USING A PROBABILITY APPROACH TO RANK IN-LINE INSPECTION ANOMALIES FOR EXCAVATION AND FOR SETTING REINSPECTION INTERVALS

by

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ABSTRACT

A probability approach to ranking in-line inspection metal-loss anomalies is one alternative to simply ranking the anomalies by predicted failure pressure from the tool vendor's feature list. Advantages of a probabilistic approach are that the effects of tool inaccuracies can be considered on a rational basis, that a numerical probability of failure can be attached to any unexcavated anomaly, that the value of further excavations in succeeding years can be calculated, and that reinspection intervals can be assessed. The method explained in this paper considers the tool vendor's stated accuracy limits, allows for adjusting the limits if warranted by what is found upon excavation, and permits any desired number of scenarios for excavations and reinspections to be assessed. The approach is best suited for high-resolution tools, but it can be used with standard resolution tools if length and depths of anomalies are provided.

INTRODUCTION

The need to develop methods for maintaining the long-term integrity of pipeline systems, prioritizing maintenance, and developing reinspection intervals has been identified. Pipeline operators use in-line inspection results as a means for remediating corrosion concerns. Typically, this involves conducting an in-line inspection and excavating "significant" corrosion features identified by the tool. Corrosion is characterized as significant based upon the maximum depth of corrosion (e.g. greater than 50% wall loss) or the ratio between the predicted burst pressure and the maximum allowable operating pressure.

Statistical methods have been developed that utilize this basic approach of anomaly assessment from the in-line inspection data. These methods are referred to as Probability of Exceedance (POE) analyses.

APPROACH

In an ideal setting, perfect agreement would exist between a given tool's predicted depth and the actual depth of corrosion. Unfortunately, this is generally not the case. It is fairly common for tool vendors to claim an accuracy level for their tools of ± 10% of the anomaly depth 80% of the time. This translates to an accuracy of ± 15% with 95% confidence. To establish the true accuracy of the tool, it is possible to make a unity plot, as shown in Figure 1, given that the actual anomaly depth information is known. If most of the data lie within the 95% confidence bounds, the error introduced can be neglected in comparison to other inherent inaccuracies in the system.

Using these predicted values, along with operating and system information, a burst pressure is calculated for each anomaly using the modified B31G formula. In prioritizing internal inspection dig locations it is beneficial to begin by looking at these calculated anomaly burst pressures versus the pipeline operating pressures. This helps to highlight anomalies that are an imminent integrity concern and at what locations immediate action (i.e. lowering the operating pressure or excavating the anomaly) may be necessary. Figure 2 depicts a typical plot of this nature. Anomalies that are immediate integrity concerns are those that fall below the abnormal operating pressure. Those defects that lie between the abnormal operating pressure and 100% SMYS denote anomalies that are pressure limiting. Any anomalies with a predicted burst pressure above 100% SMYS pose no immediate concern of failure. Figure 3 depicts a typical plot of the anomalies remaining after an initial dig program.

The POE analysis methods evaluate the probability that, given a pig call, the depth of corrosion is greater than 80% of the wall thickness (potential leak) or the predicted burst pressure is less than the abnormal operating pressure (potential pressure failure).

Figure 4 shows the relationship between the probability that an anomaly will cause a leak to the percent depth associated with that anomaly. This probability calculation considers the confidence level placed on the inspection data. A normal distribution is assumed for the relationship of actual anomaly depth versus the tool predicted depth. From this normal distribution, the probability that an anomaly with a predicted depth of 80% will actually be 80% deep is 0.5. Approximately half of the samples in a population of 80% predicted anomaly depths will actually be greater than 80% and approximately half will be less than 80%.

The probability of the anomaly burst pressure being less than the abnormal operating pressure is calculated based on the RPR, or rupture pressure ration. This ratio is calculated by taking the ratio of the predicted burst pressure and 100% SMYS for the system. For each system, an RPR value is obtained that corresponds to a predicted burst pressure equal to the abnormal operating pressure of the system. The probability of an anomaly causing a failure is based on this RPR value. As the calculated RPR values increase from this base value, the probability of the anomaly causing a pressure failure decreases. As the calculated RPR value decreases from this point, the probability of the anomaly causing a pressure failure increases. Figure 5 depicts the relationship between the rupture failure probability and the RPR value.

The larger of either the probability of a leak or a rupture, the maximum probability of exceedance, is used to rank each of the anomalies. These anomaly probabilities can stand alone as a means of prioritizing anomalies. However, an advantage of the POE technique is that it can be used to rank corrosion anomalies by joint of pipe, by milepost, by incremental distance, or by pipeline. This process highlights those areas of the pipeline with many significant anomalies. A

POE value is obtained for the length of segment chosen by calculating a cumulative probability of all the individual probabilities, from the following equation.

$$POE_{segment} = 1 - (1-POE_1)(1-POE_2)\ldots(1-POE_n)$$

where POE_1, POE_2, POE_i are the POEs of the individual anomalies in the chosen segment. The expression $(1-POE_i)$ is the probability that the i^{th} anomaly will not leak or fail. One minus the product of the $(1-POE_i)$ values is the probability that a leak or failure will occur with the segment.

Another beneficial use of the POE method is that it is possible to examine the effects of corrosion rates on the growth of the anomalies over any chosen period of time. The corrosion rate is used to recalculate the anomaly depths and burst pressures. Typically, for an initial internal inspection, the corrosion rate is calculated by taking the anomaly depths and dividing them by the age of the line. In cases where inspections have been previously completed, the corrosion rate is calculated to be the difference in the anomaly depth divided by the years between inspections. This information can be used to plan reinspection intervals.

INTERPRETATION OF RESULTS

Depending on the desires of the user, the anomalies can be ranked on an individual basis, on a per mile basis or on a chosen incremental distance basis. A cumulative probability is calculated for all the anomalies within the desired segment. In the case of the incremental distance, the cumulative probability is calculated for a chosen segment length based on a moving increment in order to locate the areas of the pipeline with the largest probabilities of failure. Several approaches can be followed to identify excavation locations and to establish a reinspection interval. This can be accomplished by either identifying a maximum POE level to not exceed for this pipeline system or by identifying excavations that will be required to not exceed a maximum POE level.

Figure 6 depicts an example of how a dig program can be implemented to obtain a set probability level by year. Based on the maximum POE levels, the top curve shows the probabilities if no additional anomalies are excavated for the year. The curve beneath this represents a scenario where 7 additional anomalies are excavated within the first year and an additional 1 anomaly excavated in each year following. The remaining curves depict various other dig scenarios and their effect on the maximum remaining anomaly probabilities. Using this type of plot, one can select an acceptable POE level and perform the necessary digs to achieve this level.

Figure 7 shows the benefits of immediately eliminating the anomalies with the greatest probability of release. An initial probability level of 1.42×10^{-1} is associated with the "worst" anomaly. Excavating this anomaly and eight additional anomalies, the probability level drops significantly to a level on the order of 10^{-7}.

Another advantage of the POE method is that it enables one to plan maintenance options for a whole system of pipelines. The POE levels can be compared for various segments to determine which sections pose the greatest integrity risk. Figure 8 is a graph of the maximum anomaly probabilities from seven different pipeline segments. This graph can be used to determine the effect of a repair program on each of the pipelines or allows resources to be utilized on the line segments with the highest probability for release.

Table 1 shows a way to select maintenance options for conducting excavations in lieu of decreasing the time interval between inspections. Three desired POE levels were selected. The results show what actions need to be taken to ensure this probability level is maintained. For example, to maintain a probability level of 5×10^{-2} with a reinspection scheduled in 7 years, an initial 7 anomalies need to be addressed with 21 additional each year.

Table 1. Maintenance Options Using Various Anomaly POE Levels and Inspection Frequencies

Number of Features	Estimated Year for Next Inspection	Number of Additional Anomalies to be Addressed
To Maintain 1×10^{-1}		
7 + 1/year	2001 (3 yrs)	3
7 + 1/year	2003 (5 yrs)	5
7 + 1/year	2005 (7 yrs)	7
7 + 1/year	2008 (10 yrs)	10
To Maintain 5×10^{-2}		
7 + 3/year	2001 (3 yrs)	9
7 + 3/year	2003 (5 yrs)	15
7 + 3/year	2005 (7 yrs)	21
7 + 3/year	2008 (10 yrs)	30
To Maintain 1×10^{-2}		
7 + 7/year	2001 (3 yrs)	21
7 + 7/year	2003 (5 yrs)	35
7 + 7/year	2005 (7 yrs)	49
7 + 7/year	2008 (10 yrs)	70

Another way to examine results of the POE analysis is presented in Table 2. The incremental POE feature can be used to determine the number of dig locations and the total pipeline footage necessary to obtain a preset probability level. This allows anomalies that are grouped together to be efficiently repaired. To maintain, for example, a probability level of 5×10^{-2}, 10 [40 foot] segments need to be addressed by the year 2001. The footages selected for the incremental analysis are chosen to determine the point at which maintenance actions are optimized.

Table 2. Maintenance Options Using Incremental Pipeline Segments for Various POE Levels and Inspection Frequencies

Year	40 ft. Incremental Segments to Address		100 ft. Incremental Segments to Address	
To Maintain 1 x 10^{-1}				
2000	6 Segments	120 ft. Total	7 Segments	200 ft. Total
2001	9 Segments	160 ft. Total	9 Segments	320 ft. Total
2003	11 Segments	200 ft. Total	12 Segments	480 ft. Total
To Maintain 5 x 10^{-2}				
2000	8 Segments	170 ft. Total	9 Segments	220 ft. Total
2001	10 Segments	210 ft. Total	12 Segments	420 ft. Total
2003	13 Segments	270 ft. Total	14 Segments	630 ft. Total
To Maintain 1 x 10^{-2}				
2000	10 Segments	210 ft. Total	12 Segments	660 ft. Total
2001	12 Segments	270 ft. Total	14 Segments	720 ft. Total
2003	15 Segments	330 ft. Total	17 Segments	800 ft. Total

CONCLUSION

The probability of exceedance method is a practical tool to aid in efficiently prioritizing in-line corrosion tool data. The results can be used to budget multi-year remediation and to calculate reinspection intervals. Multiple line segments can be plotted together to assist in budgeting resources.

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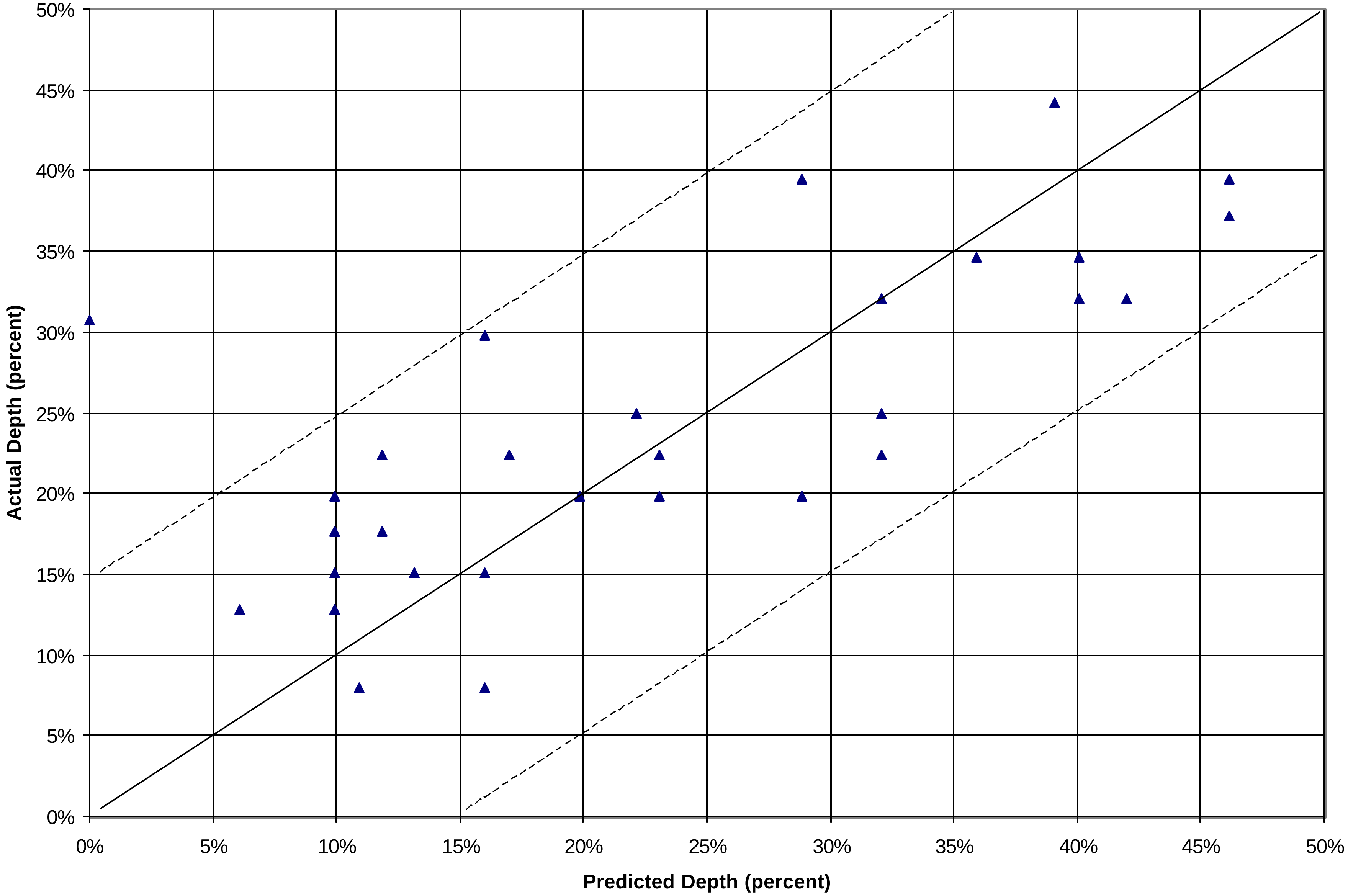

Figure 1. Unity Graph St. James to Garyville 30"

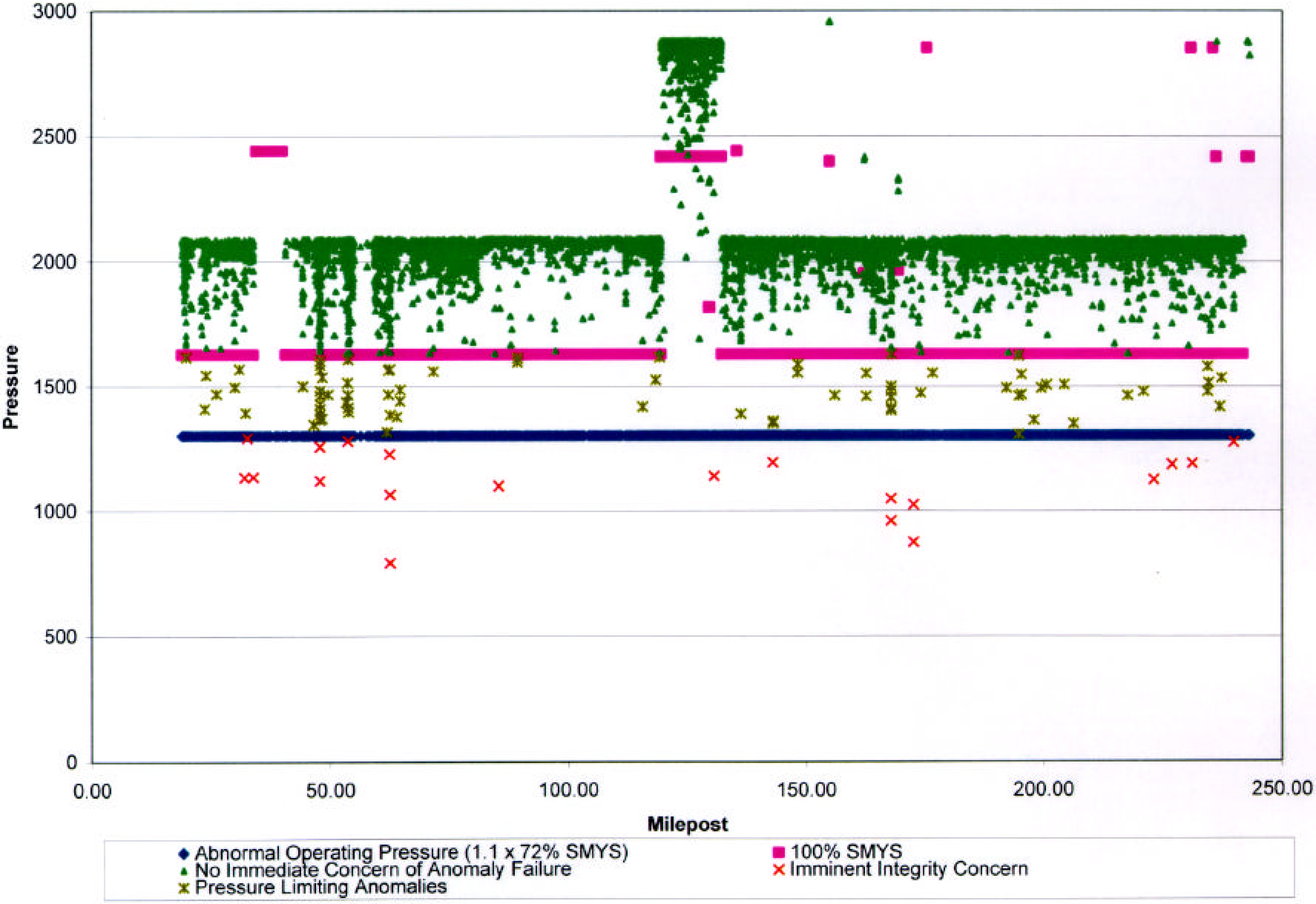

Figure 2. Pre-Investigation Predicted Burst Pressures

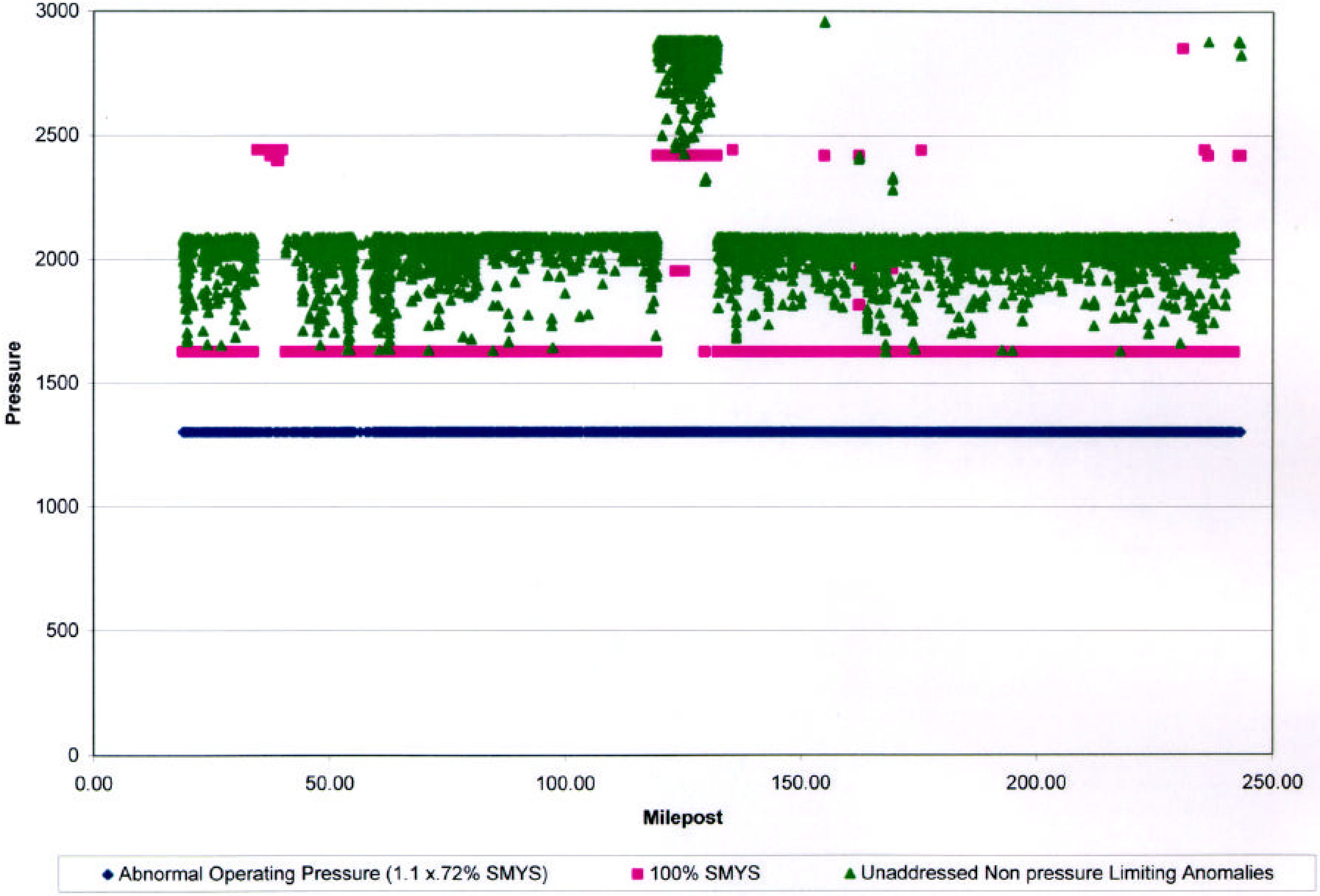

Figure 3. Unaddressed Predicted Burst Pressures (Post 1999 Work)

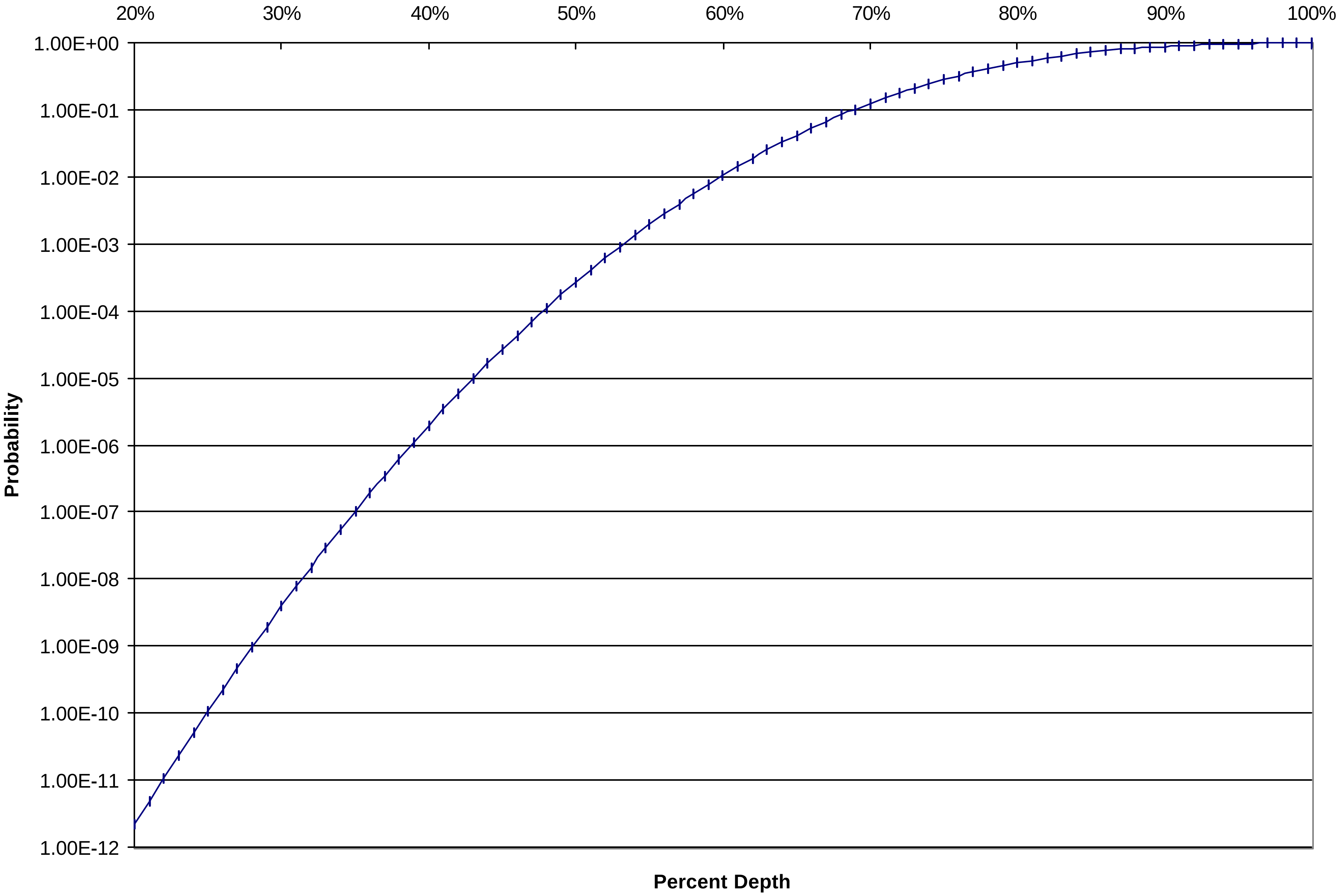

Figure 4. Relationship Between the Leak Probability and the Percent Depth

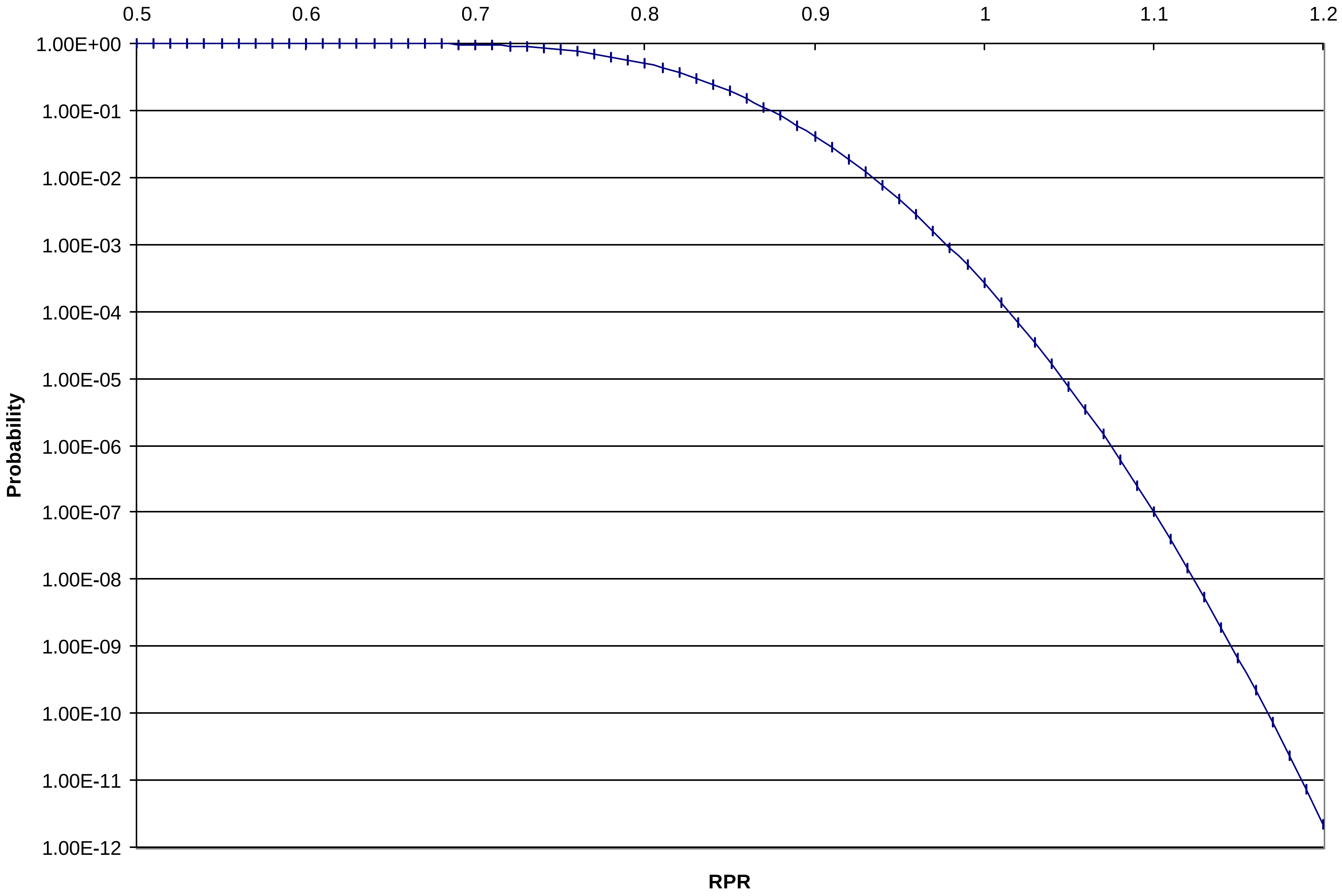

Figure 5. Relationship Between the Rupture Probability and the RPR

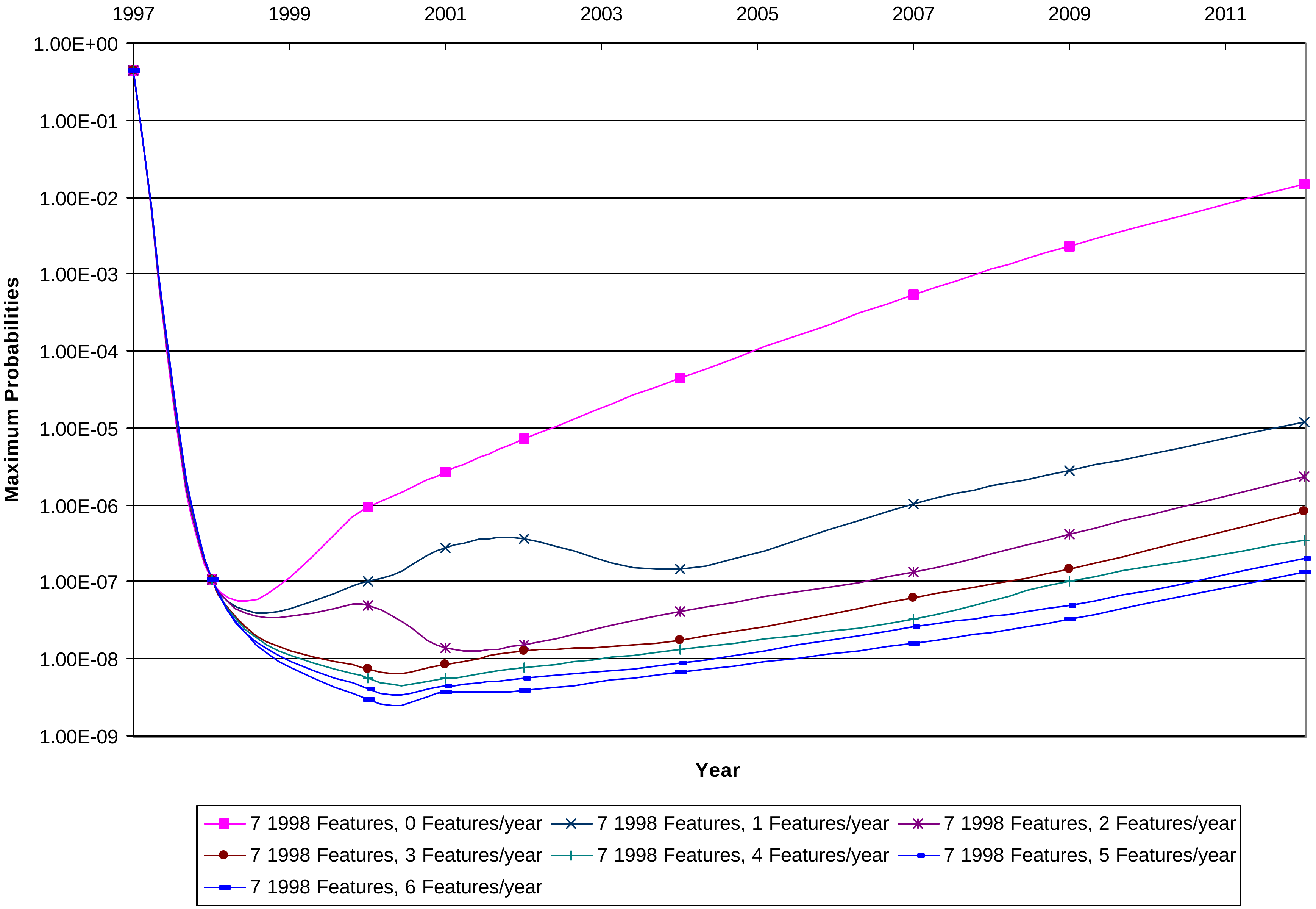

Figure 6. POE Levels Based on the Number of Digs Per Year

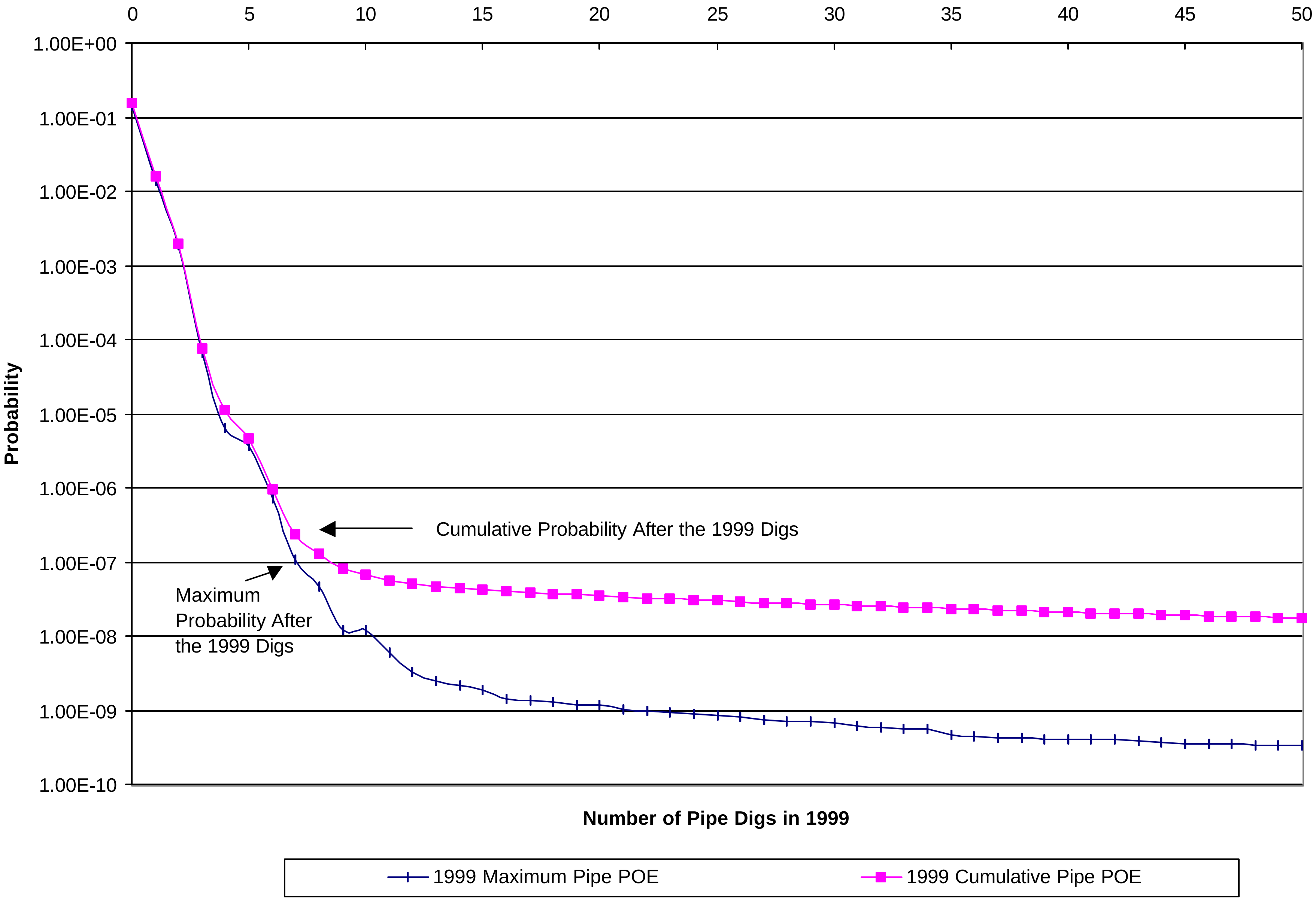

Figure 7. Largest 50 Anomaly Probabilities as of 1999

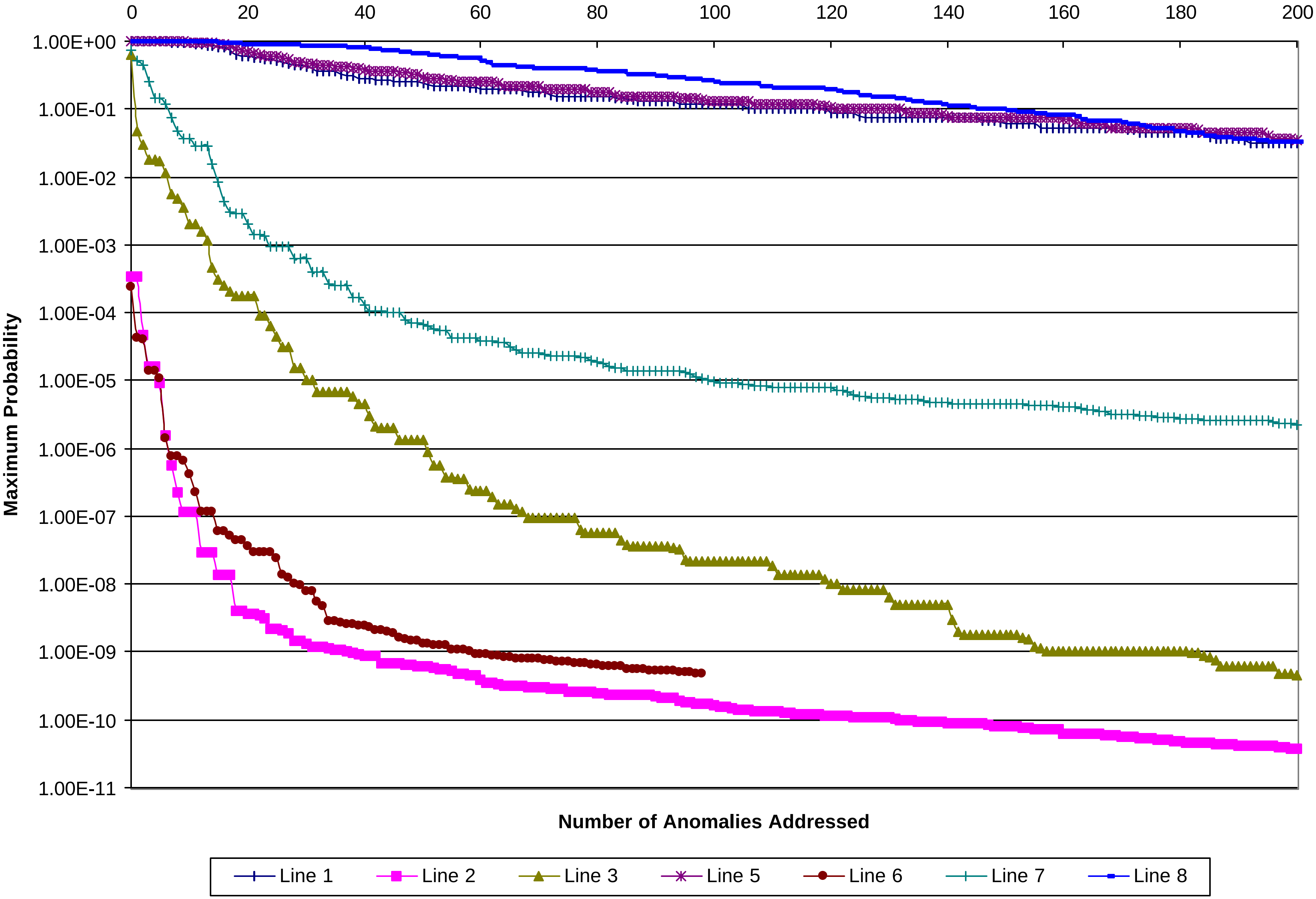

Figure 8. Multiple Line POE Graph