

**C57.139**

**Dissolved Gas Analysis  
Of Load Tap Changers**

**Working Group**

Data Analysis Update – Spring 2007

# Data Analysis Agenda

1. Update of activity

2. Data analysis

3. Review examples in reverse

4. Discuss conclusions

# Activity Update

- More data has been received
- Past concerns to identify “bad actors” using ratios and limits were discussed at the Fall meeting.
- Subcommittee formed to work further on data analysis (David Wallach, Jim Dukarm, and Shuzhen Xu) to discuss alternative methods to look at data statistically
- Subcommittee held multiple conference calls with support of WebEx & MS Live Meeting

# Activity Update

- Last meeting - we discussed working the process in reverse using LTC's with known contact problems. Two examples have been worked.

# Data Analysis

- Minutes from Fall 2006

Fredi commented that the 90<sup>th</sup> percentile selection may be too low. For thresholds, the gases have to be at least at a certain level to have confidence in the ratios. Should the 90<sup>th</sup> percentile values be used as the threshold gas levels?

Fredi suggested that we possibly need to reverse the process and look at only the problem units and set values based on those units. However, this further lowers the number of usable records. Without adequate data, we can't do more than a purely statistical approach.

Jim Dukarm discussed the statistical approach method. You want to be able to put all of your resources towards the problem units. You need to be able to distinguish the lower risk from the higher risk units. This will then allow you to focus resources at the higher risk units.

Fredi and Dave will formulate an approach. The consensus was a two table approach. The first test will tell you whether you need to increase the testing interval to look at the rate of increase. Also Jim Dukarm will look into providing a Weibull distribution for the data available from Dave for the next meeting.

A question was asked as to what constitutes a failure. Fredi indicated we are not talking about mechanical failures, but rather issues such as coking of the contacts, basically a situation or problem that can be detected by means of a DGA.

# Data Analysis

- Planning call on January 4, 2007
  - Use of 90<sup>th</sup> percentile results will depend on amount of data for a given model.
  - LTC gasses are far from a normal distribution. Most results are low so elementary methods may not apply.
  - We have not performed any advanced curve fitting techniques to date.
  - Maybe have a “don’t care” limit and above which you can analyze. Ratios give you relative rates of generation.
  - Path forward from January 4<sup>th</sup> meeting –
    - Dave provide data in Excel, model lookup table, and the latest version of the proposed LTC guide type table to Jim and Shuzhen to plot some statistical charts. Results will be exchanged. Jim will check with some customers to enlarge the database for the committee work.
    - We can also have and look at 90<sup>th</sup> and 95<sup>th</sup> percentiles by model or type.

# Update from Jim Dukarm

- Programmatic approach...
  - A spreadsheet is fine for quick exploratory data analysis, but is not suitable for doing a more extensive analysis in a repeatable way.
  - There are some kinds of statistical investigation that spreadsheets don't support.
  - Some software was written to provide fast, repeatable data analysis and graphing.
  - As new questions arise, it is not difficult to create new report-generating scripts to address those questions.

# Update from Jim Dukarm

- Programmatic approach...
  - **Question 1:** Do the distributions of gas concentrations and gas ratios differ year by year, and does lumping all measurements together change the distribution?
  - **Answer:** Apparently the distributions of concentrations and ratios are very similar year to year and also when all years are lumped together.

*Note: these distributions are for one company at a time - data from different companies was not mixed.*

# Update from Jim Dukarm

## Two-Sample Kolmogorov-Smirnov Test

(Values near zero indicate distinct distributions)

**Variable: ETHYLENE (C2H4) - DUKE LTC's - Type AS1X**

Year	1994	1995	1996	1997	1998	1999
1995	0.3364	--	--	--	--	--
1996	0.5911	0.6776	--	--	--	--
1997	0.4090	0.4512	0.3151	--	--	--
1998	0.7658	0.4756	0.9148	0.6315	--	--
1999	0.6465	0.2843	0.4316	0.5058	0.6220	--
ALL	0.4961	0.4527	0.6455	0.1629	0.8142	0.7639

**Conclusion: Year-to-year and lumped distributions do not differ.**

# Update from Jim Dukarm

## Two-Sample Kolmogorov-Smirnov Test

(Values near zero indicate distinct distributions)

**Variable: C2H4/C2H2 - DUKE LTC's - Type AS1X**

Year	1994	1995	1996	1997	1998	1999
1995	0.7848	--	--	--	--	--
1996	0.0218	0.0906	--	--	--	--
1997	<b>0.0143</b>	0.0604	0.9706	--	--	--
1998	0.0255	0.0996	0.3149	0.3071	--	--
1999	0.0629	0.3576	0.9539	0.7890	0.1796	--
ALL	<b>0.0119</b>	0.0758	0.8275	0.6539	0.0642	0.4886

**Conclusion: Year-to-year and lumped distributions do not differ.**

# Update from Jim Dukarm

- Programmatic approach...
  - **Question 2:** Does the ethylene/acetylene ratio behave similarly in all non-vacuum LTC's? Or within LTC types?
  - **Answer:** Generally not!

# Update from Jim Dukarm

## Two-Sample Kolmogorov-Smirnov Test

(Values near zero indicate distinct distributions)

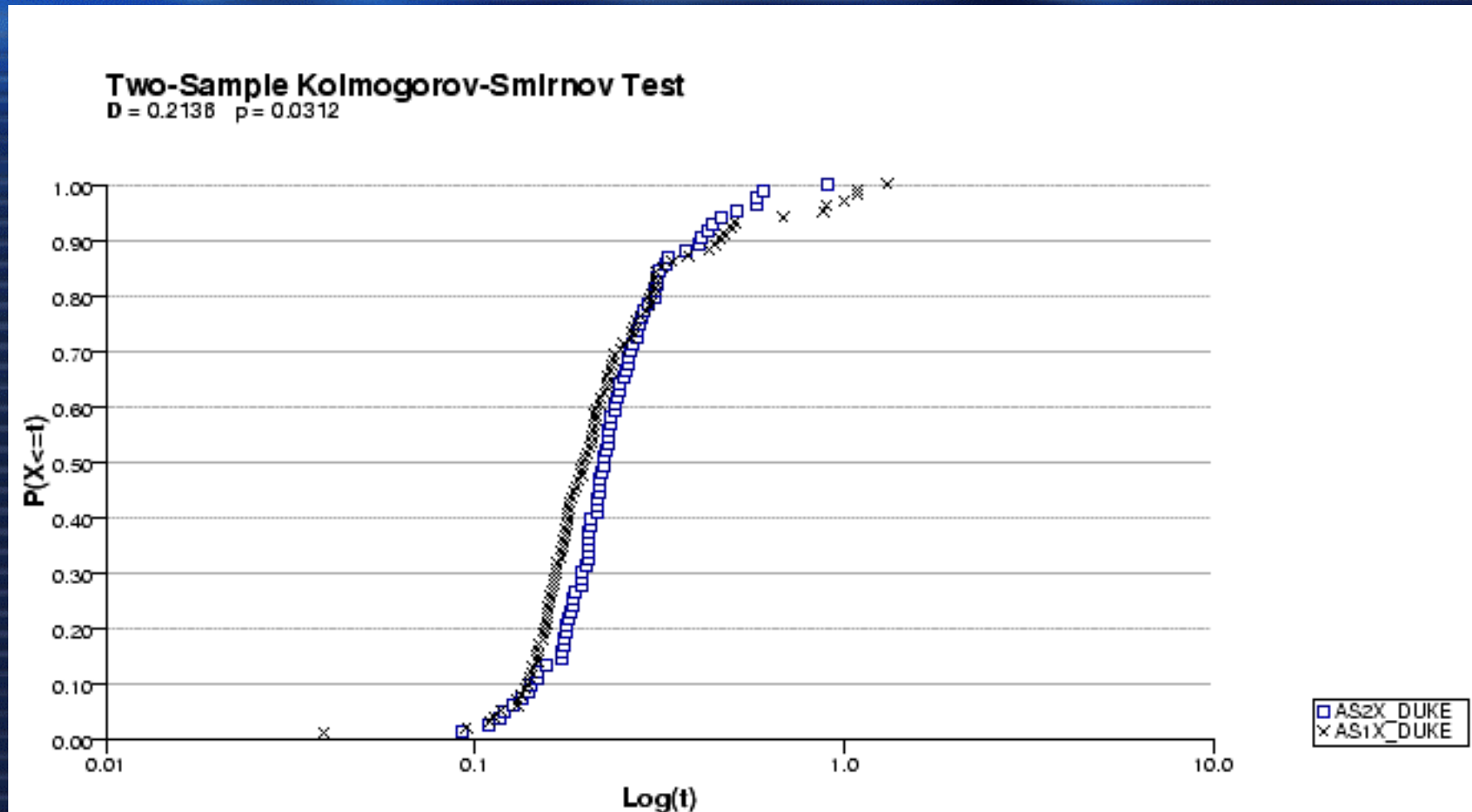
**Variable: C2H4/C2H2 - DUKE LTC's**

Type	AS1X	AS2X	ATS1R
AS2X	0.0312	--	--
ATS1R	<b>0.0001</b>	<b>0.0000</b>	--
ATS1X	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>

**Conclusion:** Multi-year distributions of C2H4/C2H2 differ between most LTC types at this company.

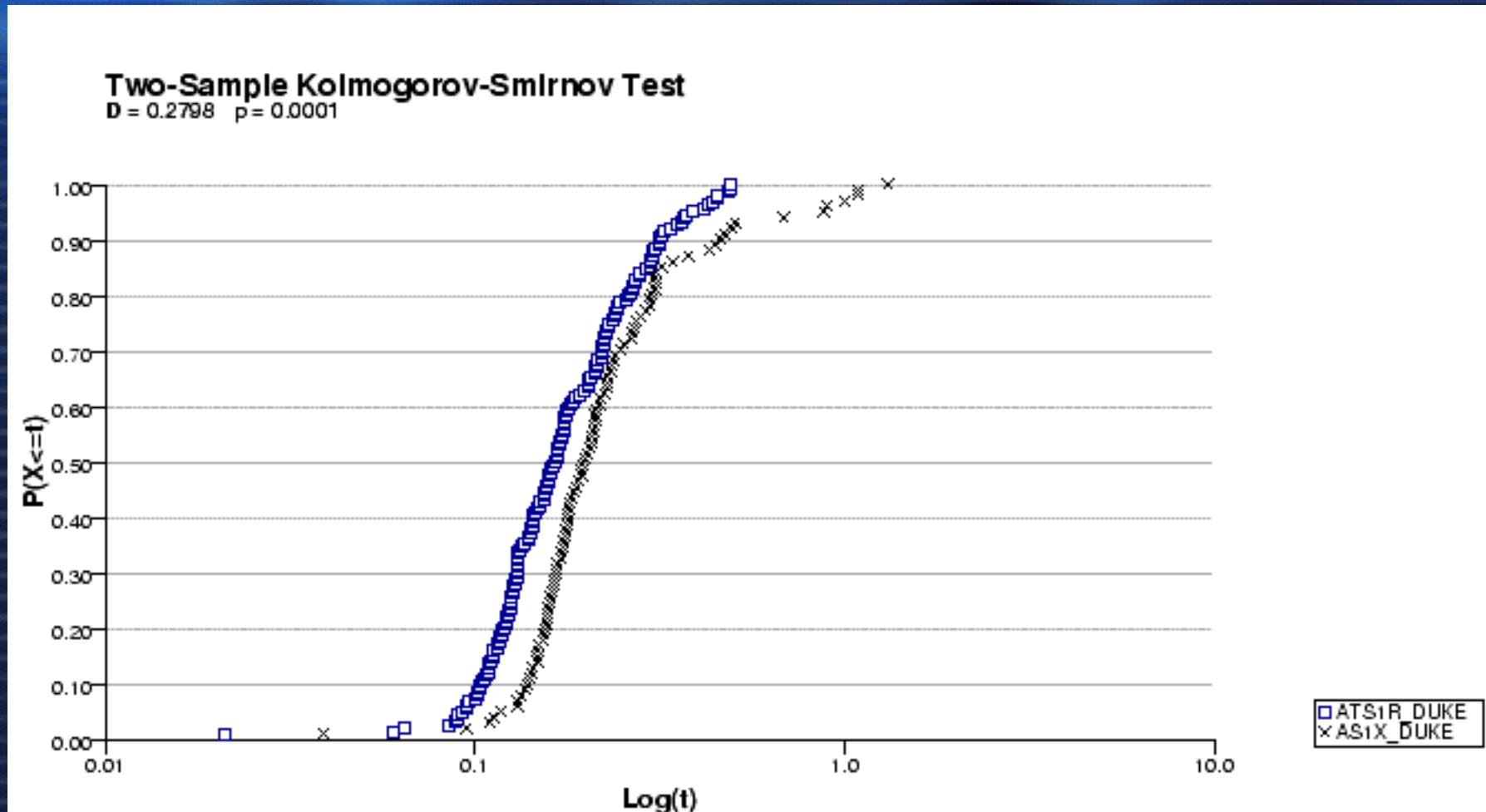
**In fact, these distributions also mostly differed even for the same LTC type between companies.**

# Update from Jim Dukarm



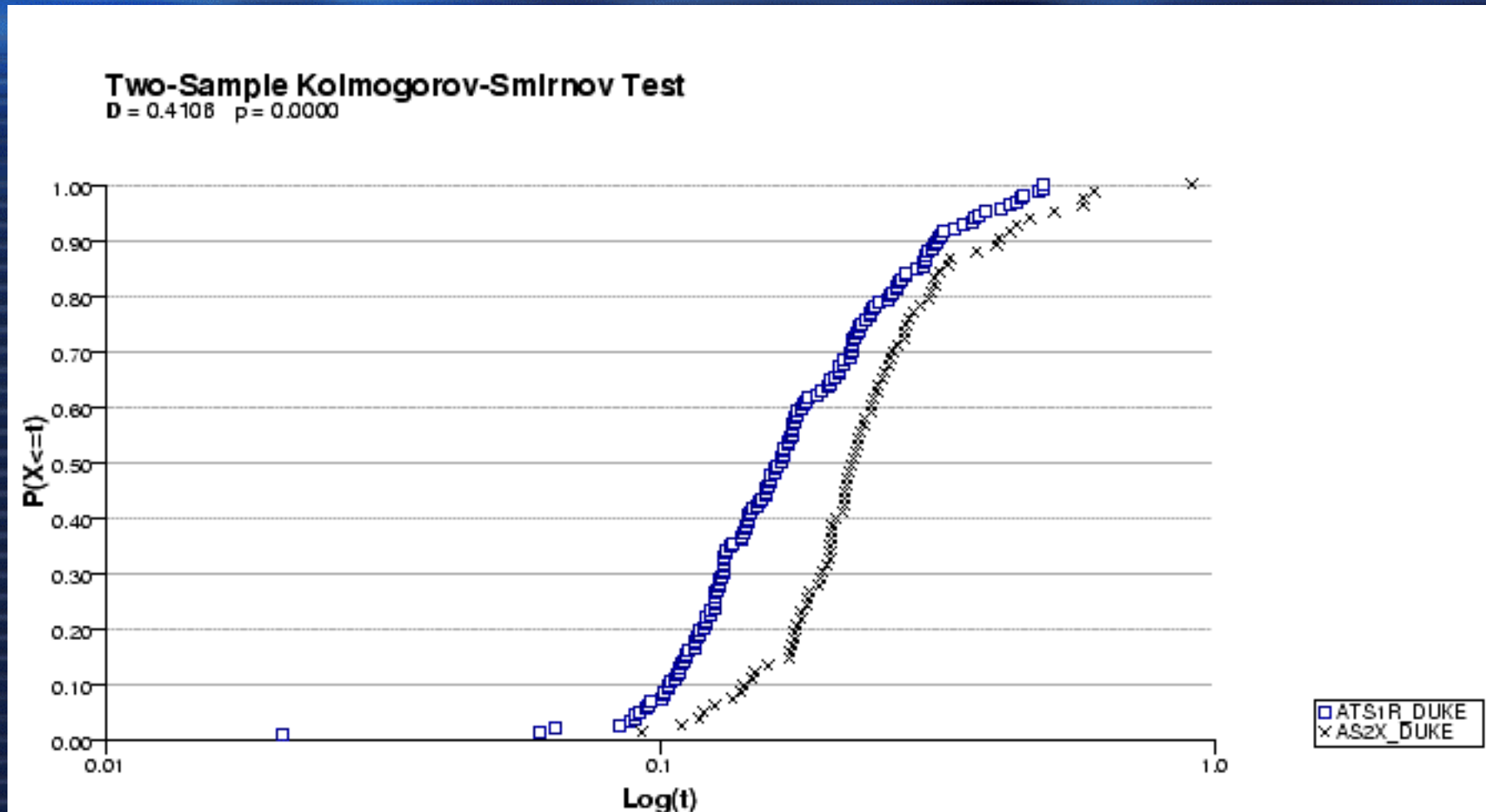
Conclusion: Duke AS2X and AS1X have similar C2H4/C2H2 distributions.

# Update from Jim Dukarm



Conclusion: Duke AT51R and AS1X have different C2H4/C2H2 distributions.

# Update from Jim Dukarm



Conclusion: Duke ATS1R and AS2X have different C2H4/C2H2 distributions.

# Update from Jim Dukarm

- Tentative Conclusions

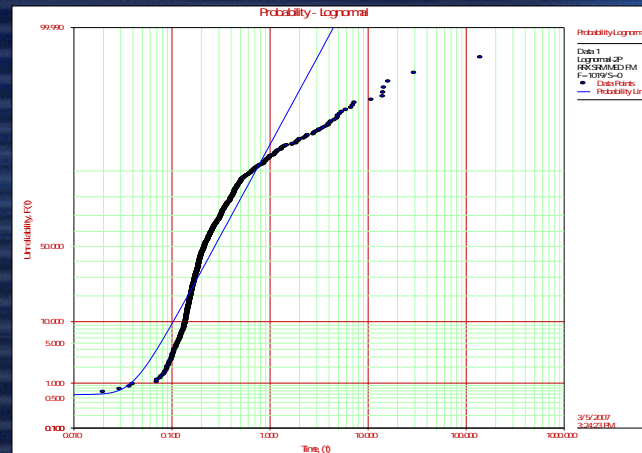
- *This analysis has not been carried out for other gas ratios, but it is expected that the results will be similar.*
- *Although some rough similarities in C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>2</sub> distributions do appear, a purely statistical approach to ratio-based LTC diagnosis seems unpromising.*
- *Common practice in the industry (and recent work by Duval) indicate that it should be possible to establish workable diagnostic limits for ratios based on study of DGA data for LTC's whose contact condition has been determined by inspection.*
- *Detailed results of statistical analysis will be made available to the WG as zipped collections of html files (web pages).*

# Update from Shuzhen Xu

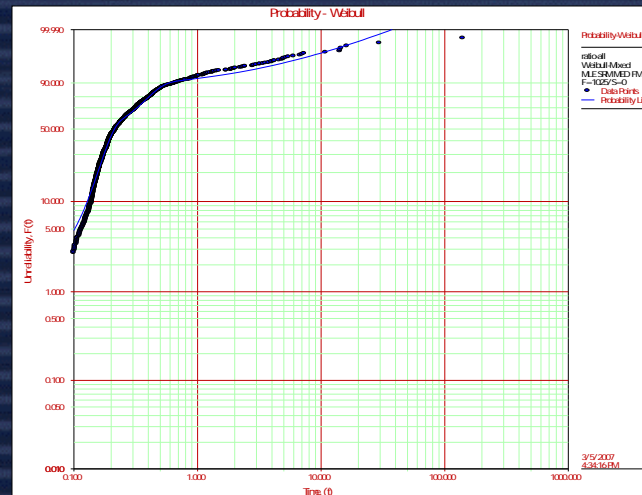
- The statistic analysis was only conducted on the data from Model AS1X (Arcing Switch in Oil, Single Compartment, Reactance type) and will be continued in the future.
- Observations from data analysis
  - The gas concentrations and ratios don't follow normal distribution.
  - The phenomenon of heterogeneousness was found in some gas concentrations and ratios distributions.
  - Differentiating the data of the “healthy” units from those of problematic units is necessary before conducting meaningful statistic analysis.
    - The differentiation may be possible for the gas ratios but may be impossible for gas concentrations due to the lack of operation counts?

# Update from Shuzhen Xu

- Example 1 of data analysis.
  - Data: the ratio between ethylene to acetylene  $R1=(C2H4/C2H4)$
  - Target model: AS1X
  - Mixed-weibull model fits the data best
  - Data are not from the same population statistically



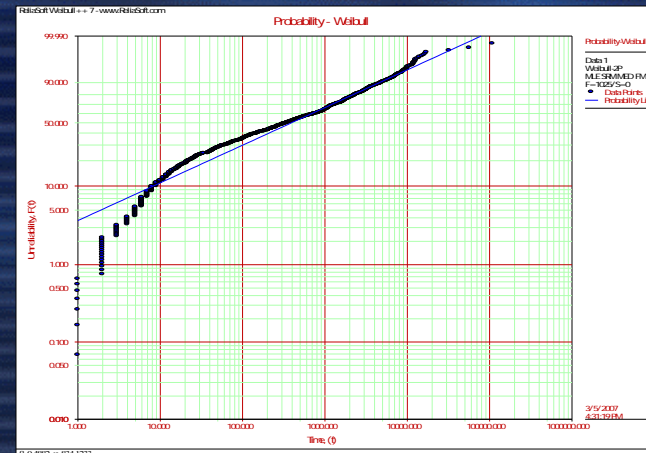
Lognormal distribution fitting results



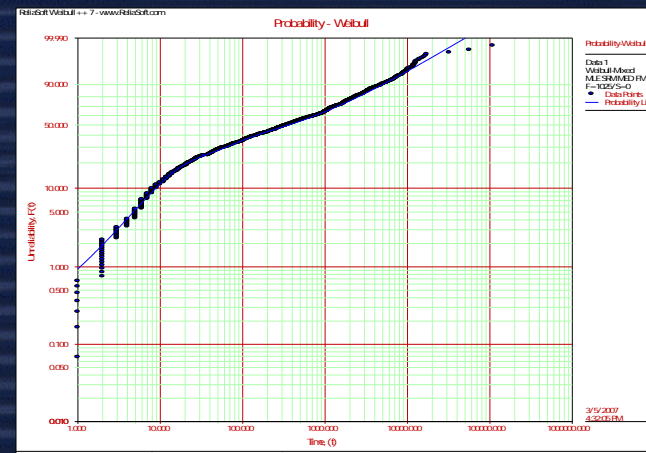
Mixed-weibull distribution fitting results

# Update from Shuzhen Xu

- Example 2 of data analysis.
  - Data: Ethylene
  - Target model: AS1X
  - Mixed-weibull model fits the data best
  - Data are not from the same population statistically



2 parameter weibull distribution fitting results



Mixed-weibull distribution fitting results

# Review in reverse – Example #1

- October 26, 2006: Duke Energy southern region had potential problems associated with Bank 3 at XXXXXX Retail (C04901515). After looking at a few other predictors it was obvious we had issues inside the LTC compartment. Internal inspection was performed. Attached you'll see photos of these findings. (z & x phases the worst)
- A little history
  - Maximo records indicated that the last internal inspection of the contacts was performed in 1999. The last external inspection/filter change was on March 8, 2006. DGA and filter condition results at that time didn't point to signs of trouble.
  - Between March 8, 2006 and October 25, 2006 the LTC has operated around 3458 operations and the filter pressure was noted at 45-50 psi. on October 25, 2006. Actual start up pressure during the last external inspection with filter change was 13 psi. on March 8, 2006.
  - Working with Voltage Quality the field installed recorders on each phase for monitoring and operated the LTC a couple of times in the lower and raise positions. Field personnel did notice a change in tone from the 9L to the 10L position (not a good sign). The results from the recordings were distorted voltage and current wave forms.
  - The LTC was locked down on a tap that was a happy medium and cleared on October 25, 2006. This unit typically stays on the lower or buck side of neutral so it was apparent these contacts would be in the worst condition. After opening the compartment this outside-in assessment was true.
  - We replaced all moving and stationary contacts, replacing all gaskets, replacing oil, ratio, dielectric, and then re-charge for load.

# Filter



# Z phase contacts



# Y phase contacts



# X phase contacts



# Serial Number C04901515 Data

SAMPLEDATE	H2	CH4	C2H6	C2H4	C2H2	CO	TOTALGAS	CO2	REASON
4/2/2004 0:00	0	1	0	1	1.5	24	8.8	303	ROUTINE
5/9/2005 0:00	41	1	0	2	3.3	204	6.1	613	ROUTINE
1/12/2000 0:00	21	1	1	2	9	37	7.6	507	ROUTINE
1/13/2003 0:00	0	3	0	2	4.9	49	6.8	582	ROUTINE
5/2/1999 0:00	25	2	0	3	5	97	10.6	714	ROUTINE
8/16/2001 0:00	60	4	2	5	11	213	8.6	1333	ROUTINE
7/17/2002 0:00	56	3	1	8	18	252	8.2	47	ROUTINE
3/8/2006 0:00	0	7	10	42	10	121	7.7	903	ROUTINE

R1	R2	R3	R4	R5	R6	Hot Metal Sum
0.666667	0.666667	1.333333	1.333333	0	0	2
0.045147	0.606061	0.06772	0.909091	0	0	3
0.066667	0.222222	0.133333	0.444444	1	2	4
0.408163	0.408163	1.020408	1.020408	0	0	5
0.1	0.6	0.166667	1	0	0	5
0.070423	0.454545	0.15493	1	0.5	2.5	11
0.108108	0.444444	0.162162	0.666667	0.333333	8	12
4.2	4.2	5.9	5.9	1.428571	4.2	59

# Example #1 - Ratios

## McGraw 550CS LTC, Sealed with continuous online filtration

Number of records 561

### Average Values, Ratios

R1	R2	R3	R4	R5	R6
0.365	0.788	0.807	2.961	0.592	4.391

### Standard Deviation, Ratios less than 90th percentile

R1	R2	R3	R4	R5	R6
0.097	0.132	0.203	0.389	0.341	4.050

### Percentiles, Ratios

Percentile	R1	R2	R3	R4	R5	R6
10.00%	0.043	0.160	0.088	0.233	0.000	0.000
20.00%	0.098	0.211	0.176	0.296	0.000	0.000
30.00%	0.127	0.235	0.222	0.337	0.146	0.143
40.00%	0.152	0.253	0.249	0.387	0.250	0.905
50.00%	0.180	0.286	0.283	0.450	0.375	2.500
60.00%	0.207	0.323	0.345	0.537	0.500	4.167
70.00%	0.244	0.373	0.438	0.667	0.600	7.000
80.00%	0.297	0.474	0.597	1.011	0.878	9.750
90.00%	0.429	0.769	1.330	2.714	1.288	11.885
95.00%	0.690	1.786	2.759	8.064	2.000	13.541
98.00%	1.898	4.366	8.529	21.289	3.089	15.629

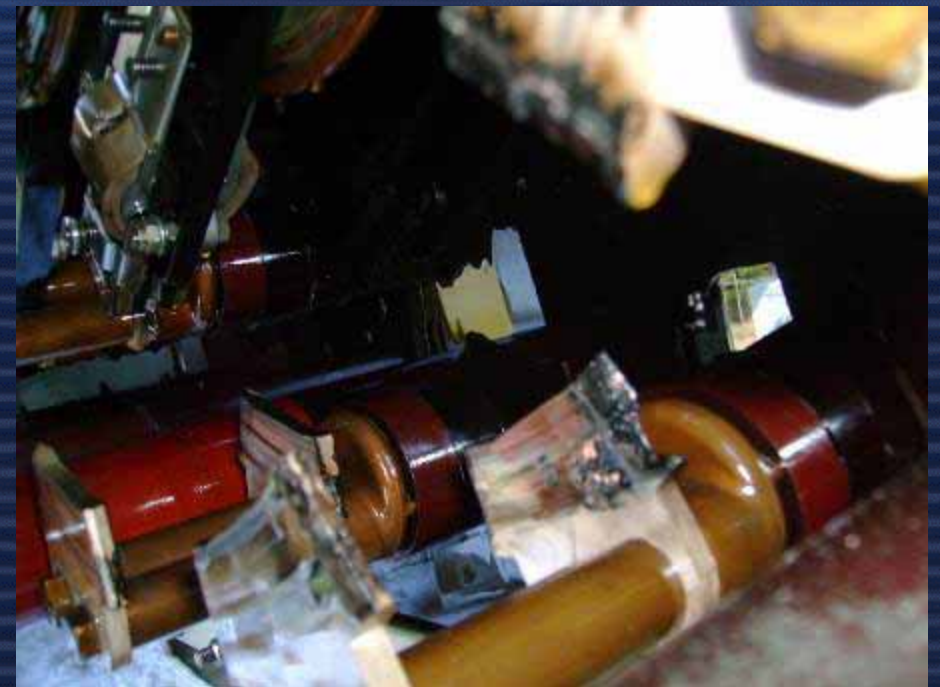
# Example #1 Conclusions

- Ratios could have triggered concerns after the “damage was done”
- Duke Energy’s traditional approach would NOT have caught this
  - Sum of hot metals
  - Hot metal ppm trend

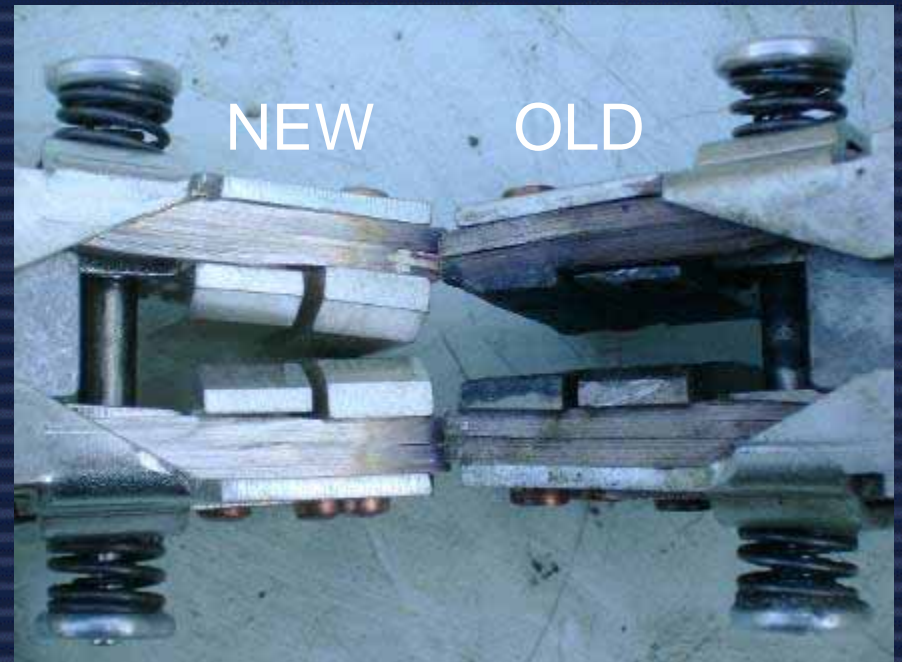
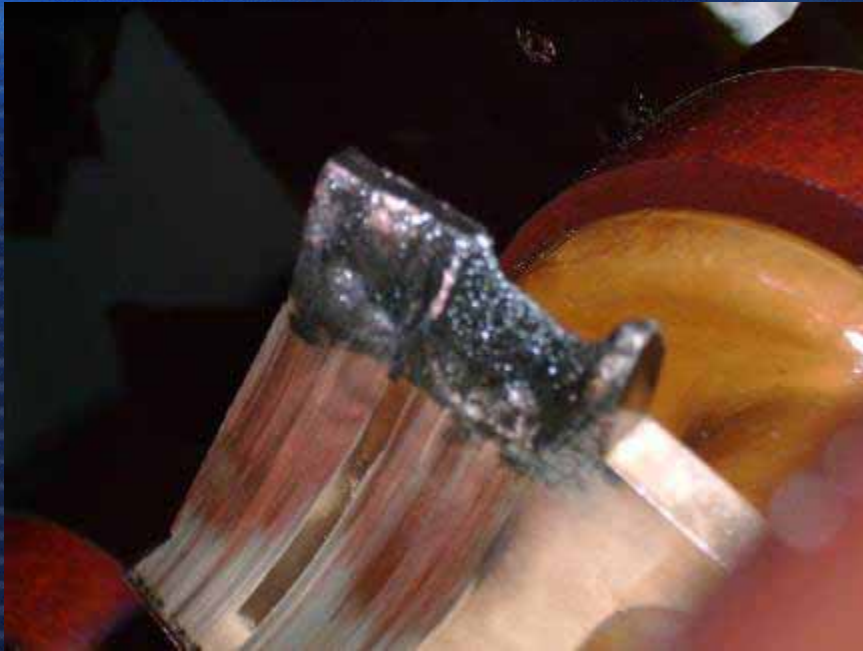
# Example #2

- XXXXXX Retail is a one bank station. This transformer (Serial Number C04901512) still had the old balance beam control. A service tech was investigating a low voltage complaint when he discovered that the LTC would not operate. Field personnel went there and noticed the LTC would attempt to raise but would only go about half way and then return to the previous step. After a few times of this happening, we decided to lock it down and install a portable transformer to clear the bank and go into the mechanism.
- The reason the LTC wouldn't operate is because one set of moving contacts had welded itself to one of the stationary. This transformer had an internal PM in 2003 and the low resistance contacts were installed at this time.
- This transformer had operated 31,133 times since January of this year in 2006 (3459/month). In 2005, it operated 31,907 times (2658/month) and was pretty much normal in 2004 operating 8157 times (680/month). Field personnel are convinced that the number of operations was due to the balance beam control. A new Beckwith 2001 two days later showed 14 operations a day. Much better! Filter was pretty much black. DGA was off of the charts.
- When the contacts were replaced and we operated the mechanism, we noticed that the motor seemed to strain when it went from neutral to raise 1. This is when the reversing switch operates also. We replaced the motor and gear box and then it sounded OK. I don't know if the motor got weak when the contacts welded and the motor stalled or because of the number of operations. Anyway, we pretty much have a new tap changer mechanism and control now.

# Second example photos



# Second example photos



# Serial Number C04901512 Data

EQUIPNUM	SAMPLEDATE	H2	CH4	C2H6	C2H4	C2H2	CO	TOTALGAS	CO2	REASON
C04901512	4/23/1998 0:00	0	0	0	1	0	32	10.6	320	AFTER DEGAS
C04901512	6/3/1998 0:00	27	0	0	8	41	77	4	439	NEW FLUID
C04901512	8/27/1996 0:00	83	7	5	25	113	133	9.9	1852	ROUTINE
C04901512	4/6/1998 0:00	28	14	4	40	218	113	8.9	1234	BEFORE DEGAS
C04901512	10/1/1998 0:00	23	16	7	84	403	10	9.3	508	ROUTINE
C04901512	6/5/1996 0:00	100	95	48	39	122	513	7.3	2870	ROUTINE
C04901512	9/3/2002 0:00	51	28	17	168	720	126	9.1	28	ROUTINE
C04901512	1/20/2003 0:00	85	62	10	145	750	28	9.7	494	ROUTINE
C04901512	5/5/1999 0:00	58	41	16	190	1031	16	11.4	511	ROUTINE
C04901512	1/6/2000 0:00	54	38	18	203	1052	3	9.4	510	ROUTINE
C04901512	1/15/2004 0:00	121	66	24	314	1400	27	7.7	391	ROUTINE
C04901512	1/17/2006 0:00	235	127	81	849	3500	15	9.1	319	ROUTINE
C04901512	11/14/2005 0:00	146	154	79	845	3300	29	8.7	524	ROUTINE

R1	R2	R3	R4	R5	R6	Hot Metal Sum
0	0	0	0	0	0	1
0.117647	0.195122	0.117647	0.195122		0	8
0.127551	0.221239	0.188776	0.327434	0.714286	5	37
0.162602	0.183486	0.235772	0.266055	0.285714	10	58
0.197183	0.208437	0.251174	0.265509	0.4375	12	107
0.175676	0.319672	0.81982	1.491803	0.505263	0.8125	182
0.217899	0.233333	0.276265	0.295833	0.607143	9.882353	213
0.173653	0.193333	0.25988	0.289333	0.16129	14.5	217
0.174472	0.184287	0.226814	0.239573	0.390244	11.875	247
0.183544	0.192966	0.234177	0.246198	0.473684	11.27778	259
0.206443	0.224286	0.265615	0.288571	0.363636	13.08333	404
0.227309	0.242571	0.282999	0.302	0.637795	10.48148	1057
0.245212	0.256061	0.312826	0.326667	0.512987	10.6962	1078

# Specific Example - Ratios

## McGraw 550CS LTC, Sealed with continuous online filtration

Number of records 561

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40.00%	0.152	0.253	0.249	0.387	0.250	0.905
50.00%	0.180	0.286	0.283	0.450	0.375	2.500
60.00%	0.207	0.323	0.345	0.537	0.500	4.167
70.00%	0.244	0.373	0.438	0.667	0.600	7.000
80.00%	0.297	0.474	0.597	1.011	0.878	9.750
90.00%	0.429	0.769	1.330	2.714	1.286	11.885
95.00%	0.690	1.786	2.759	8.064	2.000	13.541
98.00%	1.898	4.366	8.529	21.289	3.089	15.629

# Example #2 Conclusions

- Ratio of  $C_2H_4/(C_2H_2+H_2)$  appears to be sensitive but the other ratios would not have supported a concern.
- Duke Energy's traditional approach would support the problems found however internal trigger levels were not met.
  - Sum of hot metals
  - Hot metal ppm trend
- The 90<sup>th</sup> percentile of this ratio would probably not raise a flag until the contacts were already in poor condition.

# Summary

- Preliminary statistical investigation was conducted by Shuzhen and Jim on four LTC DGA data sets - from Alliant, Duke, GBC, and HSB.
- Work was concentrated on ethylene (C<sub>2</sub>H<sub>4</sub>) and the ethylene-acetylene ratio (C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>2</sub>)
- Shuzhen used some powerful statistical analysis software tools to investigate these particular cases, and Jim wrote statistical software which would be able to carry out analyses similar to Shuzhen's on a larger scale after we had figured out what seemed most fruitful.

# Summary

- We found that the distributions of ethylene and the ethylene/acetylene ratio were very messy and inconsistent from company to company and between arcing LTC types. It would not be useful to try basing diagnostic limits on percentiles of such distributions.
- By ignoring all the ratio values above a certain percentile (different for each distribution), it is possible to find a single (lognormal) distribution that apparently describes the ethylene/acetylene distribution for AS1X LTC's in good condition. From this we may be able to derive a useful limit for distinguishing between mostly good LTC's and mostly deteriorating ones.
- We expect to be able to derive combustible gas concentration limits that will be useful for vacuum-type LTC's, but so far that work has not been started.
- We will now extend the scope of our analysis to all combustible gases, all ratios, and all LTC types to try to arrive at generally useful results.

# Summary

- It seems clear that it will be necessary to use gas ratio values for inspected arcing-type LTC's to confirm the usefulness of our statistically-derived ratio limit(s) and perhaps to develop some higher limits characterizing more advanced states of deterioration.
- Other than requiring ratio values to be calculated from gas concentrations at or above the respective detection limit (to avoid gross relative uncertainty), we do not expect gas concentration limits to be diagnostically useful for arcing-type LTC's. This will be checked, however.
- Conversely, because of the low gas concentrations usually found in vacuum-type LTC's, we expect that gas concentration limits will be more diagnostically useful than gas ratios for vacuum-type LTC's.

# Proposed Path Forward for Guide

