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Estimation of Maximum Wall Thickness Loss of Five DSTs (AN-107, AP-102, AW-101, AZ-102, and SY-101)

D. R. Weier
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Prepared for the U.S. Department of Energy
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Abstract

The DST Integrity Plan requires the ultrasonic wall thickness measurement of two vertical scans of the tank primary wall from a single riser. The resulting measurements are then used in an extreme value methodology to predict the minimum wall thickness expected for the entire tank. The methodology was developed in previous work by the authors of this report. A component of the methodology is to consider the possible impact of riser differences had multiple risers instead been used. The approach is based on previous analyses of Tank AY-101 which had measurements taken from multiple risers.

This report presents estimated maximum wall thickness loss for five DST's with associated uncertainty estimation and confidence bounds. Several sources of variability are incorporated since the individual sources cannot be separated. These sources include original manufacturing plate thickness and the precision of the measurement process, as well as loss due to corrosion, the actual feature of interest.

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Summary

The DST Integrity Plan (RPP-7574, 2003, *Double-Shell Tank Integrity Program Plan*, Rev. 1A, CH2M HILL Hanford Group, Inc., Richland, Washington.) requires the ultrasonic wall thickness measurement of two vertical scans of the tank primary wall from a single riser. The resulting measurements are then used in an extreme value methodology to predict the minimum wall thickness expected for the entire tank. The methodology was developed in previous work by the authors of this report and is referenced in this report. A component of the methodology is to consider the possible impact of riser differences had multiple risers instead been used. The approach is based on previous analyses of Tank AY-101 which had measurements taken from multiple risers.

The intent of this report is to present and describe estimated maximum wall thickness loss for five DST's. The table below gives the proposed maximum measured wall thickness loss estimates for these tanks relative to design nominal thicknesses; units are inches throughout. Note that several sources of variability are incorporated in these maximum loss estimates and related confidence bounds since the individual sources cannot be separated. The sources include original manufacturing plate thickness and the precision of the measurement process, as well as loss due to corrosion, the actual feature of interest.

Because the manufacturing variability and measurement uncertainty has not been characterized, they cannot be isolated. Estimates and bounds therefore refer to a worse-case "measured" thickness loss from nominal. In one sense such bounds would over-estimate losses due to corrosion since an "extreme-case" measurement error is incorporated as well. But in the opposite sense, design nominal plate thicknesses are used which are generally less than most actual original plate thicknesses since specifications tended to result in plates exceeding nominal (in fact, even after some loss due to corrosion, a significant number of the wall thickness measurements used here are still greater than nominal). This aspect would tend to under-estimate the true wall thickness loss. The two data features just described would tend to cancel out in their over- and under-estimation of wall thickness loss and related confidence bounds, but the degree that each would do so is unknown.

Tank	Maximum Loss Estimate (in inches)	95% Estimate Confidence Bound	95% Confidence Bound including Riser Differences
AN-107	0.030	0.041	0.054
AP-102	0.118	0.142	0.148
AW-101	0.040	0.048	0.063
AZ-102	0.092	0.131	0.134
SY-101	0.102	0.127	0.132

As discussed in the report, some outlying measurement values, which have considerable impact on results, have been discarded in generating these results. The "Maximum Loss Estimate" column gives the estimated maximum measured loss from nominal that would be expected if

the primary tank wall surface area were 100 percent inspected with the ultrasonic method. The first confidence bound column in the table then incorporates only the statistical uncertainty in the estimation process for the particular tank. It is impacted by the variability in the data for that tank, the number of measurements, and how well the Weibull distribution fits the data.

Based on the Tank AY-101 studies, the final column of the table also incorporates an additional standard deviation of 0.010 inch for riser differences. Incorporating this riser uncertainty has little impact when the estimate uncertainty is already relatively large. This is because with considerable variability in the estimation process within a riser, significant differences between risers are then more unlikely. When the estimate standard deviations are instead smaller, then bounds are increased more substantially by the riser uncertainty.

Discussion

The DST Integrity Plan requires the ultrasonic (UT) wall thickness measurement of two vertical paths down the tank wall from a single riser. The UT images are about 15 inches wide and 12 inches tall. In a vertical path a measurement is thus made every foot to obtain the vertical characterization. This typically generates 34 or 35 measurements in each path down across five plate courses. To generate estimates of the minimum wall thickness, only the minimum wall thickness value from each image is used even though the thickness is actually available at each of many thousands of pixels within an image.

The methodology was developed and used in previous reports. The extreme value estimation statistical methodology is given in [1]*Statistical Analyses of AY-101 Ultrasonic Measurements of Wall Thickness* by Weier. Initial riser difference treatment was discussed by Weier in a presentation to an Expert Panel[2].

To generate a worst case prediction for an entire tank, a three-parameter Weibull distribution is fit to the UT image minimum wall thicknesses (actually to the maximum losses from nominal). The number of such images that would be needed to inspect 100 percent of the tank walls is then computed and that percentile far out in the tail of the Weibull distribution tail is used as an estimate of the worst case loss that might be expected from this many images. Rather than providing only this worst case "point estimate" of maximum loss, statistical confidence bounds on the Weibull parameter estimates are used to generate confidence bounds on the worst case losses as well.

Such "estimate" confidence bounds are based only on the measurements from the particular tank. The tightness of the bounds will depend on the number of measurements available (the more measurements, the tighter the bounds), their inherent variability, and the quality of the Weibull fit to the data. Concerns about using only a single riser for such inspections were addressed in [3]Weier, Anderson, Berman (2005). In that work, measurements from multiple risers in Tank AY-101 were used to estimate an additional variability that might be expected if multiple risers had been used in a tank. This additional "riser uncertainty" is also incorporated into a second set of confidence bound estimates for a worst case wall thickness loss.
Figure 1 shows the ultrasonic measurement results for the five tanks. The step function nature of the plots is due to the plate design nominal thicknesses varying from their thinnest at the top of tank walls (to the left on the figures) to their thickest at the bottom of tank walls (to the right on the figures). The maximum nominal thicknesses are 0.875 inch in each tank, and the minimum nominal thicknesses are either 0.5 inch or 0.375 inch depending on the tank design. As mentioned, the measurements were taken at one foot increments down the tank walls in two separate but adjacent paths.

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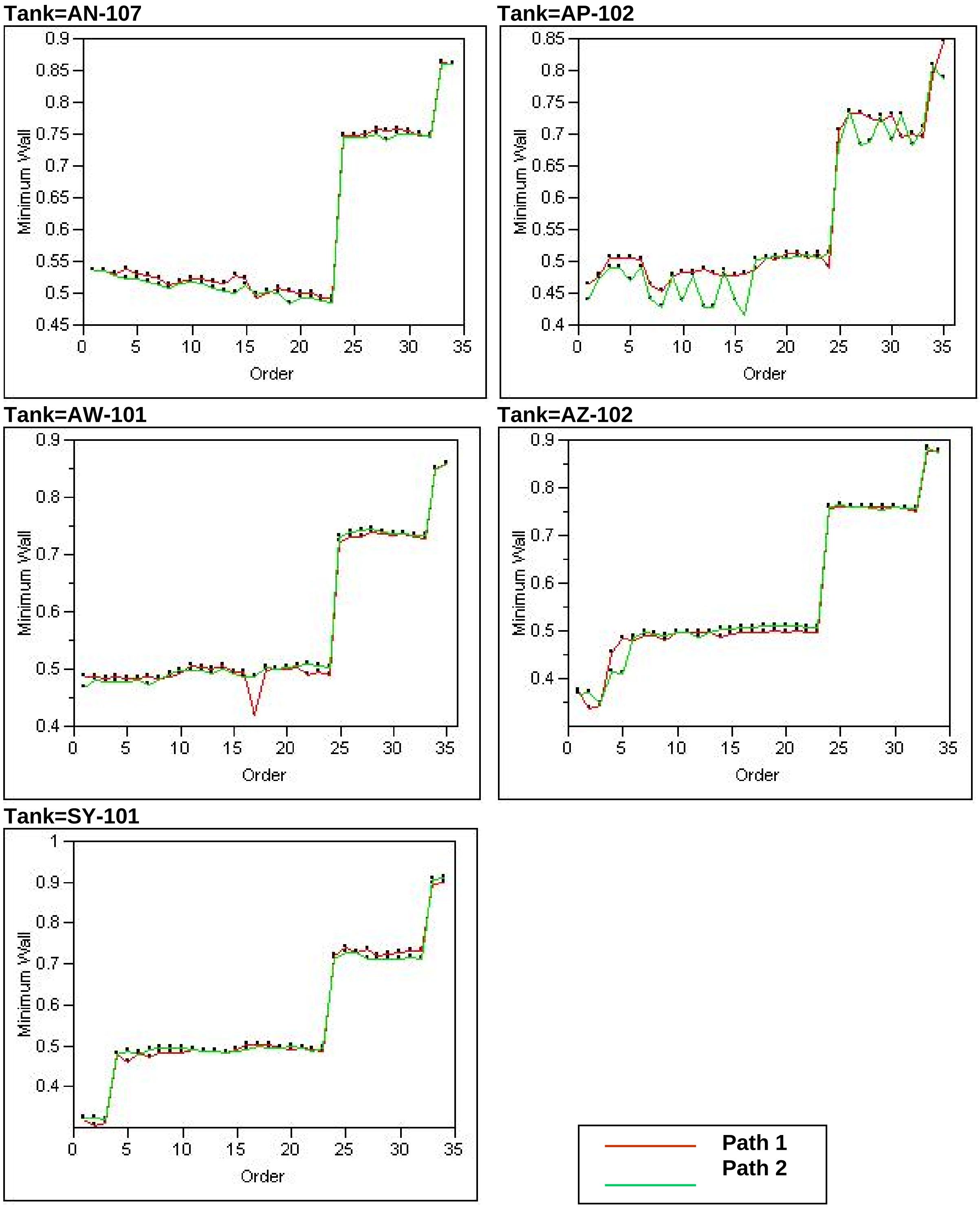
[1] D.R.Weier, *Statistical Analyses of AY-101 Ultrasonic Measurements of Wall Thickness*, PNNL-14106, October, 2002.
[2] Expert Panel Workshop for Hanford Site Double-Shell Tank Waste Chemistry Optimization, RPP-RPT-22126
[3] D.R.Weier, K.K. Anderson, H.S. Berman *Riser Difference Uncertainty Methodology Based on Tank AY-101 Wall Thickness Measurements with Application to Tank AN-107, Revision 1,* PNNL-15182, March, 2002.

Figure 1: Minimum Wall Thickness Plots
(measurements from left to right are from the top of the tank wall to the bottom)



Tank AN-107 results were discussed in Weier et al (2005). A particular measurement anomaly was addressed in that report. Part way down the tank wall for the second path, the measurement results suddenly diverged by about 0.030 inches. Discussion in the report indicated subject matter experts have suggested that current quality control procedures would not now allow that to happen. An “after-the-fact” adjustment was made to the data to compensate for this measurement anomaly. See the original report for additional discussion. The measurements shown in the top left plot in Figure 1 for AN-107 incorporate that adjustment.

Obviously in the Figure 1 plots, the major source of variability is the original design nominal thicknesses. This is eliminated in Figure 2 by subtracting the appropriate plate design nominal thickness from the wall thickness results. Recall that actual original plate thicknesses are unavailable, so only the design nominal is available to compute wall thickness losses.

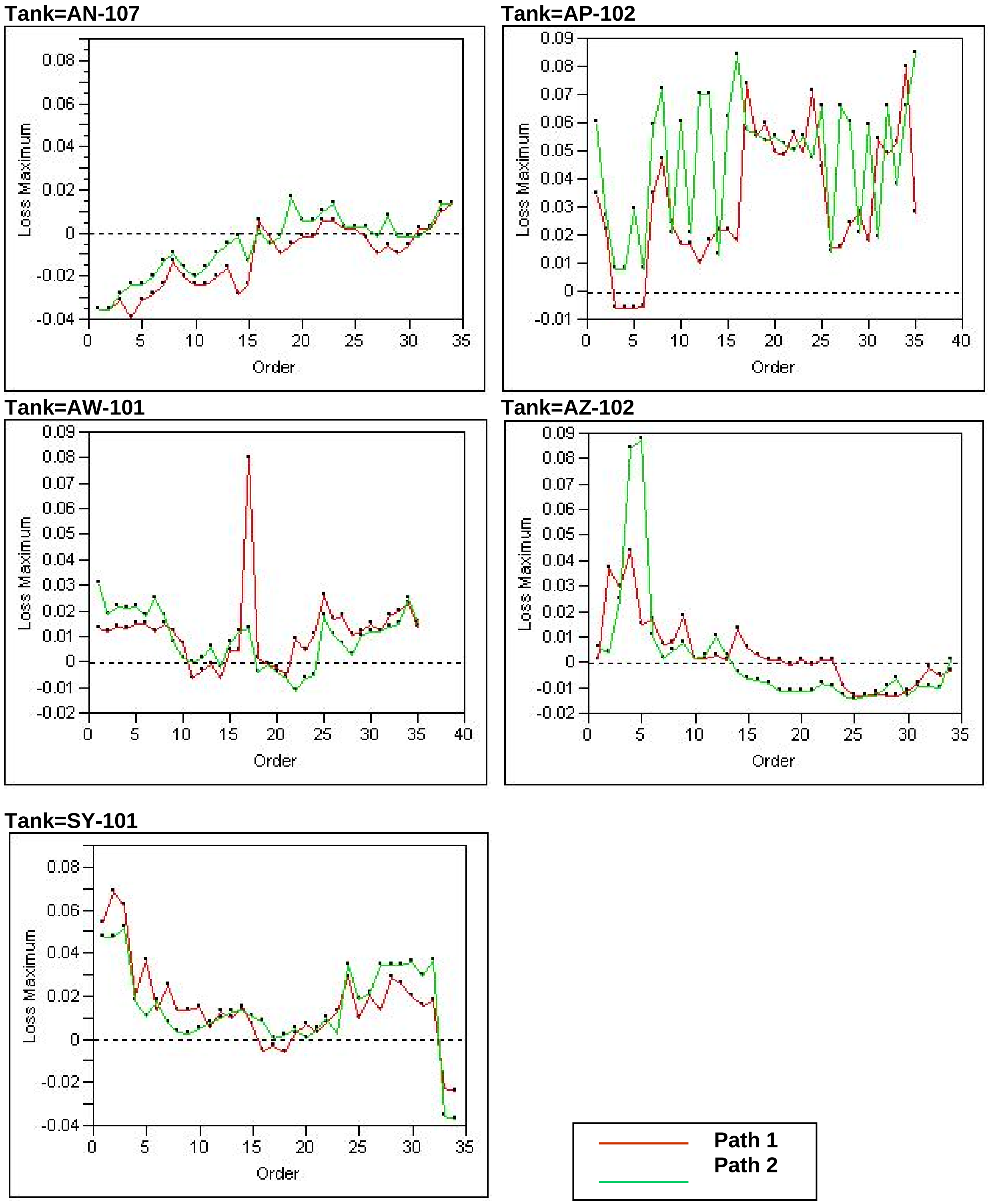
Some attempts were made to estimate individual plate thicknesses and to use those estimates in place of the design nominal, but then, in effect, one is just measuring the difference in a “best-case” and “worst-case” thickness for the plate. That approach was abandoned in deference to simply using design nominal to compute wall thickness losses which are plotted in Figure 2.

Particular data problems exist for several of the tanks that complicate the estimation process:

> For AN-107, it was already mentioned how a data shift for part of one path has been incorporated based on work in an earlier report.
>
> For AW-101 a single outlier is present that prevents a successful Weibull fit. That outlier was subsequently omitted from the analyses and is not included in the results that follow although it is displayed on the various figures.
>
> For AZ-102, two outliers were a problem as well. Analysis was done with and without those two values, with the decision made for final summary results omitting those outliers as well. Results are given later both ways.
>
> For SY-101 there are four very negative values (all from the bottom Plate 5); these are large wall thickness gains which are most certainly due to an exceptionally larger than nominal initial plate thickness. One would hope such gains would have little impact on predicting a worst case thickness at the other end of the distribution, but in fact that proves not to be the case. The fit of the Weibull distribution is considerably impacted by these numbers, which should actually be of little use in predicting worst case wall thickness loss. Again results are given with and without these wall thickness gains, and final results are proposed without them.

Results show that AN-107 walls appear the most pristine. Unfortunately, much of that result is due to wall thickness gains, apparently because some original plate thicknesses exceed nominal. AP-102 shows the most loss. The other tanks fall in between with SY-101 showing with the next most severe loss; but note that, again unfortunately, the worst losses are all from the top Plate 1 on the left of the plots in Figures 1 and 2. These losses may very well be due to

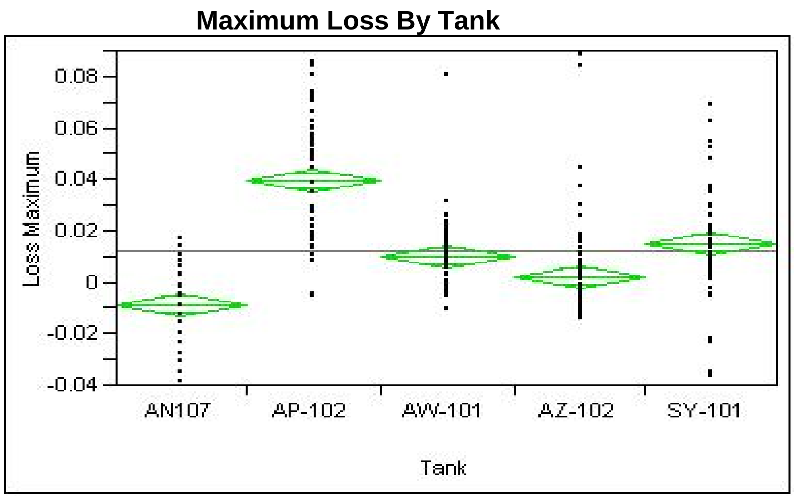
Figure 2: Maximum Loss Plots
(measurements from left to right are from the top of the tank wall to the bottom)



an exceptionally thin original plate thickness with respect to nominal. It is truly unfortunate that the original plate thicknesses are not available for these analyses.

Figure 3 compares the wall thickness results for the five tanks. The outlying values described are included in the figures and in the summary statistics. These summary statistics are generally in regard to the average wall thickness loss for the tanks, and that is not the primary interest in this report. Instead we are trying to predict a worst case loss well out into the right hand tail of a Weibull distribution to estimate a maximum loss that might be expected for the tank. But none-the-less, the figure shows a good comparison of the tank results. The vertical extent of the green diamonds can be interpreted as confidence intervals for the true average wall thickness loss in the respective tanks (also given in the last two columns of the table). Results again show AN-107 to have the least loss and AP-102 the most.

Figure 3: Average Maximum UT Image Losses by Tank



Maximum Loss Means

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
AN107	68	-0.00832	0.00223	-0.0127	-0.0039
AP-102	70	0.03999	0.00220	0.0357	0.0443
AW-101	70	0.01054	0.00220	0.0062	0.0149
AZ-102	68	0.00243	0.00223	-0.0020	0.0068
SY-101	68	0.01547	0.00223	0.0111	0.0199

Std Error uses a pooled estimate of error variance

Figure 4 shows distributions of wall thickness losses for the tanks with the resulting Weibull distribution fits. Note that the outlying values discussed are again included in these histograms but the Weibull fits do not incorporate their impact (the reasons for doing so are discussed later). These distributions are used to extrapolate into their tails to estimate an expected worst case maximum wall thickness loss. Depending on the tank design, something more than 6000 UT images would be needed for 100 percent inspection of the tank walls. If the precise number were in fact 6000, we would then seek the corresponding percentile of the Weibull. That is, we would seek that wall thickness loss that is expected to be exceeded with probability 1/6000 = 0.00017.

Figure 4: Maximum Loss Distributions with Weibull Distributions

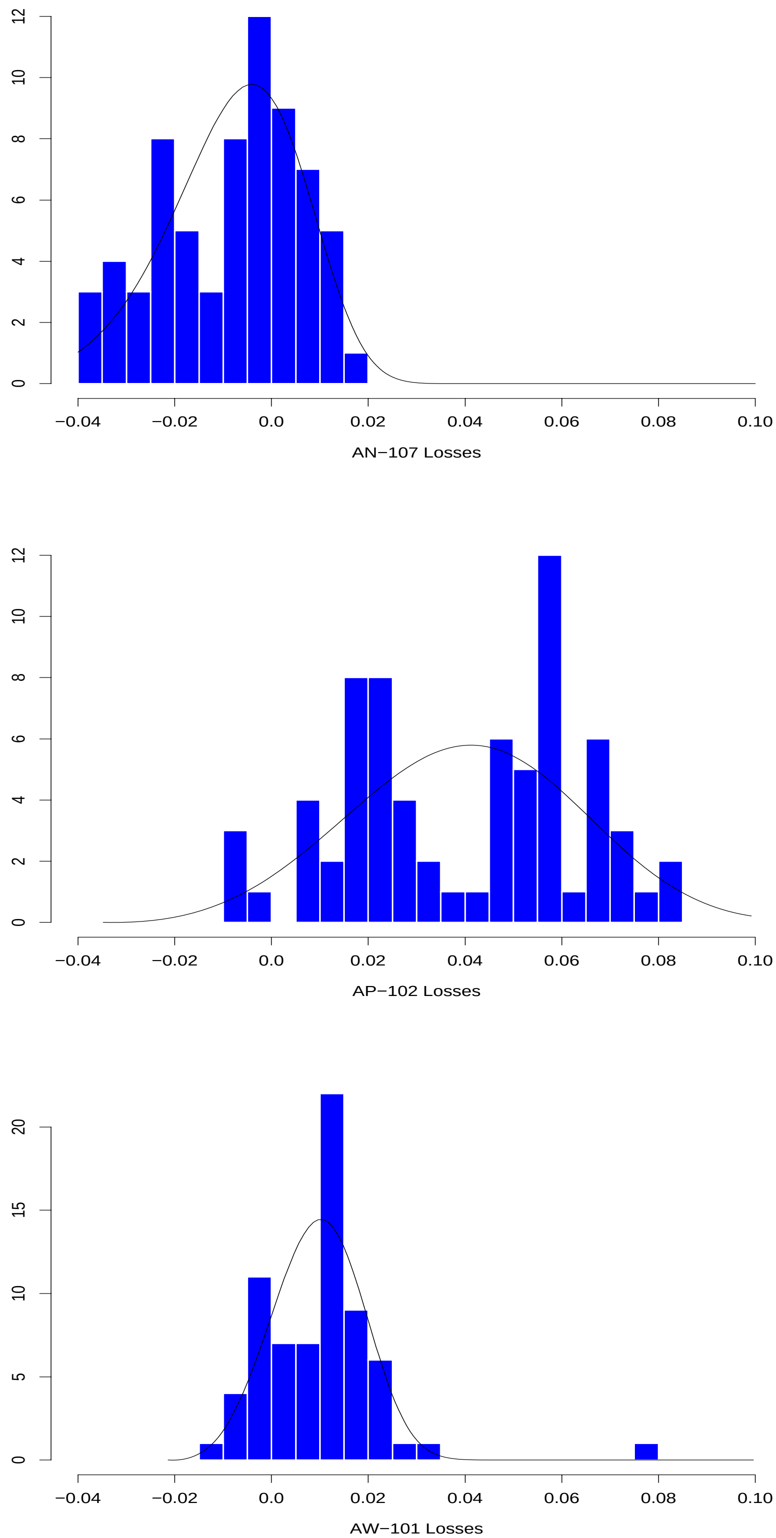


Figure 4: Maximum Loss Distributions with Weibull Distributions (continued)

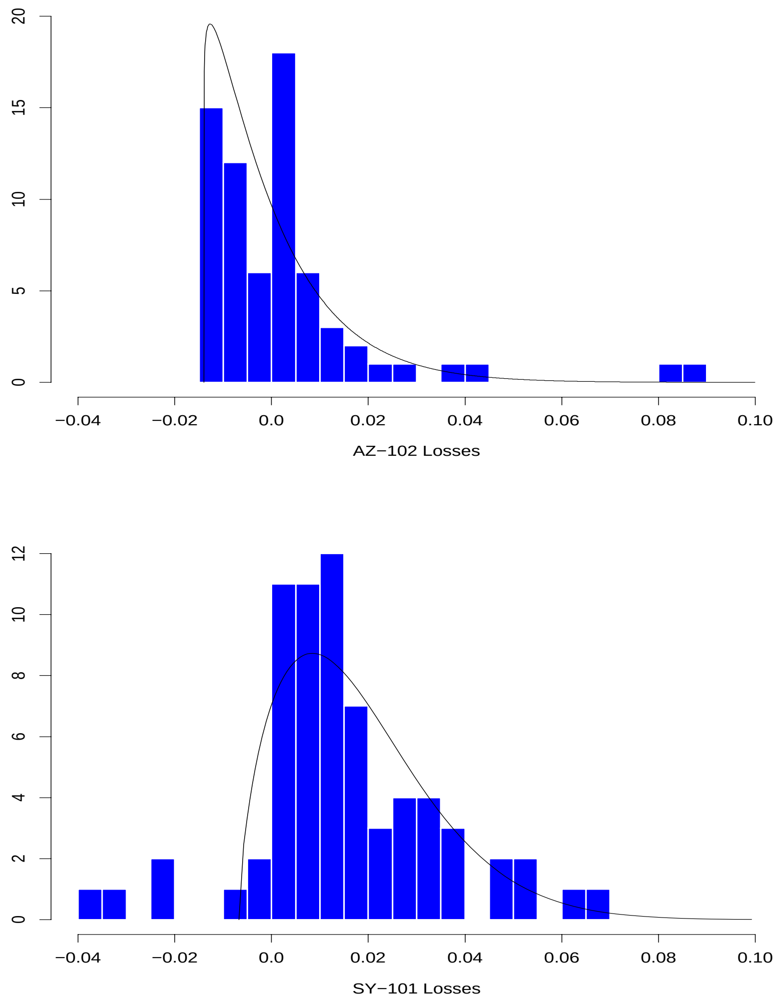


Table 1 gives the estimation results for the various tanks with and without outliers, except for AW-101, where the outlier was immediately removed since it prevented a reasonable Weibull fit. The "Estimate" column is the worse case loss point estimate obtained from extrapolating into the tail of the Weibull. AN-107 can be seen to have the smallest such estimate at 0.030 inch.

The two AZ-102 outliers result in it having a larger estimated maximum loss (0.154 inch) than even AP-102 (0.118 inch). The reason can best be observed in the Figure 3 plots of points which suggests the considerable impact of the two outliers. Whether the top two points for AZ-102 are included will indeed have considerable impact. Without the two points, the AZ-102 losses in Figure 3 are considerably less than those of AP-102, as is the estimated maximum loss in that case in Table 1 (0.092 inch).

Another disconcerting result in the table is that SY-101 has a smaller estimated maximum loss (0.081 inch) than AZ-102 with the outliers removed (0.092 inch). This does not agree with the points indicated in Figure 3. It was suspected that this was due to the large gains for SY-101 mentioned earlier and their impact on the Weibull fit. Our interest lies in the opposite tail of the

Table 1: Maximum Losses Estimation Initial Results

Tank	Estimate	Est StanDev	df	Est 95% Conf Bound	Riser StanDev	Total StanDev	df	95% Conf Bound
AN-107	0.030	0.007	65	0.041	0.01	0.012	6.3	0.054
AP-102	0.118	0.015	67	0.142	0.01	0.018	24.9	0.148
AW-101*	0.040	0.005	66	0.048	0.01	0.011	4.8	0.063
AZ-102	0.154	0.032	65	0.207	0.01	0.033	64.9	0.210
AZ-102**	0.092	0.023	63	0.131	0.01	0.025	50.9	0.134
SY-101	0.081	0.008	65	0.094	0.01	0.013	7.5	0.105
SY-101***	0.102	0.015	61	0.127	0.01	0.018	25.4	0.132

* one outlier removed ** two outliers removed *** four outliers removed

Weibull distribution; yet these four gains in the left-hand tail seem to be generating a tighter right- hand tail for the estimated distribution and a resulting smaller loss estimate. Indeed when the large gains are omitted, the SY-101 maximum loss estimate was increased to 0.102 inch, a more reasonable result when compared to AZ-102 with the outliers removed (0.092 inch). These are the types of reasons that the decisions were made to omit the outlying values in these extreme value estimation application. They have overly dramatic impact on the distribution fitting, and they are more likely caused by original plate thickness variability and not actually by wall thickness loss due to corrosion.

The “Est StanDev” column is a one standard deviation uncertainty associated with the estimates; its magnitudes are the results of the number of measurements available and the quality of the Weibull fit as mentioned earlier. The estimate column and its standard deviation, along with the df (degrees of freedom) column determine the appropriate upper confidence bound given in the “Est 95% Conf Bound” column. These would be the final estimation bound if riser differences were not incorporated. However, the earlier riser difference work suggested that a riser difference can be incorporated under the assumption that the riser differences for these tanks are likely similar to those observed in the multiple riser inspections done in Tank AY-101. Those analyses suggested an extra 0.010 standard deviation as indicated in the “Riser StanDev” column.

Under the assumption of statistical independence of the estimate and riser uncertainties, this extra riser uncertainty can be combined in quadrature (square root of the sum of squares) with the estimate standard deviation to give the total standard deviation listed in the so-named column. From these total standard deviations and the associated estimates, along with the new df column (degrees of freedom which can vary considerably due to an approximation used that is considerably affected by the relative magnitudes by the two uncertainty sources) give the final confidence bound in the last column.

It is proposed that the outliers discussed, with their considerable impact on this extreme value estimation approach, be omitted from the analyses. This then would give the results in Table 2 that were also listed in the summary section at the beginning of this report.

Table 2: Maximum Loss Estimation Final Results

Tank	Estimate	Est StanDev	df	Est 95% Conf Bound	Riser StanDev	Total StanDev	df	95% Conf Bound
AN-107	0.030	0.007	65	0.041	0.01	0.012	6.3	0.054
AP-102	0.118	0.015	67	0.142	0.01	0.018	24.9	0.148
AW-101	0.040	0.005	66	0.048	0.01	0.011	4.8	0.063
AZ-102	0.092	0.023	63	0.131	0.01	0.025	50.9	0.134
SY-101	0.102	0.015	61	0.127	0.01	0.018	25.4	0.132

A question that might be asked about these final results is why the bounds for AZ-102 are greater than those for SY-101 even though the estimates do not have the same relative orientation. The answer lies in the considerably larger estimate standard deviation for AZ-102 (0.023) than for SY-101 (0.015). The reason for this is not apparent in the Figure 3 data illustration; recall the large AZ-102 values and small S-101 values were omitted as having too severe an impact. Since about the same number of measurements were available for each, it must be the case that the Weibull fit for AZ-102 simply wasn't as good as that for SY-101. Thus larger uncertainties for the AZ-102 Weibull parameter estimates result, and in turn, the larger uncertainty on the AZ-102 extreme value estimate.

Conclusions

The DST Integrity Plan requires the ultrasonic wall thickness measurement of two vertical scans of the tank primary wall from a single riser location. The resulting measurements are then used in an extreme value methodology to predict the minimum wall thickness expected for the entire tank.

Previously developed extreme wall thickness loss estimation methodology and riser difference incorporation were used to generate wall thickness maximum loss estimates and confidence bounds as given in the final table in the report and in the initial summary section. Such estimates and bounds are for the measured maximum expected wall thickness loss from nominal for each tank. As such, they accommodate the actual variability in remaining wall thickness due to corrosion, as well as that due to the manufacturing variability in original nominal plate thickness and that due to measurement error.

Several outlying maximum and minimum values for the various tanks that have considerable impact on the extreme value distribution fitting were omitted from the analyses. This was done reluctantly since deletion of outliers should never be taken lightly. In addition, a data shift proposed by subject matter experts in earlier AN-107 analyses to correct a measurement anomaly for part of one vertical path was also incorporated.

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Expert Panel Workshop for Hanford Site Double-Shell Tank Waste Chemistry Optimization, RPP-RPT-22126.

Weier, D.R. 2002. Statistical Analyses of AY-101 Ultrasonic Measurements of Wall Thickness, PNNL-14106. Pacific Northwest National Laboratory, Richland, WA.

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