Corrosion Problems Quantified With Gumbel Lower Distribution

Abstract: Several case studies show how to separate general corrosion from accelerated corrosion and how to predict end of useful life of products.

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Gumbel Upper or Gumbel Lower?

- The Gumbel upper distribution is used when you have **BIG** numbers. It's best know for flood data (you only record the deepest [largest] stream gage reading for a single year).
- The Gumbel lower distribution is used when you have **LITTLE** numbers. It's used where you've only recorded the thinnest [smallest] wall in a single corrosion area.

The **Gumbel Smallest Extreme Value** is considered a model for a system having ***n*** elements in a series and where the failure distributions of components are reasonably uniform and similar (**See British Standard BS 5760**).

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The Weibull distribution straight line equation

$$\ln\left(\ln\left(\frac{1}{1-F(t)}\right)\right) = \beta\cdot\ln(t) - \beta\cdot\ln(\eta)$$

What's The Math Difference?

Both are also known as the double exponential →→

The **Gumbel largest extreme value** CDF is:

$$F(t) = e^{-e^{\frac{-(t-\xi)}{\delta}}}$$

Rearanging the equations to read

$$F(t) = e^{-e^{\frac{-(t-\xi)}{\delta}}} = \frac{1}{e^{\frac{-(t-\xi)}{\delta}}} \quad \text{Or} \quad \frac{1}{F(t)} = e^{\frac{-(t-\xi)}{\delta}}$$

Taking the log of both sides you get:

$$\ln\left(\frac{1}{F(t)}\right) = e^{\frac{-(t-\xi)}{\delta}}$$

Again, taking the log of both sides you get:

$$\ln\left(\ln\left(\frac{1}{F(t)}\right)\right) = \frac{-(t-\xi)}{\delta} = \frac{-t}{\delta} + \frac{\xi}{\delta}$$

Y = mX + b

$$t = \xi - \delta\cdot\ln\left(\ln\left(\frac{1}{F(t)}\right)\right)$$

For Monte Carlo modeling:

$$t = \xi - \delta\cdot\ln(-\ln(a\_random\_no))$$

The **Gumbel smallest extreme value** CDF is:

$$F(t) = 1 - e^{-e^{\frac{t-\xi}{\delta}}}$$

Rearanging the equations to read

$$1 - F(t) = e^{-e^{\frac{t-\xi}{\delta}}} = \frac{1}{e^{\frac{t-\xi}{\delta}}} \quad \text{Or} \quad \frac{1}{1-F(t)} = e^{\frac{t-\xi}{\delta}}$$

Taking the log of both sides you get:

$$\ln\left(\frac{1}{1-F(t)}\right) = e^{\frac{t-\xi}{\delta}}$$

Again, taking the log of both sides you get:

$$\ln\left(\ln\left(\frac{1}{1-F(t)}\right)\right) = \frac{t-\xi}{\delta} = \frac{t}{\delta} - \frac{\xi}{\delta}$$

Y = mX + b

$$t = \xi + \delta\cdot\ln\left(\ln\left(\frac{1}{1-F(t)}\right)\right)$$

For Monte Carlo modeling:

$$t = \xi + \delta\cdot\ln(-\ln(1 - a\_random\_n$$

Observations:

Same Y-axis

Weibull has log X-axis

Gumbel has uniform X-axis

ξ is a scale factor
δ is a shape factor
Small δ → steep lines for G- & G+ distributions

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Problem 1: Heat Exchanger Thin Tubes?

- We have a shell & tube heat exchanger
- Process fluids are inside the tubes and the tubes are loosing wall thickness with use
- Outside the tubes are cooling water
- Periodic inspections have recorded the **minimum** wall thickness in each tube selected randomly. We have only one wall thickness for each tube inspected.

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What's The Issue? How To Resolve?

- Heat exchanger is 17 years old—460 tubes
- At turnaround, eddy current wall thickness inspection occurred—**We're worried!**
- Did an IRIS inspection on 10% of tubes—**Now we're more worried**—what does the data say?
- Retube **NOW** at 17 years with T/A delays? Retube next turnaround in 3 years at 20 years? Retube at 2nd turnaround in 6 years at 23 years)?

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Time Issues

What Are Cost Consequences?

- Failure $ is dependent on outside temperatures:
  - Summer failure = $750,000 lost margins & retube
  - Fall failure = $500,000 lost margins & retube
  - Winter failure = $100,000 lost margins & retube
  - Spring failure = $250,000 lost margins & retube
- Another key issue is environmental impact along with the cost issues if failure occurs

Murphy says: Big Money Issues Will Prevail

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Why Did They Inspect?

- Rule of thumb for this facility-
  - **Inspect tubes** if wall thickness has been reduced by 1/3, i.e. from 0.083" to 0.055"
  - **Consider retubing** heat exchangers when tube wall thickness has been reduced to ½ of original wall thickness, i.e. when wall thickness has been reduced from 0.083" to 0.0415"
- This exchanger has environmental concerns

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Eddy Current vs IRIS Inspection

- Eddy current inspection is the usual quick and inexpensive inspection of each tube—minimum wall is reported for each tube
- IRIS inspection is a more detailed and more expensive inspection with a rotating head ultrasonic tool—minimum wall is reported for each tube and **tube ID's must be very clean for an accurate IRIS inspection**.

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What Did IRIS Inspection Find?

- The minimum wall thickness report shows:

Rule of thumb triggers inspection at 0.050"→

Wall*qty	
0.050*1	**0.063*9**
0.055*1	**0.064*9**
0.056*2	**0.065*4**
0.058*2	**0.066*5**
0.059*1	**0.067*2**
0.061*6	**0.069*4**

Wall thickness measured in inches

- **Minimum allowed wall thickness is 0.036" for structural integrity.**

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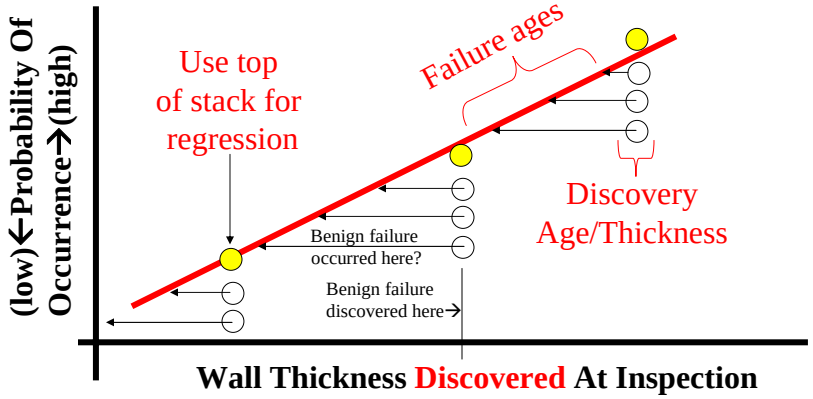
Stacks Of Data—Use Sherwin's Inspection Option



We have stacks of data from the heat exchanger inspection because the IRIS data have been rounded to three significant digits.

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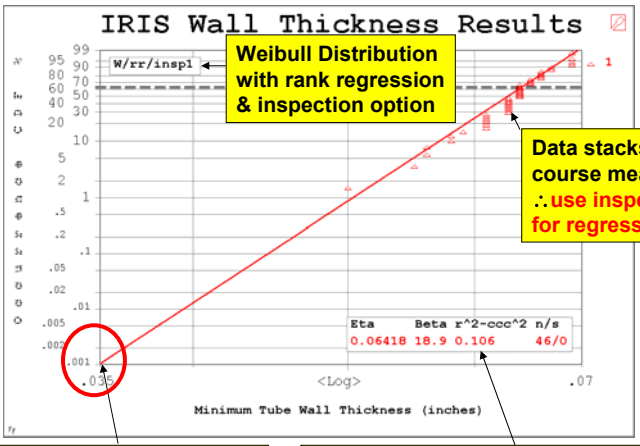
Competing Models:
Weibull? or Gumbel Distributions?



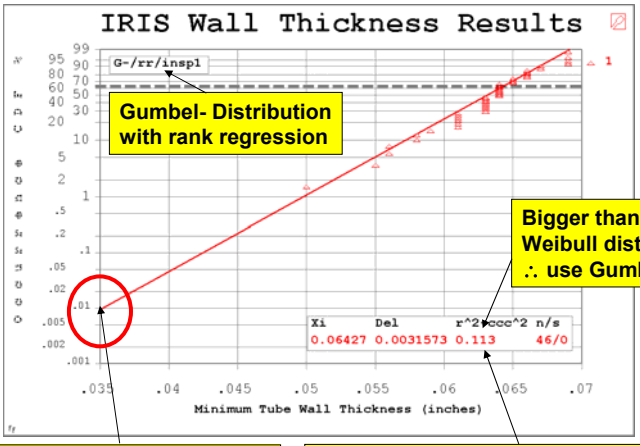
Weibull Distribution with rank regression & inspection option

Data stacks from course measurements ∴use inspection option for regression

Small risk of wall thickness less than min allowed

R= Coefficient of regression
ccc= critical correlation coefficient

Competing Models:
Weibull or Gumbel Distributions?



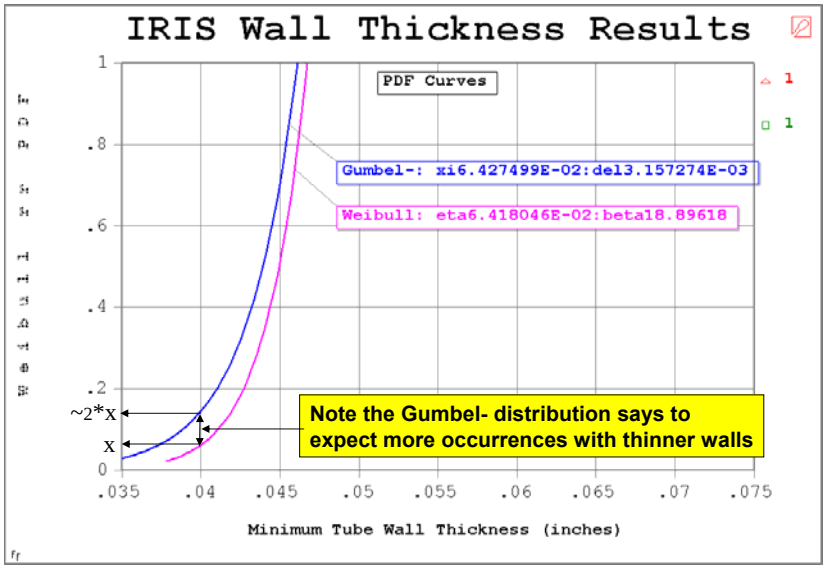
Gumbel- Distribution with rank regression

Bigger than for Weibull distribution ∴ use Gumble-

Higher risk of wall thickness less than min allowed ∴more conservative

R^2= (Coefficient of regression)^2
(ccc)^2= (critical correlation coefficient)^2

PDF Curves



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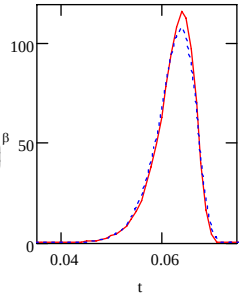
PDF Details

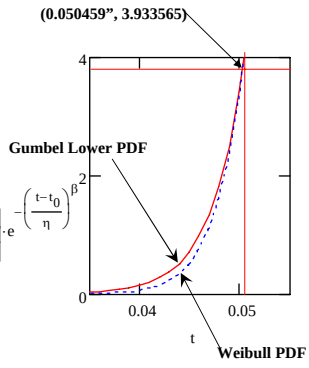
$$\left(\frac{1}{\delta}\right)\cdot e^{\left(\frac{t-\xi}{\delta}\right)-e^{\frac{(t-\xi)}{\delta}}}$$

$$\left[\left(\frac{\beta}{\eta^{\beta}}\right)\cdot(t-t_0)^{\beta-1}\right]\cdot e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}}$$



$$\left(\frac{1}{\delta}\right)\cdot e^{\left(\frac{t-\xi}{\delta}\right)-e^{\frac{t-\xi}{\delta}}}$$

$$\left[\left(\frac{\beta}{\eta^{\beta}}\right)\cdot(t-t_0)^{\beta-1}\right]\cdot e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}}$$



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Why Gumbel Lower Distribution?

- The SMALLEST value is recorded for each tube thickness which motivates use of the Gumbel smallest distribution. Just as for flood data (the largest yearly value) motivates the use of the Gumbel largest distribution.
- The Gumbel smallest distribution is a better curve fit and shows greater % potential failure than Weibull, thus more conservative.

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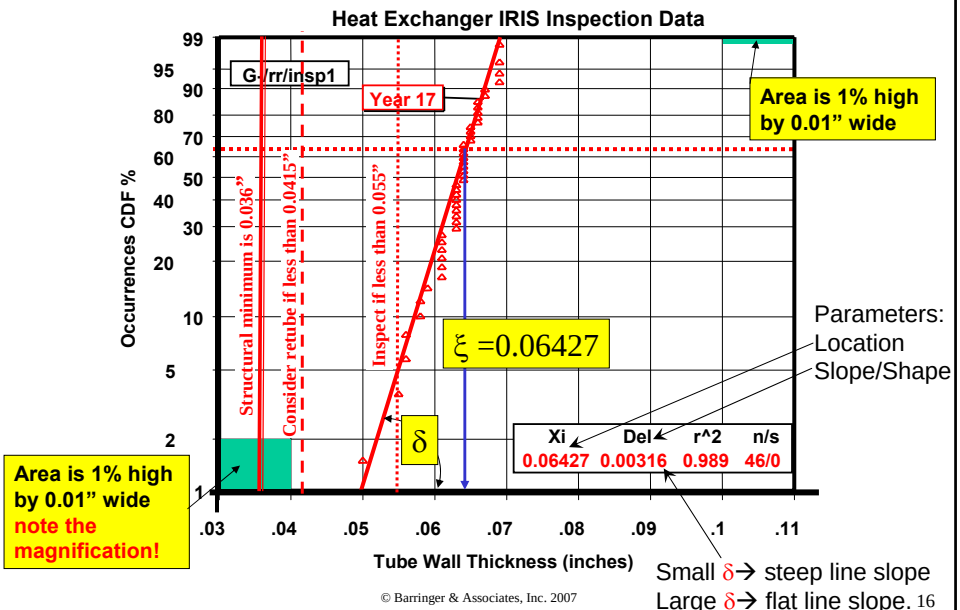
Here's Where We Are At Year 17. Can We Make Year 20?



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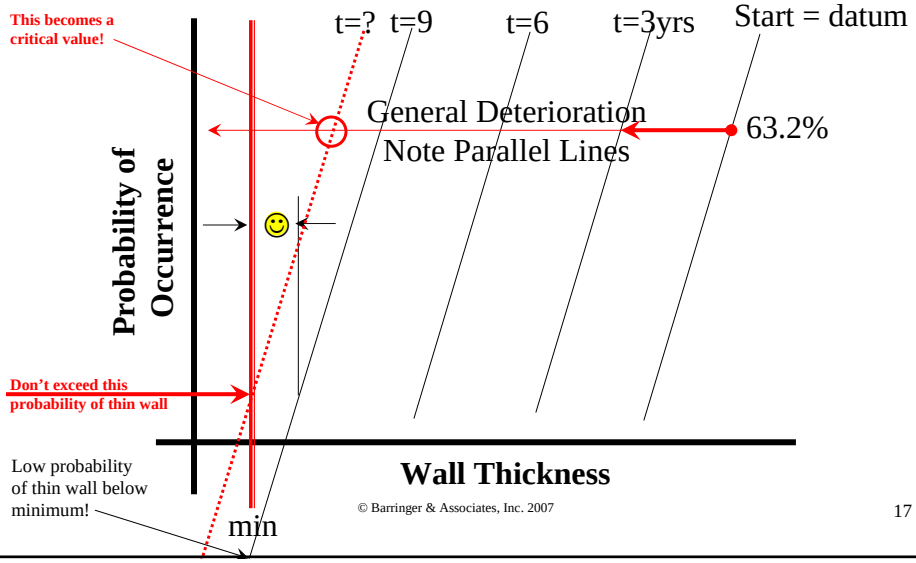
General Corrosion



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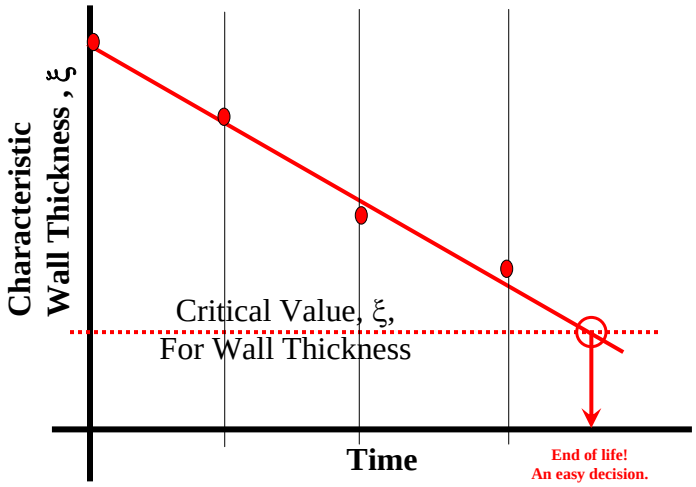
General Corrosion Trend Line



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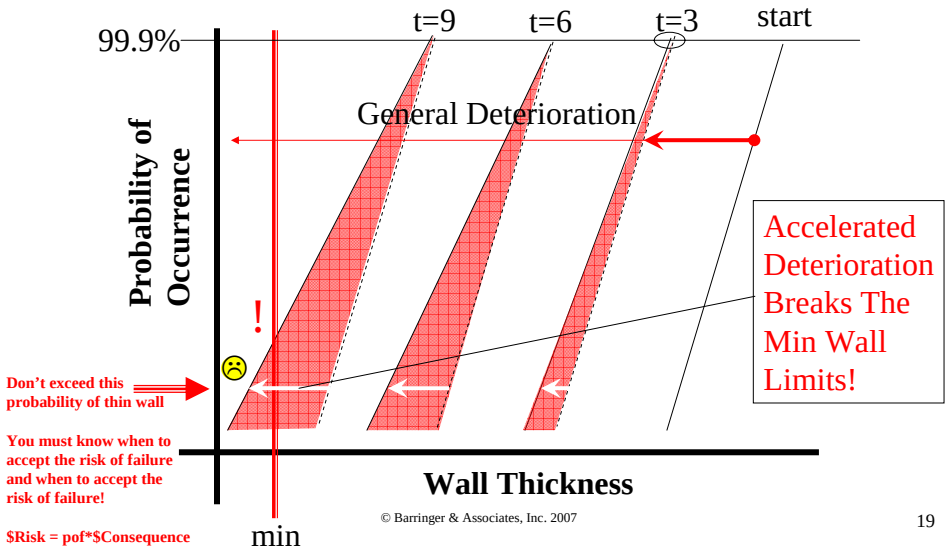
Accelerated Corrosion



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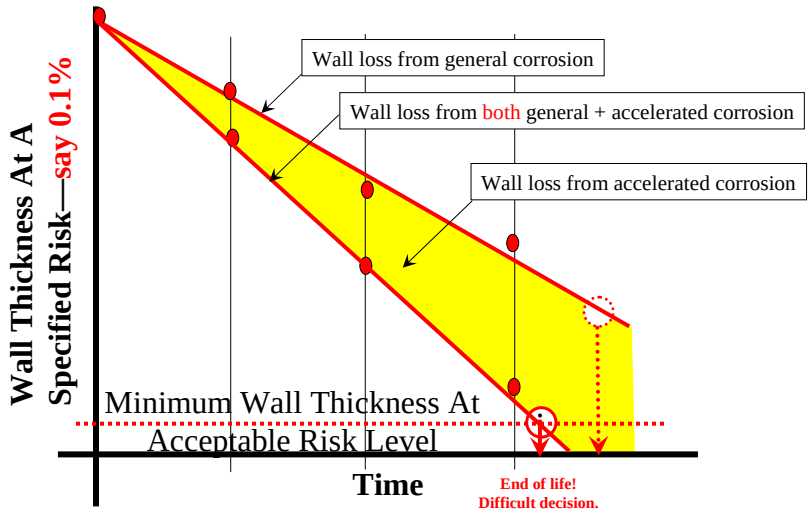
Accelerated Corrosion Trend Line



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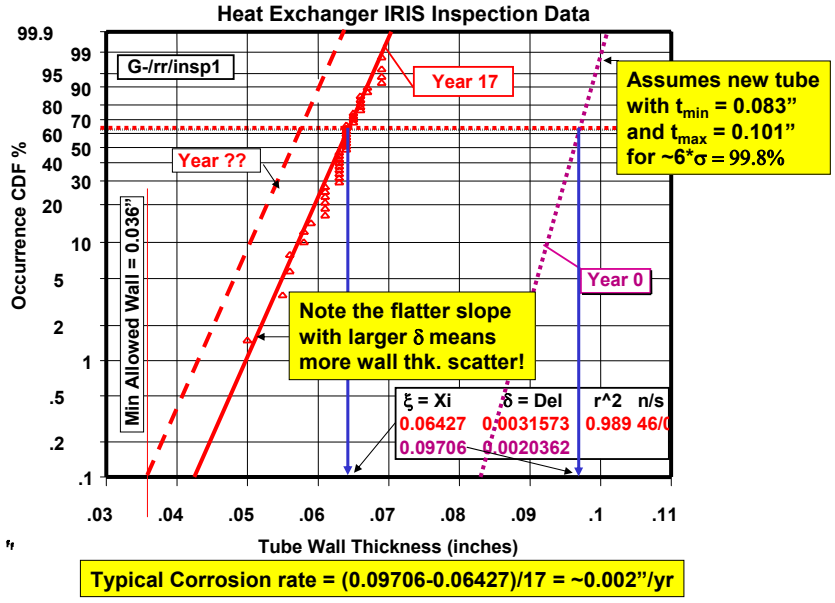
You Must Know Wall Thickness At Time Zero



Typical Corrosion rate = (0.09706-0.06427)/17 = ~0.002"/yr

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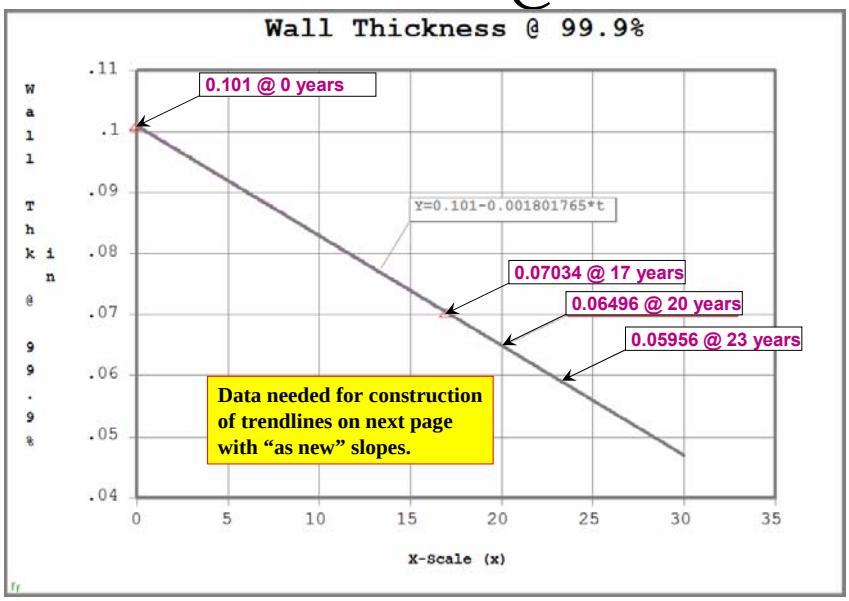
Wall Thickness @ 99.9%



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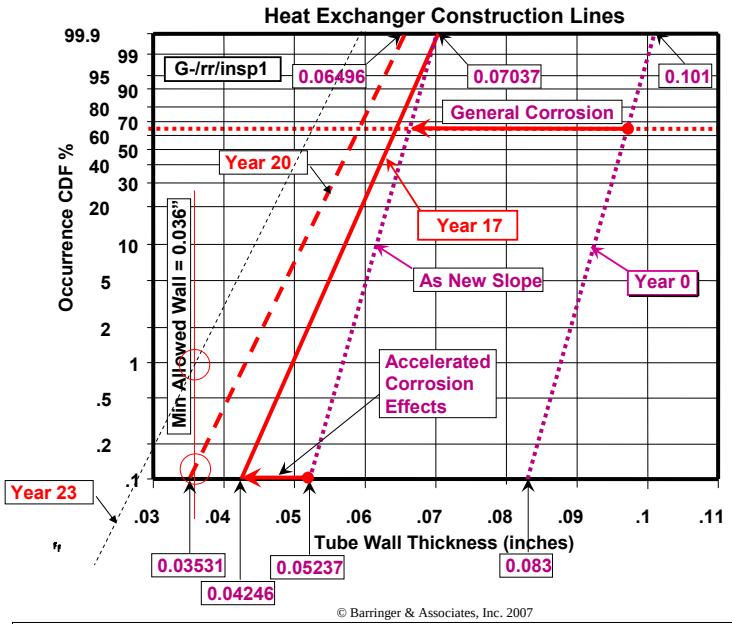

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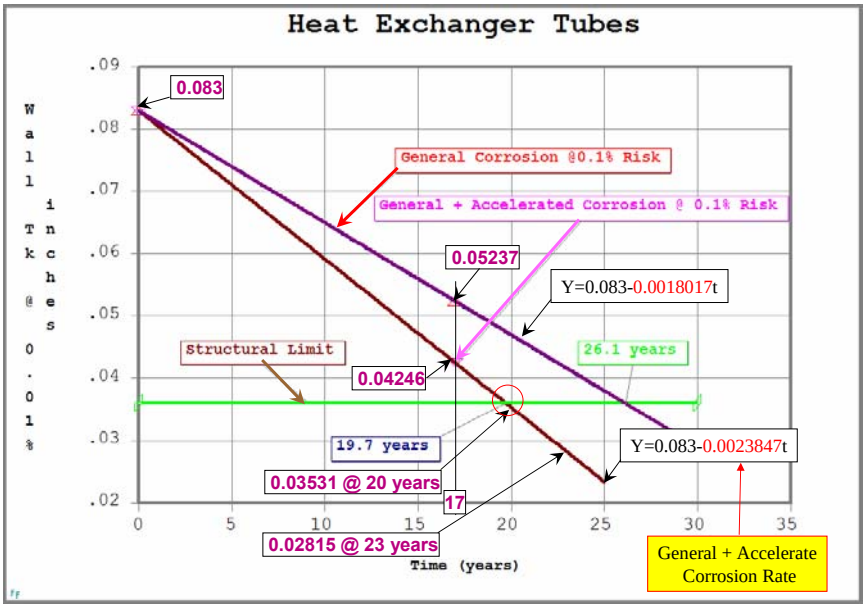
Year 20 Forecasted Line: ξ = 0.05848, δ = 0.0033541 with 0.1228% occurrence at 0.036" wall.

Wall Thickness at 0.1% Risk vs Time



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Retube Or Not Retube Now?

- At year 20 (next turnaround) the minimum wall thickness will decline to just under 0.036”
- The risk for falling below 0.036” min wall is 0.1228%

Time & Money Issues Converge

- $risk = (prob. of failure)*$Consequence, ∴ $risk exposure = 0.1228%*$750,000 = $921
- ∴ take the risk for running 3 more years **—Do not retube now. Run to TA at yr 20.**

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Tube Exchanger Summary

- Avoided the recently discovered and recently expected turnaround delay for accelerated delivery of heat exchanger ($750,000 expenditure avoided) based on use of one day analysis of data.
- Pressing on toward the next turnaround three years into the future
- **At year 20, install a new tube bundle.**
- **What’s the risk for continuing to year 23?** 0.91%*$750,000 = $6,825—if risk adverse, reject. If risk accepting—maybe, but very doubtful.

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Problem 2: Column Corrosion

- A column is rapidly loosing wall thickness.
- Fluids/gasses within the column are violent.
- Frequent Inspections—data is all over the map!
- Loss of containment will impact personnel and environment issues with big $'s
- What should we do:
  --**Run?**—if so, for how long?
  --**Shut down?**—if so, how to persuade the management team?

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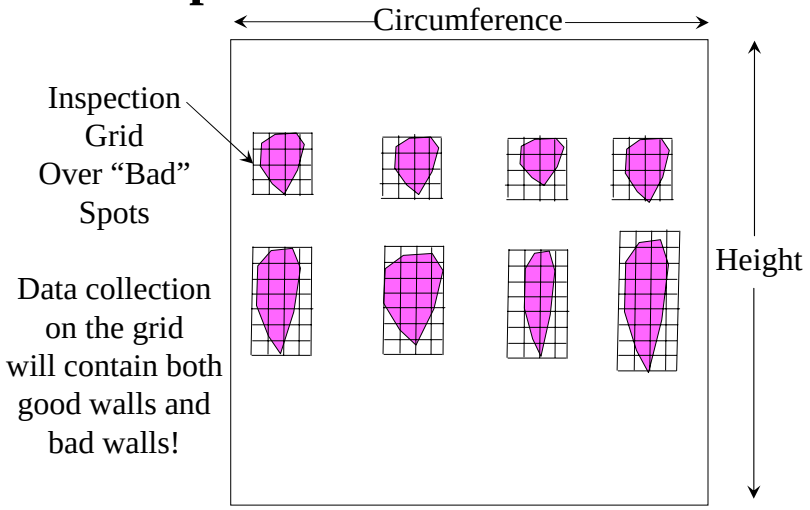
Developed Outer Surface Of Tower



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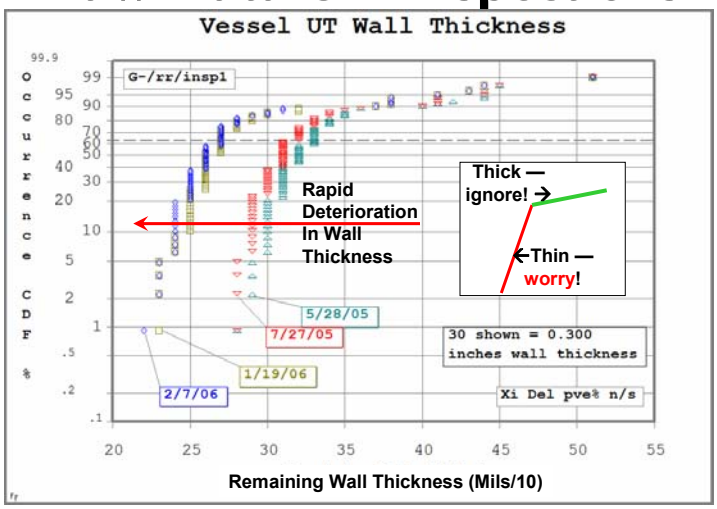
Raw Data UT Inspections



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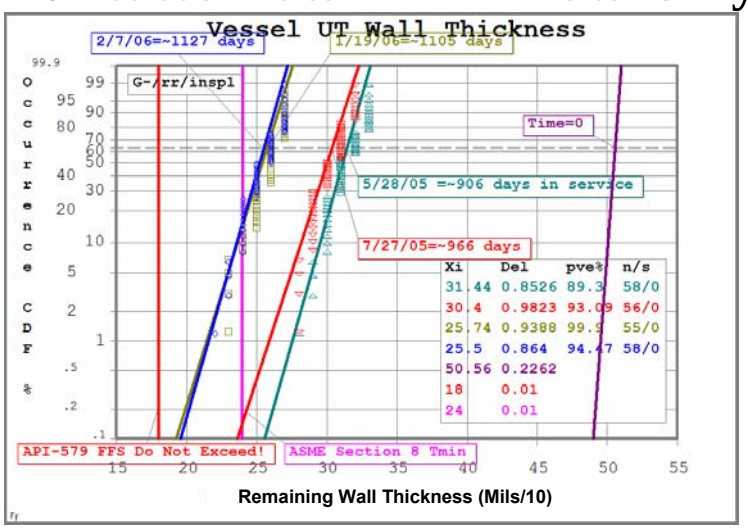
Truncated Data—Thin Data Only



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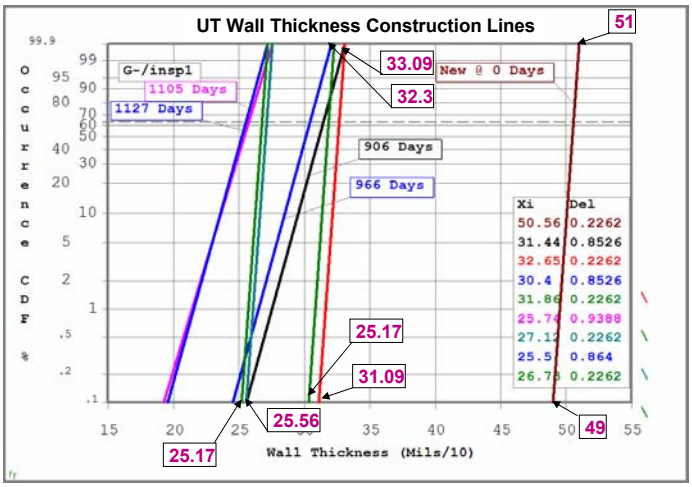
End Points For Corrosion Curve

General Corros.
@ 0.1%

Days	Thickness
0	49
906	31.09
966	25.17
1105	25.56
1127	25.17

Gen + Accel Cor.
@ 0.1%

Days	Thickness
0	49
906	25.56
966	23.61
1105	19.26
1127	19.53



Gen + Accel Cor.
@ 99.9%

Days	Thickness
0	51
906	33.09
966	32.3
1105	27.56
1127	27.17

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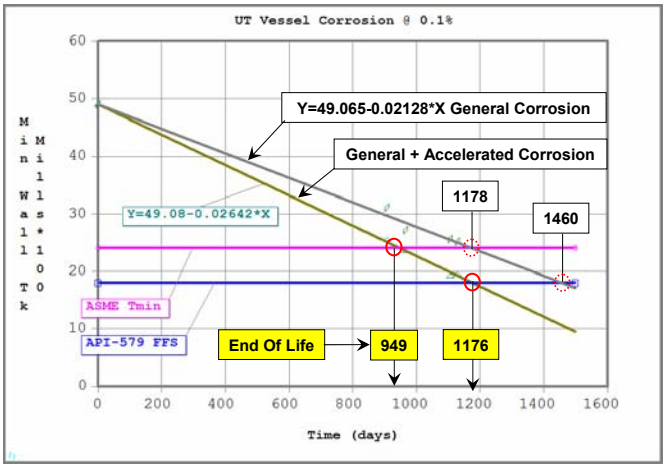
End Of Life Clearly Shown



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Summary

- ASME minimum wall was violated at 949 days
- API fitness for service will be violated at 1176 days and we are 1127 days into service
- Plan an immediate orderly shutdown for replacement
- Outage + planned replacement =$10,000,000
- Emergency outage + emergency replacement = $20,000,000 because of safety hazards
- Risk is too high! 0.1%*$10,000,000 = $10,000 and climbing toward $20,000,000. **Take action now!**

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Now, For Grins

- Consider the Gumbel **larger distribution**
- Houston flood
- Aircraft gust loads
- Space shuttle rocket motor O-ring burns

Discussions about the Gumbel lower distribution always raise questions about the Gumbel upper distribution

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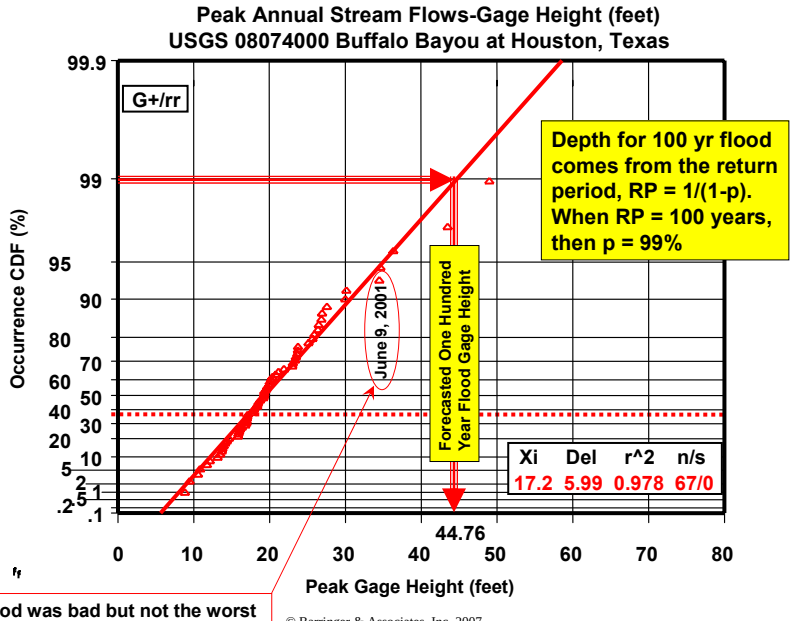
It Rained A Little On June 9, 2001—23 Inches!

Cars are submerged on US 59 highway!

35



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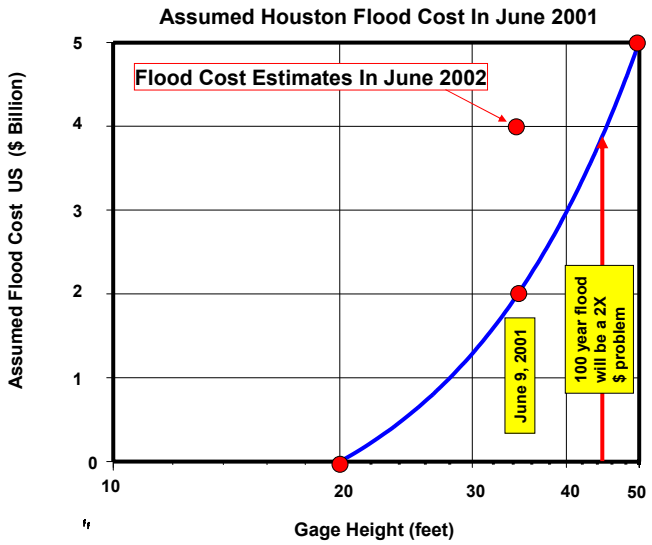

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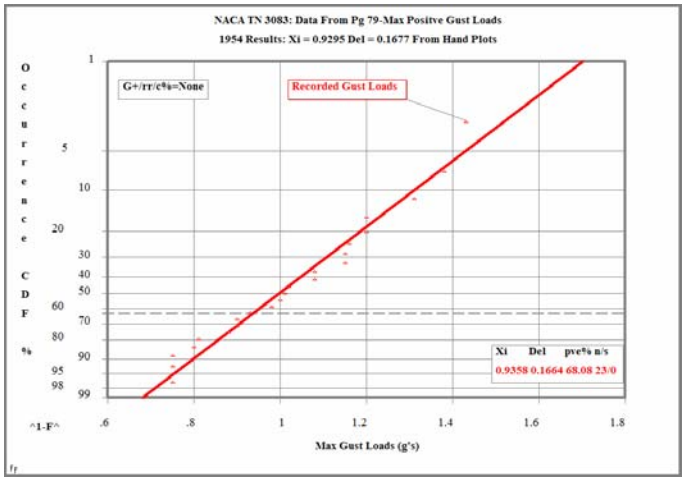
Aircraft Positive Gust Loads



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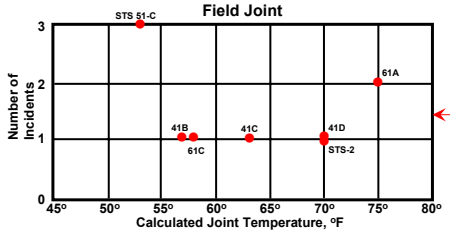
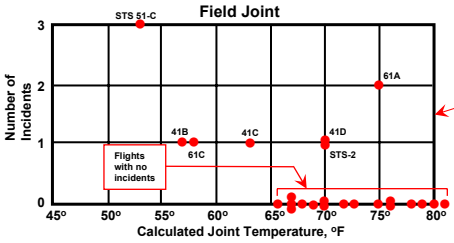
Space Shuttle Burned O-Rings



Failures Only

Data
53*3
57*1
58*1
63*1
70*2
75*2



Failures And Successes

Data
53*3
57*1
58*1
63*1
-66*1
-67*3
-68*1
-69*1
70*2
-70*2
-72*1
-73*1
75*2
-76*2
-78*1
-79*1
-80*1
-81*1

Source: **Engineering Ethics**, Gail D. Baura, Elsevier, ISBN 13:978-0-088531-2, 2006, Page 73. Data from the Rogers Commission 1986

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Good Practice Advice—Watch Out!

- Gumbel upper & lower distributions **allow the use of negative numbers on the X-axis**
- When using suspensions (as a – sign) **make sure you turn on display of the suspensions** (under magnifying glass) so you can view they are in the correct locations **AND** (under the Method icon) **make sure to turn the negative sign to indicate suspension**!
- Else, you'll get misleading results.

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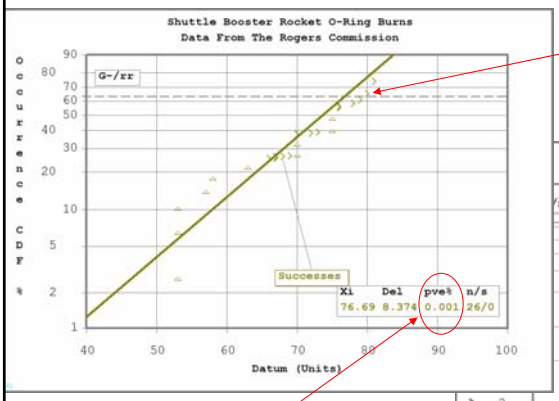
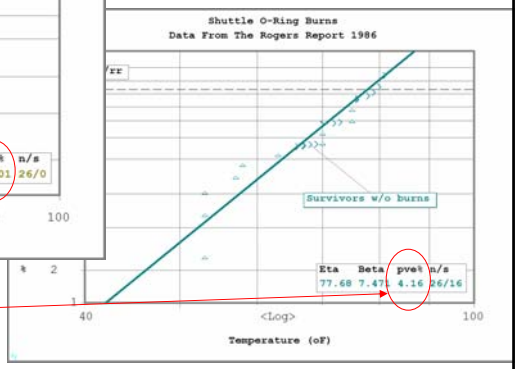
Which Plot?



Suspended data shown on plot as >



Poor curve fit

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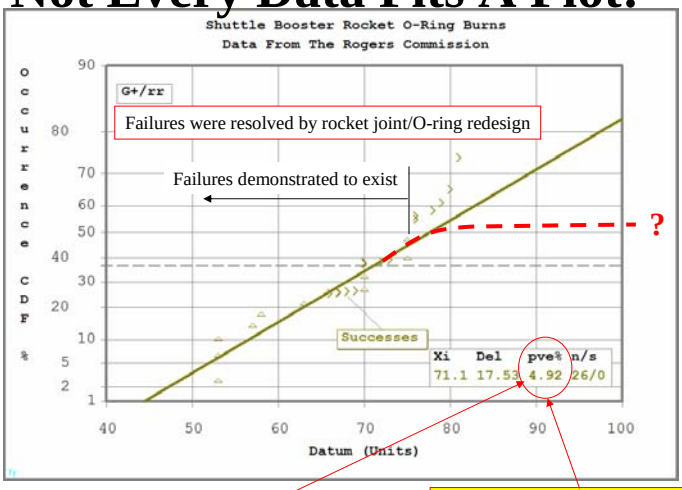
Gumble Upper Slightly Better-But Not Every Data Fits A Plot!



Better but not good curve fit

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If you fail to turn on "-" is a suspension you will conclude this is a good fit!!

Gumbel Upper Summary

- Works well when you have the largest recorded data such as **flood data**, **fatigue data**, etc.
- Watch for traps with suspensions when used without good practices can result in bad conclusions.
- If Weibull, Lognormal, etc. don't work then don't expect automatic success with all data by use of the Gumbel upper distribution.

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Want More Details?

- Got to **http://www.barringer1.com/problem.htm**
- Look at **WinSMITH Weibull software** (which also includes Gumbel large and small distributions)
- See biographies at **http://www.barringer1.com** of **Dr. Weibull** and **Dr. Abernethy** who is the world's leading expert in Weibull analysis
- Dr. Weibull got many of his ideas on extreme values while working at Bofors Steel in Sweden—you can see Bofors antiaircraft guns at the **Museum of the Pacific** in Fredricksburg, TX.
- See Gumbel, E. J., **Statistics of Extremes**, Columbia University Press, New York, 1958
- See **Statistical Theory of Extreme Values And Some Practical Applications,** A Series of Lectures, PB 175818, 12 Feb 1954 by Emil J. Gumbel, National Bureau of Standards, U.S. Dept of Commerce, NTIS

- See **A New Method Of Analyzing Extreme-Value Data**, NACA TN 3053, Jan 1954, U.S. Dept of Commerce, NTIS, by Julius Lieblein National Bureau of Standards

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