# ATTACHMENT 4

# CALDON, INC.

# ENGINEERING REPORT-160

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# CALDON, INC.

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**Supplement to Topical Report ER-80P:**
**Basis for a Power Uprate**
**With the LEFM✓ ™ System**

## Revision 0

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**Supplement to Caldon Topical Report ER-80P:**
**Basis For A 1.4% Power Uprate**
**With The LEFM✓**

## 1. Purpose and Background

On May 3, 2000, the NRC approved a rule change amending 10CFR50 Appendix K to permit power increases based on improvements in accuracy of the instrumentation used to measure thermal power. These power increases, referred to as "Appendix K Uprates", are relatively small increases on the order of 1% to 1.7%, depending on the demonstrated instrument accuracy. The purpose of this supplement is to provide a basis for a 1.4% uprate using Caldon's LEFM✓ system to measure thermal power.

## 2. Probabilistic Basis for Power Uprate

A power uprate can be obtained based on improved accuracy of the instrumentation used to measure thermal power, in accordance with the Appendix K rule change described above. As shown in Table 1, the LEFM✓ measures thermal power to within ±0.6%. To assess the increase in thermal power rating appropriate to the use of the LEFM✓, this discussion will interpret the meaning of the data of Tables 1 and 2 on a probabilistic basis.

When they developed standards for the measurement of steam turbine heat rate in power plants, the ASME performed a series of Monte Carlo analyses which demonstrated that, if the uncertainty elements of a measurement system are calculated on a 2 standard deviation basis, the uncertainty in the overall measurement that results is characterized by a normal distribution with 2 standard deviations equal to the root sum square of appropriately weighted individual elements (Reference 1). This result held even when the uncertainties of individual elements were not normally distributed. For example, a particular element might be characterized by a "roulette wheel" (flat) distribution between defined uncertainty bounds. It was subject only to one condition: that no single element dominate the calculation of the overall uncertainty.

While it is not obvious, the tabulations in Tables 1 and 2 meet this condition. The profile factor uncertainty of the LEFM✓ in Table 1 appears dominant, but is, in fact, made up of four elements, none of which is dominant. Similarly, the instrumentation allowance in Table 2 appears dominant, but is in fact made up of numerous elements in several instruments. Therefore, the overall uncertainties described in Tables 1 and 2 are likely to be normally distributed. Furthermore, the sensitivity of the results to the nature of the elemental uncertainty distribution has been investigated as described in Reference 2. This investigation shows that the distribution of the total uncertainty is likely to be normal whether the contributors are each normally distributed or distributed in roulette wheel fashion.

Table 1 implies a distribution wherein one standard deviation of LEFM✓ uncertainty is about ±0.3% full power. As shown in Table 3, with this distribution there is essentially no chance (less than one in 3 million) that an operator using the LEFM✓ to determine thermal power will exceed a power level 1.5% above that to which he is controlling. Here the odds have been computed on the basis of 5 standard deviations (Appendix to this Supplement). Similarly, Table 2 implies a normal distribution of nozzle-based uncertainty with one standard deviation of ±0.7%. As shown in Table 3, the odds of exceeding a power 3.5% above that indicated by the current instrumentation are similarly small. The one sigma value of 0.7% assumed for uncertainty of venturi-based power measurement is regarded by the NRC as representative of the low end of the scale for venturi-based uncertainty. Specifically, the NRC states, "Generally, the single loop uncertainty for thermal power appears to range from 1.8% to over 3% of power when using a venturi to measure feedwater flow based on a review of various Westinghouse PWR plants" (Reference 4).

**Table 3. Probabilities and Odds Associated With Nozzle and LEFM Uncertainty Bounds**

| Number of Standard Deviations | Venturi Nozzle Bounds (±) | LEFM✓ Bounds (±) | Probability of Operation Within Bounds | Odds of Exceeding Bounds on the High Side |
|---|---|---|---|---|
| 1 | 0.7% | 0.3% | 68% | 1/6.3 |
| 2 | 1.4% | 0.6% | 95.4% | 1/44 |
| 3 | 2.1% | 0.9% | 99.7% | 1/741 |
| 4 | 2.8% | 1.2% | 99.994% | 1/32,300 |
| 5 | 3.5% | 1.5% | 99.99994% | 1/3.3 million |

To clarify the basis for a power increase with use of the LEFM✓, the results of Table 3 are shown graphically in Figures 1 through 3. All three figures show power level (as a percent of the pre-uprate 100% power) along the "x" axis, and probability data along the "y" axis. All three figures illustrate both operation with the current instrumentation at the current 100% power level and operation with the LEFM✓ at a 1.4% power increase.

Figure 1 shows the probable operating ranges. As expected, the curves peak at the power level where operation is intended, and fall off symmetrically on either side of the peak. Of greater interest from the standpoint of operating safety is the probability that any given power level will be exceeded, as shown in Figure 2. As Figure 2 shows, the probability of exceeding a given power level is 100%, or a sure thing, just prior to the intended power level. The probability for each case equalizes at 102% power, which is the power level at which most plants' safety systems are analyzed for proper performance. Figure 3 presents the same data as Figure 2, but focuses in the vicinity of 102% power where the probability curves for the LEFM✓ and current instrumentation intersect. Though the intended operating point is higher for the LEFM✓ system due to the power increase, the probability of exceeding 102% power is the same for both instruments. In other words, the probability of exceeding the analyzed power level of 102% is the same for the current instrumentation operating at 100% as for the LEFM✓operating at 101.4%.

Figure 3 also shows another advantage of more accurate power measurements. As power measurement precision increases, the chance of a significant overpower incident decreases. For example, a plant equipped with flow nozzles, intending to operate at 100% of its licensed power, has about a 1 in 100 chance of exceeding 102.3%. On the other hand, the same plant, equipped with the LEFM✓, and intending to operate at 101.4% of its (previous) licensed power, has less than a 1 in 741 chance of exceeding 102.3%. (These odds are based on Table 3.)

There are two assumptions critical to the preceding discussion of thermal power margin. First, the necessity of an uncertainty distribution that is normal has been discussed and, based on the ASME studies and the Appendix, is satisfied. The second is that Tables 1 and 2 *actually describe* the performance of the instruments in service. Verification that the LEFM systems are operating within their design bounds is provided continuously, as mentioned above and discussed in detail in Reference 2. But there is no comparable on-line assurance that current nozzle-based instrumentation is operating within its design bounds. This is the basis for the conclusion that power increases with LEFM systems increase safety.

## 3. Benefits of On-Line Verification

To illustrate the benefits of on-line verification, Figure 4 shows the results of a survey of sustained overpower events reported in Licensee Event Reports from 1981 through 1999 (Reference 3). The 61 identified events have been categorized by cause in order to examine whether they would have been preventable with the on-line verification capabilities of LEFM systems. Figure 4 illustrates that the LEFM systems with on-line verification would have prevented all significant sustained overpower events. Looking at the extremes, five cases have been reported in Licensee Event Reports where steady state overpower has occurred in an amount not consistent with the probability predictions implied by Table 3; i.e., operation at 2% or more beyond the licensed power level. The causes for these events are summarized in Table 4.

**Table 4. Sustained Overpower Events Above 102% and Their Causes**

| LER Number | Reported Power Excursion | Reported Duration | Reported Cause of Event |
|---|---|---|---|
| 82-002 | 2.7% | 46 days | Differential pressure transmitter found out of tolerance. |
| 87-069 | 2.1% | 2 days | Procedural - nuclear instruments interval and deadband error allowed beyond limit. |
| 88-035 | 2%-3% | 10 days | Hole in venturi pressure tap. |
| 91-012 | 2.09% | 5 years | Core power calculation error; improper density compensation. |
| 94-002 | 2.6% | 8 months | Perimeter bypass flow of venturi feed nozzles. |

In three of these cases, the sustained overpower event was the result of the instrumentation system (transmitters or nozzles) failing to operate as designed. The other two cases were due to procedural errors and improper density compensation. The common link in all of these cases is that there was no indication of a problem until an independent means of measurement or calculation was employed. There is currently no indication available to the operators for the accuracy of the thermal power measurement. All of these case would have been prevented by use of LEFM systems, because LEFM systems incorporate on-line verification features and real-time control room displays that prevent occurrences of subtle failure by providing operators continuous information about the measurement, and about the accuracy of the measurement.

It is the LEFM's ability to confirm on-line that it is performing within its accuracy bounds, as well as its high accuracy, that justifies a power uprate with its use. In addition to providing for a power uprate, LEFM systems will assure that the probability of exceeding the analyzed power level (i.e., 1.02 times the current licensed rating) by as little as 0.5% is negligibly small.

## 4. Using the LEFM✓ to Control Thermal Power

With the existing instrumentation, for each feedwater flow measurement, the differential pressure transmitters provide an output proportional to the differential pressure across the flow nozzle.

Resistance thermometers (or thermocouples) measure the feedwater temperature. Typically, these outputs are supplied to the plant computer where the density and enthalpy are calculated with the aid of synthesized ASME steam tables. The thermal power is then calculated, also by the plant computer.

It is anticipated that a licensee will make use of LEFM mass flow and temperature measurements by directly substituting the LEFM indications for the nozzle-based mass flow indication and the RTD temperature indications in the plant computer. The plant computer would then calculate enthalpy and thermal power as it does now. As an alternative, the calorimetric power can be manually calculated, using LEFM indications and following a prescribed procedure.

While this discussion is focused on operation at full power, it should be noted that LEFM systems provide accurate flow and temperature indications from synchronization to full power. The LEFM✓ may be used for thermal power determinations following synchronization at 10% to 15% power (when feedwater heating commences) and up to full power, with an accuracy better than the present instrumentation.

In order to maintain control of thermal power at 100 percent power, a real-time display of thermal power as calculated using the LEFM will be available in the main control room for the reactor operator's use. The operator will use this display to maintain reactor power at or below the licensed thermal rating, with a tolerance in accordance with current plant practice. The thermal power display will also present, in the same location as the thermal power value, a clear indication of the validity of the thermal power measurement as determined by LEFM diagnostics. For example, an audible alarm will annunciate to the operators when the LEFM is not operating within its design basis accuracy. This indication will be provided by the LEFM's on-line verification system, which is discussed in detail in Reference 2.

## 5. References


1. ANSI/ASME Power Test Code PTC 19.1 – 1985, Part 1 Measurement Uncertainty, Reaffirmed 1990.
2. Caldon Topical Report ER-80P, "Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM✓ System", Rev. 0.
3. Regan, J.,"Operation Near 100% Rated Thermal Power: Historical Licensee Event Reports", Proceedings of the 1999 ANS Winter Meeting, November 1999.
4. NRC SER dated March 8 1999, "Safety Evaluation by the Office of Nuclear Reactor Regulation Topical Report ER-80P, 'Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM System', Comanche Peak Steam Electric Station, Units 1 and 2 Docket Nos. 50-445 and 50-446"

**Figure 1. Probable Operating Ranges for the LEFMCheck System at Increased Power Levels**

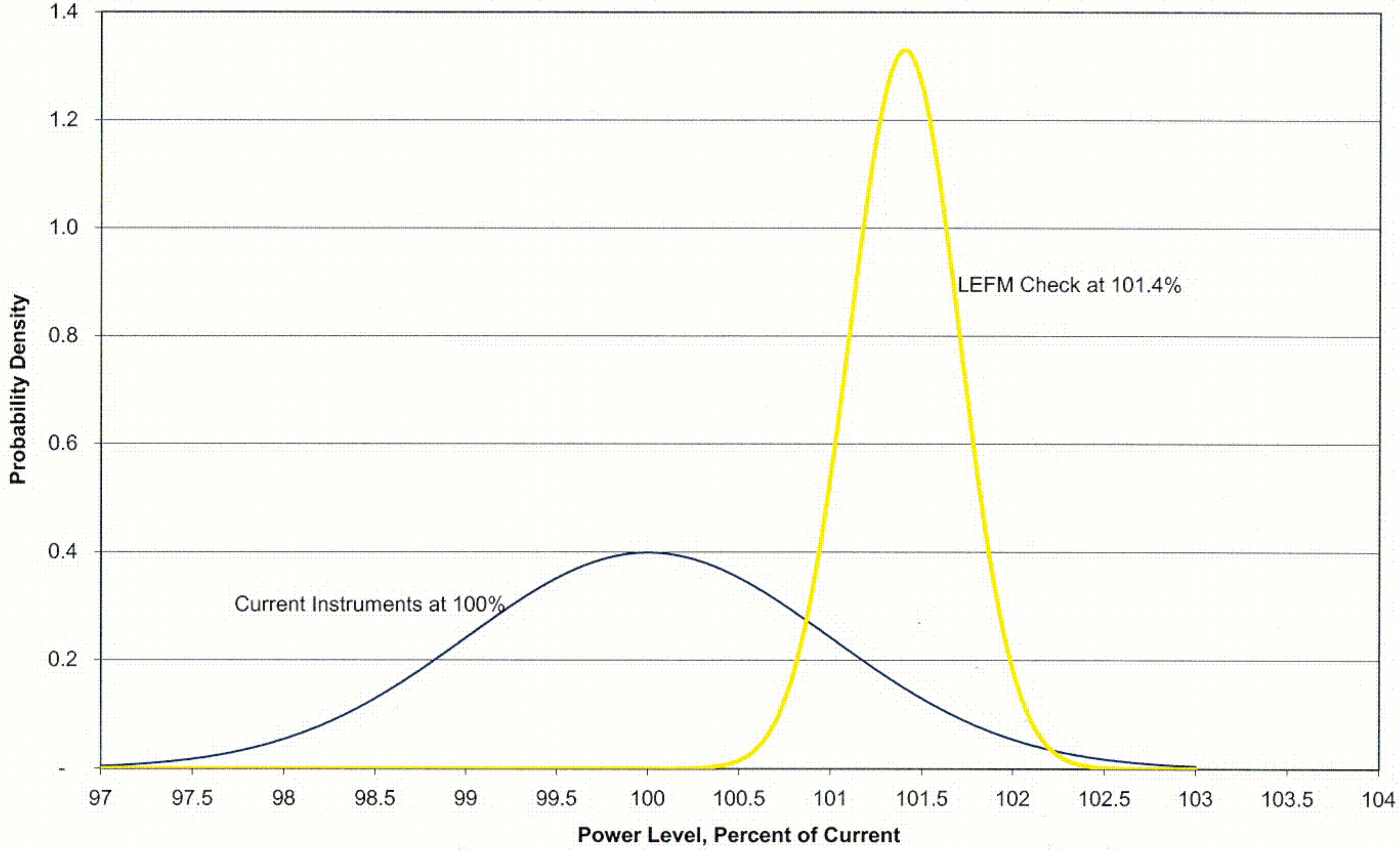




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**Figure 2. Probability of Exceeding Power Levels With the LEFMCheck System and Increased Power**

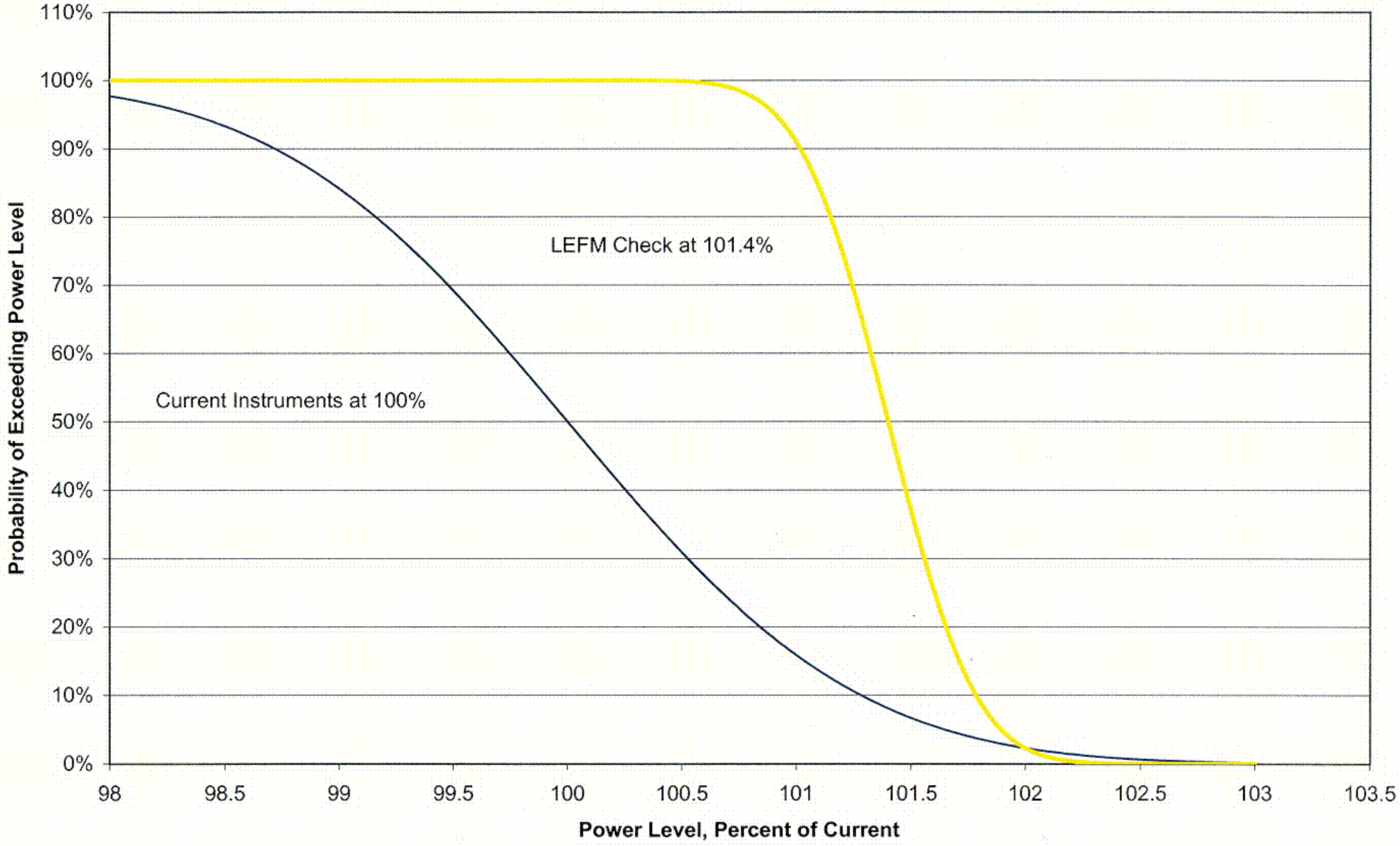




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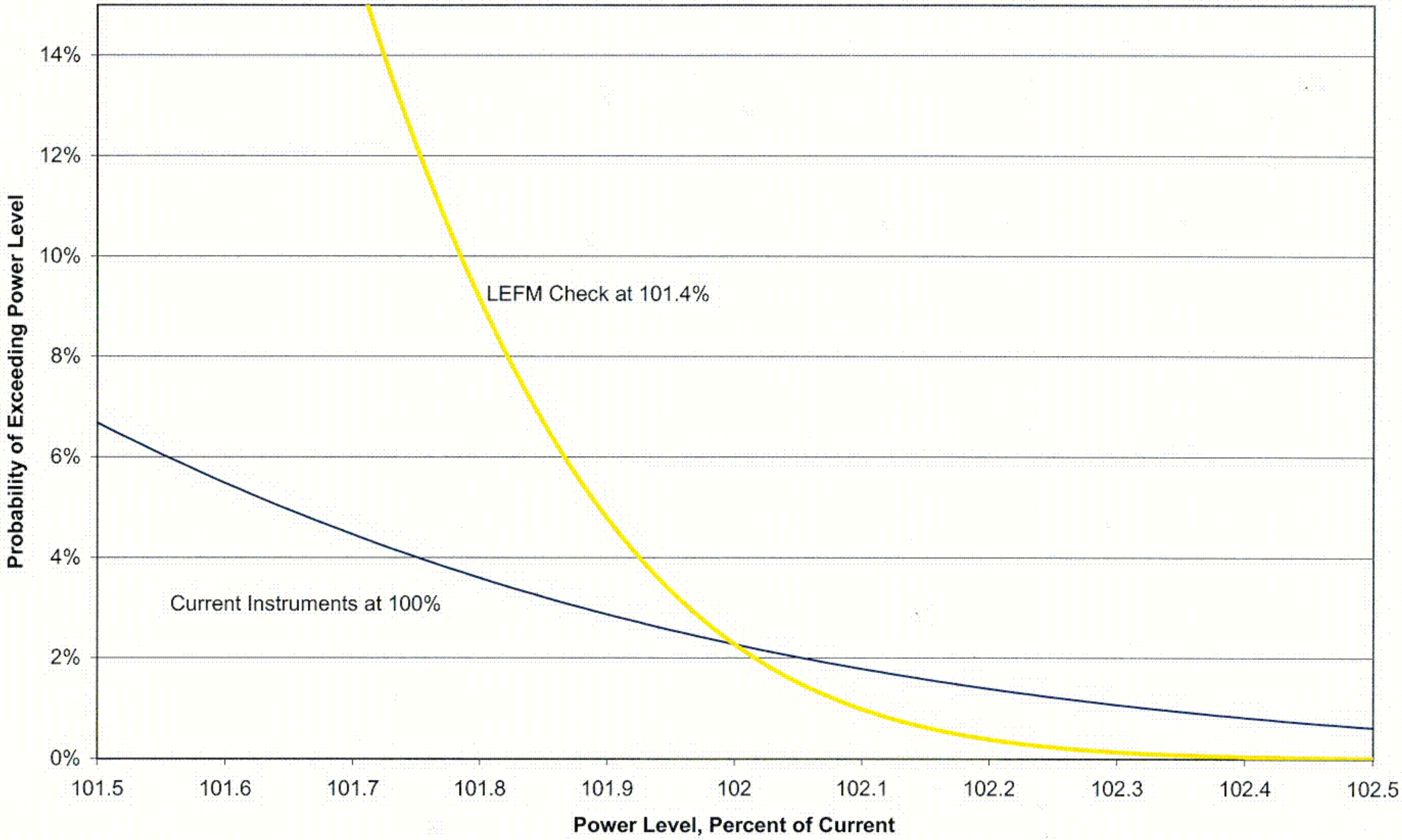
**Figure 3. Probability of Exceeding Power Level in the Vicinity of 102% Power**



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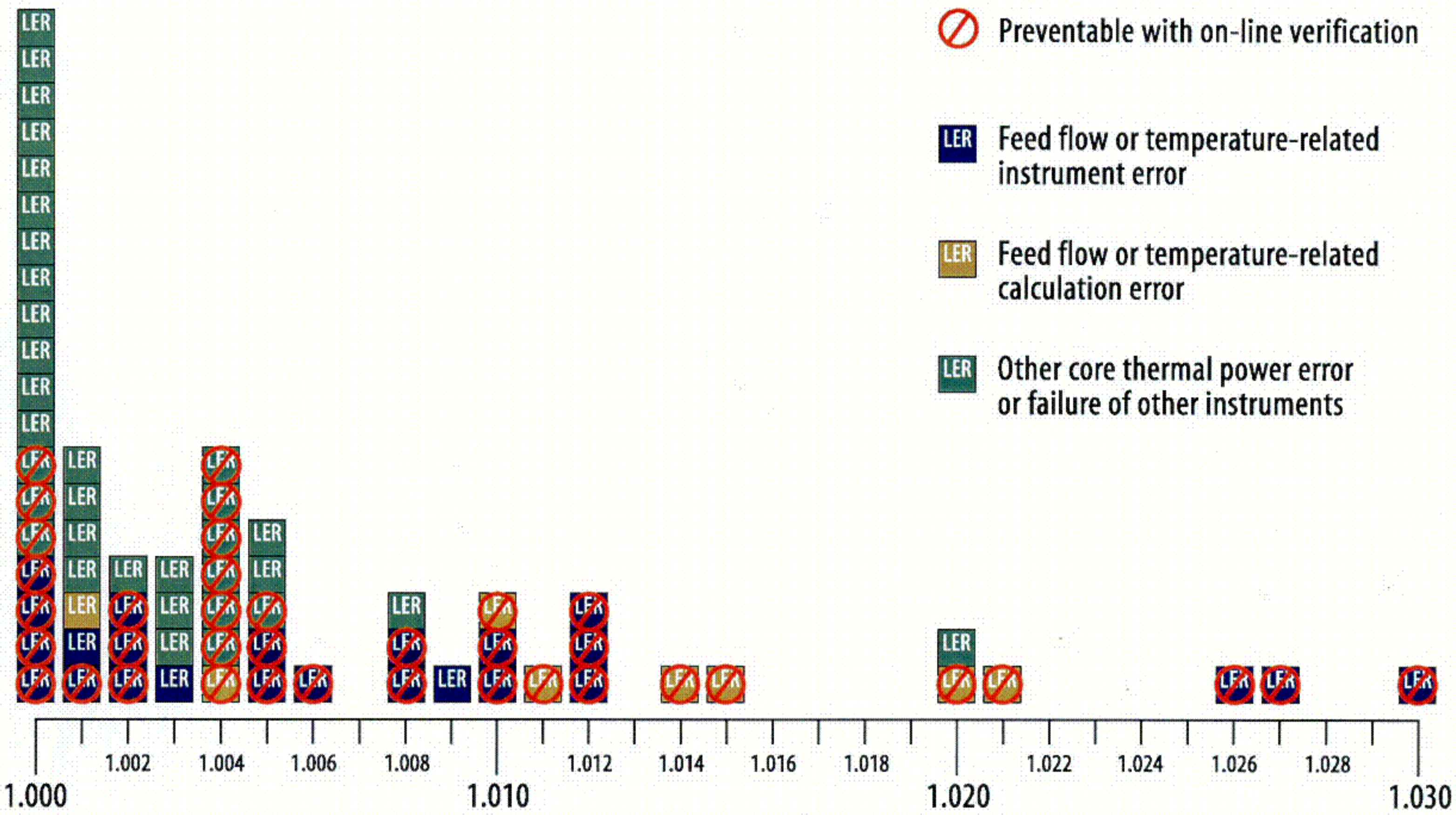


**Figure 4. Results of LER Survey 1982 – 1999**



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**Appendix is Proprietary to Caldon in its Entirety**