REVIEW OF
RESISTANCE TEMPERATURE DETECTOR
TIME RESPONSE CHARACTERISTICS

SAFETY EVALUATION BY

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
DIVISION OF SYSTEMS INTEGRATION
INSTRUMENTATION AND CONTROL SYSTEMS BRANCH

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ABSTRACT

Historically Resistance Temperature Detector (RTD) time responses have been measured by the plunge test technique. For RTDs installed in nuclear plants the plunge test is inconvenient and very inaccurate, sometimes leading to errors as large as a factor of 3. Recently EPRI has developed an in-situ method for measuring the RTD time response called the Loop Current Step Response (LCSR) method. The LCSR method is convenient to perform and it produces results that are accurate to within about 10%. In addition, EPRI has developed two other in-situ methods which detect RTD degradation, but give no detailed information on the RTD time response. These methods are the Self Heating Index (SHI) method and the Noise Analysis (NA) method. We have examined the LCSR, SHI, and NA methodologies and find all three to be viable methods for monitoring RTD time response, but we have not conducted a formal review of the SHI and NA methods. To date two vendor time response topical reports have been submitted to the NRC, one from Analysis and Measurement Services Corporation (AMS) and the other from Technology for Energy Corporation (TEC). Both vendor topicals propose only the use of the LCSR method. We have reviewed both the AMS and TEC LCSR topicals and find their methodologies acceptable for RTD time response measurement.
The extensive RTD testing done in conjunction with the LCSR development has revealed RTD time response degradation with ageing. In view of this degradation we are recommending increased surveillance testing of RTD time response.

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1.0 INTRODUCTION, BACKGROUND, AND SUMMARY

A Resistance Temperature Detector (RTD) is a type of thermometer in which the temperature in inferred from the electrical resistance of a piece of wire, which is called the element. RTDs are used extensively for monitoring water temperatures in nuclear reactor plants. The RTD element does not respond instantaneously to changes in water temperature, but rather there is a time delay before the element senses the temperature change, and in nuclear reactors this delay must be factored into the computation of safety setpoints. For this reason it is necessary to have an accurate description of the RTD time response. This Safety Evaluation (SE) is a review of the current state of the art of describing and measuring this time response.

Historically the RTD time response has been characterized by a single parameter called the plunge time constant, or simply the Plunge τ. The Plunge τ is defined as the time required for the RTD to achieve 63.2% of its final response after a step temperature change is impressed on the surface of the RTD. Such a temperature change can be achieved by plunging the RTD into a heat sink, such as water, oil, sand, or molten metal. When τ is measured by this means the technique is called the plunge test method.

Until 1977 all testing of RTD time response was performed by means of the plunge test technique. In nuclear reactors, surveillance testing posed an inconvenience in that the RTD had to be removed from the reactor coolant piping and shipped to a laboratory for testing. Nuclear reactor service conditions of 2235 psig and 540 DEGF are difficult to reproduce in the laboratory, and hence all laboratory tests were performed at more benign conditions, and the laboratory results were then extrapolated to service conditions. The combination of manipulating the RTD and extrapolating the laboratory results to service conditions lead to significant errors in the RTD time response, sometimes as high as a factor of 3. Thus there was considerable incentive to find a better way to measure an RTD's time response.

With this impetus, in 1976 EPRI launched a research project at the University of Tennessee (U of T) to investigate other possible methods for measuring an RTD's time response. Two requirements for any method being developed were: (1) that it could be performed in-situ, and (2) that it produce reasonably accurate results. The products of this investigation are described in three EPRI topical reposts, which are references 1, 2 and 3, which will henceforth be referred to as the 1977, the 1978, and the 1980 EPRI topical reports. This investigation produced three in-situ methods for testing the time response of RTDs, which are as follows:

1. Loop Current Step Response (LCSR) Method.

   In the LCSR Method the resistance element of the RTD is heated by an electric current, and the temperature transient in the element is recorded. From this transient the response of the RTD to changes in external temperature is inferred.

2. Self Heating Index (SHI) Method.

   In the SHI method a constant current is impressed through the element and the equilibrium change in resistance is recorded. The ratio of the element resistance change to the power dissipated is called the SHI. The SHI cannot be correlated with the Plunge τ, but changes in the RTD SHI can be used as a means of detecting RTD degradation.

3. Noise Analysis (NA) Method.

In the NA method the small fluctuations in RTD output under operating conditions are analyzed on line (or recorded for off line analysis) using spectral density and/or auto regressive techniques. These fluctuations are the RTD response to fluctuations in the external temperature of the RTD. If the pattern of fluctuations in the external temperature is known, then it is possible to deduce information about the time response of the RTD. The NA method has been applied to obtain consistent results under optimum reactor conditions for certain types of sensors; however, currently it has not been established in a statistically dependable manner that the NA method yields results comparable with deterministic methods. Thus, while in principle it should be possible to develop a viable deterministic method for measuring the Plunge τ using NA, the realization of this goal will still require a substantial amount of investigative work. However, at the present state-of-the-art the NA method could be useful for detecting RTD time response degradation.

Characteristics of these three in-situ methods and the plunge test method are summarized in tables 1.1, 1.2 and 1.3. All these methods have their purpose. However, for determining the RTD Plunge τ, the only currently viable method is the LCSR method.

Currently in-situ LCSR RTD measurement services and test equipment are available from two vendors, Analysis and Measurement Services Corporation (AMS) and Technology for Energy Corporation (TEC). Both these vendors began operations before the final phases of the EPRI study were complete, and as a result developed somewhat different methodologies. The AMS methodology is identical to that described in the EPRI topicals. We have reviewed both the AMS and TEC LCSR methodologies and find them both to be reliable and adequate to measure the RTD time constant to within 10%.

Table 1.1 Characteristics of Methods for Measuring RTD Time Response

Test	Where Performed	Necessary to take RTD out of service	Complexity of Measurement	Quality of Measurement
Plunge Test	In Lab	Yes	Need to remove RTD and ship to lab.	Plunge test measures Plunge τ directly, but measurement has poor quality for two reasons: (1) Manipulating RTD may change its time response and (2) Service conditions are usually not reproduced in the lab. Lab results must be extrapolated to service conditions. The combined effect of these two factors can result in errors up to a factor of 3.
LCSR Test	In-Situ	Yes	Test simple. Special test equipment needed.	LCSR provides an indirect measure of τ. Results are generally accurate to within 10%.
SHI Test	In-Situ	Yes	Test simple. Uses simple standard electronic test equipment.	SHI can be measured quite accurately. From changes in the SHI, RTD degradation can be detected. No good correlation between Plunge τ and SHI exists.
NA Test	In-Situ	No	Test simple. Special test equipment needed.	A good deal of sophisticated work has gone into NA. However, NA measurements of Plunge τ conducted to date have been in error by up to a factor of 5. A number of investigators are still endeavoring to develop a viable method for measuring the Plunge τ using NA, and it is hoped that future work will lead to much improved agreement between theory and experiment. NA is still a useful tool for detecting RTD degradation.

Table 1.2 Practical Aspects and Availibility [illegible]TD Time Response Testing Methods

Test		Utility of Test Procedure	Rosemont & Sostman Provide	AMS Provides	TEC Provides
Plunge Test	Test for RTD Degradation	None		Yes	Yes
	Measure Plunge τ	Poor -- Errors to a factor of 3	Service Only (Lab Tests)	Yes	Yes
LCSR Test	Test for RTD Degradation	OK -- However if the utility buys equipment for degradation test they might as well buy equipment for measuring Plunge τ.		Equipment and Training	Equipment and Training
	Measure Plunge τ	Good 10% Accuracy		Service or Equipment and Training	Service or Equipment and Training
SHI Test	Test for RTD Degradation	Good -- No special test equipment needed.		Training	Training
	Measure Plunge τ	Poor -- No good correlation with τ exists.			
NA Test	Test for RTD Degradation	Good. Need Special Test Equipment. RTD need not be taken out of service.		Equipment and Training	Equipment and Training
	Measure Plunge τ	Initial attempts to measure Plunge τ produced poor results with errors up to a factor of 5. Over a period of 2 years a limited number of careful NA measurements have produced results with $\pm$10% variation. No systematic correlation of these results with deterministic measurements has been made.			Equipment and Training

Table 1.3 Modes of RTD Surveillance Testing

1. Historical Method: Plunge Test.

   Because of the inconvenience of removing the RTD for testing and the inaccuracy of the test results this method is being abandoned by a number of utilities. The NRC should take steps to encourage all utilities to abandon this method in a timely fashion.

2. LCSR Method: Maximum Utility Involvement.

   The utility can purchase their own electronic equipment and have their own trained personnel perform the LCSR tests.

3. LCSR Method: Moderate Utility Involvement.

   The utility personnel can do regular degradation tests using either the SHI or NA methods. If evidence of RTD degradation is found then a consultant can be brought in to measure the RTD time constant using the LCSR method.

4. LCSR Method: Minimum Utility Involvement.

   The utility can have the consultants measure the RTD time constants on their regular surveillance schedule.

The current Standard Technical Specifications require that one quarter of the safety channel RTDs be tested once every 18 months. The data on RTD degradation collected to date is rather scant, but does appear to give positive evidence of RTD time constant degradation with service. A prudent interim regulatory position would be to require the utilities to either:

a. Perform a surveillance test of all their safety channel RTDs at least once every 18 months, and verify that the time response of the slowest RTD is at least as fast as that assumed in the safety analysis. In addition perform a test of each newly installed RTD at operating conditions as soon as practical after its installation.

b. Continue with the present RTD surveillance requirements and schedules in the Technical Specifications, but in the safety analysis assume an RTD time constant equal to the greater of:

1.2 * [longest time constant measured in last surveillance test (including a 10% allowance for measurement uncertainty)] or

CE ----- Rosemont Model 104 RTD ------ 12 sec.
W ------ Rosemont Model 176 RTD ----- 0.8 sec.
B&W ---- Rosemont Model 177 RTD ------ 12 sec.

The rationale for options (a) and (b) above are discussed in section 8.0 of this report.

2.0 RTD TIME RESPONSE CHARACTERIZATION AND MEASUREMENT

2.1 RTD TIME CONSTANT CONCEPT

If an RTD were a first order system, the Laplace Transform of the sensing element's response to an external temperature change would be:

$$\frac{T(\text{element})}{T(\text{external})} = \frac{1}{(1 + \tau s)}$$

The response [T(element)] to a step function change in T(external) is

$$T(\text{element}) = T(\text{ext,final}) - [T(\text{ext,final}) - T(\text{ext,initial})] * \exp(-t/\tau)$$

At time $t = \tau$ the element temperature has reached $100\%/\varepsilon = 63.2\%$ of its final response. For this reason the time required for the RTD output to attain 63.2% of its final response has been named the RTD plunge time constant.

In fact, RTDs are not first order systems, but the historical definition of RTD time constant is still used and is still a useful concept.

In applications in nuclear plants the external temperature changes to an RTD are typically ramp functions, and the parameter of importance is the time by which the sensing element temperature lags the external RTD temperature. This time is called the Ramp Delay Time (RDT). In the AMS Topical Report (Reference 5) pages 105-109 the relationship between the Plunge τ and the RDT is discussed, and it is shown that the Plunge τ is always equal to or longer than the RDT, the maximum difference being about 2%. Thus the Plunge τ can be used as a conservative measure of the RDT, and in practice all Technical Specifications are written in terms of the Plunge τ and hence all measurement techniques are directed toward evaluating the Plunge τ.

2.2 LCSR METHOD FOR MEASURING RTD TIME CONSTANT

2.2.1 LCSR TEST PROCEDURE

In the LCSR method a constant current is impressed on the RTD sensing element which heats the element and the whole of the RTD experiences a temperature transient. A time plot of either the heating of the element while the current is impressed or the cooling after the current is discontinued is recorded. From this plot the RTD plunge time constant is inferred by means of the LCSR transformation, which is described in the next section.

The element temperature is inferred from its electrical resistance which is measures by a bridge circuit. The required electronic test equipment is discussed in detail in the subject references, and this discussion will not be reiterated in this SE.

2.2.2 THE LCSR TRANSFORMATION

The mathematical theory for analyzing heat transfer in an RTD is developed in the subject references. Two different approaches are described in detail: (1) a nodal approach and (2) a continuum approach. In the 1980 EPRI Topical Report, page 3-34 and Appendix B, numerical results of the two approaches are compared, and for the two cases cited the differencer are 1.5% and 1.1% respectively. Thus for practical purposes the two approaches can be considered to be identical.

It is shown that if:

(1) The RTD has cylindrical symmetry and

(2) There is neglegible heat capacity inside the sensing element

then the transfer function which describes the RTD's response to an external temperature change is (AMS Topical page 23)

$$(2.1) \qquad \frac{T(\text{element})}{T(\text{external})} = \frac{1}{(\tau_1 s + 1)(\tau_2 s + 1)(\tau_3 s + 1) \ldots\ldots (\tau_n s + 1)} .$$

n is finite if the nodal approach is used and infinite if the continuum approach is used. This difference is not significant in that the higher order factors contribute little to the solution.

The important feature of the above equation is that the transfer function contains poles, but no zeroes. As will soon become evident, this fact permits the inference of an RTD's response to an external temperature change from the results of an LCSR transient.

It is shown that the plunge time constant is given by (AMS Topical page 27).

$$(2.2) \qquad \tau = \tau_1[1 - \ln(1 - \tau_2/\tau_1) - \ln(1 - \tau_3/\tau_1) - \ln(1 - \tau_4/\tau_1) \ldots\ldots].$$

It is shown that the response of an RTD to a step change in element current (LCSR transient) is given by (1978 EPRI Topical page 49)

$$(2.3) \qquad T(\text{element}) - T_o = \sum_n a_n \exp(-t/\tau_n) ,$$

where the a_n (also defined in page 49 of the 1978 EPRI Topical) are functions of the poles and zeroes of the transfer function.

Experimentally, the τ_n can be determined by breaking the temperature response into a series of exponentials. Once the τ_n are determined they can be plugged into equation 2.2 to determine the plunge time constant. Thus all the information required to evaluate the plunge time constant is contained in the LCSR transient.

2.2.3 APPLICATION OF THE LCSR TRANSFORMATION

In an ideal world the LCSR transformation could be used as follows:

(1) Conduct an LCSR test to obtain a plot of T(element).

(2) Resolve this plot into a series of exponentials according to equation (2.3). This gives numerical values for the τ_i.
[It is not necessary to evaluate the a_i.]

(3) Plug these values of τ_i into equation (2.2) to obtain the Plunge τ.

In practice step 2 is performed either by exponential stripping or a least squares fit. Using either method it is usually possible to find τ_1 and τ_2. In exceptionally good cases it is possible to find τ_1, τ_2 and τ_3, and in bad cases it is possible to only find τ_1. If equation (2.2) is truncated after the τ_2/τ_1 term the result can be nonconservative by as much as 20%, and if equation (2.2) is truncated to $\tau = \tau_1$ the result can be nonconservative by as much as 47%. AMS and TEC correct for this problem in different ways, which will be discussed in sections 2.2.5 and 2.2.6.

2.2.4 DEMONSTRATION OF CONSERVATISM OF THE LCSR TRANSFORMATION

In reference 4 it is shown that if either the assumption of cylindrical symmetry is violated (say by a crack in the RTD) or the assumption of having no heat capacity within the element is violated, then the transfer function (equation 2.1) would have zeroes as well as poles. If this were the case, then the Plunge τ expression (equation 2.2) would contain terms with these poles. It is shown in reference 10 that these terms would decrease the computed value of τ, and hence applying the LCSR method when the two assumptions for the LCSR mathematical development are violated leads to a conservative computed value of the Plunge τ.

2.2.5 EPRI (AMS) METHOD FOR CORRECTING FOR UNKNOWN HIGHER EIGENVALUES

After trying a number of correlation schemes, the U of T investigators found that a very good approximation for the Plunge τ is given by

$$\text{(2.4)} \qquad \text{Plunge } \tau = f(\tau_2/\tau_1) * \tau_1[i - \ln(1 - \tau_2/\tau_1)] ,$$

where $f(\tau_2/\tau_1)$ is given by the emperical relationship of figure 2.1. Figure 2.1 was constructed by mathematically computing the Plunge τ (equation 2.2) and $\tau_1[1 - \ln(1 - \tau_2/\tau_1)]$ for a number of different hypothetical RTDs and plotting the ratio of the two. The hypothetical RTDs had a variety of sized and geometries, which included both hollow core and central element RTDs. Thus the curve of figure 2.1 applies to any RTD which fulfills the two requirements of section 2.2.2. The fact that this large variety of RTDs all enjoy the same $f(\tau_2/\tau_1)$ is, on the surface, rather amazing. With such a good correlation, one would naturally be inclined to search for an underlying physical reason for all RTDs to display the same $f(\tau_2/\tau_1)$. However, to date this underlying physical relationship has eluded us.

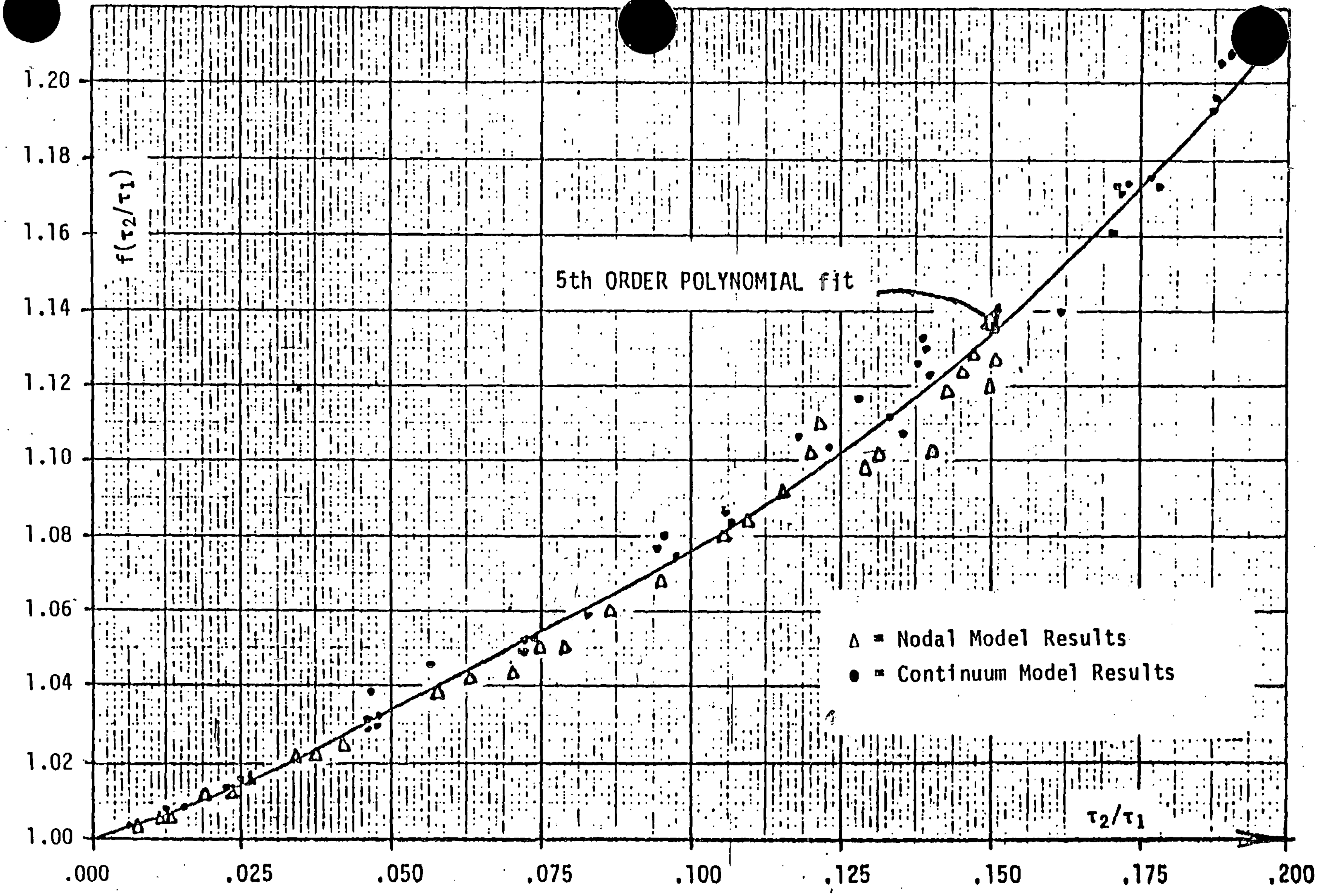

Figure 2.1 Plot of correction factor $[f(\tau_2/\tau_1)]$ vs pole ratio $[\tau_2/\tau_1]$.

[Reproduced from Figure 5.3 of the 1980 EPRI Topical Report]

This function is used in equation 2.4: $(\text{Plunge } \tau) = f(\tau_2/\tau_1)*\tau_1[1 - \ln(\tau_2/\tau_1)]$.

2.2.6 TEC METHOD FOR CORRECTING FOR UNKNOWN HIGHER EIGHEVALUES

The method used by TEC is the following:

(1) Assume a continuum model for the RTD which geometrically consists of a thermowell (pipe which houses the RTD), and air gap, a steel sheath, a ceramic layer, a platinum element, and a ceramic core.

(2) Assume realistic values for the thermal properties of the thermowell and the RTD steel sheath. (the element is so small that it can be ignored in the thermal calculation)

(3) The thermal resistance fo the film between the thermowell and water and that of the air gap between the thermowell and the sheath are not well known. These two thermal resistances are combined into a single resistance R(film + gap) which is left unknown. The thermal resistance of the ceramic R(ceramic) is also left unknown.

(4) The RTD continuum equations are solved for τ_1 and τ_2 using various values of R(film + gap) and R(ceramic). This procedure is iterated until the values derived for τ_1 and τ_2 match those measured experimentally.

(5) The now known values of R(film + gap) and R(ceramic) are used in the RTD continuum equation and the Plunge τ is computed.

The TEC method has the advantage over the EPRI (AMS) method that it uses a recognizable line of physical reasoning to attain its result, whereas the EPRI method is emperical. The TEC method has the disadvantage that it requires a detailed knowledge of the geometry of the RTD, which is not needed for the EPRI method. However both the EPRI and the TEC method produce about equally accurate results, and thus from a regulatory point of view must be considered equally good.

3.0 RTD DEGRADATION TESTS

Although neither AMS or TEC have presented proposals to do degradation tests, the subject of degradation tests is discussed in the EPRI reports, and it seems worthwhile to summarize the status of these degradation tests here.

3.1 RTD DEGRADATION TESTS USING LCSR METHOD

A simple application of the LCSR method is a degradation test. For this test an LCSR transient is impressed on the RTD and the time required for the RTD to achieve 62.3% of its final response is measured. This time is called the LCSR τ. An increase in the LCSR τ is a sign of RTD degradation.

The U of T investigators attempted to correlate the Plunge τ with the LCSR τ. In making this correlation the time response of the RTD was varied by adding tape or rubber insulation around the RTD and measuring both the Plunge τ and the LCSR τ. Two such correlations are shown in figures 3.1 and 3.2.

An obvious difficulty with this method is the following: This correlation was formed by altering the thermal resistance on the surface of the RTD. When an RTD degrades, it is most likely due to increases in the thermal resistance of the RTD internals or the RTD-thermowell gap. Therefore one would expect to find a different correlation for normal degradation than that determined by adding insulation to the surface of the RTD. For this reason we do not, at present, consider the correlations of figures 3.1 and 3.2 to be sufficiently well substantiated to be used in the determination of the Plunge τ.

While not providing an accurate means of computing the Plunge τ, these correlations are useful for the degradation test. If in a degradation test the LCSR τ is found to increase, then from the correlation the approximate increase in the Plunge τ can be determined. If the Plunge τ determined in this way is near the value assumed in the safety analysis, this would indicate that it is necessary to measure the Plunge τ via the usual LCSR procedure.

Using the LCSR technique to detect detector degradation is a rather wasteful use of the LCSR electronic equipment. With the addition of one microprocessor the degradation test equipment can be used to measure the Plunge-τ as described in section 2.2.1.

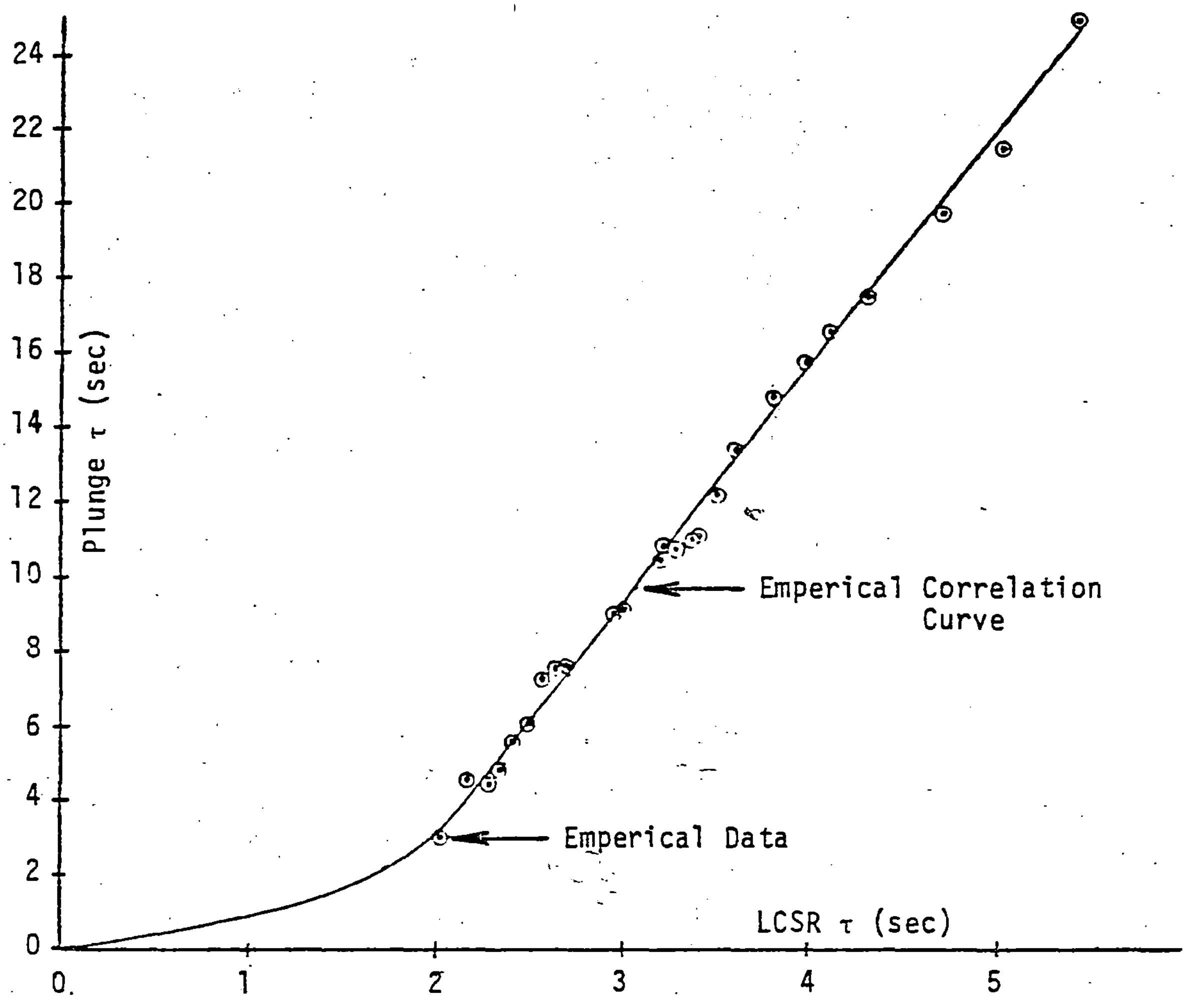

Figure 3.1 Emperical Correlation Curve for Plunge τ versus LCSR τ for Rosemont RTD Model 104AFC. (Combustion Engineering RTD)

[Reproduced from Figure 6.4 of the 1978 EPRI Topical Report]

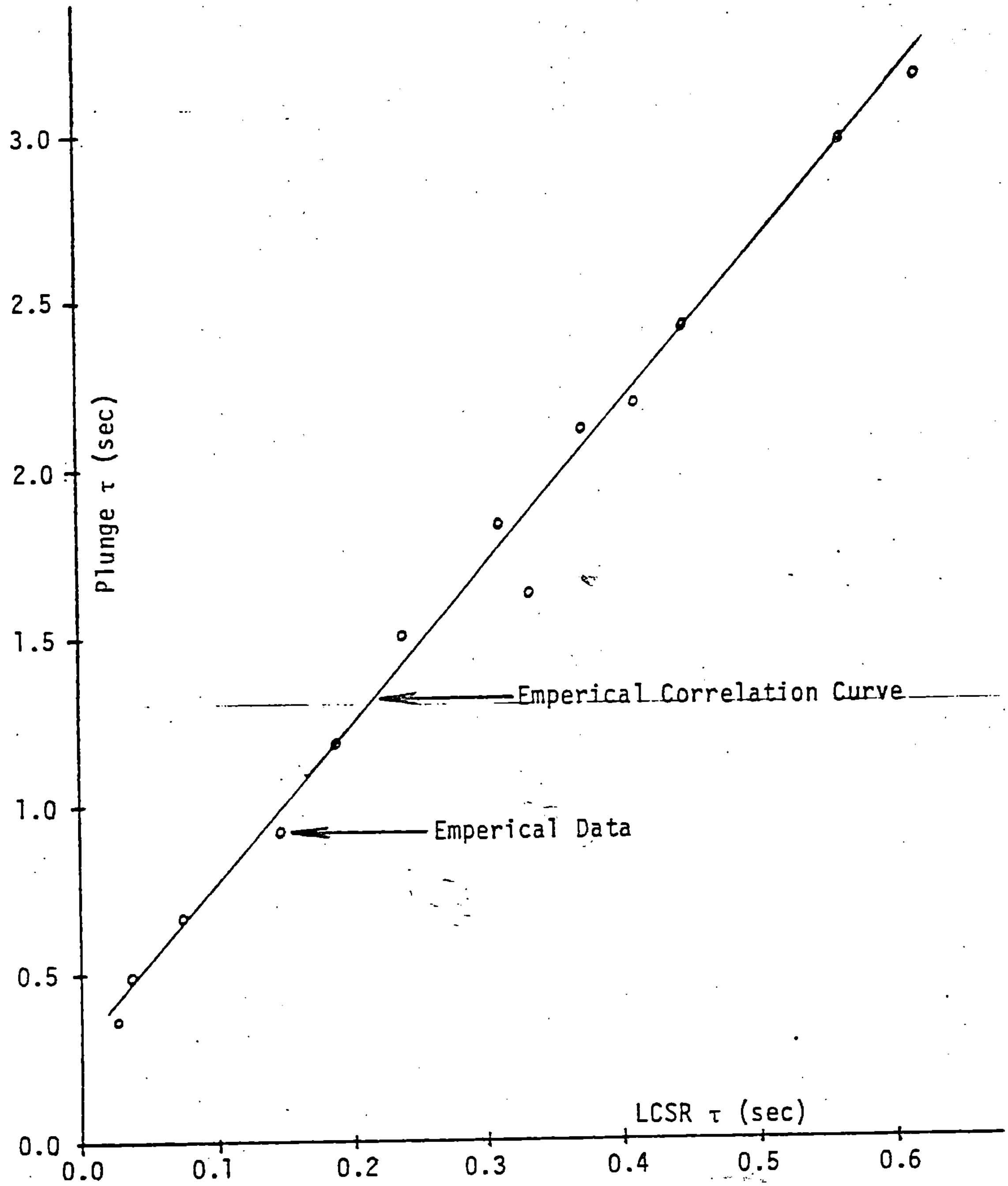

Figure 3.2 Emperical Correlation Curve for Plunge τ versus LCSR τ for Rosemont RTD Model 176KF. (Westinghouse RTD)

[Reproduced from Figure 6.5 of the 1978 EPRI Topical Report]

3.2 RTD DEGRADATION TESTS USING THE SELF HEATING INDEX (SHI)

In the SHI test, a constant current is impressed through the RTD element and the steady state change in element resistance is measured. This test is performed at several different currents, and a plot is made of power dissipated by the element versus increase in element resistance. Emperically this has always been found to be a straight line, and the slope of this line (ohms/watt) is called the SHI.

An increase in SHI is a positive indication of RTD degradation.

As with the LCSR τ, the U of T investigators attempted to correlate the SHI with the Plunge τ.
Again, as with the LCSR τ measurement, the RTD time response was varied by adding insulation to the surface of the RTD, and plots of Plunge τ versus SHI were constructed. Two such plots are shown in figures 3.3 and 3.4. These correlations suffer the same problem as the Plunge τ versus the LCSR τ correlations, and thus we do not, at present, accept them as viable means for computing the Plunge τ. However, like the Plunge τ versus LCSR τ correlation, the Plunge τ versus SHI correlations would be useful in a degradation test.

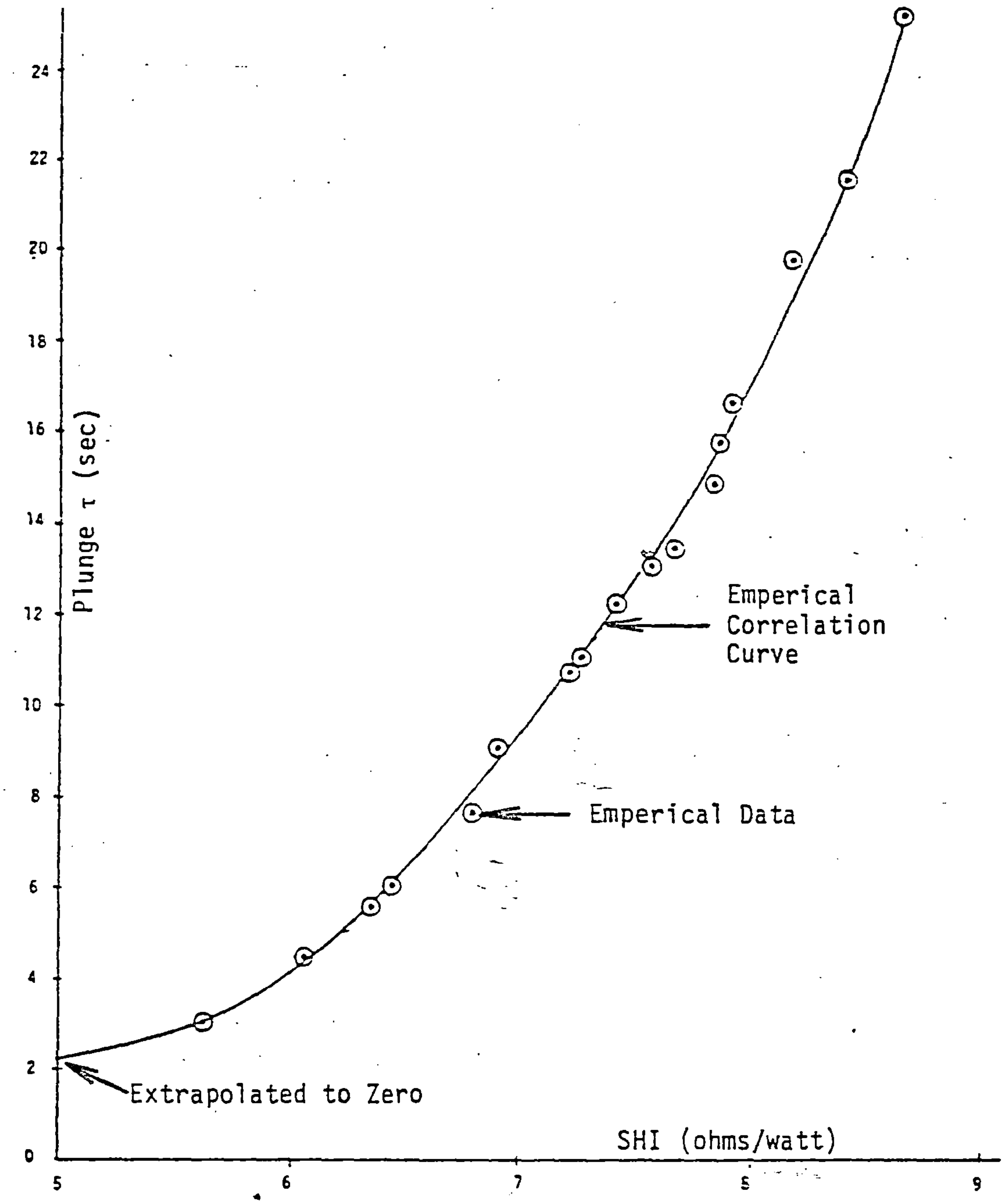

Figure 3.3 Empirical Correlation Curve for Plunge τ versus SHI for Rosemont RTD Model 104AFC. (Combustion Engineering RTD)

[Reproduced from Figure 6.7 of the 1978 EPRI Topical Report]

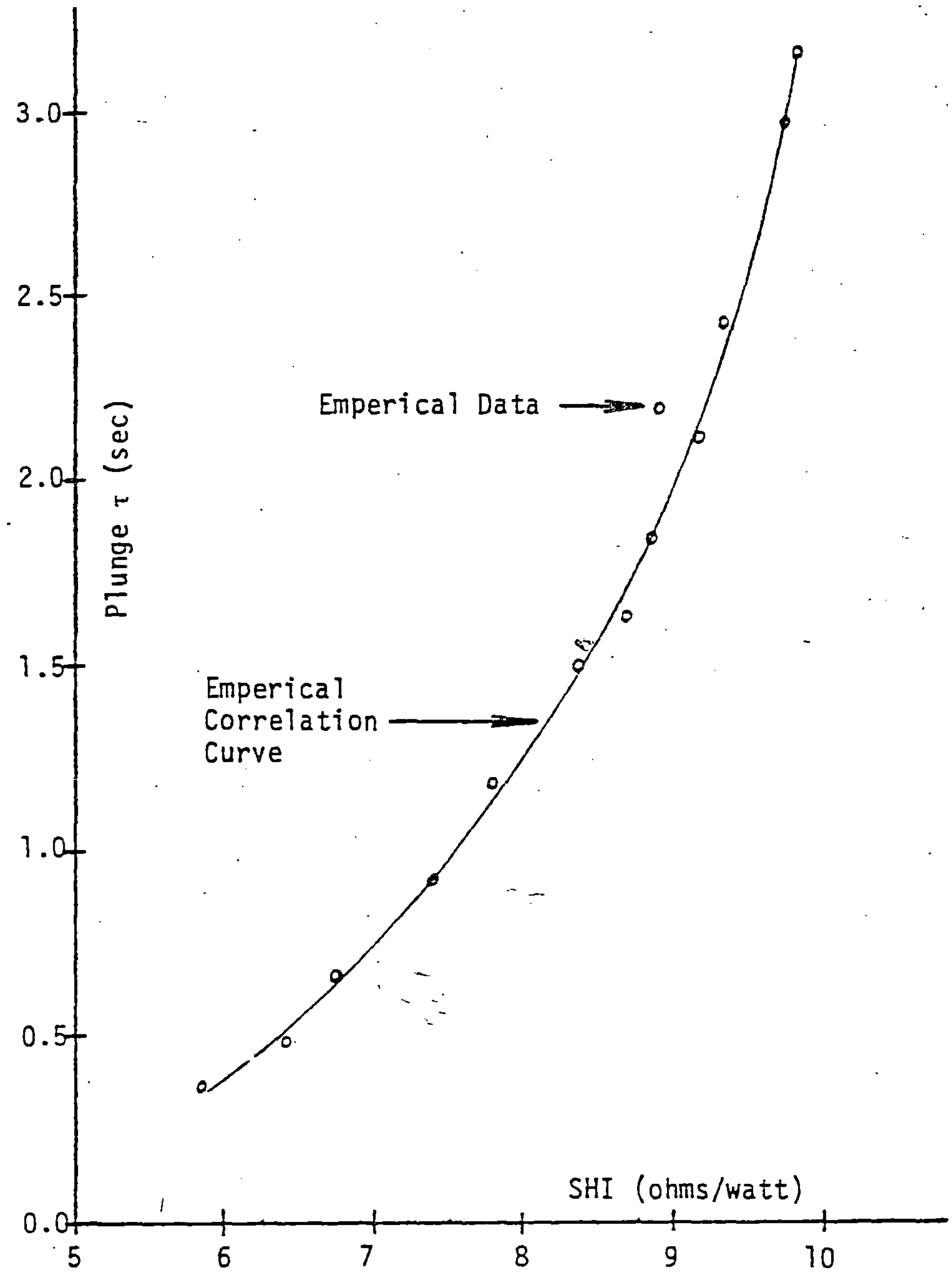

Figure 3.4 Emperical Correlation Curve for Plunge τ versus SHI for Rosemont RTD Model 176KF. (Westinghouse RTD)

[Reproduced from Figure 6.8 of the 1978 EPRI Topical Report]

3.3 RTD DEGRADATION TESTS USING NOISE ANALYSIS (NA)

NA tests are performed by carrying out statistical (spectral, correlation, zero crossing rate and/or auto regressive) analysis of normal fluctuations of the RTD output signal during normal steady state reactor operation. These fluctuations are the RTD's response to the fluctuations in the reactor coolant temperature. The statistical methods referred to above will not be discussed here, and the reader is referred to the three EPRI topical reports for a discussion of these methods.

In the application of the NA method, assumptions must be made regarding the statistical properties of the coolant temperature fluctuations. If some minimum set of assumptions, such as stationarity and repeatability are met, the NA method is a valid degradation method since any change in the output fluctuations can be directly attributed to the RTD itself. If, in addition to stationarity and repeatability, the coolant temperature fluctuations are "white" (having fluctuations whose Fourier representation displays constant energy per unit band width at every frequency in the range of interest), NA can be used to determine a Plunge τ.

The initial theoretical work in NA done by EPRI was directed toward developing a deterministic method for measuring the Plunge τ, and this work produced some very sophisticated physical and mathematical developments. However, when the theory was applied to experiment, it was found that NA predictions of the Plunge τ were seriously in error, sometimes by as much as a factor of 5. The EPRI researchers concluded that their principal problem was that the reactor coolant fluctuations were not white, as they has assumed. Having no other reasonable model for reactor coolant fluctuations, EPRI has, at least for the time being, abandoned efforts to perform a deterministic measurement of the Plunge τ using NA.

Researchers at TEC are still pursuing a deterministic method for measuring the Plunge τ using NA. Over a period of 2 years TEC has demonstrated that for certain types of sensors and certain reproducable reactor coolant conditions, careful NA measurements of the various statistical parameters have produced results with $\pm 10\%$ variation. However, it has been established that coolant temperature fluctuations do not meet the requirements for a Plunge τ determination under all reactor conditions for all sensors. To date TEC has not succeeded in developing a systematic correlation between the measured statistical parameters and deterministic measurements of the Plunge τ, but there are reasons to believe that such a correlation can be derived for certain sensors under certain verifiable reactor conditions.

As was just stated, the conditions for the coolant temperature fluctuations for an RTD degradation test are less restrictive than those for a deterministic Plunge τ measurement. It has been established that the measured statistical parameters which can be extracted from NA of RTDs under verifiable reactor conditions are highly reproducable and changes in these parameters can be used to infer changes in the RTD Plunge τ. Therefore NA methods can be used for RTD degradation measurements subject to the statistical accuracy of the measurement.

4.0 POTENTIAL FOR RTD TIME RESPONSE DEGRADATION

4.1 MODES OF RTD TIME RESPONSE DEGRADATION

The U of T investigators have evaluated various modes of RTD degradation in section 2.5.3.1 of the 1978 EPRI report and part II, chapter 7 and part V of the 1980 EPRI report. Their conclusion is that the main modes of RTD degradation are due to deterioration of the PBX cement used to hold the RTD element in place and deterioration of NEVER-SEEZ, a substance used to increase the thermal conductivity between the thermowell and the RTD.

Most of the deterioration in the PBX and NEVER-SEEZ is due to high temperatures and takes place fairly soon after the elevated temperature is reached. Thus the RTDs are expected to show a marked degradation shortly after they are put in service, and afterward degrade more gradually. If future data bears out this trend, then a reasonable surveillance schedule would require frequent testing of the newer RTDs and less frequent testing of the older ones. However, with the data currently available, this point is inconclusive.

In the TEC topical report it is suggested that RTD time response degradation may be caused by fouling of the thermowell by crud and cracking of the ceramic insulator in the RTD. While these are plausable modes of degradation, there is no evidence that either of these mechanisms is active in the observed time response degradations.

4.2 EVIDENCE OF RTD TIME RESPONSE DEGRADATION

Records of measured RTD time constants for various reactors are presented in tables 4.1 and 4.2. The AMS data from Millstone 2 indicates a systematic degradation of RTDs with service. However most of the other data does not show this consistent trend. A prudent regulatory position for the present would be to increase the required surveillance at all plants until enough data is collected to determine if a consistent trend in RTD degradation does exist.

Table 4.1 Comparison of In-Plant LCSR and SHI Time Response Tests Conducted by AMS

[Taken from Table 11.1 of the AMS Topical Report and Reference 4]

Time Response Test Results for Rosemont Model 104 RTDs at Millstone Unit 2

For the Millstone tests, judging from either the Plunge τ or the SHI test, almost all detectors degraded and a few remained unaffected by service. None improved.

RTD Number	August 1977 Plunge τ* (sec)	December 1978 Plunge τ* (sec)	August 1977 SHI (ohms/watt)	December 1978 SHI (ohms/watt)
A7770	3.2	5.2	5.6	7.4
A7765	2.8	3.2	4.5	4.8
75313	4.7	5.6	6.2	6.5
A7774	3.8	4.3	5.8	6.2
75294	3.7	4.4	6.0	6.4
75299	5.5	9.3	8.6	9.1
75310	4.6	4.9	6.2	6.5
75300	4.6	4.7	6.5	6.5
75297	3.6	3.6	4.7	4.9
80364	4.0	4.4	5.6	6.1
75309	4.0	4.7	5.5	5.8
A7769	3.1	3.6	4.8	5.0

Time Response Test Results for Rosemont Model 176 RTDs at Farley Unit 1

In these tests there was no evidence of time response degradation.

RTD Number	October 1978 Plunge τ (sec)	January 1980 Plunge τ (sec)	October 1978 SHI (ohms/watt)	January 1980 SHI (ohms/watt)
412B	0.10	0.11	7.5	7.4
412C	0.12	0.12	5.8	5.7

*Since the correction factor had not been developed at the time of the August 1977 measurements, all time constants shown here are uncorrected values.

Table 4.2 Comparison of In-Plant LCSR Time Response Test Results Conducted by TEC on Rosimont Model 104 RTDs at Saint Lucie Unit 1

[Taken from References 7 and 8]

In these tests there is no evidence of time response degradation.

	January 1978 Plunge τ (sec)	May 1978 Plunge τ (sec)	October 1978 Plunge τ (sec)	March 1979 Plunge τ (sec)
TE-1112CA	4.0 ± 0.2	4.2 ± 0.4	4.0 ± 0.4	4.1 + 1.2/-0.7
TE-1112HA	6.2 ± 0.5	4.4 ± 0.3	4.4 ± 0.2	4.5 ± 0.3
TE-1122CA	5.5 ± 0.2	5.7 ± 0.3	6.0 ± 0.6	6.0 ± 0.7
TE-1122HA	5.0 ± 0.5	5.6 ± 0.3	5.3 ± 0.5	5.7 + 0.7/-0.5
TE-1112CB	----------	----------	5.0 ± 0.5	4.8 + 0.6/-0.4
TE-1112HB	----------	----------	5.0 ± 0.9	5.3 ± 0.6
TE-1122CB	----------	----------	5.9 ± 0.3	5.4 ± 0.2
TE-1122HB	----------	----------	5.8 ± 0.3	5.6 ± 0.4
TE-1112CC	----------	----------	4.5 ± 0.7	4.3 + 0.8/-0.5
TE-1112HC	----------	----------	5.4 ± 0.4	5.4 + 0.7/-0.5
TE-1122CC	----------	----------	5.4 ± 0.3	5.7 ± 0.5
TE-1122HC	----------	----------	5.4 ± 0.4	5.0 + 0.7/-0.5
TE-1112CD	----------	----------	4.8 ± 0.3	4.9 ± 0.5
TE-1112HD	----------	----------	4.9 ± 0.5	5.7 + 1.0/-0.7
TE-1122CD	----------	----------	5.7 ± 0.5	5.6 + 0.9/-0.7
TE-1122HD	----------	----------	4.3 ± 0.5	4.8 + 1.6/-0.9

5.0 RTD TIME RESPONSE TEST RESULTS

5.1 PARAMETERS THAT AFFECT RTD TIME RESPONSE

The time response is not only a function of the RTD itself, but depends as well on the properties of the thermowell and the thermal characteristics of the medium in which the thermowell or RTD is immersed. The thermal properties of all these components change with temperature and the heat transfer properties of the medium (water) change with flow velocity. The match between the RTD and the thermowell affects the time response, and even the slight change in match that occurs when an RTD is removed from a thermowell and placed back in the same well can significantly change the time response. Thus it is important to simulate service conditions as closely as possible when testing the RTD time response.

As stated earlier, historically the time-response of RTDs has been measured by a plunge test in the laboratory. Normal service conditions of 2235 psig and 540 DEGF are difficult to reproduce in the laboratory. For this reason, in the past most laboratory tests were performed at more benign conditions and the results extrapolated to service conditions. With the advent of the LCSR method, the plunge test methodology has been re-examined, and it was found that the historical plunge test procedure often produced results which were grossly in error, sometimes by as much as a factor of 3.

One of the first suggestions for achieving 540 DEGF without elaborate laboratory equipment was to use hot oil or sand as the medium, rather than water. This was soon demonstrated to be unsatisfactory. The reason is that the heat conduction properties of oil and sand are so different from water that a test in oil or sand gives no indication of what would happen in water. In numerical terms, the thermal match between the medium and the RTD is given by a quantity called the Biot modulus, which is defined as the ratio of the film thermal conductance to the internal conductance of the RTD [More specifically, Biot modulus = hR/k, where h is the film coefficient, R is the RTD radius, and k is the thermal conductivity of the RTD]. When the Biot modulus is less than about 0.1 the thermal resistance is dominated by the film resistance, and when it is greater than about 10 the thermal resistance is dominated by the RTD internal resistance. The response of an RTD in one heat transfer regime indicates very little about how the RTD will respond in a different heat transfer regime. Values for the Biot modulus for several cases are given in table 5.1.

Table 5.1 Variation of Biot Modulus due to the Different Film Coefficients Associated with Different Testing Conditions

[Taken from Reference 9]

	RTD / Testing Conditions	Rosemont 104 (Combustion Engineering)	Rosemont 176 (Westinghouse)
Biot Modulus = hR/k	Reactor Service Conditions	300	3.8
	3 ft/sec 180 DEGF Water	27	0.34
	1 ft/sec 500 DEGF Solder	115	1.5
	500 DEGF Oil	0.8	0.02
	500 DEGF Sand	0.4	0.01
	Comments	Internal resistance dominates for both water and solder tests. Good service condition simulation is possible in laboratory tests.	No available laboratory test condition simulates service conditions well.

5.2 RTD TIME RESPONSE TESTING CONDITIONS USED IN PRACTICE: ROOM TEMPERATURE LABORATORY CONDITIONS

While room temperature tests do not indicate much about the RTD's behavior at service conditions, room temperature tests are a good way to compare various measurement methodologies. The main testing criteria for comparing methodologies is that all methodologies are compared under identical conditions, whether these be service conditions or room temperature laboratory conditions. In fact, all of the development work for the LCSR methodology was done under room temperature laboratory conditions. Results of the room temperature tests are given in tables 5.2 and 5.3.

With the development work on the LCSR methodology complete, it seemed worthwhile to test the LCSR method versus the plunge method at simulated service conditions. The next two sections describe how this was accomplished.

5.3 RTD TIME RESPONSE TESTING CONDITIONS USED IN PRACTICE: EPRI SERVICE CONDITION TESTS [EDF TESTS]

In order to test the LCSR method at service conditions, the U of T investigators in conjunction with Electricite de France (EDF), performed tests on a simulated reactor coolant test loop constructed by EDF. This loop operates at reactor service conditions of temperature, pressure and flow, and has special valves to induce a step change in temperature for the purposes of simulating a plunge test. The results of this test are shown in table 5.2. It can be seen that the agreement between the LCSR test and the plunge test is excellent.

Table 5.2 Results of LCSR and Plunge Testing done by the U of T

[Taken from Table 10.1 of 1978 EPRI Report and Tables 7-1 & 7-3 of 1980 EPRI Report]

Room Temperature Tests at U of T Thermometry Laboratory

RTD Model	Measured Plunge τ (sec)	Plunge τ Inferred from LCSR: Without Higher Mode Correction	Plunge τ Inferred from LCSR: With Higher Mode Correction	Percent Error
Rosemont 176KF	0.38	0.39	0.41	+7.9
Rosemont 104ADA (without thermowell)	3.1	2.9	3.1	0.0
Rosemont 104ADA (with thermowell)	7.1	5.9	7.2	+1.4
Rosemont 104VC (without thermowell)	2.3	1.7	2.1	-8.7
Rosemont 104VC (with thermowell)	5.3	4.5	5.5	+3.8
Rosemont 177GY	5.8	5.1	6.2	+6.9
Rosemont 177GY	6.1	5.2	6.3	+3.3
Sostman 8606	2.0	1.7	2.1	+5.0
Rosemont 104AFC (air in well)	5.3	-----	5.2	-1.9
Rosemont 104AFC (NEVER-SEEZ in well)	3.9	-----	3.9	0.0
Rosemont 177HW	11.7	-----	12.3	+5.1
Rosemont 176KF	0.42	-----	0.41	-2.4

Service Condition Tests at EDF Test Loop

RTD Model	Measured Plunge τ (sec)	Plunge τ Inferred from LCSR Test (sec)	Percent Error
Rosemont 104AFC (Air in well)	6.2	5.9	-4.8
Rosemont 104AFC (NEVER-SEEZ in well)	4.1	3.7	-9.8
Rosemont 177HW	8.8	8.4	-4.5
Rosemont 176KF	0.14	0.13	-7.1

5.4 RTD TIME RESPONSE TESTING CONDITIONS USED IN PRACTICE: TEC SERVICE CONDITION TESTS [SOLDER TESTS]

TEC has gotten around the problem of getting service condition temperatures by using molten solder, rather than pressurized water, as was done in the EPRI-EDF tests. As can be seen in table 5.1, for the Rosemont 104 RTD the molten solder provides a very good simulation of service conditions. For the Rosemont 176 RTD the simulation is rather poor.

The TEC comparison of plunge tests and LCSR tests is shown in table 5.3. As with the EPRI tests, the agreement is excellent.

Table 5.3 Results of LCSR and Plunge Testing done by TEC on Rosemont Model 104 RTDs

[Taken from Tables 3.1 and 3.2 of Reference 11]

Room Temperature Tests

Thermo Well	RTD Number	Measured Plunge τ* (sec)	Plunge τ Inferred from LCSR Tests** (sec)	Percent Error
60	57161	5.9±0.2	5.6±0.3	-5.1
60	57165	5.9±0.2	6.0±0.3	+1.7
60	A8994	6.8±0.5	6.7±0.3	-1.5
60	B5642	8.3±0.7	7.2±0.6	-13.3

540 DEGF Solder Tests

Thermo Well	RTD Number	Measured Plunge τ* (sec)	Plunge τ Inferred from LCSR Tests** (sec)	Percent Error
60	57147	5.9±0.2	6.0±0.4	+1.7
60	57151	6.0±0.2	6.0±0.4	0.0
60	57161	5.0±0.2	4.8±0.3	-4.0
60	57165	6.9±0.2	6.5±0.4	-5.8
60	57170	5.4±0.2	5.2±0.2	-3.7
60	A8994	6.7±0.2	7.0±0.4	+4.5
60	B5630	5.6±0.2	5.8±0.4	+3.6
60	B5642	6.8±0.2	6.9±0.4	+1.5
66	57161	5.4±0.2	6.0±0.2	+11.1
66	57165	5.9±0.2	5.3±0.5	-10.2
66	A8994	6.2±0.2	7.0±0.5	+12.9
66	B5642	5.9±0.2	5.7±0.3	-3.4

*Uncertainty = 1σ based on historical uncertainty in reproducibility of plunge tests.

**Uncertainty = upper and lower bounds of all variables with uncertainty in them. Uncertainties combined additively.

6.0 AMS AND TEC FIELD EXPERIENCE

AMS has performed LCSR measurements at the following plants:

Millstone Unit 2 ------- Aug 1977, Dec 1978, June 1979, July 1980

ANO1 Unit 2 ------------ Nov 1978

North Anna Unit 1 ------ Aug 1979

Farley Unit 1 ---------- Oct 1978, Jan 1980

Farley Unit 2 ---------- May 1980

AMS has sold testing equipment to North Anna, Farley, V.C.Summer, San Onofre, LOFT, and ORNL. In addition Millstone plans to purchase AMS test equipment in the near future.

TEC has performed LCSR measurements at the following plants:

Saint Lucie Unit 1 ----- Jan 1978, May 1978, Oct 1978, Mar 1979

LOFT ------------------- Mar 1979

Sequoya ---------------- May 1979

Zion ------------------- Aug 1979

TEC has sold LCSR testing equipment to Saint Lucie

7.0 NRC RESERVATIONS FOR IN-SITU TESTS

Most of the reservations we have with in-situ tests have been iterated in other sections of this SE. We are listing them here in order to have a compact list for reference. These are:

(1) Using the Plunge τ versus the LCSR τ correlation to infer the Plunge τ from a measurement of the LCSR τ (Section 3.1).

(2) Using the Plunge τ versus SHI correlation to infer the Plunge τ from a measurement of the SHI (Section 3.2).

(3) Using the NA method for measuring the Plunge τ (Section 3.3).

(4) Using the expression $P_i = P_1[1 + (i - 1)]^2$ to estimate the higher poles of the transfer function. [This appears on page 29 of the 1977 EPRI Topical Report. It is demonstrated to be a poor approximation on page 42 of the same report.]

(5) On page 46 of the 1978 EPRI Topical Report it is stated that if only one eigenvalue, τ_1, can be found, then an upper limit for the Plunge τ is $1.4 * \tau_1$. This should be $1.47 * \tau_1$, which for practical purposes can be rounded to $1.5 * \tau_1$.

The first four of these techniques were originally described in the EPRI Topical Reports at a time when they were still in the experimental stage, and there was hope that these techniques would be proved viable. Since then the U of T investigators have conceded that these are not viable techniques. The disclaimers for these techniques appear on page 42 of the 1977 EPRI Topical Report and page 140 of the 1978 EPRI Topical Report.

8.0 REGULATORY POSITION

(1) The LCSR method has been demonstrated to be the only reliable method for measuring the time response of RTDs in nuclear plants. We should take a position that would favor the universal adoption of the LCSR method in a timely fashion.

(2) The historical plunge test has been demonstrated to be inadequate for measuring the time response of RTDs in nuclear plants. We should cease putting credance in RTD time constants which have been measured by a plunge test.

(3) Both the AMS and TEC LCSR measurement procedures have been demonstrated to consistently predict the Plunge τ to within 10%. The number of comparisons done to date is inadequate to form a basis for any sophisticated statistical model, and the best procedure to account for uncertainties would be to simply add 10% to the measured Plunge τ and use this as the measured upper bound. [in some cases (e.g. the EDF data on table 5.2) the errors appear to be composed of a substantial bias plus a random fluctuation. In this case simply adding a 10% uncertainty to the best estimate Plunge τ is a reasonable procedure.]

(4) While the RTD degradation tests are discussed in some detail both here and in the EPRI Topical Reports, neither AMS nor TEC nor any other vendor/consultant/utility has submitted a proposal to employ degradation tests. Degradation tests should not be permitted as a substitute for LCSR tests until such a proposal has been submitted, reviewed, and approved by us. Once degradation tests are approved they may be used by utilities instead of LCSR tests to detect RTD degradation, and then only those RTDs which show degradation would need to be tested via the LCSR procedure.

(5) The extensive RTD time response testing done recently has revealed that the RTDs in operating reactors are suffering time response degradation as they age. Current Technical Specification surveillance schedules permit such deficiencies in RTDs to go undetected for several years. Consequently the RTD time lags assumed by utilities in their RPS setpoint computation may in some instances be unrealistically short. In these cases the computed RPS setpoints will be nonconservative, and this situation should be corrected. Fortunately, the transients against which RTDs provide protection are all rather slow. Assuming a slightly slower RTD time response in the safety analysis would change the RPS setpoints only a very small amount, and would not present severe restrictions on reactor operations. In order to guarantee that all utilities are using conservative RTD time lags in their safety analyses, we recommend that they comply with one of the following options:

a. Perform a surveillance test of all their safety channel RTDs at least once every 18 months, and verify that the time response of the slowest RTD is at least as fast as that assumed in the safety analysis. In addition perform a test of each newly installed RTD at operating conditions as soon as practical after its installation. If this option is chosen the Technical Specifications must be modified to match the new surveillance schedule. (As mentioned previously, most current Technical Specifications require that a quarter of the RTDs be tested every 18 months.)

b. Continue with the present RTD surveillance requirements and schedules in the Technical Specifications, but in the safety analysis assume an RTD time constant equal to the greater of:

1.2 * [longest time constant measured in last surveillance test (including a 10% allowance for measurement uncertainty)] or

CE ----- Rosemont Model 104 RTD ------ 12 sec.
W ------ Rosemont Model 176 RTD ----- 0.8 sec.
B&W ---- Rosemont Model 177 RTD ------ 12 sec.

A few words are in order to explain the rationale for options (a) and (b) above. The present Technical Specification RTD surveillance schedule was formulated before any evidence of RTD time response degradation appeared, and it was thought that an occasional spot check would be adequate to assure that no degradation was taking place. However, with the testing done recently, it has become apparent that RTD degradation is widespread, and we must take steps to assure that in every instance it occurs it is soon detected, and corrective measures taken.

For utilities which have procured LCSR test equipment, option (a) is decidedly preferable both from NRC's and the utilities point of view. From the NRC point of view the frequent and thorough surveillance testing would assure us that conservative values for RTD lags were being used in the safety analyses. From the utilities point of view, the accurately measured time lags of their RTDs, without any extra conservatism factors being added, would be direct input data to their safety analysis. This would give them the most relaxed RPS setpoints possible, which would add to their operating flexibility.

In most instances utilities without LCSR equipment remove the RTDs from their reactors and send them to the Rosemont laboratories for surveillance testing. For these utilities having option (a) imposed upon them in a short time frame would represent a severe and unnecessary hardship. For this reason we are recommending option (b) for those utilities which cannot easily comply with option (a). The time constants of 12 seconds and 0.8 seconds in option (b) are the longest time constants observed to date for the RTDs in question. It would not be prudent to assume any faster response for an RTD which has not been tested in several years. While we do not anticipate measuring time constants greater than 12 seconds and 0.8 seconds, if this should occur, then the longest measured time constant, with an appropriate conservatism factor added should be used as the RTD time constant input into the safety analysis.

9.0 REFERENCES

1. EPRI NP-459, IN SITU RESPONSE TIME TESTING OF PLATINUM RESISTANCE THERMOMETERS, Kerlin, Miller, Mott, Upadhyaya, Hashemian, Arendt, January 1977. [Herein called the 1977 EPRI Topical Report]

2. EPRI NO-834, IN SITU RESPONSE TIME TESTING OF PLATINUM RESISTANCE THERMOMETERS, Kerlin, Miller Hashemian, Poore, July 1978. [Herein called the 1978 EPRI Topical Report]

3. EPRI Report (To be Published), TEMPERATURE SENSOR RESPONSE CHARACTERIZATION, Kerlin, Miller, Hashemian, Poore, Skorska, Cormault, Upadhyaya, Jacquet. [Herein cassed the 1980 EPRI Report]

4. Material extracted from a papar in preparation entitled ACCURACY OF LOOP CURRENT STEP RESPONSE TEST RESULTS, T.W.Kerlin, April 22,1980

5. RESPONSE TIME QUALIFICATION OF RESISTANCE THERMOMETERS IN NUCLEAR POWER PLANT SAFETY SYSTEMS, Northeast Utilities Topical Report prepared by Dr.T.W.Kerlin of Analysis and Measurement Services Corporation (AMS), November 1979. [Herein called the AMS Topical Report]

6. RESPONSE TIME OF PLATINUM RESISTNACE THERMOMETERS USING THE LOOP CURRENT STEP RESPONSE TECHNIQUE, Mott, Robinson, Jones, Mathis, Fisher, Technology for Energy Corporation (TEC), April 1978. [Herein called the TEC Topical Report]

7. RTD TIME CONSTANT SURVEILLANCE REPORT, Letter from Robert E. Uhrig (FPL) to Robert W. Reid (NRC), January 3, 1979.

8. RTD TIME CONSTANT SURVEILLANCE REPORT, Letter from Robert E. Uhrig (FPL) to Robert W. Reid (NRC), May 1, 1979.

9. TEC handout at NRC meeting entitled REVIEW OF TEMPERATURE SENSOR RESPONSE TIME USING LOOP CURRENT STEP RESPONSE TECHNIQUE, Ackermann,& Mott, August 16, 1978.

10. Letter, T.W.Kerlin (AMS) to P.S.Kapo (NRC), April 28, 1980

11. TEC LCSR METHOD TEST RESULTS, Letter from R.E.Uhrig (FPL) to R.W.Reid (NRC), December 4, 1979.

3/4.3.2 ENGINEERED SAFETY FEATURE ACTUATION SYSTEM INSTRUMENTATION

LIMITING CONDITION FOR OPERATION

3.3.2 The Engineered Safety Feature Actuation System (ESFAS) instrumentation channels and bypasses shown in Table 3.3-3 shall be OPERABLE with their trip setpoints set consistent with the values shown in the Trip Setpoint column of Table 3.3-4 and with RESPONSE TIMES as shown in Table 3.3-5.

APPLICABILITY: As shown in Table 3.3-3.

ACTION:

a. With an ESFAS instrumentation channel trip setpoint less conservative than the value shown in the Allowable Values column of Table 3.3-4, declare the channel inoperable and apply the applicable ACTION requirement of Table 3.3-3 until the channel is restored to OPERABLE status with the trip setpoint adjusted consistent with the Trip Setpoint value.

b. With an ESFAS instrumentation channel inoperable, take the ACTION shown in Table 3.3-3.

SURVEILLANCE REQUIREMENTS

4.3.2.1 Each ESFAS instrumentation channel shall be demonstrated OPERABLE by the performance of the CHANNEL CHECK, CHANNEL CALIBRATION and CHANNEL FUNCTIONAL TEST operations for the MODES and at the frequencies shown in Table 4.3-2.

4.3.2.2 The logic for the bypasses shall be demonstrated OPERABLE during the at power CHANNEL FUNCTIONAL TEST of channels affected by bypass operation. The total bypass function shall be demonstrated OPERABLE at least once per 18 months during CHANNEL CALIBRATION testing of each channel affected by bypass operation.

4.3.2.3 The ENGINEERED SAFETY FEATURES RESPONSE TIME of each ESFAS function shall be demonstrated to be within the limit at least once per 18 months. Each test shall include at least one channel per function such that all channels are tested at least once every N times 18 months where N is the total number of redundant channels in a specific ESFAS function as shown in the "Total No. of Channels" Column of Table 3.3-3.

TABLE 3.3-5

ENGINEERED SAFETY FEATURES RESPONSE TIMES

INITIATING SIGNAL AND FUNCTION	RESPONSE TIME IN SECONDS
1. Manual	
a. SIAS	
Safety Injection (ECCS)	Not Applicable
Containment Isolation	Not Applicable
Shield Building Filtration System	Not Applicable
Containment Purge Valve Isolation	Not Applicable
b. CSAS	
Containment Spray	Not Applicable
c. CIAS	
Containment Isolation	Not Applicable
Shield Building Filtration System	Not Applicable
Containment Purge Valve Isolation	Not Applicable
d. MSIS	
Main Steam Isolation	Not Applicable
e. SBFAS	
Shield Building Filtration System	Not Applicable
f. SRAS	
Containment Sump Recirculation	Not Applicable
g. CPAS	
Containment Purge Valve Isolation	Not Applicable
h. CCAS	
Containment Cooling	Not Applicable
i. EFAS	
Emergency Feedwater Pumps	Not Applicable

TABLE 3.3-5 (Continued)

ENGINEERED SAFETY FEATURES RESPONSE TIMES

INITIATING SIGNAL AND FUNCTION	RESPONSE TIME IN SECONDS
2. Pressurizer Pressure-Low	
a. Safety Injection (ECCS)	≤ ___*/___**
b. Containment Isolation	≤ ___*/___**
c. Shield Building Filtration System	≤ ___*/___**
d. Containment Cooling	≤ ___*/___**
3. Containment Pressure-High	
a. Safety Injection (ECCS)	≤ ___*/___**
b. Containment Isolation	≤ ___*/___**
c. Shield Building Filtration System	≤ ___*/___**
d. Containment Cooling	≤ ___*/___**
4. Containment Pressure--High-High	
a. Containment Spray	≤ ___*/___**
5. Containment Radiation-High	
a. Containment Purge Valves Isolation	≤ ____/____**
b. Shield Building Filtration System	≤ ___*/___**
6. Steam Generator Pressure-Low	
a. Main Steam Isolation	≤ _____/_____**
b. Emergency Feedwater	≤ _____/_____**
7. Refueling Water Storage Tank-Low	
a. Containment Sump Recirculation	≤ _____/_____**
8. 4.16 Kv Emergency Bus Undervoltage (Loss of Voltage)	
a. Loss of Power	≤ _____
9. 4.16 kv Emergency Bus Undervoltage (Degraded Voltage)	
a. Loss of Power	≤ _____

TABLE 3.3-5 (Continued)

ENGINEERED SAFETY FEATURES RESPONSE TIMES

INITIATING SIGNAL AND FUNCTION	RESPONSE TIME IN SECONDS
10. Steam Generator Level-Low	
a. Emergency Feedwater	≤ ____*/____**
11. Steam Generator WP-High-Coincident With Steam Generator Level Low	
a. Emergency Feedwater	≤ ____*/____**

NOTE: Response time for Motor-Driven Auxiliary Feedwater Pumps on all S.I. signal starts	≤ (60.0)

TABLE NOTATION

*Diesel generator starting and sequence loading delays included. Response time limit includes movement of valves and attainment of pump or blower discharge pressure.

**Diesel generator starting and sequence loading delays not included. Offsite power available. Response time limit includes movement of valves and attainment of pump or blower discharge pressure.

BASES

3/4.3.1 and 3/4.3.2 REACTOR PROTECTIVE AND ENGINEERED SAFETY FEATURES (ESF) INSTRUMENTATION

The OPERABILITY of the reactor protective and ESF instrumentation systems and bypasses ensure that 1) the associated ESF action and/or reactor trip will be initiated when the parameter monitored by each channel or combination thereof reaches its setpoint, 2) the specified coincidence logic is maintained, 3) sufficient redundancy is maintained to permit a channel to be out of service for testing or maintenance, and 4) sufficient system functional capability is available for protective and ESF purposes from diverse parameters.

The OPERABILITY of these systems is required to provide the overall reliability, redundancy and diversity assumed available in the facility design for the protection and mitigation of accident and transient conditions. The integrated operation of each of these systems is consistent with the assumptions used in the accident analyses.

The surveillance requirements specified for these systems ensure that the overall system functional capability is maintained comparable to the original design standards. The periodic surveillance tests performed at the minimum frequencies are sufficient to demonstrate this capability.

The measurement of response time at the specified frequencies provides assurance that the protective and ESF action function associated with each channel is completed within the time limit assumed in the accident analyses. No credit was taken in the analyses for those channels with response times indicated as not applicable.

Response time may be demonstrated by any series of sequential, overlapping or total channel test measurements provided that such tests demonstrate the total channel response time as defined. Sensor response time verification may be demonstrated by either 1) in place, onsite or offsite test measurements or 2) utilizing replacement sensors with certified response times.

3/4.3.3 MONITORING INSTRUMENTATION

3/4.3.3.1 RADIATION MONITORING INSTRUMENTATION

The OPERABILITY of the radiation monitoring channels ensures that 1) the radiation levels are continually measured in the areas served by the individual channels and 2) the alarm or automatic action is initiated when the radiation level trip setpoint is exceeded.