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RESPONSE OF LIMITORQUE IN-CONTAINMENT
MOTORS TO THE BYRON/BRAIDWOOD
HELB/LOCA ENVIRONMENT

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I. PURPOSE

This report provides an evaluation, utilizing available test data, test results, and engineering analysis of the response of Limitorque/Reliance Class RH in-containment electric motors on site at Bryon/Braidwood to the specified HELB/LOCA environment at Byron/Braidwood and concludes that the motors will operate during and after the specified HELB/LOCA.

II. BACKGROUND

A. Previous Limitorque Testing

In 1975 Limitorque performed a type test sequence on an SMB-0-40 motor operator. The motor stator was thermally aged and the entire motor operator was mechanically aged, gamma radiation aged, vibration/seismic tested and DBE tested. The DBE profile involved two temperature/pressure transients from 120°F to 300°F (saturation conditions) in ten seconds, with the 300°F peak being held for approximately 24 minutes. After the second transient peak, the temperature was reduced to 250°F in one hour. The 250°F temperature was maintained for approximately three days with a cool down to approximately 192°F maintained for 26 days. The motor operator was operated during and after the test sequence and successfully completed all this testing. The entire second transient profile is shown in Figure 1. The details of this entire test sequence are discussed in Reference 1.

In 1978 Limitorque performed a "Super Heat" test on an SMB-00-15 actuator in order to determine the effect of short duration, high temperature transients on the motor operator. This test involved exposing the motor operator to three temperature/pressure transients of 385°F for 2-4.5 minutes. After the third transient peak the temperature was reduced to 365°F for 12 minutes and then 327°F for approximately 2 1/2 hours. The internal temperature of the motor was monitored during the entire test. The test results in terms of the motor temperature are shown in Figure 2. Limitorque concluded from the test results that short duration high temperature transients will not affect the results of the Reference 1 test since the motor and motor operator will not reach a temperature higher than the saturation temperature associated with the environmental pressure during the DBE profile. This is true as long as the "super heat" peak temperature is of short duration, i.e. on the order of several minutes. The details of this testing are discussed in Reference 2.

B. Westinghouse Generic Testing

In 1980 Westinghouse performed a type test sequence on an SMB-00-15 motor operator. This test sequence was similar to the Limitorque test sequence of Reference 1 except that in the Westinghouse test the entire motor/motor operator were thermally aged and the DBE profile for the Westinghouse test was more severe. The Westinghouse generic profile is depicted in Figure 1. Of particular importance is the higher peak temperature, the longer and higher saturation temperature plateau and slower cooldown in the Westinghouse generic DBE profile of Figure 1 compared to the Limitorque PWR test Figure 1 DBE profile.

Three motor operators all failed to complete the Westinghouse DBE profile. Subsequent testing and analysis by Westinghouse showed that the electric motor had failed in each case as a result of the caustic spray at high motor temperatures (340°F) reacting with the stator insulation over a period ot time to cause shorts in the stator. The operator itself (minus the motor) had not experienced any failure and in fact successfully completed the testing after a new motor was installed.

Westinghouse determined, utilizing actual supplemental test data, that the motor reached a temperature of approximately 340°F (corresponding to the saturation temperature at the specified DBE pressure) after the second peak transient and stayed atapproximately this temperature for a period of hours while the Westinghouse DBE profile gradually cooled from 340°F after 20 minutes to 250°F after 24 hours. During the Limitorque test of reference 1 the motor could only have reached a temperature of 300°F, since this was the peak DBE temperature, and based on the much faster Limitorque test cooldown, the motor would have cooled to a 250°F range in the 1-3 hour range. The higher motor temperature attained during the Westinghouse test (340°F) compared to the Limitorque Reference 1 test (300°F) and the longer span time at this temperature (several hours at least for the Westinghouse test versus about 1 hour for the Limitorque Reference 1 test) accelerated and increased the deleterious effect of the caustic spray solution on the motor stator insulation causing stator failures in the Westinghouse test that were not experienced during the Limitorque Reference 1 test.

C. Conclusions From Previous Tests

Based on the previous testing by both Westinghouse and Limitorque, several conclusions can be reached regarding the ability of the Limitorque motor operator to successfully complete a typical HELB profile for PWR type plants. These are identified below:

1. The electric motor is the most critical part of the operator in this environment. This is based on the facts that the operator itself passed both the Westinghouse generic test and the Limitorque Reference 1 test.

2. The failure mechanism of the motor in these environments is the reaction of the caustic spray with the stator insulation at high temperatures over a period of time causing shorts in the stator. The higher the motor temperature, the faster and more potent is the reaction mechanism.

3. For HELB/LOCA profile,where a fairly short duration high temperature spike is followed by a longer cool down at progressively lower temperatures, the motor rapidly heats up to the saturation temperature corresponding to the HELB pressure. The motor stays at the temperature as the DBE environmental temperature is reduced and generally follows, albeit lagging somewhat, the cool down of the environment.

4. The motor can successfully withstand temperatures up to 300°F for twenty minutes or more without shorting out the stator windings. This is based on the Limitorque Reference 1 test where 300°F was maintained for 24 minutes and the motor successfully completed the test.

D. The Byron/Braidwood HELB/LOCA Environment

Figure 1 shows the Byron/Braidwood HELB/LOCA Envelope including 15°F margin as compared to both the Westinghouse Generic Envelope and the Limitorque PWR test of Reference 1. The Limitorque PWR Envelope encompasses the Byron/Braidwood Envelope everywhere except in the initial three minutes where the Byron/Braidwood temperature/pressure transient reaches 335°F and 55 psia for three minutes before cooling to 285°F in five minutes.

In order to demonstrate that the Limitorque inside containment motor operator will successfully pass the Byron/Braidwood Envelope, it is necessary to show that the electric motor will not reach a temperature in excess of 300°F during the exposure to the entire Byron/Braidwood Envelope. From the visual inspection of the Envelopes of Figure 1, it can be seen that the only time when the Byron/Braidwood Envelope exceeds 300°F (or for that matter the Limitorque PWR Envelope of Reference 1) is during the first three minutes of the Envelope where the temperature reaches 335°F and presssure is 55 psia.

This evaluation will show, using actual test data from the three tests discussed in part II of this report and modeling the heat transfer coefficient for heat-up of the motor, that the short duration (3 minutes) peak temperature (335°F) does not cause the motor to exceed 300°F (15°F higher than the saturation temperature of 285°F at 55 psia in the Byron/Braidwood Envelope). Thus the Limitorque PWR test of Reference 1, coupled with this analysis, verifies that the motor will successfully operate during and after the Byron/Braidwood Envelope.

III. THE HEAT TRANSFER MODEL

If the geometry of the sample is simple and the Biot number (ratio of the surface convective heat transfer coefficient to the materials thermal resistance times the thickness of the material) is low, i.e. $Bi = hc(L)/k < 0.1$, a reasonably simple heat transfer model can be developed for the motor in this environment. Fortunately the motor is cylindrical, a simple geometry, and $hc(L)/k$ (the Biot number) is less than 0.1. The fact that the Biot number is less than 0.1 means that the motor will not develop a significant temperature distribution and neglecting internal resistance of the motor's material will not effect the model's accuracy by more than 5%.[1]

The motor temperature is an important factor in determining the motor response to the environment because the temperature itself affects the surface heat transfer coefficient dramatically. When the temperature of the motor is below saturation temperature, the superheated steam condences on the motor. Large amounts of energy are released in the phase change, and the resulting condensate conducts this thermal energy rapidly to the motor. During this time the motor temperature rises rapidly until the motor reaches saturation temperature. In Frank Kreith's third edition of "Principals of Heat Transfer" there is a table which gives ranges of various types of average convective heat transfer coefficients. ($\overline{hc}$). For steam condensing, the table gives this range 1,000 - 20,000 BTU/hr ft^2°F. For steam or air in forced convection, the range is 5 to 50 BTU/hr ft^2°F. Thus the heat transferred from the steam to the motor will be large, accompanied by rapid temperature rise in the motor, until the temperature of the motor reaches saturation temperature. At this time the heat transfer coefficient will decrease greatly and the heat transferred to the motor will be by forced convection with a subsequent slow rise in motor temperature.

In order to determine the actual heat transfer coefficient of the motor under these conditions, the Limitorque Superheat Test of Reference 2 was chosen as a source of data for three reasons. First, of the test data available, it is the closest to the Byron/Braidwood D.B.E. The Limitorque Superheat Test was conducted at a saturation temp. of 310°F while the Byron and Braidwood conditions call for a saturation temperature of 285°F. Second, it contained a third Superheat transient conducted when the operator was at saturation temperatures. This third transient produced sufficient data to conservatively correlate the model. Third, the motor in the test is identical to the smallest motor in containment at the Byron/Braidwood plants, even though the superheat test motor delivers 5 ft lbs more torque than the smallest motor at Byron/Braidwood.

The smallest motor was modeled because the surface area of the motor is roughly a function of the square of its radius, while the mass is roughly a function of the cube. Thus a larger motor will have less surface area to convect thermal energy and more metal to heat; a larger motor will rise in temperature more slowly.

[1]Frank Kreith, "Principles of Heat Transfer," 3rd Edition, Harper & Row New York, 1973.

The model was developed for the super heat region, when the motor is at saturation temperature or above (TM ≥ TSAT), since the only time the Byron/Braidwood conditions excede the Limitorque P.W.R. qualification test is during the first three minutes of the test when the Byron/Braidwood curve goes above 300°F.

The first step required to develop the model was to define the test chamber conditions during the Limitorque superheat test, since exact data on mass flow rate of steam is not available from Limitorque. The environmental state properties were taken straight from test data. The mass flow rate of steam which is required to determine the velocity of the steam was calculated based on conservative assumptions. It was assumed that when the motor was well below saturation temperatures, during the initial temperature rise of the first transient, all the steam that struck the motor condensed and as a result, the following equation describes the heat or energy transferred from the steam to the motor.

$$C(Mm)\ (\Delta T) = \Delta H\ m_s \Delta t$$

Where: C = The heat capacity of steel (the motor material)

Mm = Mass of motor

ΔT = 200 - 120 (chosen)

ΔH = Change in internal energy of the steam (superheat condition to saturated liquid)

ms = Mass flow rate of steam impinging on the motor

Δt = Change in time (0.5 min)

The resulting mass flow rate was multiplied by the ratio of the cross sectional area of the chamber over the crossectional area of the motor to determine the mass flow rate into the chamber. This calculated chamber flow rate was then verified by matching the mass flow rate to typical values needed for this size chamber for these temperatures and motor/operator sizes in similar tests done by Westinghouse and Limitorque.

The average heat transfer coefficient $\overline{hc}$ was then calculated by using the following formula which is based on emperical data gathered by S. Whitaker, "Forced Convection Heat Transfer Correlations for Flow in Pipes, Past Flat Plates, Single Cylinders, Single Spheres, and for Flow in Packed Beds and Tube Bundles," AI.Ch.E. Journal, Vol. 18 (1972), pp. 361-371.

$$\frac{\overline{hc}\ D}{k} = (0.4\ Re_D^{0.5} + 0.06\ Re_D^{0.67})\ Pr^{0.4}(\mu_s/\mu_o)^{0.25}$$

Where Re = Reynolds number; Pr = Prantl number

D = Diameter of cylinder (motor)

k = Thermal conductivity of steam $\left(\frac{BTU}{hr\ ft\ °F}\right)$

μ_o = Absolute viscosity of steam in chamber

All variables are determined from free stream conditions, except μ_o which is the absolute viscosity at the average surface temperature at the motor. This $\overline{hc}$ was then used to calculate the Biot number. This was found to be 0.004, which i

less than 0.10, thus verifying the assumption of low internal heat transfer resistance of the motor in relation to the heat being transferred to the motor.

The second transient in the Limitorque super heat test was then modeled by using the following equation:

$$(t)\ \frac{\overline{hc}(Am)}{Cm(Mm)} = Ln\ \left(\frac{Tm2 - Too}{Tm1 - Too}\right)$$

Where: Am = The exposed surface area of the motor
Tm2 = The temperature to be obtained by the motor
Tm1 = The original temperature of the motor
Too = Free stream temp of the steam

Mm = Mass of the motor
t = Time at super heat temp.
Cm = Specific heat of the motor

The model was verified by allowing the time "t" to be 3 minutes (The length of the third transient in the Limitorque Super Heat Test) and Tm1 was assigned Tsat or the saturation temperature (312°F). The model then predicted the temperature rise of 0.328°F per minute or .974°F at the end of the transient.

The model results were next compared to actual test data from the Limitorque Super Heat test. The data indicates an approximately 1°F change in temperature during the actual three minute transient. There is a good correlation between the predicted results of the model and the actual test results.

This same technique was next used to evaluate the motor's response to the Byron/Braidwood environment. The evaluation involved first reformulating $\overline{hc}$ for the Byron/Braidwood super heat conditions. Then the transient equation was solved to determine the length of time that the motor would be required to be in super heat conditions to reach a temperature of 300°F, assuming the motor at the initiation of the superheat time span was at 285°F (saturation temperature). This required time was 1 hr. 51 minutes. Thus the motor in the Byron/Braidwood super heat transient (335°F for 3 minutes) would not reach 300°F. Utilizing the $\overline{hc}$ calculated by the model and the Byron/Braidwood transient conditions of 335°F and three minutes, the calculated temperature rise of the motor 0.48°F. Thus the motor temperature would be 285.48°F and the motor temperature would always be below that of the Limitorque PWR test of Reference 1.

IV. ACTUAL CALCULATIONS

The actual calculations are on file at Westinghouse.

V. CONCLUSIONS

A. Based on actual test data and the analysis described herein, the Limitorque Class RH Inside-containment motor will not rise above 300°F at any time during the Byron/Braidwood HELB/LOCA temperature peak of 335°F in three minutes.

B. Only the 335°F, three minute temperature peak portion of the Byron/Braidwood profile is not enveloped by the Limitorque PWR test profile. The motor during the portions of the Byron/Braidwood profile enveloped by the Limitorque PWR test profile will be at a lower temperature than the motor in the Limitorque PWR test.

C. Based on A and B above, the motor will operate successfully during all phases of and after the Byron/Braidwood HELB/LOCA profile identified herein.

D. Since a fully aged (40 year qualified life) in-containment design Limitorque operator successfully completed the Westinghouse Generic HELB/LOCA test profile identified herein. The Limitorque in-containment operator at Byron/Braidwood will successfully operate during all phases of and after the Byron/Braidwood HELB/LOCA profile.

E. The Limitorque motor utilized in the Limitorque PWR test Reference 1 was not thermally aged as a complete assembly. Rather the motor stator was aged separately by Reliance (manufacturer of the motor) for a 40 year period. This aging was in accordance with standard practice at the time, but is not in complete compliance with the Westinghouse interpretation of in-containment aging requirements in WCAP 8587. In particular the motor bearings were not thermally aged. Westinghouse notes that testing performed on these type design motor bearings by Westinghouse showed that at the maximum temperatures reached by the motor during the Byron/Braidwood HELB/LOCA profile, i.e. 285-290°F, no loss of bearing functions is evident even after extended exposure (up to 4 days at 300°F) to these conditions.

F. Based on C and E above the Limitorque electric motors used on in-containment Class 1E valves are acceptable for interim usage until new design Limitorque motors can be installed. These new design Limitorque motors will have passed the Westinghouse Generic HELB/LOCA profile in the fully aged condition.

VI. MARGINS

A. The Byron/Braidwood HELB/LOCA profile identified herein contains a 15°F margin over the actual calculated values of these environmental conditions. Thus the 335°F peak temperature would be only 320°F and the ΔT driving force during the short duration transient would be 20°F rather than 35°F.

B. The short term, peak temperature transient in the Byron/Braidwood HELB/LOCA profile occurs at the beginning of the profile. Actual test data from the tests referenced herein show that it takes approximately 1.5-2 minutes for the motor to heat up from ambient to the saturation temperature. This heat up time would reduce the three minute peak transient for Byron/Braidwood to actually about 1.5 to 1 minute. The analysis performed assumed the motor for Byron/Braidwood was already at 285°F when the 3 minute transient started. This adds significant conservatism to the calculated temperature rise.

VII. REFERENCES

1. Limitorque Report, "Nuclear Power Station Qualification Type Test Report, Limitorque Valve Actuators for PWR Service," Project #600456, dated 12/9/75.

2. Limitorque Report, "Limitorque Valve Actuator Temperature Related to High Superheat Ambient Temperatures," Project #600508, Report *B-0027, dated 8/31/78.

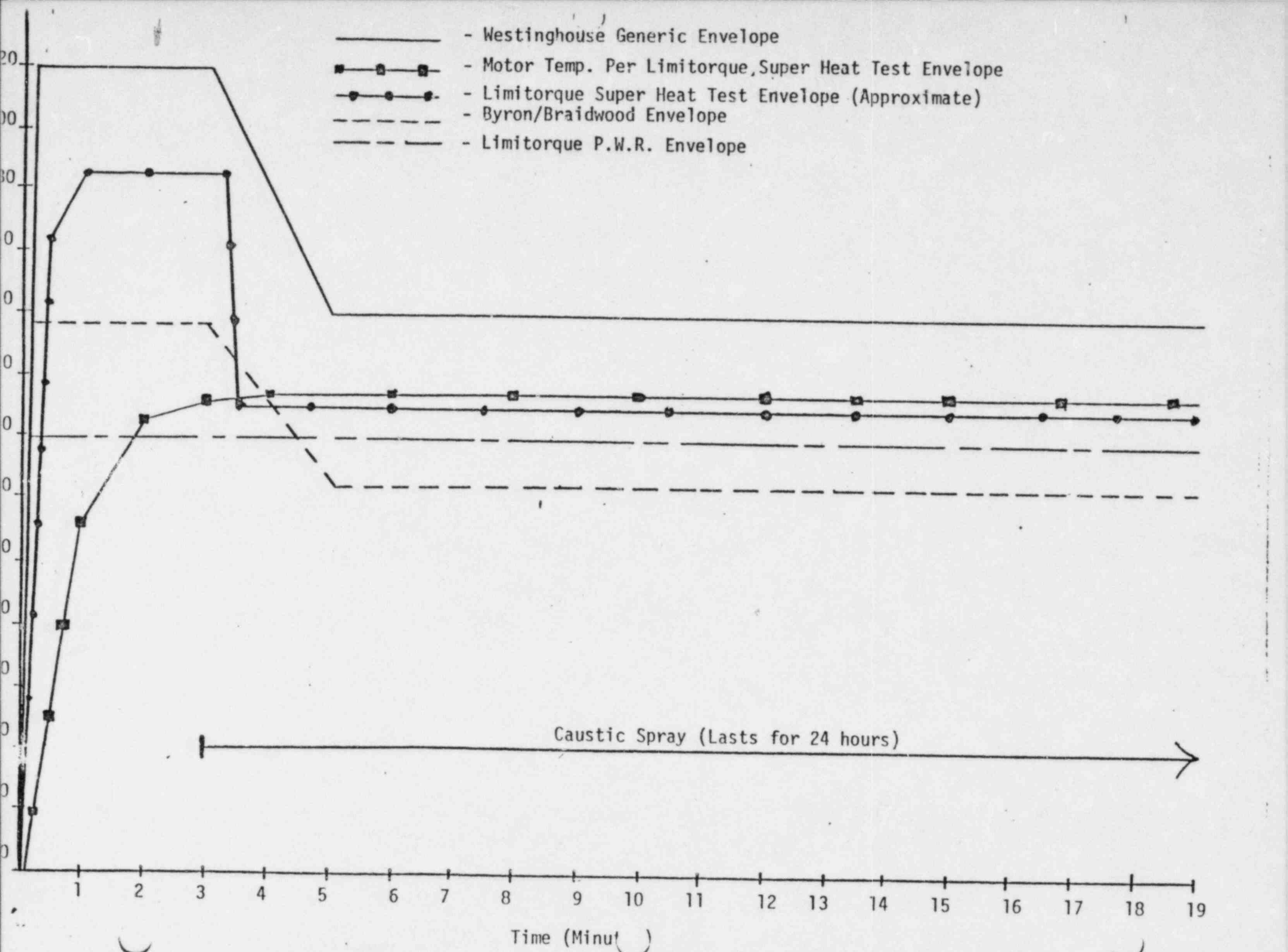
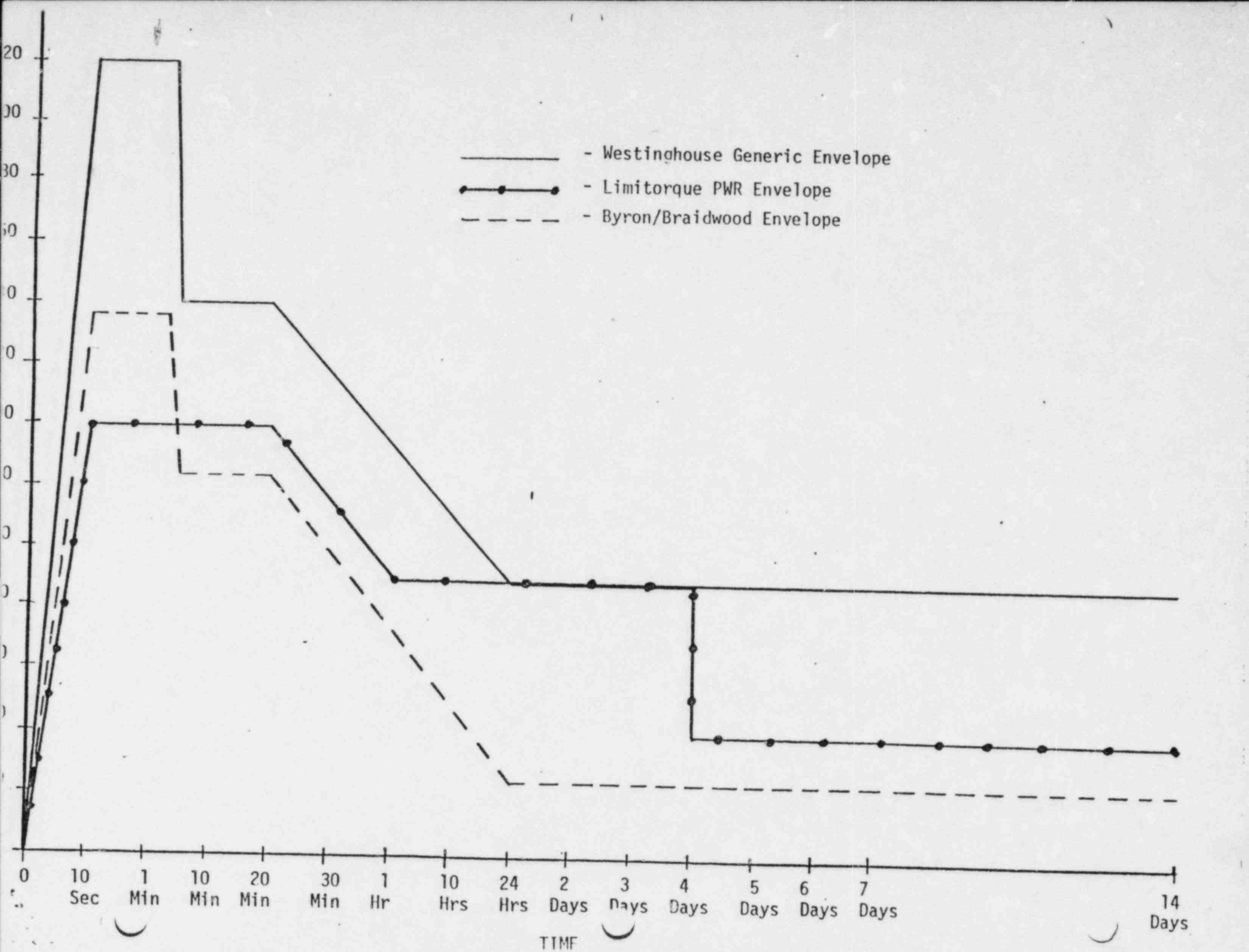


Figure 2 Comparison of Short Term Thermal Transi...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- Limitorque PWR Envelope
- Byron/Braidwood Envelope
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