsuperpipe) downstream of the five-way restraint is in nodes 9 and 10 in the auxiliary building MSIV compartment and in node 8 of the control building MSIV compartment. The main steam line branch lines are in nodes 1, 2, 5, 8, 9 and 10 of the auxiliary building MSIV compartment and in nodes 1, 2, 4, 5 and 7 of the control building MSIV compartment. The MSLBs in the superpipe region and the branchline breaks are taken in node 5 of the auxiliary building and in node 1 of the control building because it has been shown that taking breaks in these nodes give conservatively high temperatures in the break node and the surrounding nodes. MSLBs in the nonsuperpipe are taken in node 9 in the auxiliary building and node 8 of the control building MSIV compartment. MSLBs are not considered in node 10 of the auxiliary building MSIV compartment because there is no safety-related equipment located in this area and the temperatures in the other nodes are less than for a break in node 5.

MSLBs with superheated steam blowdown were considered in both the auxiliary building and control building MSIV compartments, but the environmental response of the control building MSIV compartment was the worst. This is mainly due to the smaller break node volume and flow areas to the surrounding nodes in the control building than in the auxiliary building. The calculated maximum peak temperature is 422°F in the break node (node 1 of the control building MSIV compartment) and is of short duration. The worst case for each of the four break sizes considered is summarized in table 1.

Summary of Facility Response and Evaluation of Equipment Qualification

A facility response evaluation was performed for the safety-related equipment located in the MSIV compartments. The facility response evaluation considered the following questions to determine if the equipment was essential for a MSLB in the area.

- Is the equipment required to mitigate the effects of the MSLB?

- Is the equipment required to function for post-accident monitoring?

- Is the equipment required to function for post-accident recovery?

- Will consequential actuation have an adverse impact on the event?

If the equipment was determined to be essential for a MSLB in the area, the environmental qualification test reports for the equipment were reviewed to ensure that the equipment is qualified for the MSLB event.

For five components (MSIVs, MSIV bypass valves, steam generator atmospheric relief valves, auxiliary feedwater discharge valves and the solenoid valves for the main feedwater bypass isolation valves and main feedwater control valves) the maximum environmental temperatures achieved during the qualification tests did not envelope the maximum MSLB environmental temperature profiles considering superheat (limiting profiles are shown in figures 4 through 8) developed for the control building and auxiliary building MSIV compartments. A thermal lag analysis was performed on these components to demonstrate that the actual safety-related component temperature achieved under the VEGP MSLB conditions is less than the component temperature reached in the qualification testing program.

The thermal response of a component exposed to an MSLB is characterized by the heat transfer mechanism occurring at a given point in time. The component temperature will rise rapidly to the saturation temperature and remain at this temperature until the water which condenses on the valve changes state from saturated liquid to saturated vapor. After "drying off" the component temperature will rise based on the forced convection heat transfer mechanism. Attachment 1 provides a summary of the thermal lag methodology used in the evaluation of these components. This methodology is consistent with NUREG-0588 requirements for thermal lag analyses.

CONCLUSIONS

The essential equipment for an MSLB in the auxiliary and control building MSIV compartments has successfully completed environmental qualification test programs which, in conjunction with thermal lag analysis, demonstrate that the equipment is qualified for the maximum MSLB environmental temperature postulated in these compartments. It is concluded that no required safety components are precluded from performing their safety function in the event of an MSLB in either of the MSIV compartments. Therefore, no safety implications exist to prevent safe shutdown of the VEGP.

TABLE 1

MSIV COMPARTMENT BREAK NODE TEMPERATURES

Break Location	Break Size (ft^2)	Peak Temperature (°F)	Time above 320°F* (sec)
Control Building Node 1	1.0	422	100
	0.7	397	250
	0.5	374	400
	0.4	358	600
Control Building Node 8	0.7	144**	NA
Auxiliary Building Node 5***	1.0	333	20

*320°F is the current specified environmental qualification temperature requirement.

**Because there is no essential equipment located in the break node, the peak temperature is for node 1 rather than the break node.

***For all the other cases analyzed for the auxiliary building MSIV compartment, the temperature is less than 320°F.

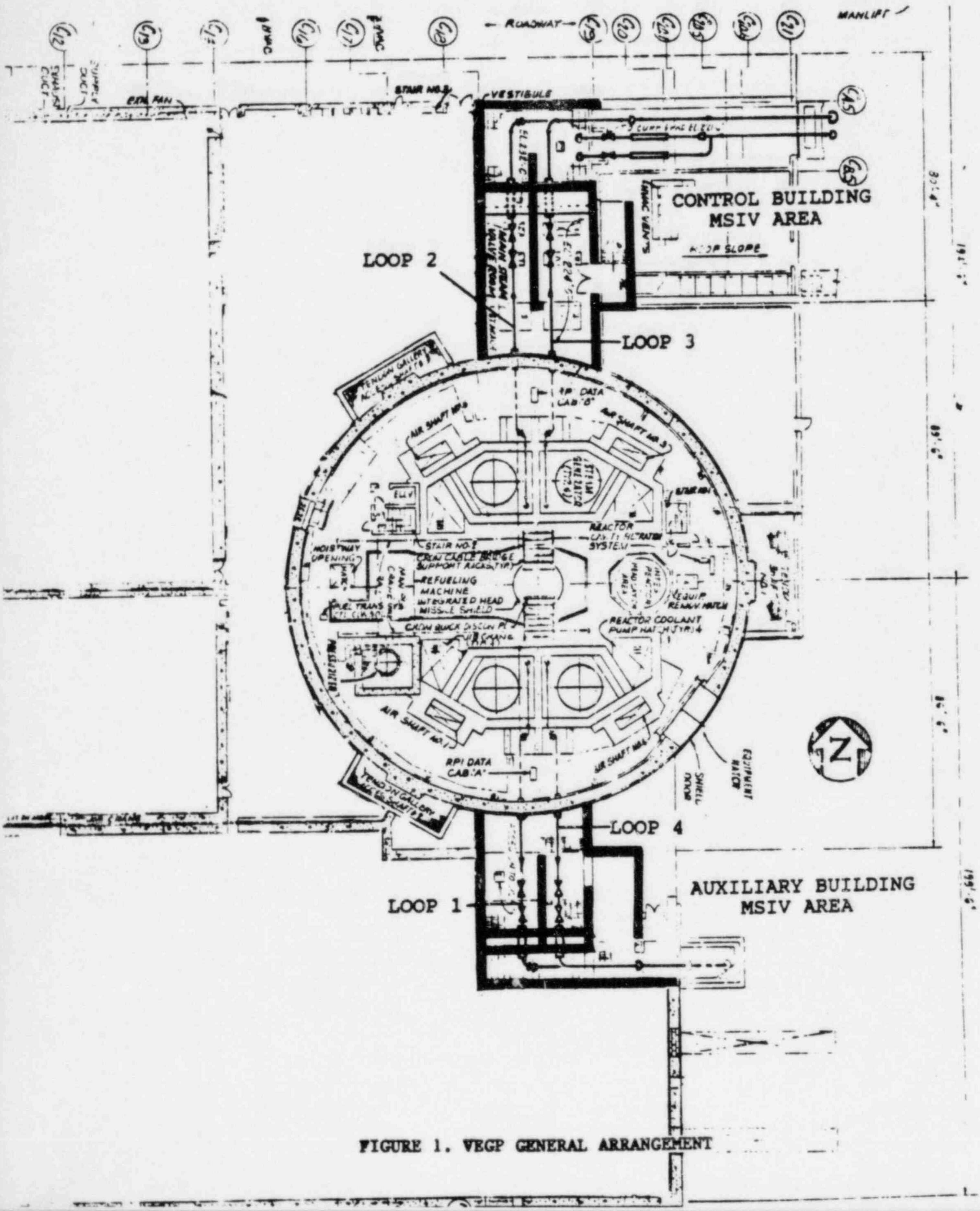

FIGURE 1. VEGP GENERAL ARRANGEMENT

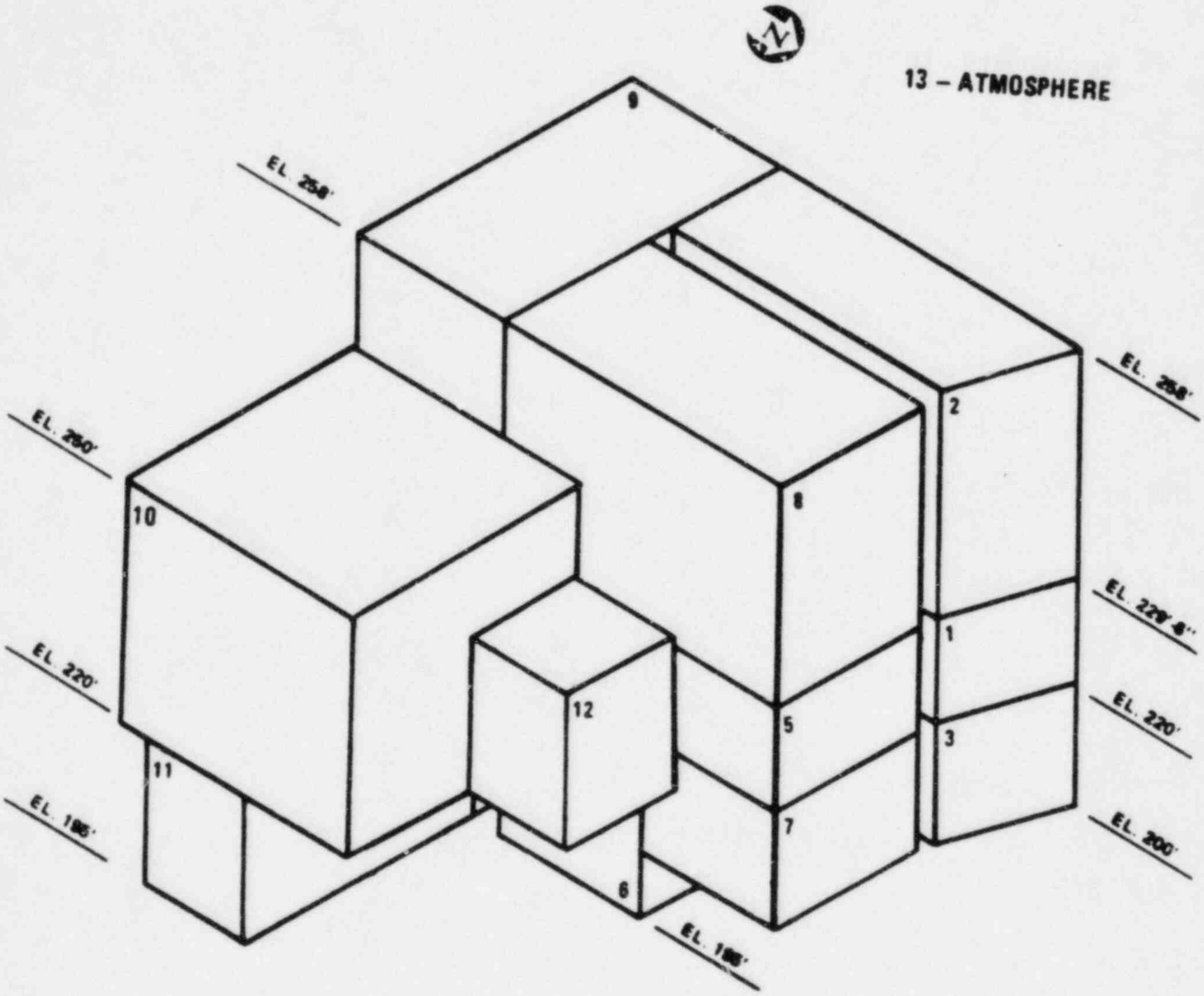

FIGURE 2. AUXILIARY BUILDING
MSIV AREA NODALIZATION MODEL

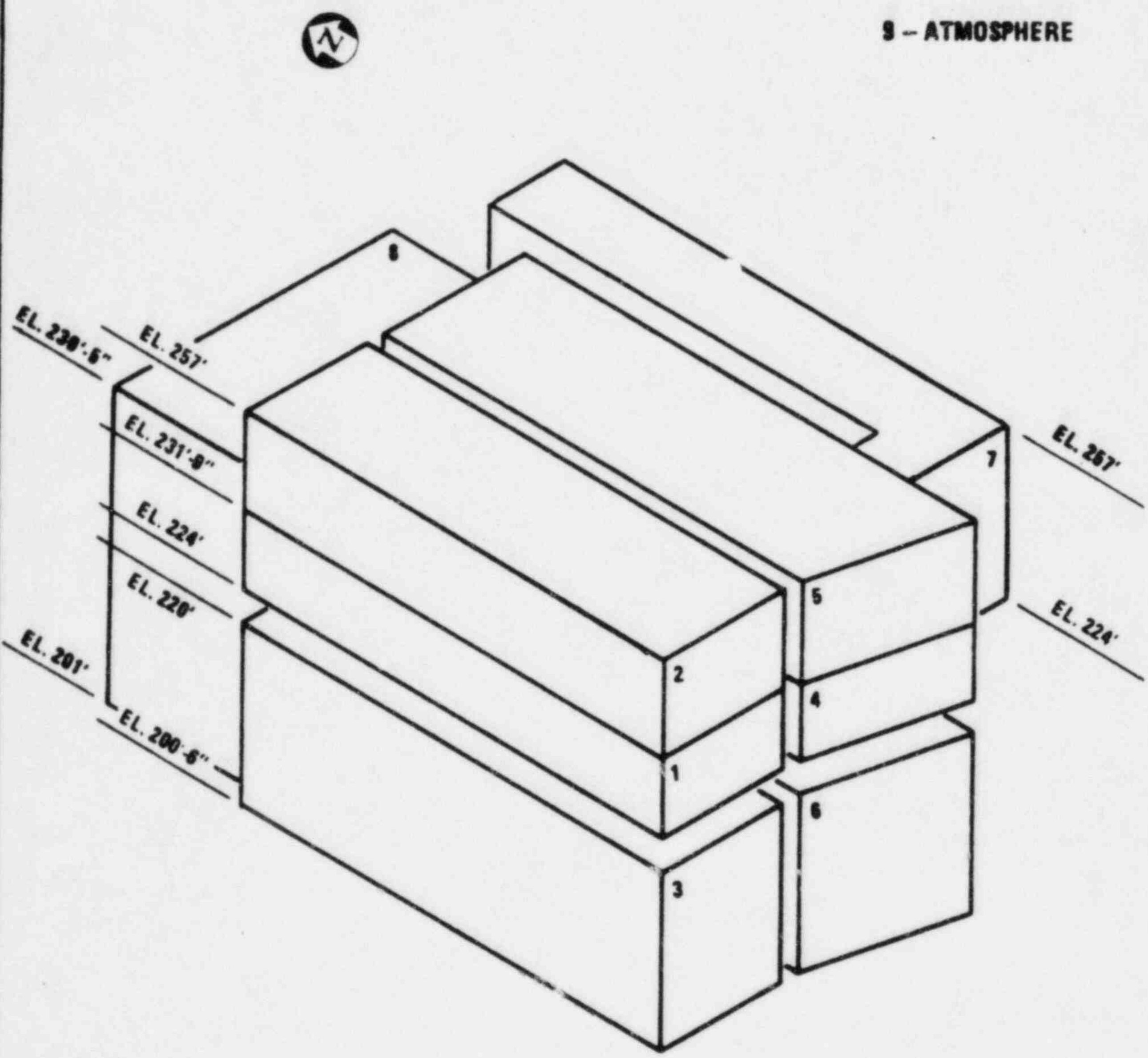

FIGURE 3. CONTROL BUILDING
MSIV AREA NODALIZATION MODEL

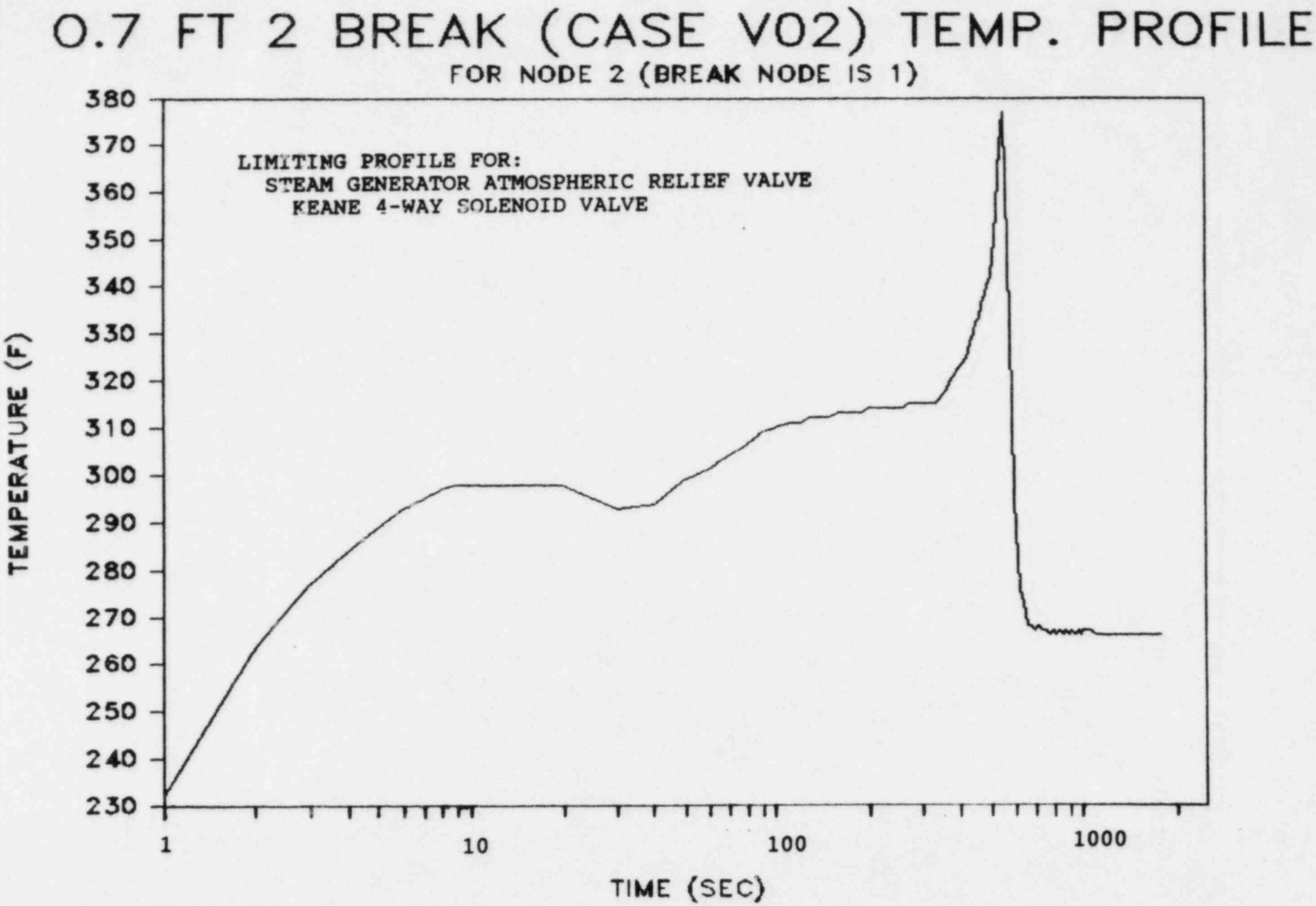
O.7 FT 2 BREAK (CASE VO2) TEMP. PROFILE
FOR NODE 2 (BREAK NODE IS 1)
LIMITING PROFILE FOR:
STEAM GENERATOR ATMOSPHERIC RELIEF VALVE
KEANE 4-WAY SOLENOID VALVE
TEMPERATURE (F)
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
1
10
100
1000
TIME (SEC)

FIGURE 4.

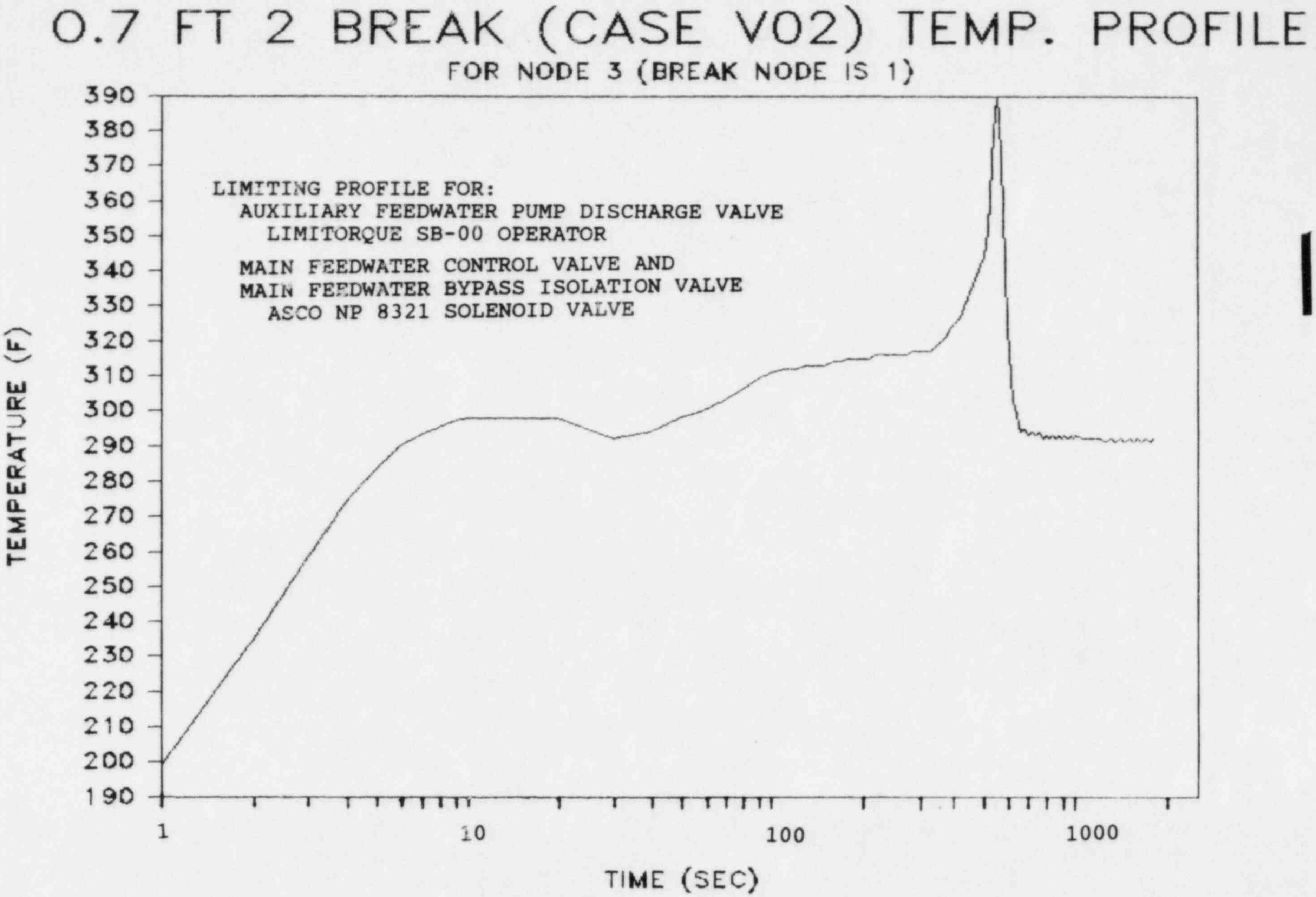
0.7 FT 2 BREAK (CASE V02) TEMP. PROFILE
FOR NODE 3 (BREAK NODE IS 1)
LIMITING PROFILE FOR:
AUXILIARY FEEDWATER PUMP DISCHARGE VALVE
LIMITORQUE SB-00 OPERATOR
MAIN FEEDWATER CONTROL VALVE AND
MAIN FEEDWATER BYPASS ISOLATION VALVE
ASCO NP 8321 SOLENOID VALVE
TEMPERATURE (F)
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
1
10
100
1000
TIME (SEC)

FIGURE 5.

0.7 FT 2 BREAK (CASE V02) TEMP. PROFILE

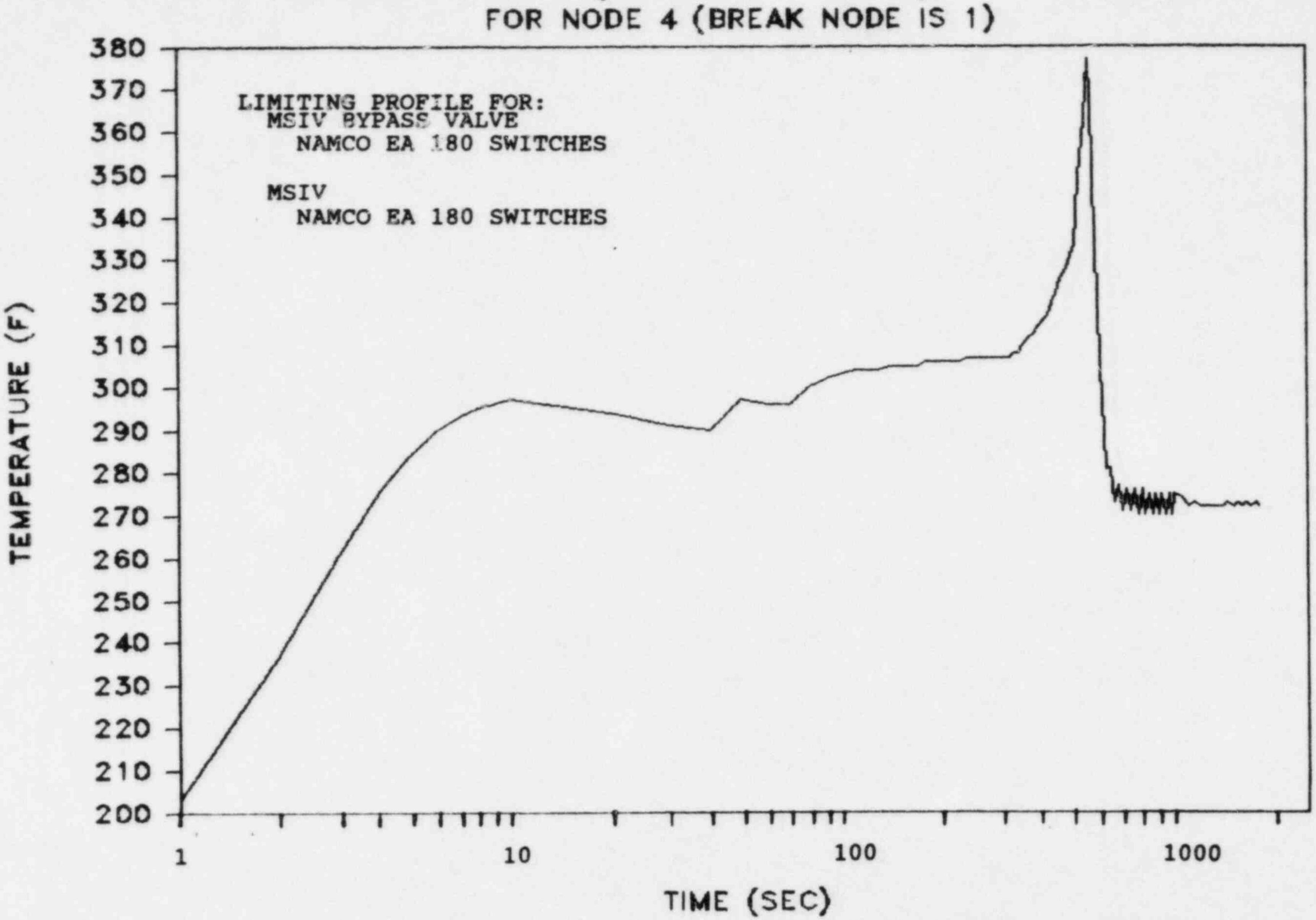

FIGURE 6.

0.5 FT 2 BREAK (CASE V11) TEMP. PROFILE

FOR NODE 2 (BREAK NODE IS 1)

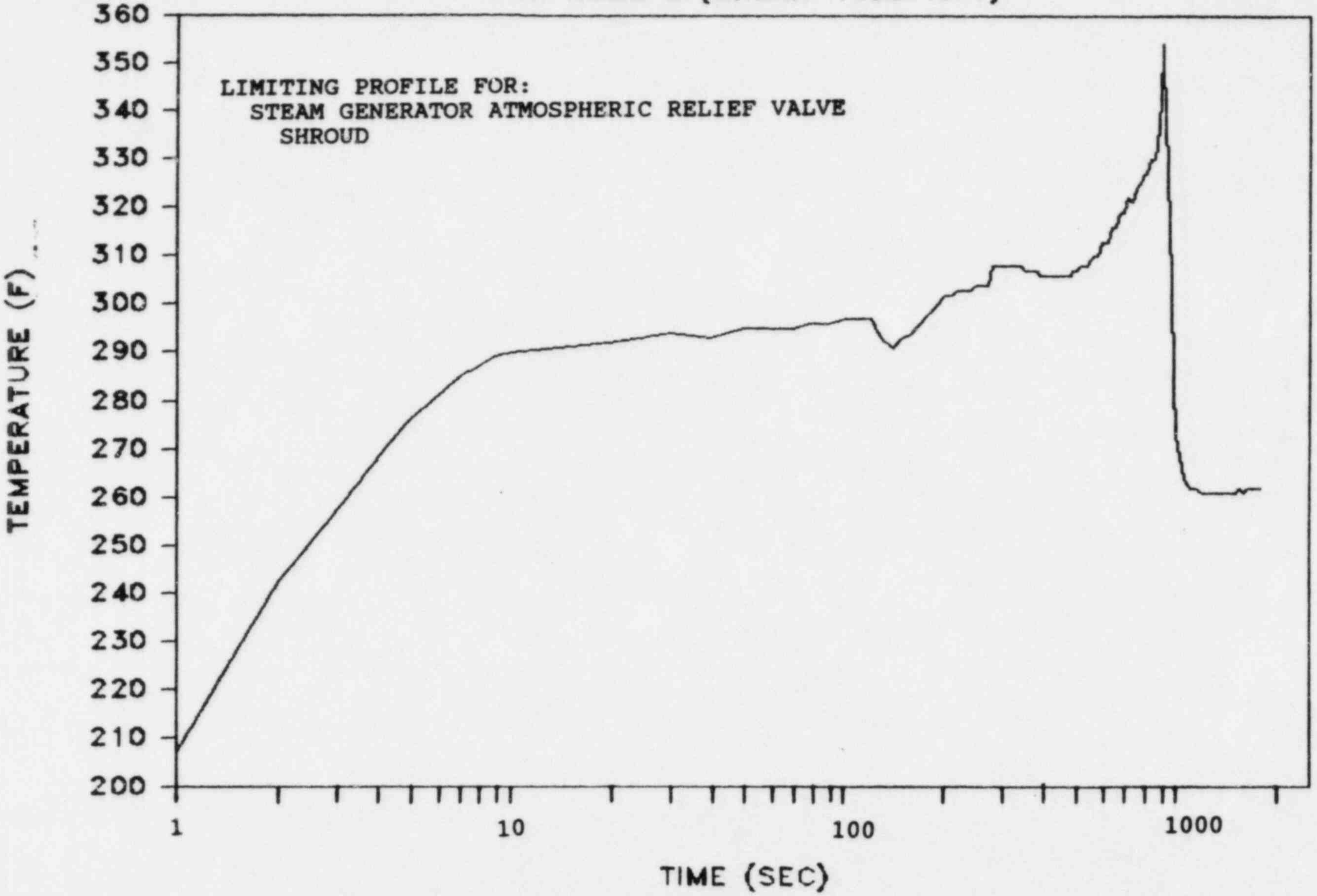

FIGURE 7.

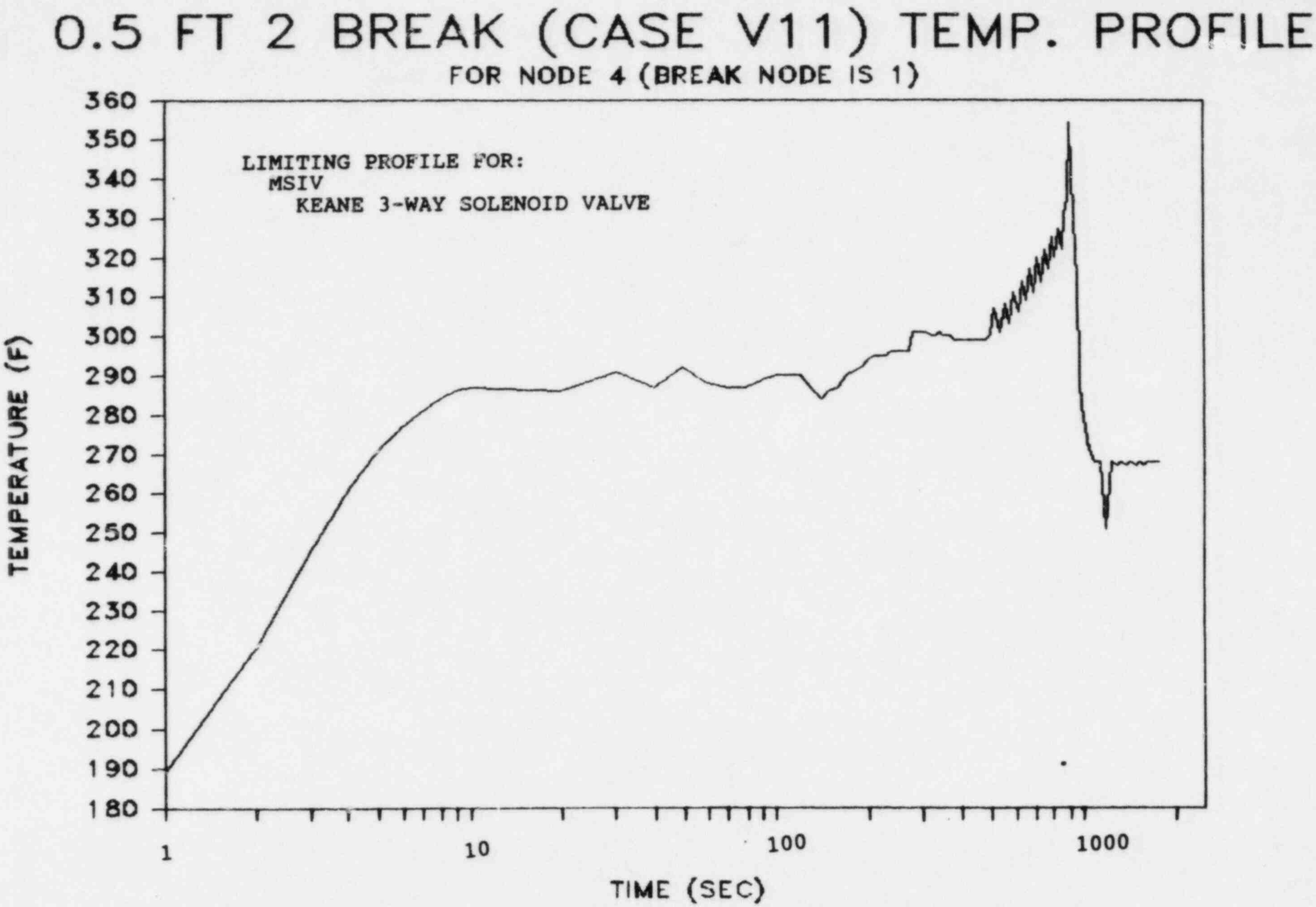
0.5 FT 2 BREAK (CASE V11) TEMP. PROFILE
FOR NODE 4 (BREAK NODE IS 1)
LIMITING PROFILE FOR:
MSIV
KEANE 3-WAY SOLENOID VALVE
TEMPERATURE (F)
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
1
10
100
1000
TIME (SEC)

FIGURE 8.

THERMAL ANALYSIS OF SAFETY RELATED VALVES EXPOSED TO VEGP CONTROL AND AUXILIARY BUILDING STEAM LINE BREAKS

TABLE OF CONTENTS

Changes to the text of this report from the previous revision of this report are marked by a vertical bar in the margin of this report.

1.0 BACKGROUND

Vogtle Electric Generating Plant (VEGP) has several Class 1E valve assemblies, located in the Control and Auxiliary Buildings, which can be exposed to superheated steam resulting from various postulated main steam line breaks (MSLB). Ambient temperatures resulting from these MSLB's can reach maximum values as high as 422°F. The superheated steam temperature profiles are based on VEGP-specific mass and energy release data and subcompartment analysis performed by Bechtel. While all the safety related Class 1E components, which may be subject to the postulated MSLB, have successfully completed environmental qualification test programs, the maximum MSLB environmental temperatures achieved during these qualification tests did not in all cases envelop the maximum MSLB environmental temperature postulated in the VEGP Control and Auxiliary Buildings. Based on this situation and in order to demonstrate qualification of the specific equipment at VEGP under these conditions, it is necessary to demonstrate that the actual safety related component temperature achieved under the VEGP MSLB's is less than the component temperature reached in the qualification testing program. Five specific valve types - the main steam isolation valves (MSIV), main steam isolation valve bypass valves, the solenoid valves associated with the feedwater control valve and main feedwater bypass isolation valves, the auxiliary feedwater pump discharge valves, and the atmosphere steam dump valves (PORV) were evaluated.

2.0 PURPOSE

The purpose of the analysis is to verify the environmental qualification of various safety related, Class 1E valve components identified herein by demonstrating that the temperatures actually achieved by these components during the postulated VEGP MSLB's are less than the temperatures achieved by these components during their respective qualification tests.

3.0 HEAT TRANSFER MODEL

3.1 Component Thermal Response

The thermal response of a component exposed to an MSLB can be characterized by the heat transfer mechanism occurring at a given point in time. The heat transfer mechanisms are as follows:

a. The component temperature rises rapidly during the initial temperature rise from ambient to peak until the component reaches saturation temperature corresponding to ambient pressure. Initially, the steam impinging the component condenses and gives up its heat to the cooler component. The heat transfer rate of condensing steam is very high and the condensing heat transfer coefficient is in the order of 1,000 - 20,000 Btu/hr - sq ft-°F (Reference 1). The temperature of the component rises rapidly at a rate dependent upon the steam temperature, environment pressure, the surface area and specific heat of the component, and the mass flow rate of the steam.

b. Once the component reaches saturation temperature, the temperature stabilizes. The component remains at saturation temperature until the water which condensed on the component during the initial phase changes from saturated liquid to saturated vapor. The amount of time at this plateau is dependent upon the mass of water condensed on the component, the surface area of the component, environment pressure, and the temperature and mass flow rate of steam at the component.

c. After the water which condensed on the component evaporates, the temperature of the component begins to rise again. The heat transfer mechanism occurring during this phase is one of forced convection and depends primarily upon the mass and surface area of the component, the velocity of the steam, the temperature of the steam, and the initial temperature of the component. The heat transfer mechanism during the forced convection stage is not as efficient as the mechanism in a. above and the heat transfer coefficient is of the order of 5-50 Btu/hr-sq ft°F (Reference 1).

- The thermal response of the subject components exposed to the VEGP Control Building or Auxiliary Building MSLB temperature profiles will reflect the above heat transfer mechanisms. The component temperature will rise very rapidly to 221°F (saturated temperature at 3 psig), and then the component will remain at saturated temperature until the water which condensed on the valve changes state from saturated liquid to saturated vapor. After "drying off," the component temperature will rise based on the forced convection heat transfer mechanism.

3.2 Heat Transfer Methodology

Westinghouse has developed a heat transfer model that predicts the temperature response of a component that is exposed to a steam line break in the Vogtle Control and Auxiliary Buildings. The overall model is based on evaluating, as appropriate, the three heat up stages described in Section 3.1 above. For the purposes of evaluating the time required for heat up of the component to saturation temperature (Section 3.1.a) and the time required for "drying off" the component at saturation temperature (Section 3.1.b), the model is based on previous test results on an ASCO NP 8316 valve exposed to superheated steam at the Franklin Research Center (References 2 and 3). These parts of the model are applied to specific components as discussed below. In all cases the component heat-up in the forced convection mode above the saturation temperature is evaluated based on empircial forced convection heat transfer correlations. This forced convection mode is determined to be the dominating mode of heat transfer for the subject components in the given Vogtle superheat transients. This is true because the transients last for relatively long periods of time, reaching peak ambient temperatures at least several minutes after the start of the transient, compared to relatively short periods of time (on the order of seconds) required for the component to reach saturation temperature and "dry out." Therefore the final component temperature has been calculated based on the components' reaching saturation temperature and "drying out" instantaneously at the start of the transient and heating up above saturation temperature for the entire duration of the transient in the forced convection mode. The results of the different models are given in Table 1 and discussed in the appropriate sections on each component type.

3.2.1 Heatup to Saturation Temperature

In Reference 2, the initial valve heatup from normal ambient temperature to saturated temperature was modeled by calculating the rate of increase in the valve internal energy. This rate can be expressed by the following equation:

$$Q = cm\Delta T/t \qquad \text{(Equation 1)}$$

where:

- Q = Rate of increase of Valve Internal Energy (Btu/sec)
- c = Specific Heat of Valve Material - Brass (Btu/lb-°F)
- m = Weight of Valve (lbs)
- ΔT = Saturation Temperature - Initial Temperature (°F)
- t = Time required for initial heat-up (sec)

From the FRC test results, the rate of increase of the NP8316 valve internal energy was calculated to be:

Q = 4.29 Btu/sec (Reference 2).

The value of Q is also given by the expression:

$$Q = \bar{h}\, A_c\, (T_{sat} - T_c) \qquad \text{(Equation 2)}$$

where:

Q = Rate of increase of component enternal energy (Btu/sec)
$\bar{h}$ = Average heat transfer coefficient for condensing steam (Btu/hr-ft^2-°F)
A_c = Surface area of the component (ft^2)
T_{sat} = Saturation temperature (°F)
T_c = Component temperature (°F)

The value of $\bar{h}$ for condensing steam can be estimated based on classical Nusselt film theory and is given by the expression:

$$\bar{h} = 0.943 \left[\frac{\rho_\ell (\rho_\ell - \rho_v)\, g h'_{fg}\, k_\ell^3}{\mu_\ell L_c (T_{sat} - T_c)}\right]^{1/4} \qquad \text{(Equation 3)}$$

where:

ρ_ℓ = Density of the liquid (lb/ft^3)
ρ_v = Density of the vapor (lb/ft^3)
g = Gravitational force
k_ℓ = Thermal conductivity of the liquid (Btu/hr-ft-°F)
μ_ℓ = Viscosity of the liquid (lb/ft-sec)
L_c = Vertical dimension of the component in the flow stream (ft)
T_{sat} = Saturation temperature (°F)
T_c = Component temperature (°F)
h'_{fg} = Adjusted latent heat of condensation (Btu/lb)

The physical properties of the liquid in Equation 3 should be evaluated at the average film temperature. Thus for a component at a given temperature the average heat transfer coefficient is a function of the $L_c^{-1/4}$ and $(Tsat - Tc)^{-1/4}$.

Relating this result back to Equation 2 it follows that:

$$Q = \bar{h} A_c (Tsat - Tc) = f \left[\frac{A_c (Tsat - Tc)}{L^{1/4} (Tsat - Tc)^{1/4}} \right]$$

$$Q = f \left[\frac{A_c}{L^{1/4}} \right] (Tsat - Tc)^{3/4} \quad \text{(Equation 4)}$$

Therefore the value of Q derived in Reference 2 for the NP 8316 value can be conservatively applied to other components in other condensing steam conditions as long as the ratios $(Ac/L^{1/4})$ and $(Tsat - Tc)^{3/4}$ are less for that component under those steam conditions than the NP8316 value in the Reference 3 test. The time required for the initial heatup can be conservatively determined by using the Q calculated from the FRC data and solving Equation 1 for time (t).

3.2.2 Time at Saturation Temperature

The time that the component remains at saturation temperature was modeled in Reference 2 by the following expression:

$$m\Delta h_w = \dot{m} h_s \Delta t \quad \text{(Equation 5)}$$

where

m = Mass of water on component (lbs)

Δh_w = Enthalpy of vaporization of water at saturated temperature (Btu/lb)

$\dot{m}$ = Mass flowrate of steam impinging the component (lb/hr)

h_s = Enthalpy of the superheated steam (Btu/lb)

Δt = Time at saturated temperature (hr)

From the FRC test results (Reference 2):

$\dot{m}$ = 0.71 lbs/hr

m = 0.021 lbs of water

The mass flow rate of steam can be expressed as:

$$\dot{m} = \rho A_c v \qquad \text{(Equation 6)}$$

where:

$\dot{m}$ = Mass flow rate of superheated steam on the component (lb/sec)
ρ = Density of superheated steam (lb/ft^3)
A_c = Surface area of the component (ft^2)
v = Velocity of superheated steam (ft/sec)

The mass flow rate derived in Reference 2 will bound the Vogtle superheated steam conditions for those components with surface areas equal to or less than the NP8316 value, since the density of superheated steam in the Reference 3 testing (420°F, 68 psig) is over four times greater than the density of superheated steam at Vogtle (310°F, 3 psig) and the velocity of superheated steam, as calculated based on the forced convection heat transfer coefficient in the Reference 3 testing, is at least 1.7 times greater than the highest superheated steam velocity at Vogtle.

The mass of the water remaining on a component after the component initially reaches the saturation temperature is a function of the portion of surface area of the component where the gravitational force does not greatly aid condensing heat transfer. Thus those parts of the component surface area that are essentially horizontal with respect to the gravitational force will retain water that must be "dried out" by forced convection. Thus the ratio of horizontal area of a component in a given mounting arrangement to the horizontal area of the NP8316 valve in the Reference 3 test can be used to ratio the mass of water on the components to the mass of wtaer on the NP 8316 valve in the Reference 3 test. If the total surface area ratio of the component with respect to the NP 8316 total surface area is less than the ratio of the horizontal surface areas, than the mass of water on the component that must be "dried out" can be expressed as:

$$m_w = \left(\frac{A_{component}}{A_{8316}}\right) m \qquad \text{(Equation 7)}$$

where:

$A_{component}$ = Surface Area of the component (ft^2)

A_{8316} = Surface Area of ASCO 8316 valve (ft^2)

m_w = Mass of water on component (lb)

m = 0.021 lbs of water (mass of water on NP 8316 valve)

The time (Δt) at saturation temperature can be calculated by solving Equation 5 for time and inserting the applicable values for m, $\dot{m}$, Δh_w (956 BTU/lb, saturated water at 3 psig) and h_s (1191 BTU/lb, superheated steam at 300°F).

3.2.3 Forced Convection Heat Transfer

The component temperature departs from saturation temperature after the component has "dried off." If the temperature gradients within the component are assumed to be negligible (i.e., the interior component temperature is equal to the surface temperature) the component temperature at any given point in time can be predicted by the following equation (Reference 4):

$$\ln \frac{T - T_s}{T_i - T_s} = \frac{hA_s}{mc} t \qquad \text{(Equation 8)}$$

where:

- T = Component Temperature at Time t (°F)
- T_s = Superheated Steam Temperature (°F)
- T_i = Initial Component Temperature (°F)
- h = Forced Convection Average Heat Transfer Coefficient (Btu/hr-ft^2-°F)
- A_s = Surface Area of Component (ft^2)
- m = Weight of Component (lbs)
- c = Specific Heat of Component Material - (Btu/lb-°F)
- t = Time (hrs)

The average forced convection heat transfer coefficient, h, is a function of the geometry of the component and the velocity and temperature of the superheated steam. Since the geometry of the components in question vary (flat plate, cube, cylinder, sphere, and combinations of these shapes), heat transfer coefficients were calculated for the applicable shapes.

The heat transfer correlations for the various geometries are:

A. Cylinder (Reference 5)

$$Nu = \frac{hD}{k} = (0.4\ Re^{0.5} + .06\ Re^{0.67})\ Pr^{0.4} \left(\frac{\mu_s}{\mu_f}\right)^{0.5} \qquad \text{(Equation 9)}$$

where:

- Nu = Nusselt's Number
- D = Hydraulic Diameter (ft)
- Re = Reynold's Number
- $Re = \frac{VD}{\nu}$; V = Steam Velocity (ft/sec)
  - D = Hydraulic Diameter (ft)
  - ν = Kinematic Viscosity (ft^2/sec)

Pr = Prandtl Number of Steam

μ_s = Steam Viscosity at Component Surface (lb/ft-sec)

μ_f = Free Stream Steam Viscosity (lb/ft-sec)

k = Thermal Conductivity of Steam (Btu/hr-ft-°F)

B. Sphere (Reference 5)

$$Nu = \frac{hD}{k} = 2 + (0.4\ Re^{0.5} + .06\ Re^{0.67})\ Pr^{0.4}\ \left(\frac{\mu s}{\mu_f}\right)^{0.25} \quad \text{(Equation 10)}$$

C. Cube (Reference 6)

$$Nu = \frac{hD}{k} = .102\ Re^{0.675}\ Pr^{0.33} \quad \text{(Equation 11)}$$

D. Flat Plate (Reference 5)

$$Nu = \frac{hD}{k} = .20\ Re^{2/3} \quad \text{(Equation 12)}$$

Equation 7 provides accurate results as long as the ratio of the internal resistance to heat flow to the external resistance to heat flow is less than 0.1 (Reference 7). The ratio of resistances is expressed as the Biot number as follows.

Biot Number = $\bar{h}L/k$

Where:

$\bar{h}$ = Average unit-surface conductance (Btu/hr-ft-°F)

L = Significant length dimension obtained by dividing the volume of the component by the surface area (ft)

k = Thermal conductivity of the component (Btu/hr-ft^2-°F)

For the components being investigated the Biot number was calculated and checked against the 0.1 criteria. Regardless of this result, the temperature gradient across the components was calculated at the maximum component temperature. Based on this gradient a conservative factor was added to the average temperature determined by Equation 8 to account for the difference in the outside surface temperature versus the average component temperature calculated by Equation 8.

3.2.4 Temperature Results

Utilizing the thermal response model discussed above and the VEGP specific MSLB temperature and steam velocity profiles, the maximum temperature reached by safety-related, Class 1E valve components located in the Control and Auxiliary Buildings at VEGP has been determined. The highest (worst case) temperatures reported in Table 1 neglect the first two phases of component heatup, i.e., time to reach saturation temperature and "dry out," and the valve temperature is assumed to be saturation temperature at time zero. In addition the maximum temperature includes a conservative factor to account for the outside surface temperature. Where appropriate, Table 1 also lists the maximum component temperatures including the first two stages of heatup. These results, when compared to ignoring these two stages, indicate the amount of conservatism involved in the calculations. The methodology and analysis discussed meet the requirements of NUREG 0588.

3.2.4.1 MSLB profiles for 7 separate cases of MSLB conditions in both the Control and Auxiliary Buildings were provided. Detailed evaluations of all these cases revealed that the cases in the Control Building were more severe than those in the Auxiliary Building. Of the cases (V01, V02, V07, V09, V10, V11 and V15) in the Control Building, three cases (V01, V02, V11) included the most severe conditions (highest peak temperature and longest total time above qualification test peak temperature). Cases V01, V02 and V11 in the Control

Building were therefore analyzed to represent and envelope all the other cases at VEGP for the MSLB condition in the Control and Auxiliary Buildings.

4.0 VALVE DESCRIPTION AND THERMAL RESPONSE

The five valve types have been reviewed and a thermal analysis performed, as described in Section 3.0, to determine the worst case temperature reached by any of the valve components critical to the safety function of the valve. This temperature was then compared to the previously established qualification temperature for the valve/valve component. Table 1 provides a summary of the results of the analysis of each valve design and critical component. The specific results of each analysis for each valve type/valve component are discussed below.

4.1 Main Steam Isolation Valve Bypass Valves

The MSIV Bypass Valve is described on Fisher Controls Drawing 50B0608 Revision B. The valve air actuator assembly has four NAMCO Model EA-180 series limit switches and one ASCO Model NP8320 series solenoid valve which are critical to the safety function of the MSIV Bypass Valve. Other degradable, non-metallic components such as the actuator diaphragm and O-ring are not critical to the safety function of the MSIV Bypass Valve. The worst MSIV Bypass Valve location is Node 4 of the Control Building.

4.1.1 The NAMCO Model EA-180 series limit switches weigh 4.5 lbs, have brass bodies and are cubic in shape with a total area of 0.47 square feet and a maximum length of 0.5 ft. Since the $[Ac/L^{1/4}]$ ratio and the total surface area of the limit switch are less than these same values for the NP8316 solenoid value, the methodology of Section 3.2.1 and 3.2.2 can be utilized and results in a time for the switches to reach saturation temperature of 11 seconds and a time at saturation temperature of 77 seconds. Examining Cases V01, V02 and V11 for the forced convection heat transfer region and utilizing the methodology of Section 3.2.3, a maximum limit switch temperature of 310°F is determined. Neglecting the first two phases of limit switch heatup and assuming that forced convection begins at the start of the transient with the switch already at saturation temperature, application of Equations 7 and 10 result in a switch maximum temperature of 314°F. This maximum temperature includes a 1°F adjustment (versus 0.3°F calculated temperature gradient) to account for the difference between the average switch body temperature and the switch outside surface temperature. The Biot number applicable to the switch varies because the value of the forced convection heat transfer coefficient varies with the velocity of the superheated steam, but it is always less than .004. Reference 8 lists a qualification temperature of 340°F for this model limit switch.

4.1.2 The ASCO Model NP 8320 series solenoid valves weigh 1.8 lbs, have brass bodies and are of a complex shape with a total surface area of 0.28 square feet and a maximum length of .4 ft. Reference 9 lists a qualification temperature of 420°F for the ASCO NP 8320 model solenoid valve. Since this temperature of qualification exceeds the highest peak temperature (399°F) in node 4, the value is qualified by the actual testing of Reference 9.

4.2 Auxiliary Feedwater Pump Discharge (AFPD) Valves

The AFPD Valves are described in Fisher Controls Drawings 57A5347 Revision B and 57A5345 Revision B. The valves are motor operated valves with a Limitorque motor operator Model SB-00-10 and Model SB-00-15. The Limitorque motor operator assemblies are critical to the safety function of the AFPD Valve. No other degradable parts of the valve, critical to the valve safety function exist. The worst AFPD Valve location is in Node 3 of the Control Building.

4.2.1 The Limitorque SB-00-10 motor operator is slightly smaller in weight than the SB-00-15 operator due to the smaller motor size and thus will be the worst case for analysis. The SB-00-10 operator weighs 250 lbs, has a cast iron body and is a complex shape, with a total surface area of 9.3 square feet. Since the majority of the mass and surface area of the Limitorque operator is in a cubic shape, this shape was used for the forced convection portion of the analysis. Utilizing the methodology of Section 3.2.1, but with the Limitorque physical properties and the actual test results of Reference 10, the time for heatup to saturation temperature is 113 seconds. In the case of Limitorque the Reference 10 testing documents a superheated steam test wherein the Limitorque operator was exposed to numerous superheated steam transients at temperatures as high as 385°F at 66 psig. The actual temperature of the operator was measured during this test and thermocouple data indicated that the operator never rose above the saturation temperature (314°F) throughout the whole test. Comparing the total heat input to the operator after the operator has reached saturation temperature during the Reference 10 test to the same total heat input after reaching saturation temperature during the worst case VEGP superheat condition, reveals that more total heat above saturation temperature was available during the Reference 10 test. Thus it can be concluded, since the operator never rose above saturation temperature during the Reference 10 test, that the operator would never rise above the saturation temperature of 221°F at VEGP. Neglecting the first two phases of motor operator heatup and considering forced convection to begin at start of the transient with the operator already at saturation temperature, application of Equations 7 and 10 result in an operator maximum temperature of 255°F. This maximum temperature includes a 1°F adjustment (versus 0.8°F calculated temperature gradient) to account for the difference between the average operator body temperature and the operator outside surface temperature. The Biot number applicable to the operator varies because the value of the forced convection heat transfer coefficient varies with the velocity of the superheated steam, but it is always less than .03. Reference 11 lists a qualification temperature of 300°F for this model Limitorque operator.

4.3 Atmosphere Steam Dump Valves (PORV)

The PORV is described on Paul Monroe Hydraulics, Inc., drawings PD 86620 Revision C, PD 86297 Revision E, PD 86642 Revision E and PD 86905 Revision D. The parts list for the PORV is given in PA 86285 Revision E. While the PORV actuator is a complicated hydraulic/pneumatic assembly of smaller valves, pumps, piping, fittings, etc., the entire PORV is enclosed in a cubic-shaped shroud made of Hetron 197P Polyester Resin. The shroud consists of a series of 1/2 inch thick plates with the largest plate having a surface area of 6.3 square feet and a weight of 19.7 lbs. Since this shroud (along with the stainless steel base) totally enclose the PORV actuator, it is the shroud which will heat up first as a direct result of the superheated steam. While the shroud plates do not form a hermetic seal around the PORV actuator internals and will allow steam to penetrate inside the shroud, the velocity of this superheated steam which penetrates the shroud will be so small that forced convection heat transfer will be minimal. Thus the worst case temperature rise for the PORV actuator can be determined by analyzing the total heatup of the shroud plates themselves. The worst PORV location is Node 2 of the Control Building.

4.3.1 The PORV shroud has a variable Biot number because the value of the forced convection heat transfer coefficient varies with the velocity of the superheated steam. The maximum value of the shroud Biot number is 2.3 indicating that a significant temperature distribution across the shroud half-inch thickness exists. This is to be expected, since the shroud is made of a thermal insulating (relatively low thermal conductivity = .14) material. In terms of the function of the shroud (to protect the main valve assembly from the ambient environment), the temperature of the inside surface is most relevant since the valve assembly will not heat up to a higher temperature than the shroud inside surface temperature. Calculating the average shroud temperature by means of Equations 7 and 11 results in a temperature that is conservative with respect to the inside surface temperature. A more detailed calculation of the inside and outside surface temperatures of the shroud, taking into consideration the internal heat flow resistance of the material as a flat plate, results in maximum temperatures of 256°F and 290°F for the inside and outside surfaces respectively. Table 1 lists the inside surface temperature since this is the surface temperature relevant to the function of the shroud as a passive shield for the main valve assembly. Reference 12 lists a qualification temperature of 350°F for the PORV actuator assembly.

4.3.2 Even though the PORV actuator is totally enclosed in the shroud as described above, the maximum temperature of the 4-way Keane solenoid valve located within the shroud was determined. The Keane solenoid valve was chosen since it has the smallest mass of those assemblies critical to the operation of the PORV actuator. O-rings and gaskets which are also critical to the operation of the PORV actuator, while smaller themselves in mass than the Keane solenoid valve, are enclosed in surrounding masses, which as an assembly, are heavier than the Keane solenoid valve. The Keane solenoid valve was conservatively analyzed as though the shroud did not exist under conditions of direct exposure to superheated steam. Neglecting the first two phases of valve heatup and assuming that forced convection begins at start of the transient with the valve already at saturation temperature, application of Equations 7 and 10 result in a valve maximum temperature of 294°F. This maximum temperature includes a 1°F adjustment (versus 0.3°F calculated temperature gradient) to account for the difference between the average switch body temperature and the valve outside surface temperature. The Biot number applicable to the valve varies because the value of the forced convection heat transfer coefficient varies with the velocity of the superheated steam, but it is always less than .004. Reference 12 lists a qualification temperature of 350°F for the PORV actuator assembly.

4.4 Main Steam Isolation Valve (MSIV)

The MSIV is described on Rockwell International Drawing PD-155159 Revision E. The MSIV actuator assembly is a gas hydraulic design. The actuator has four 3-way Keane solenoid valves and four NAMCO Model EA-180 series limit switches which are critical to the safety function of the MSIV. Other degradable, soft parts, e.g., O-rings and gaskets while smaller in mass than the solenoid valves and limit switches and critical to the safety function of the MSIV, are enclosed in much larger mass assemblies than the solenoid valves and limit switches. Thus the O-rings and gaskets will thus not heat up to as high a temperature as the solenoid valves and limit switches. Other critical subassemblies, e.g., the hemisphere, are much larger in mass than the solenoid valves and limit switches and are attached to the massive actuator structure so as to become, from a thermal standpoint, part of that superstructure. Thus these parts also will not heat up to as high a temperature as the solenoid valves and limit switches. The analysis thus considered the Keane solenoid valves and the NAMCO limit switches as the most conservative cases. The worst MSIV location is Node 4 of the Control Building.

4.4.1 The analysis of the NAMCO Model EA-180 series limit switches has been discussed in Section 4.1.1. Since the NAMCO switches for the MSIV are also in Node 4, the maximum temperature reached by these switches is 314°F. Reference 8 lists a qualification temperature of 340°F for this model limit switches.

4.4.2 The Keane 3-way model solenoid valve weighs 6 lbs, has a steel body and is a combination of a cubic and cylindrical shape with a total surface area of .45 square feet and a maximum length of 0.5 ft. Since the $[Ac/L^{1/4}]$ ratio and the total surface area of the Keane MSIV solenoid are less than these same values for the NP 8316 solenoid valve, the methodology of Sections 3.2.1 and 3.2.2 can be utilized and result in a time for the Keane valve to reach saturation temperature of 15 seconds and the time at saturation temperature of 76 seconds. Examining Cases V01, V02 and V11 for the forced convection heat transfer region and utilizing the methodology described in Section 3.2.3, a maximum valve temperature of 309°F is determined. Neglecting the first two phases of valve heatup and considering forced convection to begin at start of the transient with the valve already at saturation temperature, application of Equations 7 and 10 result in a valve maximum temperature of 314°F. This maximum temperature include a 1°F adjustment (versus .5°F calculated temperature gradient) to account for the difference between the average valve body temperature and the valve outside surface temperature. The Biot number applicable to the valve varies because the value of the forced convection heat transfer coefficient varies with the velocity of the superheated steam but is always less than .008. Reference 13 lists a qualification temperature of 355°F for the Keane solenoid valves on the MSIV.

4.5 Solenoid Valves Associated With Feedwater Control Valve (FWCV) and Feedwater [redacted] Bypass Isolation Valve (FWCBIV)

The FWCV and FWCBIV solenoid valves are ASCO Model NP 8321 series solenoid valves. The solenoid valve weights 2.5 lbs, has a brass body and is a complex shape with a total surface area of 0.35 square feet. Since the shape of the valve is complex, the valve was analysed for all applicable transients as a sphere and cylinder and the worst case result (sphere) was used to compare to the existing qualification. Using the methodology described in Section 3.2.3 and assuming only forced convection with the valve at saturation temperature at the start of the transient, the valve surface maximum temperature is 326°F. This temperature includes a 1°F adjustment (versus 0.2°F calculated temperature gradient) to account for the difference between the average valve temperature calculated by Equation 7 and the valve outside surface temperature. The Biot number applicable to the valve varies because the valve of the forced convection heat transfer coefficient varies with the velocity of the superheat, but it is always less than .004. Reference 14 lists a qualification temperature of 346°F for this model solenoid valve. The worst location for these valves is Node 3 of the Control Building.

5.0 RESULTS

Table 1 presents the results of the thermal analysis discussed herein for the critical components on all five valve types for Cases V01, V02 and V11 at VEGP. The maximum calculated temperature for all three cases for the critical parts analyzed for all five valve types is less than the established qualification temperature. The detailed calculations for all the equipment and cases discussed herein are on file at Westinghouse and are available for audit.

6.0 MARGIN

Significant margin has been incorporated throughout this analysis as described below.

6.1 A margin of more than 15°F exists in all cases between the maximum critical component temperature determined in this analysis and the previously established qualification test temperature.

6.2 The heat sink effect of the masses of material attached to the critical components analyzed herein was neglected. Since the calculated component temperature is inversely proportional to the mass of the component, inclusion of the larger masses in the analysis would reduce the component temperature.

6.3 The maximum component temperatures in Table 1 listed under the ** column neglect totally the time a component takes to reach saturation temperature and the time for the component to "dry off". While this conservatism varies in magnitude, the results of modelling the Franklin data for appropriate components indicates that 1-5°F additional margin is obtained by neglecting these affects on applicable components.

6.4 The geometric shapes used to calculate the maximum component temperature are the worst shapes applicable to that component in terms of forced convection heat transfer.

7.0 CONCLUSION

Based on the thermal analysis discussed herein, the maximum temperatures of all the equipment discussed herein exposed to MSLB's in the Control and Auxiliary Building will be less than the established qualification test temperatures for that equipment as referenced herein.

8.0 REFERENCES

1. Frank Kreith, Principals of Heat Transfer, Third Edition, p.14.

2. P. J. Biondo, "ASCO Solencid Valve Qualification to a Derated Westinghouse Generic LOCA/MSLB Profile," WCAP 8687, Supplement 2 - H-02A/H05A, Addendum 1.

3. NUREG/CR-3424, "Test Program and Failure Analysis of Class 1E Solenoid Valves."

4. Incorpera and Dewitt, Fundamentals of Heat Transfer, 1981, p. 183.

5. Frank Kreith, Principals of Heat Transfer, Third Edition, pp. 468-473.

6. Incorpera and Dewitt, Fundamentals of Heat Transfer, 1981, p. 345.

7. Frank Kreith, Principals of Heat Transfer, Third Edition, p. 140.

8. NAMCO Qualification Test Report, No. QTR 105, Revision 1, August 28, 1980.

9. ASCO Test Report No. AQR-67368, Revision 1, August 19, 1983.

10. Limitorque Test Report No. B-0027, Revision A, October 18, 1978.

11. Limitorque Test Report No. 600456, December 9, 1975.

12. Paul Monroe Hydraulics Generic Modulating Operator Report, PA 86468, February 13, 1981.

13. Rockwell International Report No. 2938-01, April 1980, "Generic Qualification and Seismic Qualification Program for the Rockwell Type A Gas Hydraulic Valve Actuators."

14. Isomedix Test Report No. AQS21678/TR, Revision A, July 1979.

Table 1
THERMAL ANALYSIS RESULTS

Component	Calculated* Tmax (°F)	Calculated** Tmax (°F)	Qualification*** Test Tmax (°F)
1. MSIV Bypass Valve			
a. NAMCO EA180 switches	310	314	340
b. ASCO NP8320 valve	-	-	420****
2. Aux. FW Pump Discharge Valve			
a. Limitorque SB-00 Operator	-	255	300
3. Atmos Steam Dump Valve (PORV)			
a. Shroud	-	256	350
b. Keane 4-way solenoid valve	-	294	350
4. Main Steam Isolation Valve (MSIV)			
a. Keane 3-way solenoid valve	309	314	355
b. NAMCO EA-180 switches	310	314	340
5. Feedwater Control and Feedwater [redacted] Bypass Isolation Valves			
a. ASCO NP 8321 valve	-	326	346

The temperature listed in the first two columns represents the worst case of the three cases (V01, V02, V11) analyzed.

* These temperatures reflect, where appropriate, the time to heat up to saturation temperature and the time to "dry off" at saturation temperature.

** These temperatures reflect only forced convection starting at saturation temperature at t = 0

*** These temperatures reflect actual test temperatures obtained during qualification testing.

****This qualification temperature of 420°F exceeds the worst case Vogtle superheat temperature in Node 4. Thus no thermal analysis is necessary.