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SUBJECT: DETERMINATION OF TEMPERATURES REACHED BY EQUIPMENT DURING HYDROGEN BURN IN McGUIRE PLANT

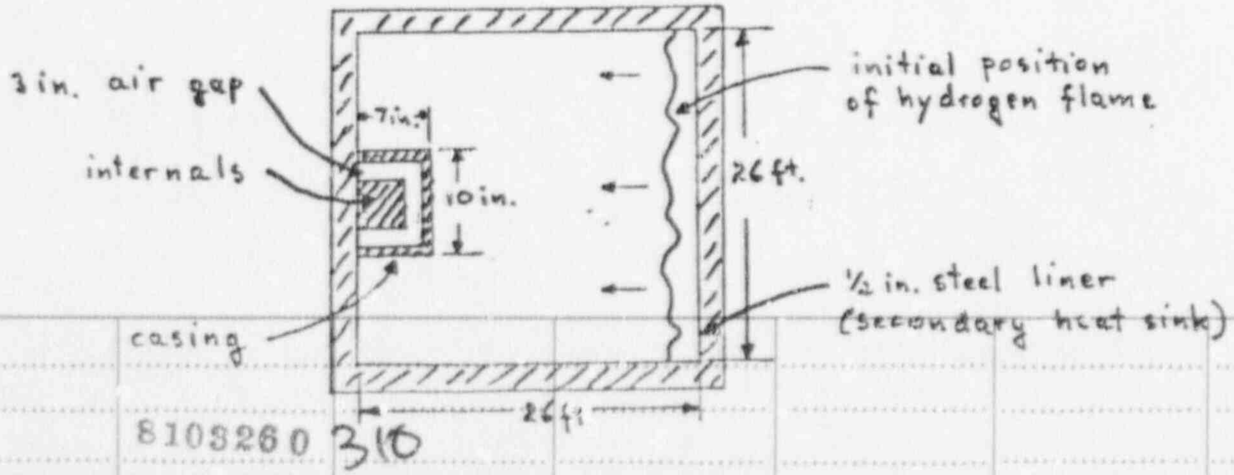
Purpose and Conclusion

This memo describes the methodology, assumptions and results of the analytical study which was performed to determine the temperatures reached by a typical piece of equipment (instrument transmitter) during hydrogen burn in a dead-ended compartment of the McGuire plant. The results of this analysis indicate that the temperature reached by the equipment does not exceed 320°F.

Assumptions

The equipment modelled in the study consisted of a transmitter having a rectangular parallelepipedic casing 10 in. X 10 in. X 7 in. in size, made from ¼ in. thick metal plate and internal electronic equipment represented by a 4 in. X 4 in. X 4 in. cube made of a material having the thermal capacity of steel, but only about one half of its density (it is assumed that there is about 50 percent of voids present). There is an assumed 3 in. gap between the casing and the internals. The transmitter is attached to the center of a vertical wall in a 26 ft. X 26 ft. X 26 ft cubical compartment.

The geometrical arrangement used in modelling is shown in the sketch below:



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The major assumptions made in this analysis are:

1. The compartment is surrounded by a ½ in. thick steel liner which simulates a structural heat sink in the analysis.
2. Initially, the compartment contains air with 10 v/o of hydrogen and the whole system is at 160°F.
3. Hydrogen starts burning at the opposite side of the compartment and the flame propagates towards the wall containing the transmitter. During this process the flame front occupies the whole vertical cross sectional plane of the compartment.
4. The transfer of thermal energy between the casing and the compartments environment occurs in two phases:
   (a) In Phase I heat is transferred by radiation from the traveling flame front and by convection from the gas in front of it.
   (b) In Phase II heat is transferred from the hot gas by both radiation and convection.
5. During both these phases, heat from the hot gas is transferred by radiation and convection to the structural liner.
6. There is neither exchange of heat between the liner and the containment concrete behind the liner nor between the casing or the internals and the liner.
7. An infinite thermal diffusivity of all solid materials is postulated and hence in each individual component uniform temperature is achieved.
8. The exchange of heat between the casing and the internals occurs by radiation and conduction through the 3 in. gap (no convention transfer is assumed).
9. The temperatures of hot gas after a hydrogen burn are based on the output of the CLASIX computer code provided by Duke Power Company (see attached Fig. 1). However, they are readjusted by considering heat loss to the structural heat sinks (secondary heat sink) represented in the model by the ½ in. steel liner.

Description of Analysis

With the assumptions listed in the previous section the following heat transfer mechanisms are postulated:

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1. Heat transfer between compartment's environment and the casing

(a) Phase I

$$\Phi_{T1} = \Phi_f + \Phi_{cgc} \qquad (1)$$

where: Φ_{T1} - total heat flux during Phase I between compartment's environment and the casing

Φ_f - heat flux from the flame by radiation

Φ_{cgc} - heat flux from the cold gas by convection

Note: All heat fluxes are in: Btu/hr ft^2

$$\Phi_f = \sigma \cdot \epsilon_f \cdot \epsilon_c \cdot F \left[(460+\theta_f)^4 - (460+\theta_c)^4 \right] \qquad (2)$$

where: σ - Stefan-Boltzman constant = 0.1713×10^{-8} Btu/hr ft^2 oR

ϵ_f - emissivity of flame = 0.2

ϵ_c - emissivity of casing = 0.8

F - view factor = 0.58

The value of the view factor F is obtained by arithmetically averaging two values of F: one when the flame is still at the opposite wall (F = 0.16) and the other when the flame reaches the equipment (F = 1.0)

θ_f - temperature of flame = 2053°F, based on adialsatic temperature of burning mixture of air and 10 v/o hydrogen.

θ_c - temperature of casing, °F

$$\Phi_{cgc} = 0.32 \left(\theta_{gc} - \theta_c \right)^{1.25} \qquad (3)$$

This ia an expression for natural convection heat transfer in laminar regime.

where: θ_{gc} - temperature of cold gas, defined by equation 19, °F

(b) Phase II

$$\Phi_{T2} = \Phi_{rgh} + \Phi_{cgh} \qquad (4)$$

where: Φ_{T2} - total heat flux during Phase II between compartment's hot gases and the casing

Φ_{rgh} - heat flux from the hot gas by radiation to the casing

Φ_{cgh} - heat flux from hot gas by convection to the casing

The heat fluxes from the hot gas to the casing are based on the average gas temperature obtained by averaging the highest and the lowest gas temperatures reached between two successive burns. The averaging is calculated differently for radiation and convection (equations 6 and 8).

$$\Phi_{rgh} = \sigma \cdot \epsilon_g \cdot \epsilon_c \cdot F \left[(460 + \theta_{ra})^4 - (460 + \theta_c)^4 \right] \qquad (5)$$

where: ϵ_g - emissivity of gas = 0.6

F - view factor = 1.0

$$(460 + \theta_{ra})^4 = \tfrac{1}{2} \left[(460 + \theta_{gh})^4 + (460 + \theta_{gc})^4 \right] \qquad (6)$$

θ_{gh} - temperature of hot gas, defined by equation 18, °F

$$\Phi_{cgh} = 0.32 \left(\theta_{ca} - \theta_c \right)^{1.25} \qquad (7)$$

where: $$\theta_{ca} = \tfrac{1}{2} \left(\theta_{gc} + \theta_{gh} \right) \qquad (8)$$

2. Heat transfer between the casing and the internals

$$\Phi'_T = \Phi_{re} + \Phi_{ce} \qquad (9)$$

where: Φ'_T - total heat flux between the casing and the internals

Φ_{re} - heat flux by radiation

Φ_{ce} - heat flux by conduction through 3 in. air gap.

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$$\Phi_{rc} = \sigma \cdot \epsilon_c \cdot \epsilon_e \cdot F \left[(460+\theta_c)^4 - (460+\theta_e)^4 \right] \qquad (10)$$

where: ϵ_e - emissivity of internals = 0.8

F - view factor = 1.0

θ_e - temperature of internals, °F

$$\Phi_{ce} = \frac{K}{0.25} \left(\theta_c - \theta_e \right) \qquad (11)$$

where: K - thermal conductivity of air = 0.25 Btu/hr ft °F.

3. <u>Heat transfer between compartment's hot gases and the liner (secondary heat sink)</u>

$$\Phi''_T = \Phi'_{rgh} + \Phi'_{cgh} \qquad (12)$$

where: Φ''_T - total heat flux between compartment's hot gases and the liner (secondary heat sink)

$$\Phi'_{rgh} = \sigma \cdot \epsilon_g \cdot \epsilon_l \cdot F \left[(460+\theta_{ra})^4 - (460+\theta_l)^4 \right] \qquad (13)$$

where: ϵ_l - emissivity of liner = 0.8

θ_{ra} - average hot gas temperature, defined by equation 6, °F

θ_l - temperature of liner, °F

F - view factor = 1.0

$$\Phi'_{cgh} = 0.13 \left(\theta_{ca} - \theta_l \right)^{1.333} \qquad (14)$$

This is an expression for natural convention heat transfer in turbulent regime.

where θ_{ca} - average hot gas temperature, defined by equation 8, °F

4. Adjustment of gas temperatures given by the CLASIX Code

The adjustment consists of including structural heat sink (the liner) in addition to the heat sinks considered originally in the CLASIX Code (ventilation and ice condenser) and calculating the fraction of heat from the gas in the compartment which would go to this sink.

The fraction of heat removed from the gas in the compartment is given by the following expression:

$$N = \frac{\frac{1}{2}(\theta_{max} + \theta_{min}) - (160 - \Delta\theta)}{\frac{1}{2}(\theta_{max} + \theta_{min}) - 160} \qquad (15)$$

where: N - fraction of the sensible heat of the gas in the compartment, as determined by CLASIX Code, which is transferred to the structural heat sinks

θ_{max}, θ_{min} - maximum and minimum temperatures from CLASIX Code, defined in Fig. 1

$$\Delta\theta = \int_0^t \frac{\Phi''_T}{\lambda_a \cdot \rho_a \cdot C_a}\, dt \qquad (16)$$

where: λ_a - volume to area ratio (for heat transfer) for the compartment = 4.3 ft.

ρ_a - density of gas = 0.0534 lb/ft^3

C_a - specific heat of gas = 0.25 Btu/lb ^{o}F

t - time between burns 0.061 hr. (220 sec)

$$(\theta_l)_n = 160 + \sum_1^n \left[\int_0^t \frac{\Phi''_T}{\lambda_l \cdot \rho_l \cdot c_l}\, dt \right] \qquad (17)$$

where: $(\theta_l)_n$ - temperature of liner after nth burn, ^{o}F (the maximum value of n is 10)

λ_l - volume to area ratio (for heat transfer) for the liner = 0.0417 ft.

ρ_L - density of liner = 439 lb/ft^3 (steel)

C_L - specific heat of liner =0.4 Btu/lb ^{0}F (steel)

$$\theta_{gh} = \theta_{max} \cdot (1-N) + 160\,N \qquad (18)$$

$$\theta_{gc} = \theta_{min} \cdot (1-N) + 160\,N \qquad (19)$$

The value of N and (θ_L)n were determined by solving equations: 6, 8, 12, 13, 14, 15 and 16 using iteration techniques. The results are shown in Fig. 2. They indicate that more than 75% of the heat, which normally would go to the gas in the compartment and raise its temperature, is transferred to the secondary heat sink. In calculating the temperatures of the casing and the equipment the value of N = 0.75 is therefore used.

5. Determination of temperatures reached by the casing

These temperatures were calculated by means of the following equations:

$$(\theta_c)_n = 160 + \sum_{1}^{n} \left[\frac{1}{\lambda_c \cdot \rho_c \cdot C_c} \left(\int_0^{t_1} \Phi_{T1}\, dt + \int_{t_1}^{t} \Phi_{T2}\, dt \right) \right] \qquad (20)$$

where: $(\theta_c)_n$ - temperature of casing after nth burn, ^{0}F

λ_c - volume to area ratio (for heat transfer) for the casing = 0.208 ft.

ρ_c - density of casing = 439 lb/ft^3 (steel)

C_c - specific heat of casing = 0.14 Btu/lb ^{0}F (steel)

t_1 - time needed for the flame to cross the compartment, hr.

$$t_1 = \frac{0.0072}{V} \qquad (21)$$

V - flame velocity = 1.7 ft/sec

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The values of (θ_c)n were determined for ten consecutive burns by solving equations: 2, 3, 4, 5, 6, 7, 8, 20 and 21 using iteration techniques. The results are shown in Fig. 3.

6. Determination of temperatures reached by the internals

These temperatures were calculated using the expression shown below:

$$(\theta_e)_n = 160 + \sum_{1}^{n} \left[\int_0^t \frac{\Phi'_T}{\lambda_e \cdot \rho_e \cdot c_e} \, dt \right] \qquad (22)$$

where: (θ_e) - temperature of internals after n^{th} burn, °F

λ_e - volume to area ratio (for heat transfer) for the internals = 0.0667 ft.

ρ_e - density of internals = 200 lb/ft.

c_e - specific heat of internals = 0.14 Btu/lb °F.

The values of (θ_e)n were determined for 10 consecutive burns by solving equations: 9, 10, 11 and 22 by iteration techniques. The results are shown in Fig. 3.

Results

The temperatures of the casing and the simulated electronic internals were determined for all 10 burns postulated by the CLASIX Code to occur in a dead-ended compartment of the containment in the McGuire plant. The maximum temperature reached by the transmitter's casing after the 10th burn is 320°F. The corresponding temperature for the sjmulated internals is: 204°F. (see attached Fig. 3).

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Fig. 1

~~FIGURE 4~~

DEAD-ENDED COMPARTMENT TEMPERATURE
CLASIX Output

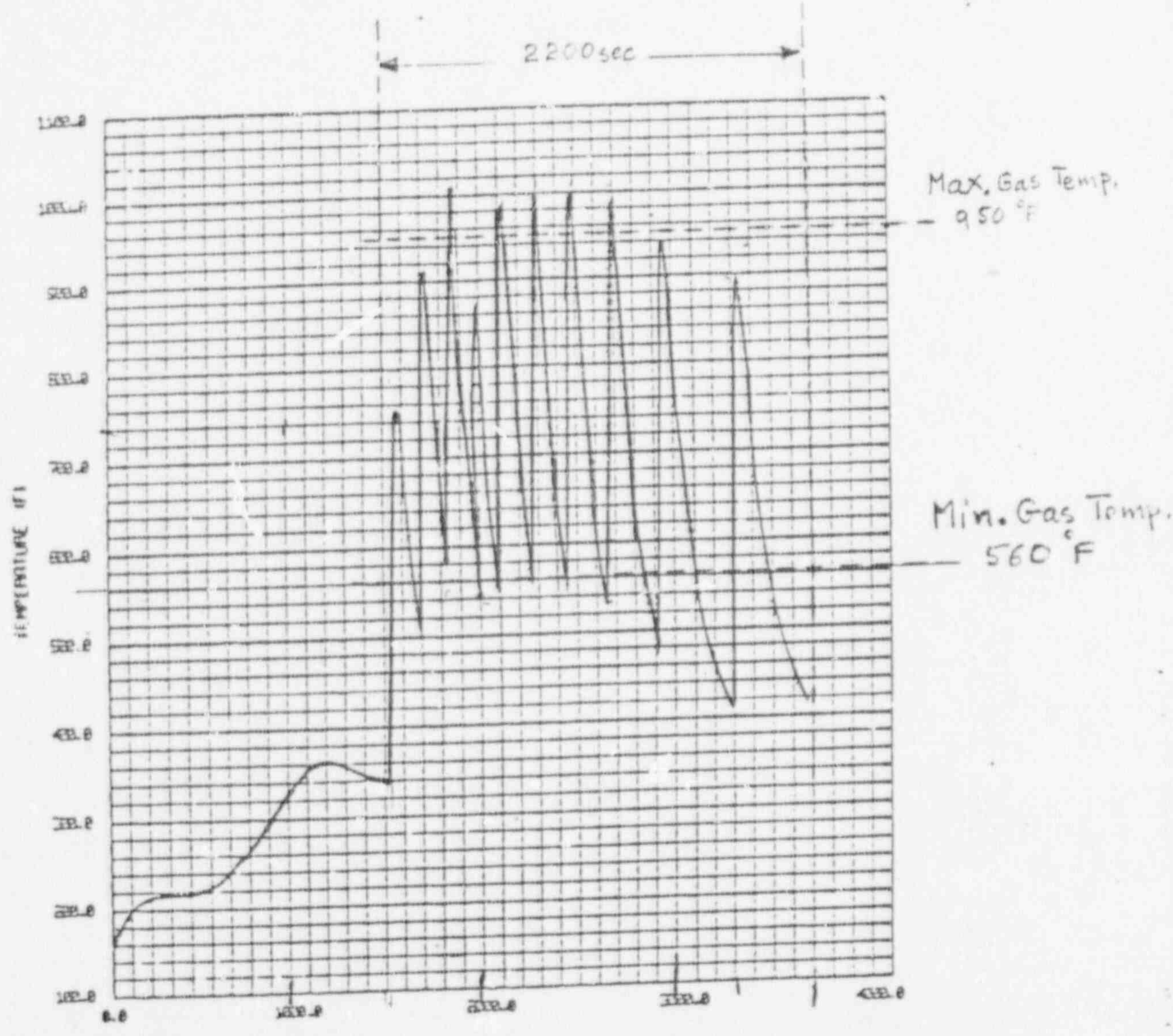

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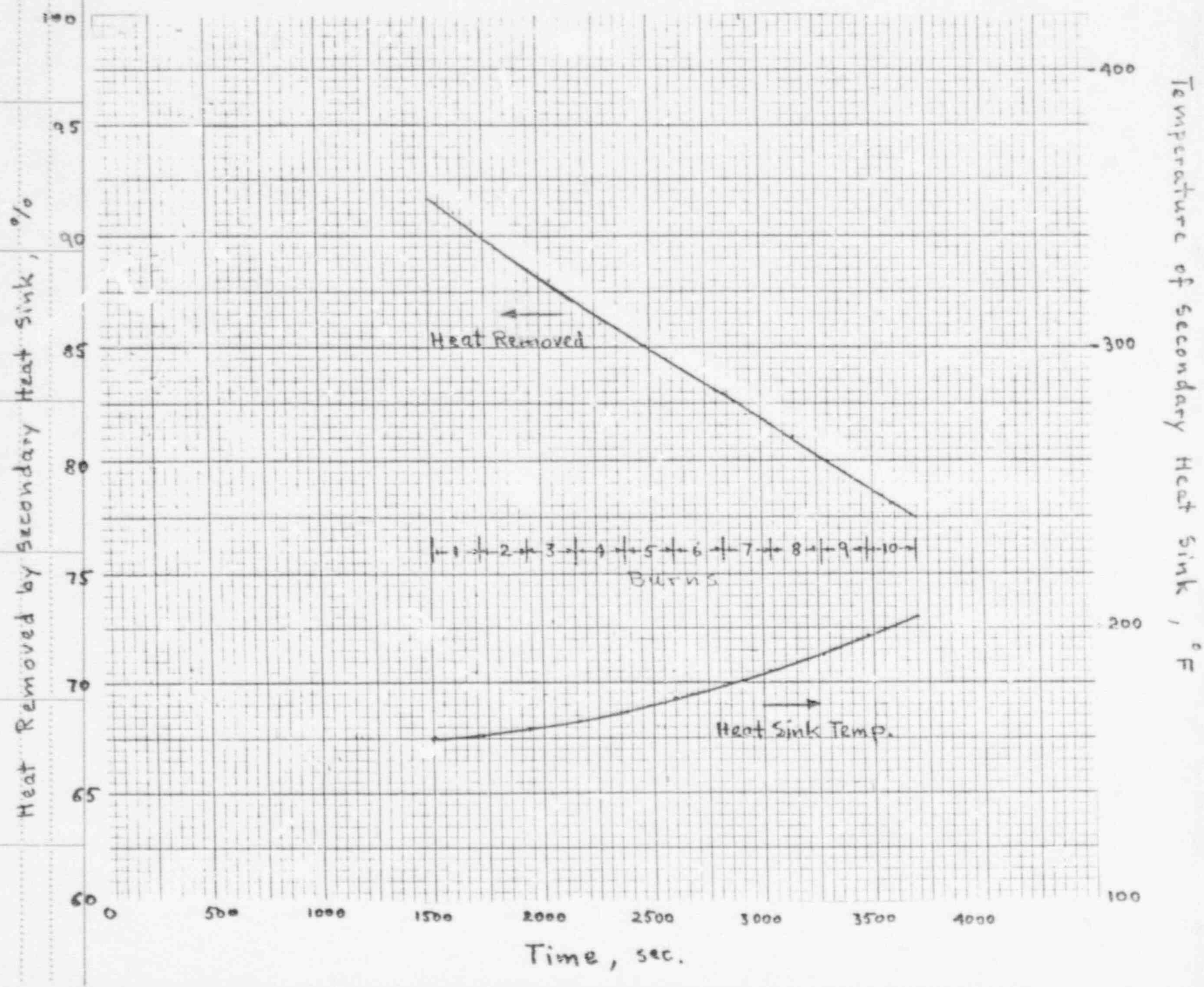
Fig. 2 Heat Removed from Hot Gas by Secondary [illegible] Sink
Dead-Ended Compartment



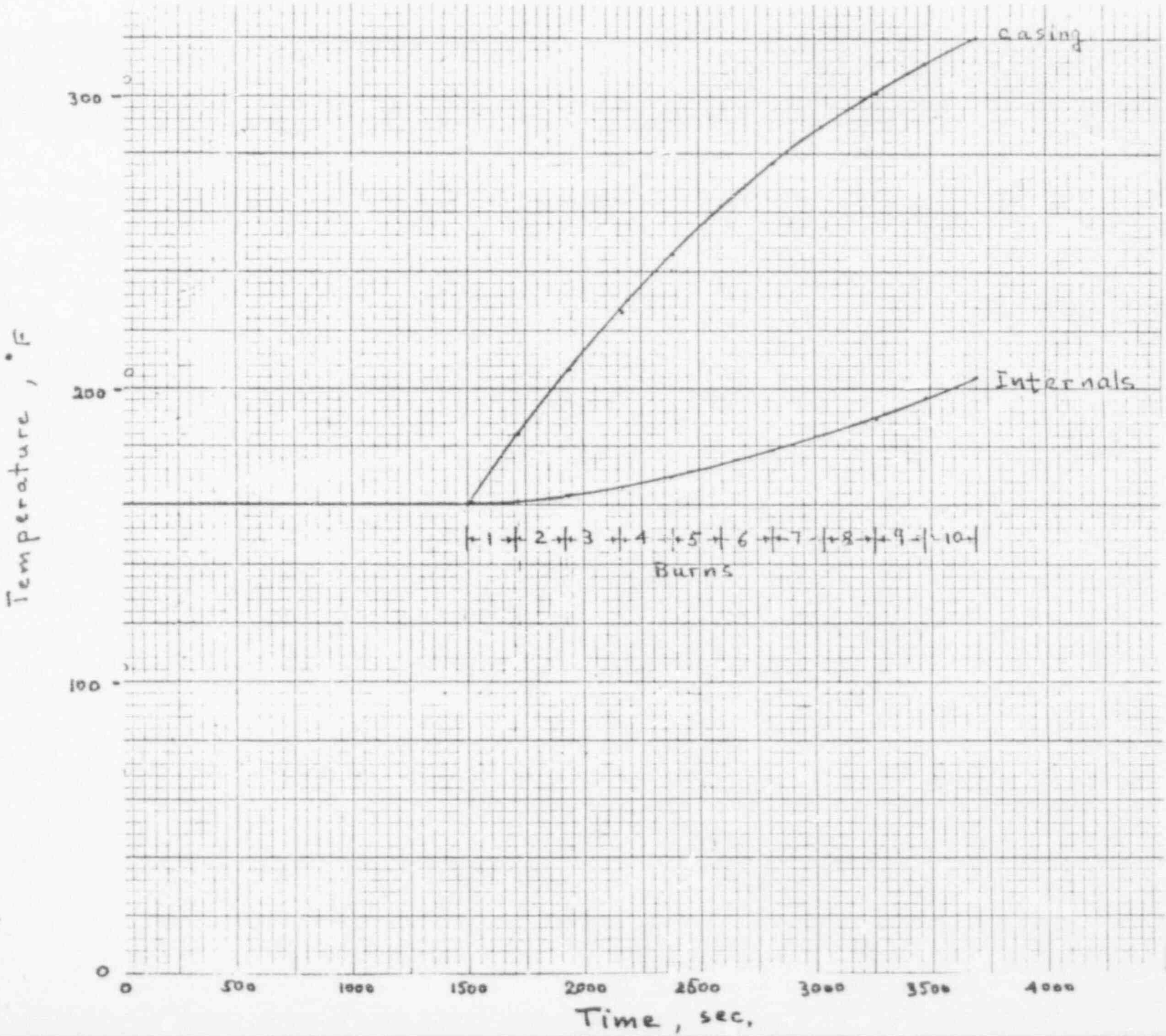


Fig. 3 Temperature of Casing and Internals
Dead-Ended Compartment