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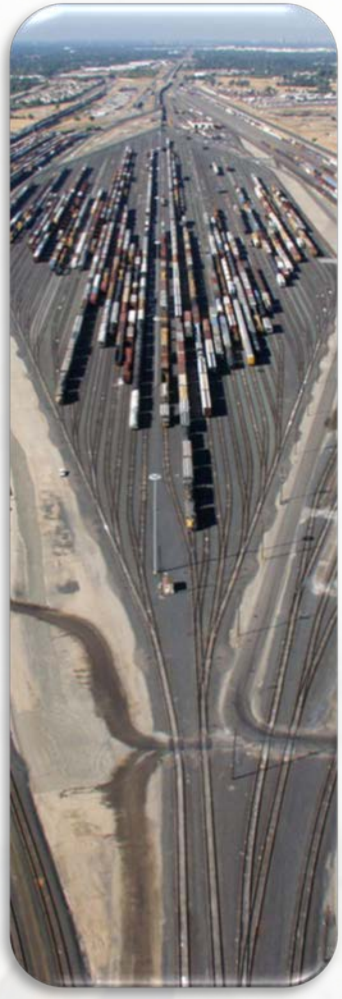

Reliability for Qualification and Maintenance

Case Studies

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TOPICS

- Objective
- Reliability Basics
- Definitions
- Case #1 – Attachment Welds
- Case #2 – Service Equipment
- Challenger

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OBJECTIVE

"To teach reliability principles for setting valid qualification intervals and managing fleet risk through case studies."

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OBJECTIVE

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OBJECTIVE

RELIABILITY BASICS

1. COLLECT DATA
   - Obtain data for analysis
2. EVALUATE DATA FORMAT
   - Match data to correct analysis methods and techniques
3. ANALYSIS METHOD
   - Select initial model that correctly analyzes data (MLE, etc.
4. MODEL DATA
   - Match distribution that best predicts performance (Normal, LN, Weibull, etc.)
5. ANALYSIS REVIEW
   - Review analysis, ensure results ‘make sense’ from statistical / scientific / practical engineering point of view

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RELIABILITY BASICS

COLLECT DATA → EVALUATE DATA FORMAT → SELECT ANLAYSIS METHOD → MODEL DATA → ANLAYSIS REVIEW

1. EXACT FAILURE TIME, SMALL DATASET = RRX
2. EXACT FAILURE PROBABILITY, SMALL DATASET = RRY
3. NO / FEW FAILURES, LARGE DATASET = MLE
4. COMPLETE DATASETS = EXACT FAILURE / SUSPENSION TIMES
5. RIGHT CENSORED DATA = FAILURES EXCEED TIME 'T'
6. INTERVAL CENSORED DATA = FAILURES OCCURE BETWEEN T_1 AND T_2
7. LEFT CENSORED DATA = FAILURES BETWEEN TIME = 0 AND TIME = T_1

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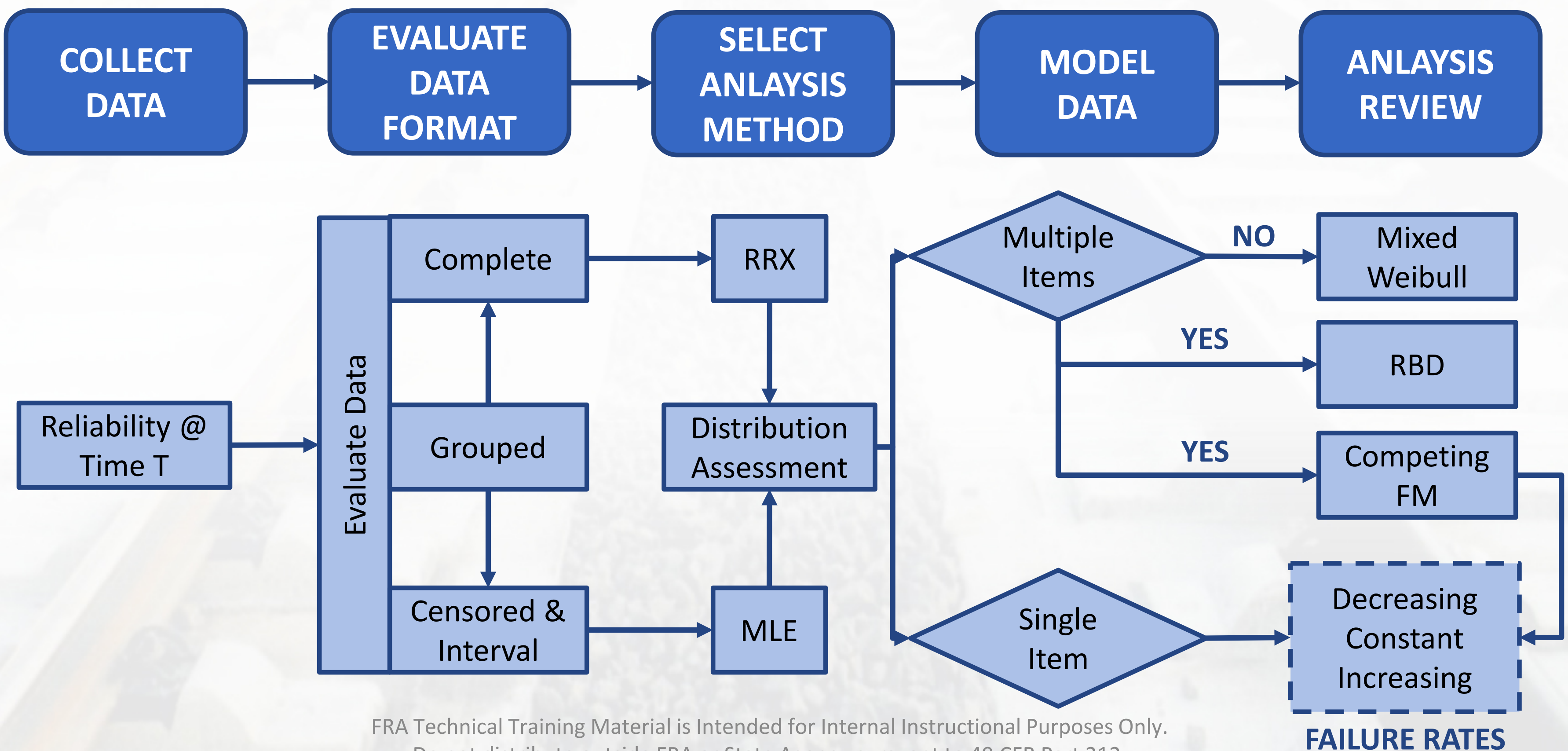
RELIABILITY BASICS - DAP



RELIABILITY BASICS

- Non-repairable System – An item, service, or process that, once it fails, is not repaired and put back into service. Reliability analysis is performed on initial failure data.
- Repairable System – An item, service, or process that, once it fails, is repaired and put back into service. Reliability analysis is performed on initial failure and repaired system data.

RELIABILITY BASICS

- How is Reliability Measured?
  Statistical Measures Come From Data Models!
  - Data is collected from laboratory tests of new (non-repaired) items (DRS);
    Or
  - Data can be collected from in-service (repaired) items (Service Reliability Assessment);

    Or Both!

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RELIABILITY BASICS

- Common Statistical Data Models (Distributions)
  - Weibull – Beta and Eta – Decreasing failure rate – (Infant mortality);
  - Exponential – Lambda – Constant failure rate (Random);
  - Weibull & Lognormal – Mean / Standard Deviation – Increasing failure rate.

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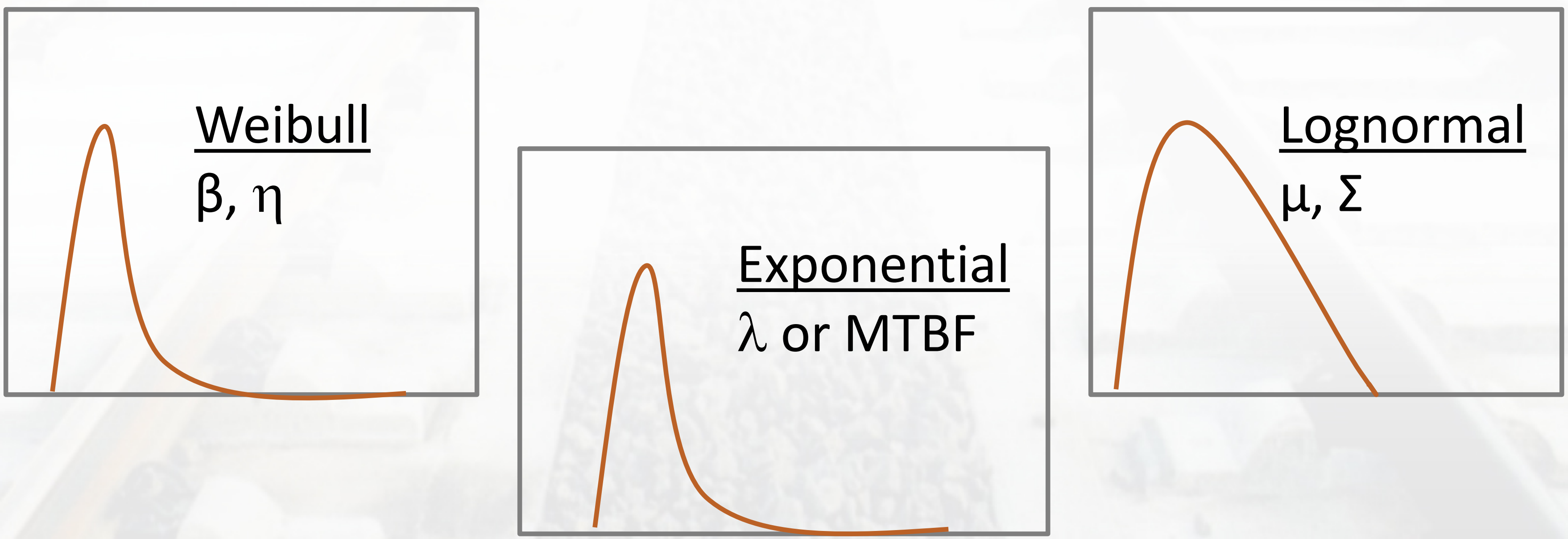
RELIABILITY BASICS

- Statistical Measures Come From Reliability Data Models



RELIABILITY BASICS

- Measures of Reliability

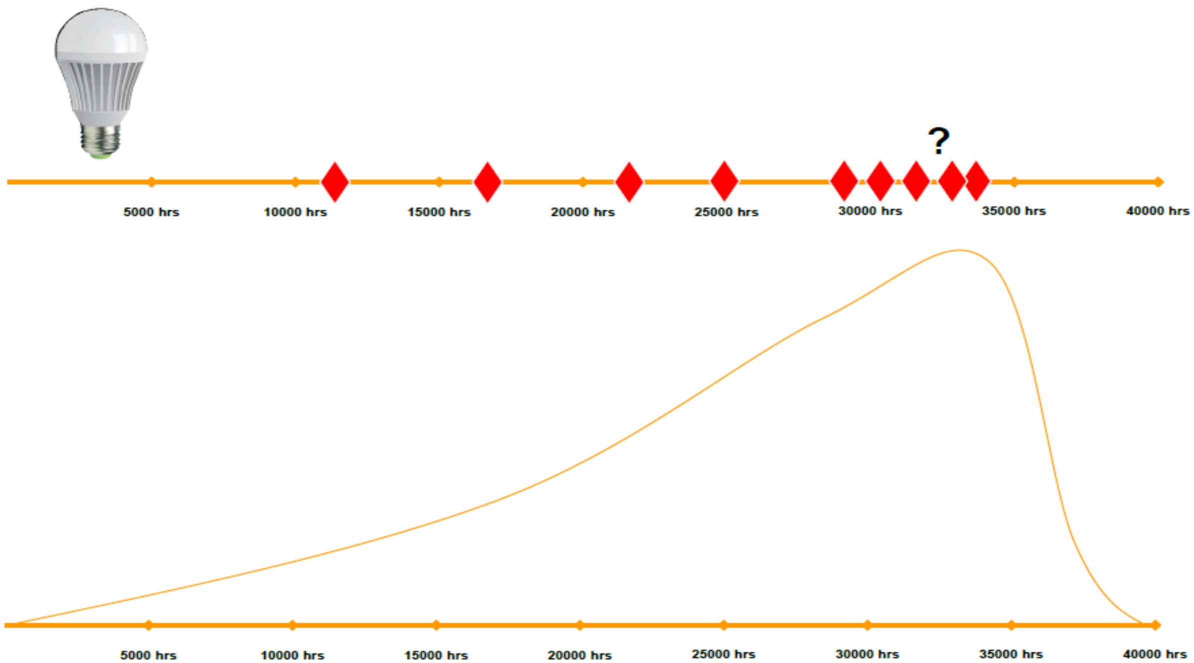
  1. Mean time to failure (MTTF) – MTTF is the average length of time a device is expected to function in service.

$$MTTF = \frac{\Sigma\,(\text{Failures} * \text{Time to Failure})}{\Sigma\,\text{Failures}}$$

This is the average random failure rate for a component and can be found in non-repairable and repairable systems.

RELIABILITY BASICS

- 9 random bulbs run to failure:



Bulb #	Failure Time (Hrs.)
1	13000
2	18000
3	22000
4	24000
5	26000
6	32000
7	33000
8	35000
9	36000
MTTF	26556

RELIABILITY BASICS

MTTF = 26,556 Hrs.

RELIABILITY BASICS

- Measures of Reliability

2. For random failures in non-repairable systems, MTTF usually decreases as components age.

3. For repairable systems, MTTF can increase or decrease.

MTTF lacks sufficient selectivity to determine when items can fail and how many can fail based on age/usage.

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RELIABILITY BASICS

- If Quality = "Conformance to Requirements." Crosby

- And Reliability = "Quality Over Time."

THEN

- Reliability = Conformance to Requirements Over Time.

RELIABILITY BASICS

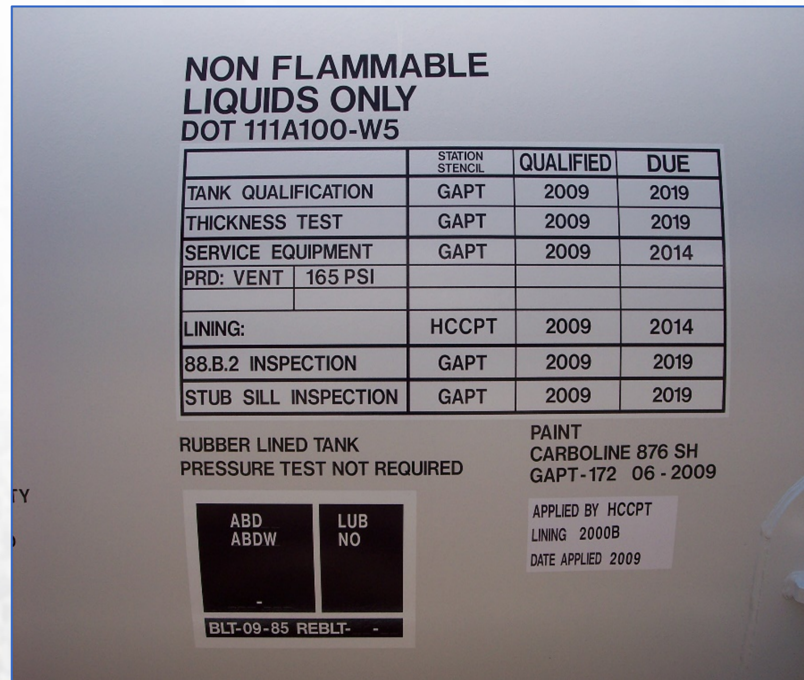
- Measures of Reliability

Is there another way ???

- Weibull Analysis:
  - Uses experimental or in-service data to estimate item life:
  - Provides probabilities item will fail given it has operated for a specific time:
  - Provides system estimates for number of failures and replacements needed over time.

DEFINITIONS

- Railworthy / Railworthiness – The tank, service equipment, interior coatings / linings, safety systems, and all other components covered by Subpart F conform to the HMR and are capable of performing their design function.



DEFINITIONS

- Reliability – The quantified ability of a tank car or component to perform its design function, without failure, for the specified design life/qualification interval in a given environment.
- Design Level of Reliability & Safety (DRS) – The quantified level of reliability & safety built into a tank car or component due to it's specification, design, and manufacture.

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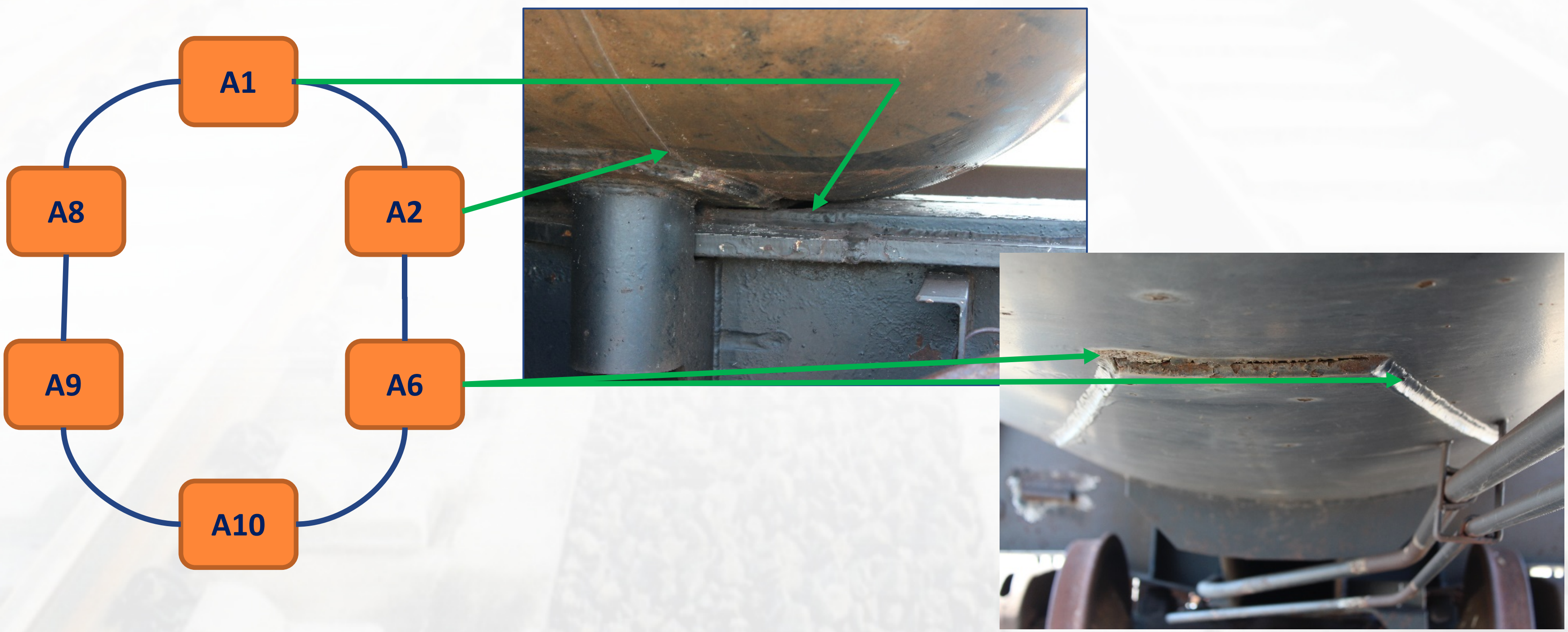
DEFINITIONS

- Qualification (FRA) – Inspections/tests to ensure the tank car and components conform to the specification to which they were designed, manufactured, or modified, and to the owner's acceptance criteria.
- Maintenance (FRA) – Preservation / upkeep / repair to ensure the tank car & components conform to the specification until the next qualification.

CASE STUDY #1

ACF 200 Attachment Welds:



CASE STUDY #1

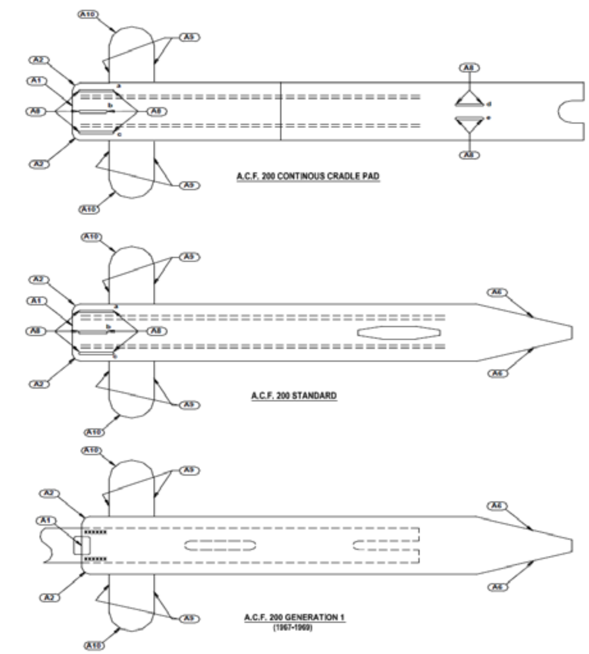
ACF 200 Attachment Welds:

Work Instruction:

1. Pad-to-Tank (Designated by 'A' codes)

Code	Meets	Description	Location	Inspect
A1[1,2]	HM-201 SS-2 88.B.2	7" Transverse weld.	A- & B-Ends	Full length of weld.
A2[3,4]	HM-201 SS-2 88.B.2	Outboard termination of longitudinal pad-to-tank weld.	AR, AL, BR, BL	Full length of weld to termination at bolster pad.
A6[5]	HM-201 88.B.2	Inboard termination of cradle pad longitudinal welds.	AR, AL, BR, BL	Last 6" of weld to termination.
A8[6]	HM-201	Cradle pad-to-tank slot welds.	A- & B-Ends (42 to 106 places per car)	Inboard and outboard slot welds. See Note 7. See Note 7
A9[7]	HM-201 88.B.2	Bolster pad-to-tank transverse weld.	AR, AL, BR, BL	See Note 7NI Cars Only
A10	HM-201	Top of Body BBolster Cradle Pad. pad-to-tank longitudinal weld.	AR, AL, BR, BL	See Note 7NI Cars Only

Sketch/Description:



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CASE STUDY #1

ACF 200 Attachment Welds – Usage / Results

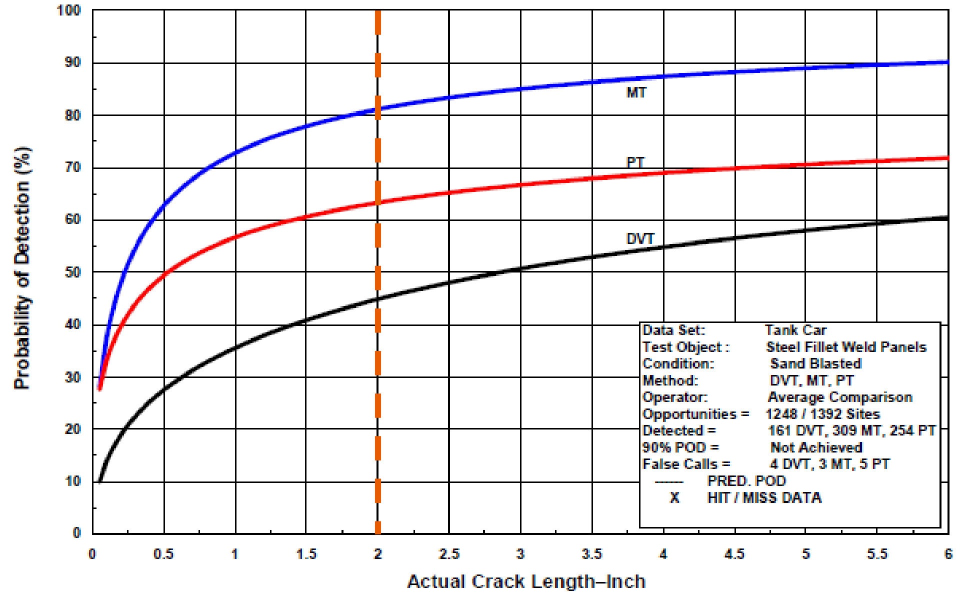

Figure 33. Combined Average POD Comparison for the DVT, MT, and PT Methods

Usage	Location	Results
202,134	A1/A2/A6	3/0/0
312,560	A1/A2/A6	0/1/0
183,023	A1/A2/A6	1/1/0
286,212	A1/A2/A6	1/2/0
401,233	A1/A2/A6	3/3/3
89,567	A1/A2/A6	0/1/0
301,444	A1/A2/A6	0/1/1
222,086	A1/A2/A6	1/1/1
156,444	A1/A2/A6	0/1/1
333,188	A1/A2/A6	2/1/1
201,433	A1/A2/A6	1/1/0
199,310	A1/A2/A6	2/0/1
252,666	A1/A2/A6	1/2/2
179,286	A1/A2/A6	0/0/0
111,338	A1/A2/A6	3/2/2

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CASE STUDY #1

ACF 200 Attachment Welds – Usage / Results

MILEAGE	NDT	A1	POD %	A2	POD %	A6	POD %
202,134	MT	3"	85	0"	0	0"	0
312,560	DVT	0"	0	1"	0	0"	0
183,023	DVT	1"	36	1"	36	0"	0
286,212	MT	1"	73	2"	81	0"	0
401,233	MT	3"	85	3"	85	3"	85
89,567	PT	0"	0	1"	57	0"	0
301,444	MT	0"	0	1"	73	1"	73
222,086	PT	1"	57	1"	57	1"	57
156,444	MT	0"	0	1"	73	1"	73
333,188	MT	2"	81	1"	73	1"	73
201,433	PT	1"	57	1"	57	0"	0
199,310	MT	2"	81	0"	0	1"	73
252,666	MT	1"	73	2"	81	2"	81
179,286	DVT	0"	0	0"	0	0"	0
111,338	MT	2"	81	2"	81	2"	81

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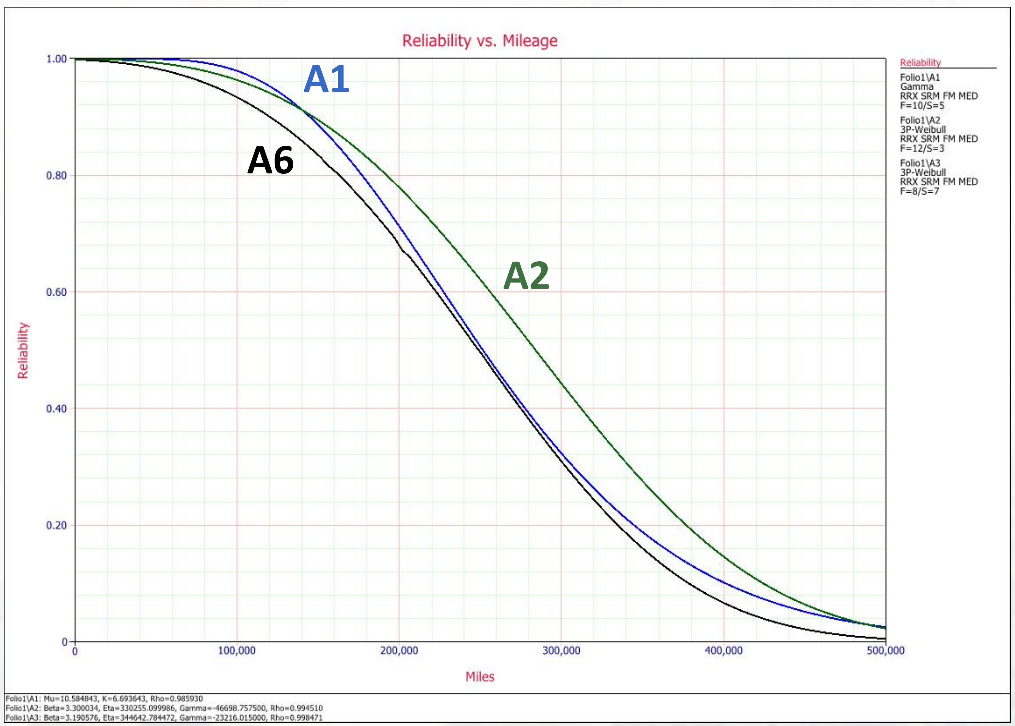
CASE STUDY #1

ACF 200 Attachment Welds ≥ 1” – Usage / Results



A1, A2, A6 Weld Analysis @ 100K miles

- **A1 Reliability @ 100K miles = 0.98**
- **A2 Reliability @ 100K miles = 0.96**
- **A6 Reliability @ 100K miles = 0.93**

Total Reliability @ 100K miles =

0.98*0.96*0.93 = 0.875 = 87.5%

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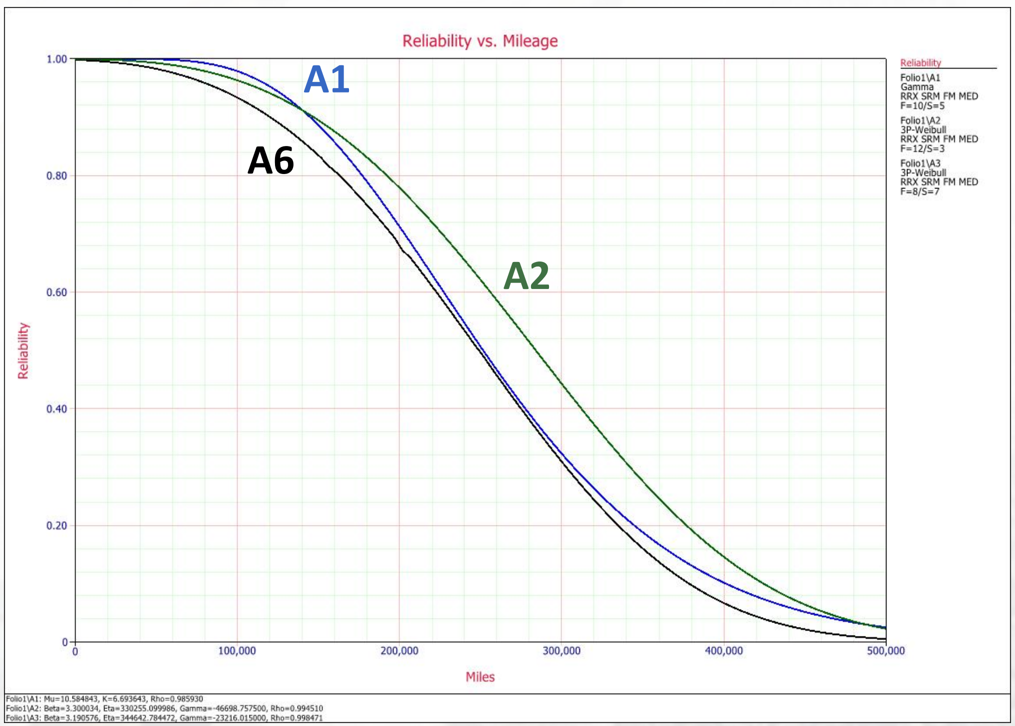
CASE STUDY #1

ACF 200 Attachment Welds ≥ 1" – Usage / Results

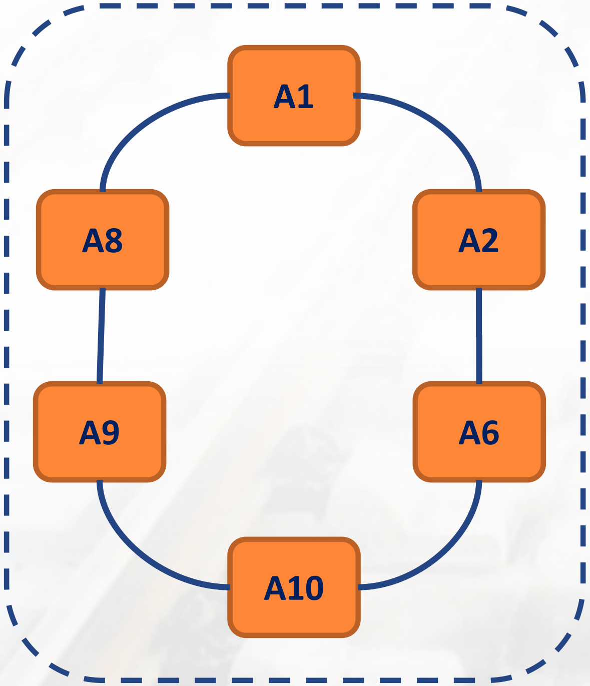


85.6% Reliable @ 100K miles means:

- **For a 100 car ACF 200 fleet, 12 cars have ≥ 1" cracks at any of the A1, A2, or A6 welds**
- **For a 1,000 car ACF 200 fleet, 125 cars have ≥ 1" cracks at any of the A1, A2, or A6 welds**
- **For a 10,000 car ACF 200 fleet, 1,250 cars have ≥ 1" cracks at any of the A1, A2, or A6 welds**

CASE STUDY #1

ACF 200 Attachment Welds – Reliability Block Diagram:

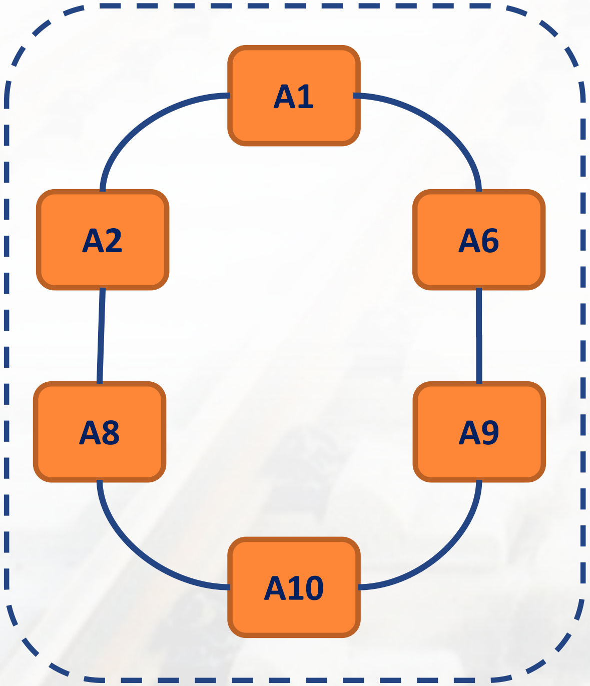


Example – Probability that one or more A1, A2, or A6 attachment welds will reach critical crack length after 100,000 miles.

RBD "Container"

CASE STUDY #1

ACF 200 Attachment Welds – Reliability Block Diagram:



Define critical crack length (a_{crit}) – FEA, fracture mechanics (K_{ic}), or other stress analysis techniques;

Welds are connected in "series" – Any crack $\geq$ 2" will Bad Order the tank car.

For this example, we set critical crack length to 2" for all locations.

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CASE STUDY #1

ACF 200 Attachment Welds – Usage / Results

MILEAGE	NDT	A1	POD %	A2	POD %	A6	POD %
202,134	MT	3"	85	0"	0	0"	0
312,560	DVT	0"	0	1"	0	0"	0
183,023	DVT	1"	36	1"	36	0"	0
286,212	MT	1"	73	2"	81	0"	0
401,233	MT	3"	85	3"	85	3"	85
89,567	PT	0"	0	1"	57	0"	0
301,444	MT	0"	0	1"	73	1"	73
222,086	PT	1"	57	1"	57	1"	57
156,444	MT	0"	0	1"	73	1"	73
333,188	MT	2"	81	1"	73	1"	73
201,433	PT	1"	57	1"	57	0"	0
199,310	MT	2"	81	0"	0	1"	73
252,666	MT	1"	73	2"	81	2"	81
179,286	DVT	0"	0	0"	0	0"	0
111,338	MT	2"	81	2"	81	2"	81

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CASE STUDY #1

ACF 200 Attachment Welds $\geq$ 2” – Usage / Results

A1, A2, A6 Weld Analysis @ 100K miles

- **A1 Reliability @ 100K miles = 0.96**
- **A2 Reliability @ 100K miles = 0.96**
- **A6 Reliability @ 100K miles = 0.96**

Total Reliability @ 100K miles =

0.96*0.96*0.96 = 0.885 = 88.5%

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CASE STUDY #1

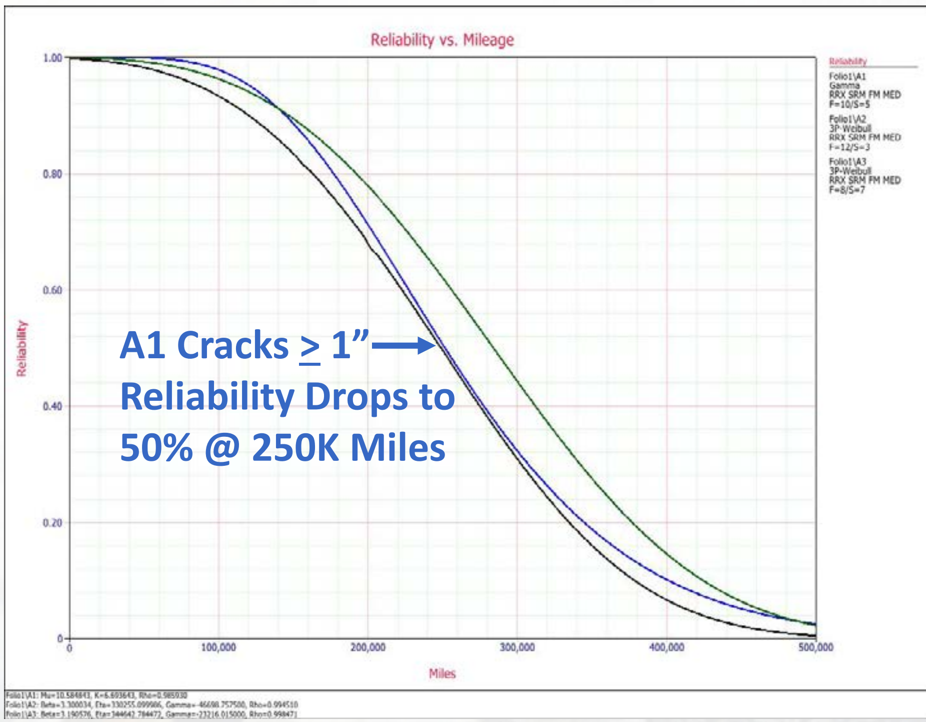
ACF 200 Attachment Welds ≥ 2” – Usage / Results

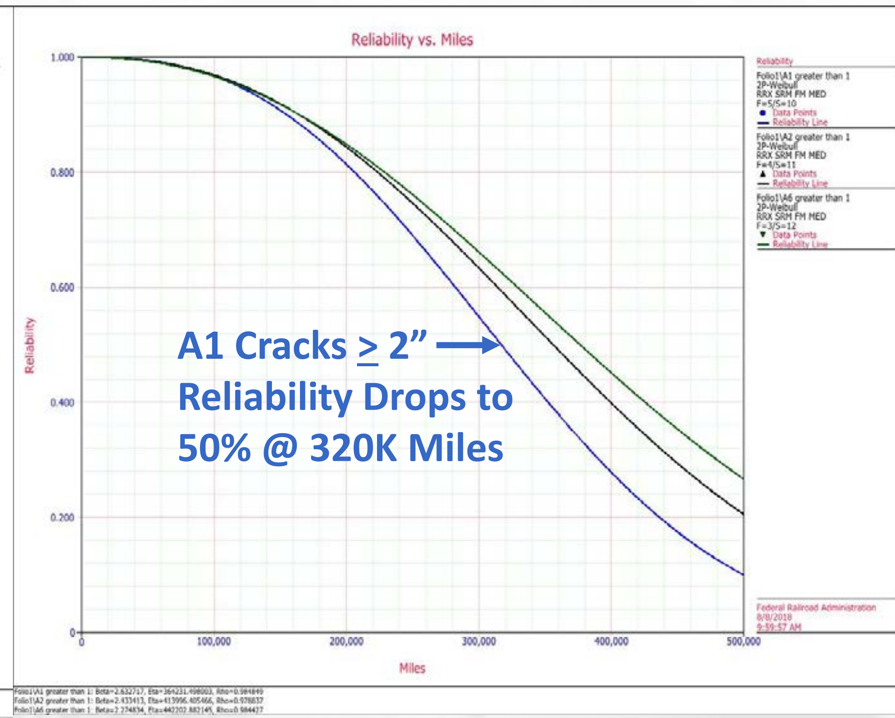
88.5% Reliable @ 100K miles means:

- **For a 100 car ACF 200 fleet, 11 cars have ≥ 2” cracks at any of the A1, A2, or A6 welds**
- **For a 1,000 car ACF 200 fleet, 115 cars have ≥ 2” cracks at any of the A1, A2, or A6 welds**
- **For a 10,000 car ACF 200 fleet, 1,150 cars have ≥ 2” cracks at any of the A1, A2, or A6 welds**

CASE STUDY #1

ACF 200 Attachment Welds – Summary





CASE STUDY #1

ACF 200 Attachment Weld

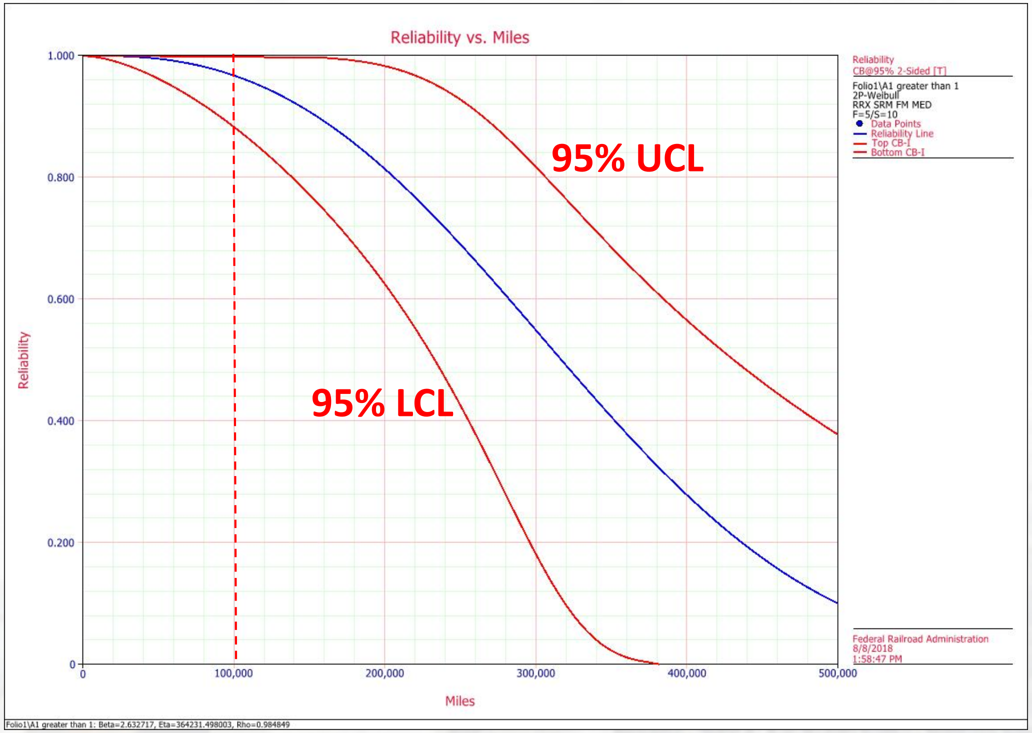
But Wait …

What about Confidence Limits

???

CASE STUDY #1

ACF 200 A1 Attachment Weld ≥ 2” – Confidence Limits



96% Reliable @ 100K miles is the mean value:

- **Based on sample size, 95% two-sided confidence may be as low as 88% or as high as 100%**
- **LCL should be used for high risk applications**

CASE STUDY #1

ACF 200 Attachment Welds – Summary

- Depending on fleet size (1 car rule), calendar time may not be a valid measure of tank (structural) integrity !

CASE STUDY #2

Service Equipment:

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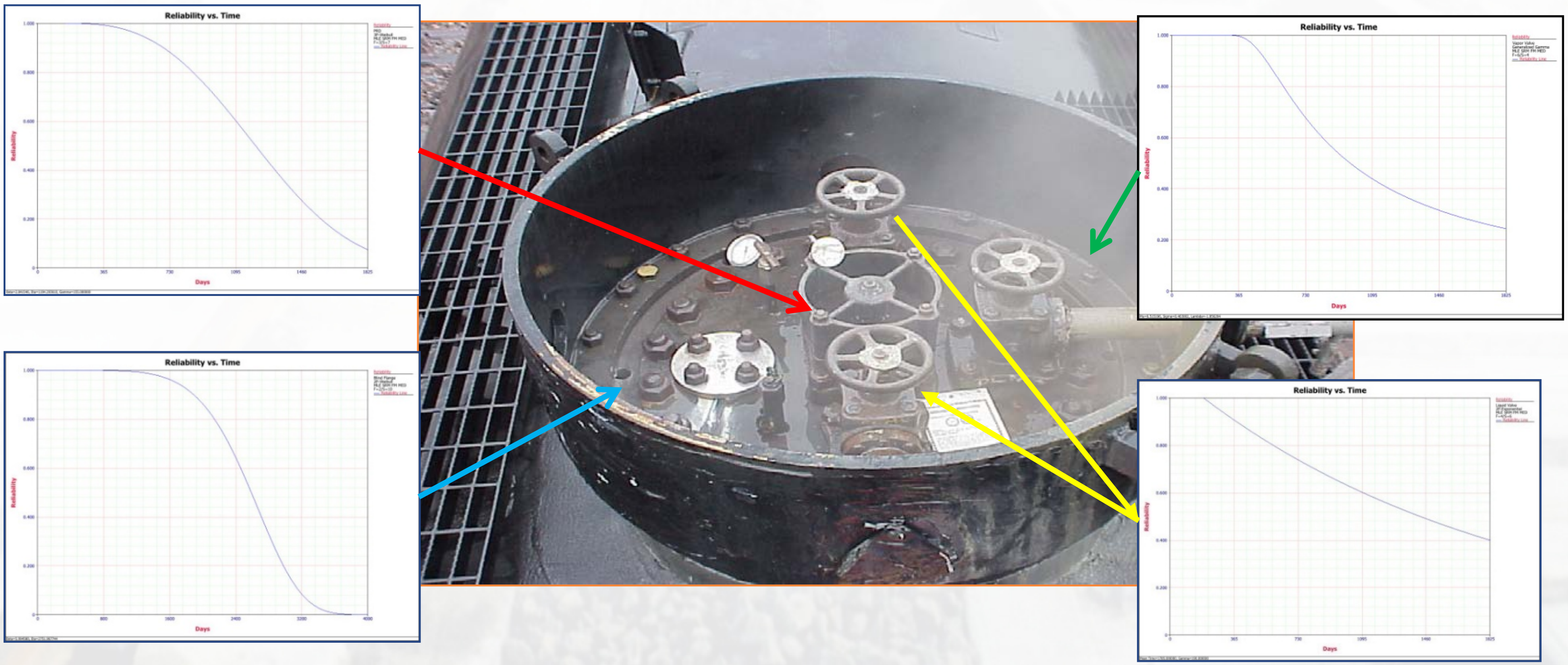
CASE STUDY #2

Service Equipment – A Complex System . . . **OR**



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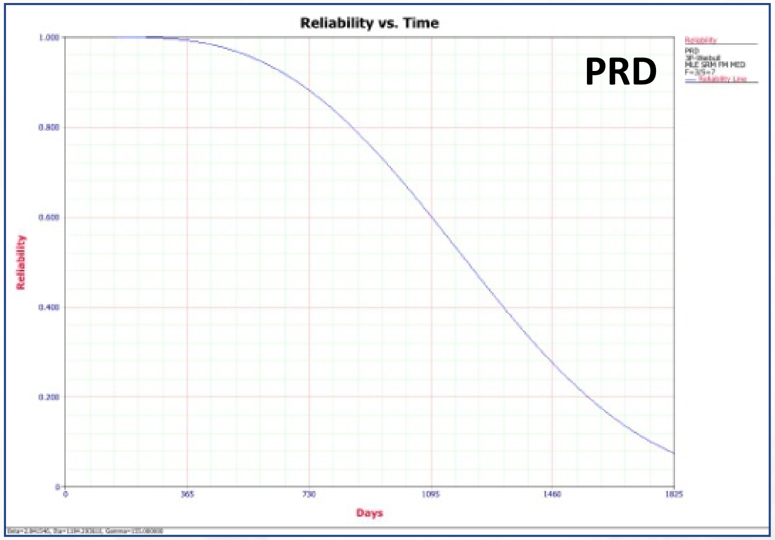
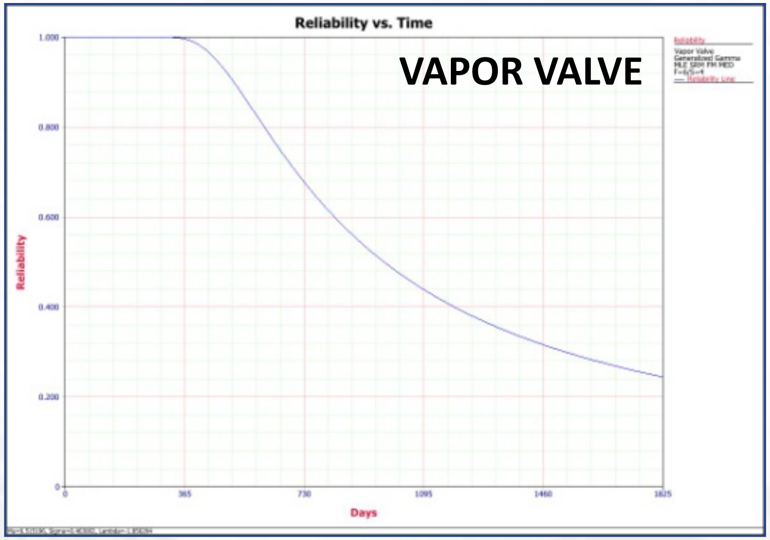
CASE STUDY #2

Service Equipment – A Complex System



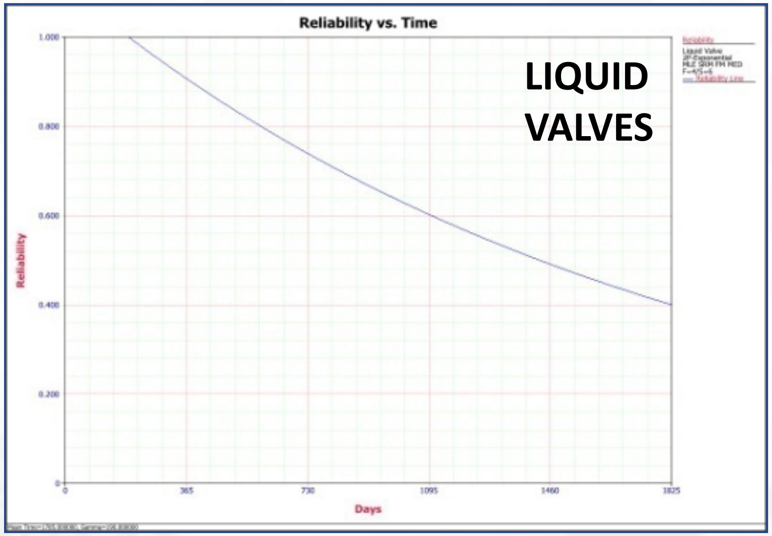


1 Year Valve Set Reliability = 0.99*0.99

5 Year Valve Set Reliability = 0.08*0.25

CASE STUDY #2

Service Equipment – A Complex System



1 Year Valve Set Reliability = 1.00*0.91*0.91

5 Year Valve Set Reliability = 0.03*0.40*0.40

CASE STUDY #2

Service Equipment – A Complex System

1 Year Valve Set Reliability = 0.99*0.99* 1.00*0.91*0.91 = 0.812 = 81.2%

5 Year Valve Set Reliability = 0.08*0.25*0.03*0.40*0.40 = 0.000096 = 0.0096%

89.2% Reliable @ 1 Year means:

- For a 100 car fleet, 11 cars have at least one service equipment failures
- For a 1,000 car fleet, 108 cars have at least one service equipment failure

0.0096% Reliable @ 5 Years means:

- For a 100 car fleet, all cars have at least one service equipment failure
- For a 1K car fleet, all cars have at least one service equipment failure
- For a 10K car fleet, 9,999 cars have at least one service equipment failure

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CASE STUDY #2

Service Equipment – A Collection of Subcomponents

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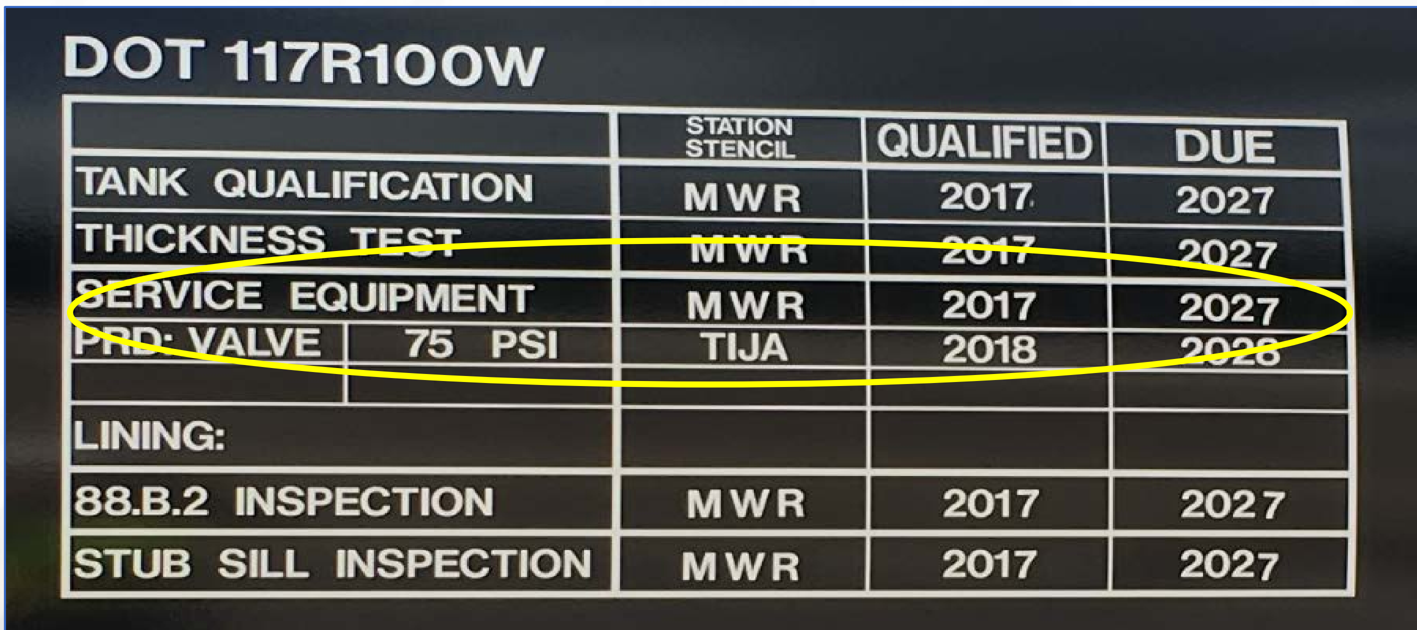
CASE STUDY #2

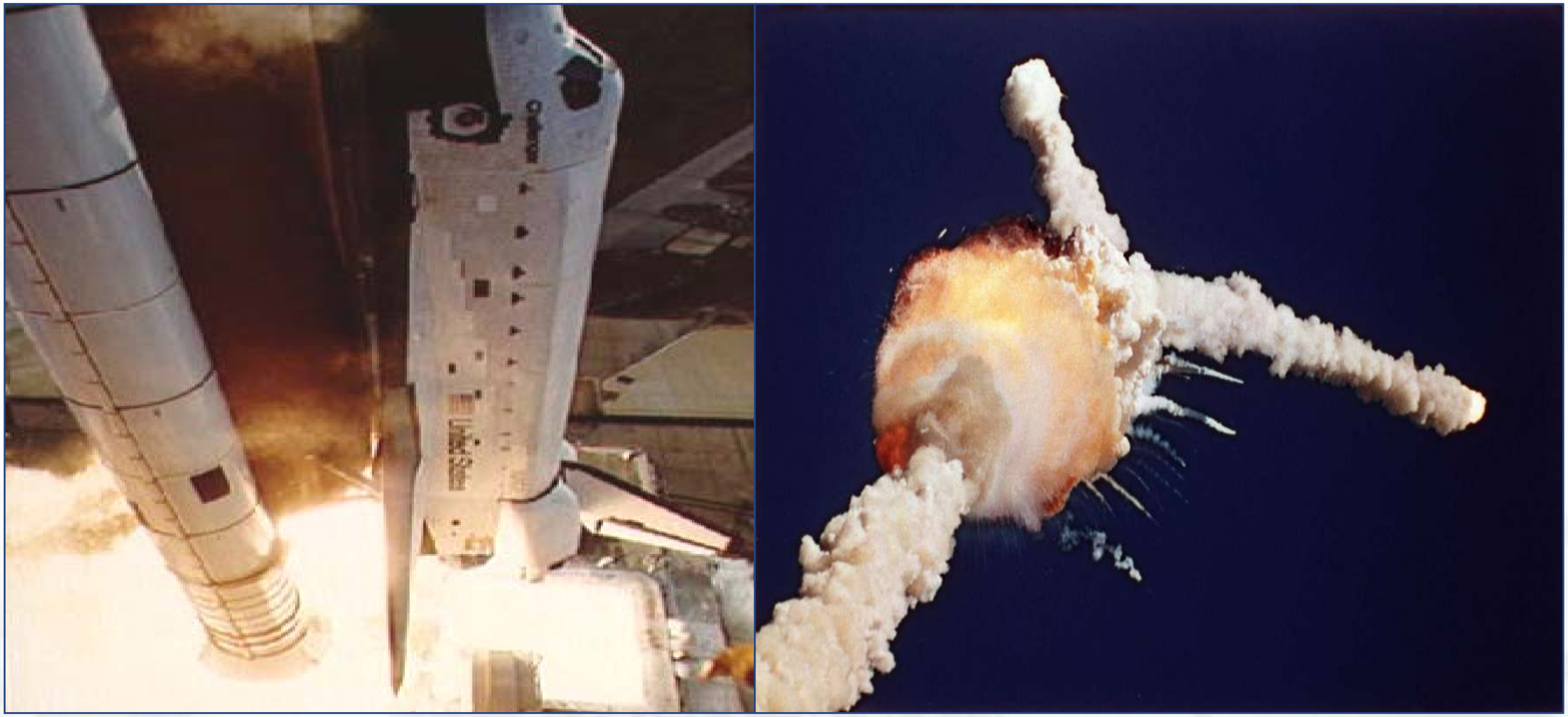
Service Equipment – Summary – 10 Years Not Valid



DOT 117R100W

		STATION STENCIL	QUALIFIED	DUE
TANK QUALIFICATION		MWR	2017	2027
THICKNESS TEST		MWR	2017	2027
SERVICE EQUIPMENT		MWR	2017	2027
PRD: VALVE	75 PSI	TIJA	2018	2028
LINING:				
88.B.2 INSPECTION		MWR	2017	2027
STUB SILL INSPECTION		MWR	2017	2027

CHALLENGER



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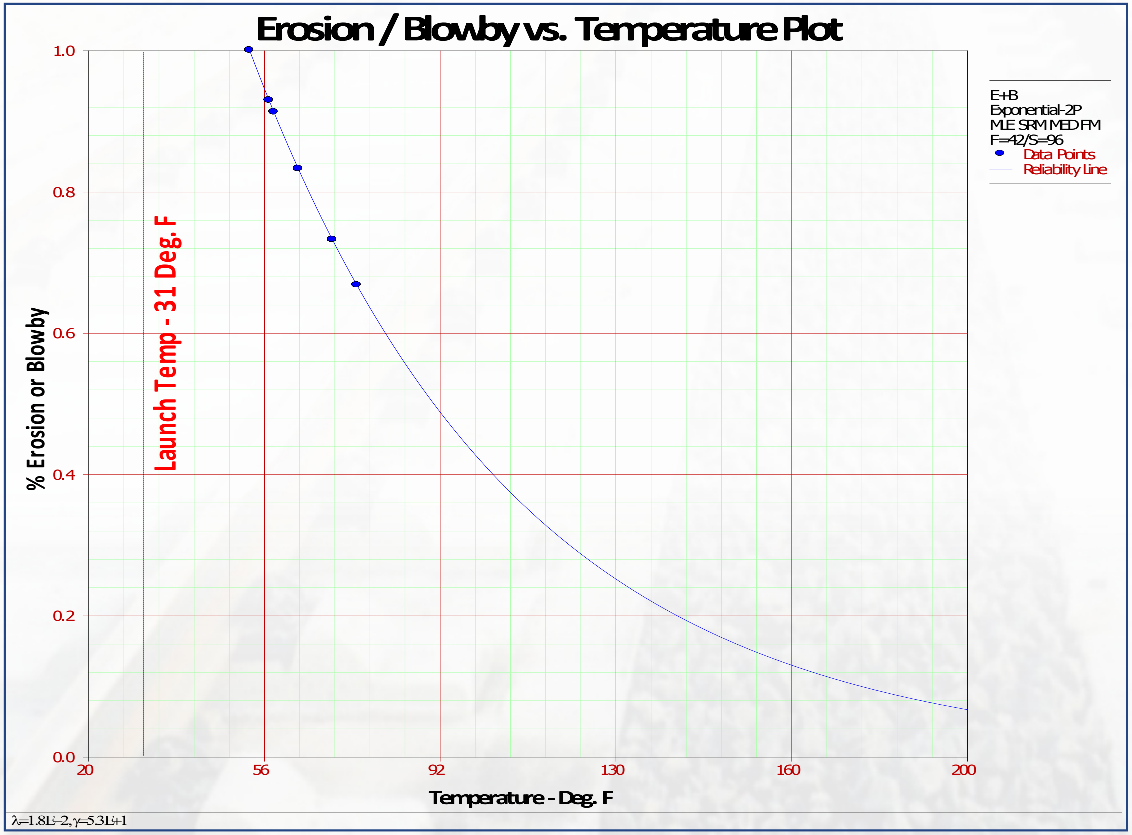
CHALLENGER



Cause of Escaping Gas –
O-ring Erosion and / or Blowby

- 100% Probability of O-ring Erosion or Blowby at 50 deg.F launch temperature
- 150% Probability of O-ring Erosion or Blowby at 31 deg.F launch temperature

No wonder Challenger exploded !

Why didn't NASA & Thiokol use Weibull ???

QUESTIONS

?