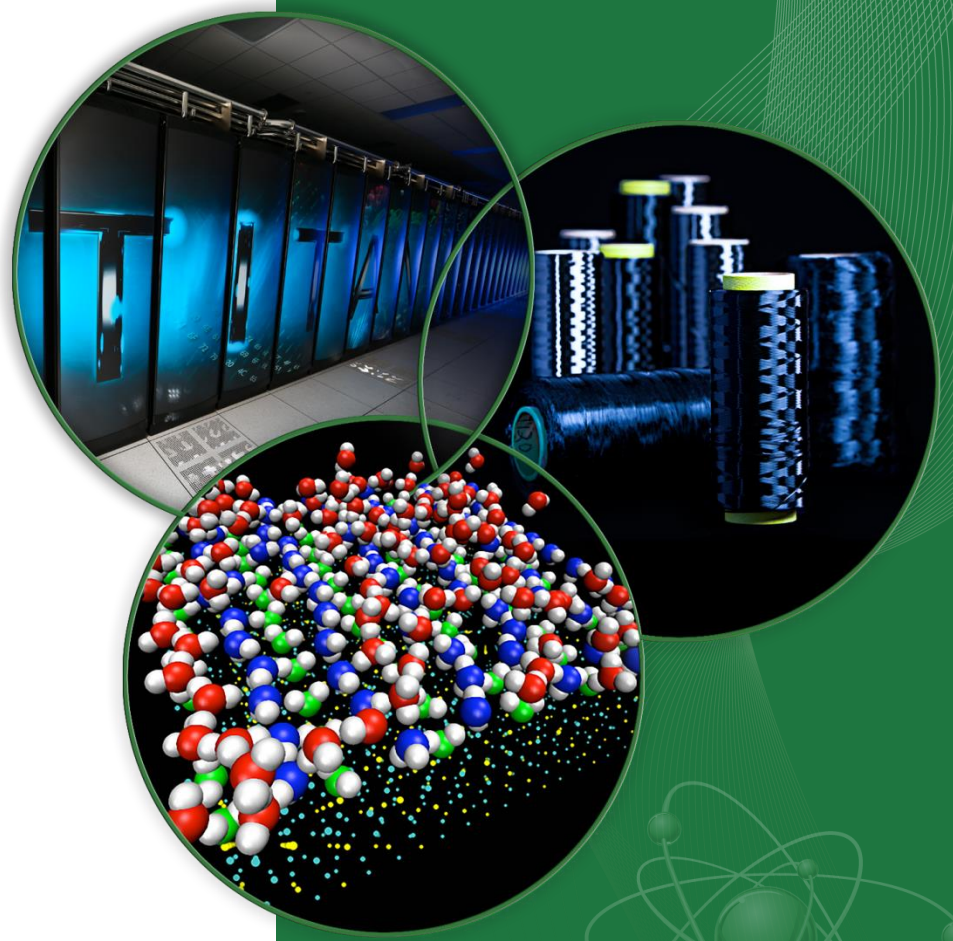
Employing Software for Efficient Retrieval of Reliability Data

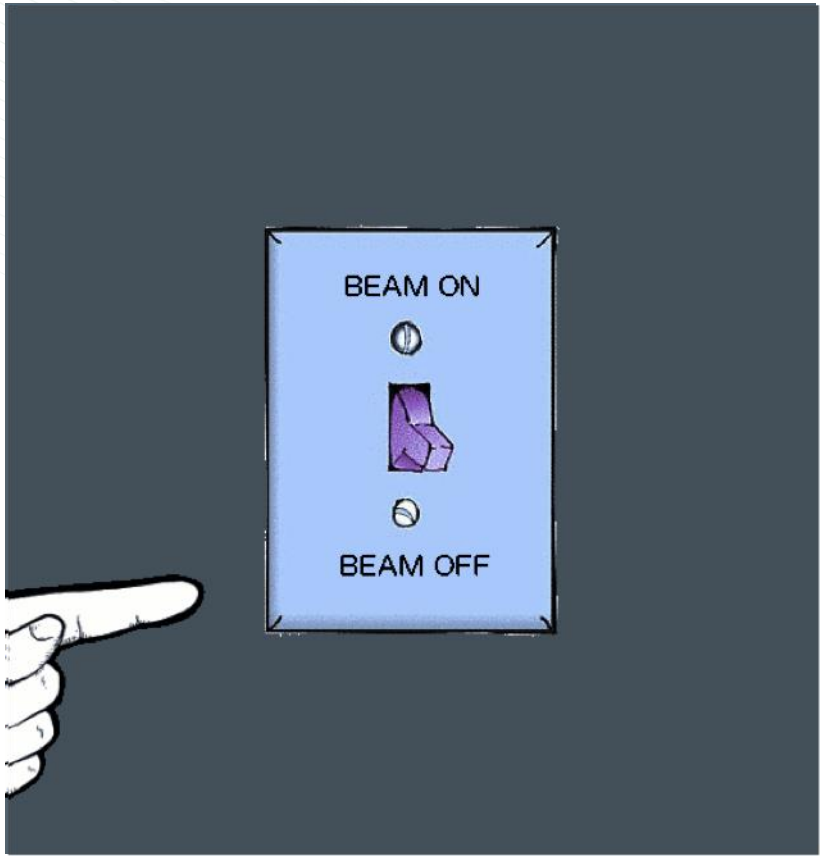
David Brown, Robert Saethre, and Mark Crofford

Research Accelerator Division/Spallation Neutron Source

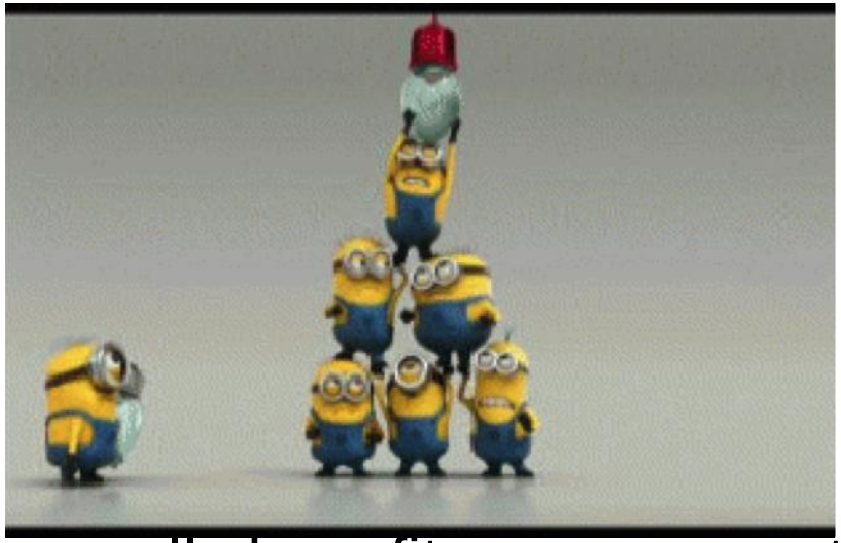


Reliability in the Real world

How Achieving World-Class Reliability Can Appear



More Real Depiction (Delicate Dance)



The process generally benefits some more than others

How Reliability is achieved

- Diligent, system-specific characterization and re-characterization
  - Constant monitoring
  - Gathering data
- Understand Failure Mechanisms and Failure Rates to proactively schedule Preventative Maintenance
- Understanding the interdependence of one sub-system to another
- Intelligent Data Logging facilitates in-depth analysis in support of the aforementioned bullet points

Why Intelligent Data Logging?

- Automation is possible
- Data collection is consistent
- Can be adapted to similar systems quickly
- Type of data and data storage allows for easy software integration
- Examples
  - Dissolved Gas Analysis (DGA) Data Collection Software
  - Radio Frequency Quadrupole (RFQ) Field Flatness Measurement Tool

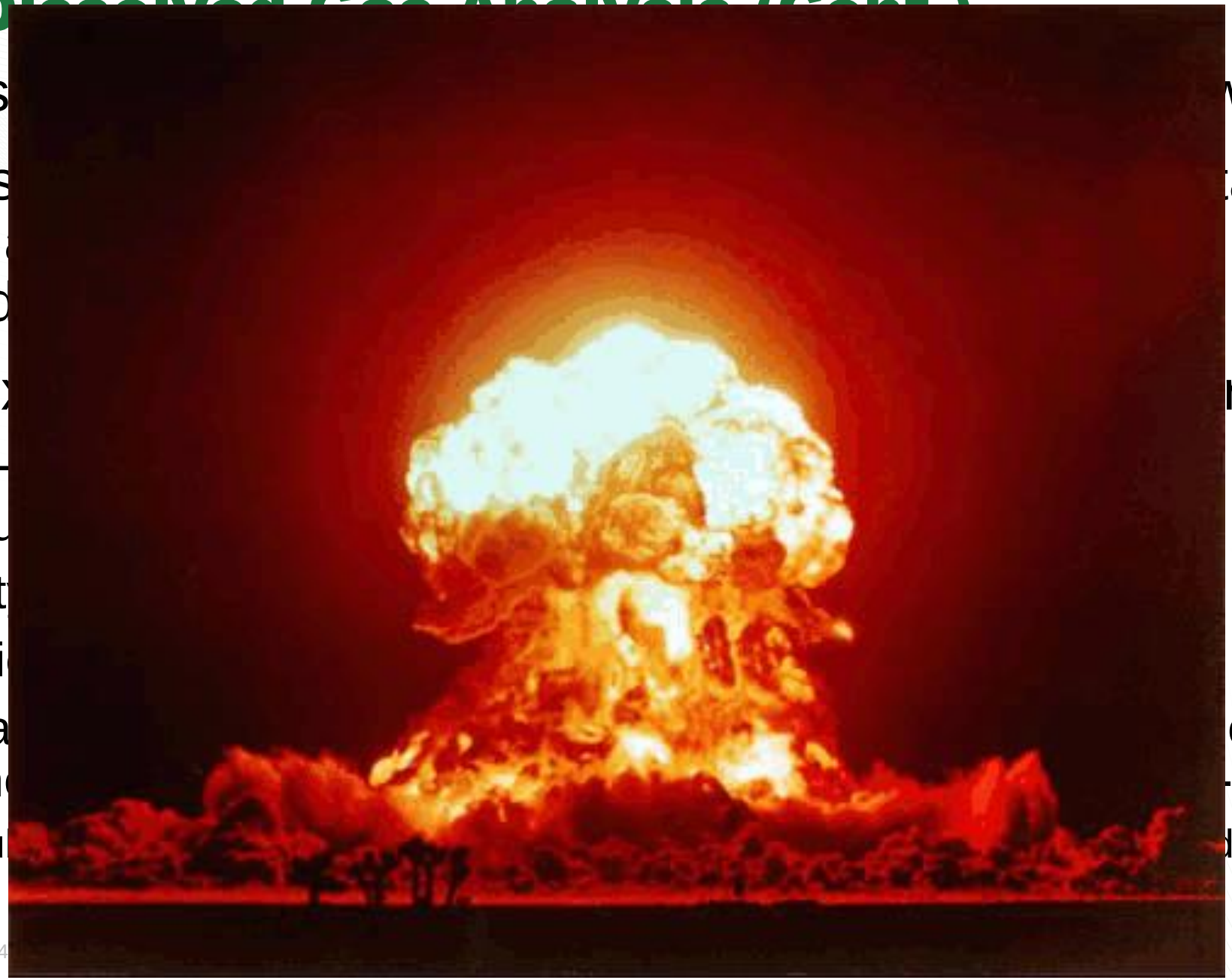
High Voltage Converter Modulator Nominal Setup CCL4

- Components of the High Voltage Converter Modulator (HVCM) produce the pulsed power needed to power the klystrons

SNS HVCM Setup (Cont.) Inside Modulator tank

Why Dissolved Gas Analysis (Cont.)

- Gases
- Analys
- One ex



wn stages

tal insulating
be scheduled

r for Drift

  - Impu
  - Acet
  - Suffi
  - Cata

of the top cover
-4 inches)

    - Su

downtime

Serveron Dissolved Gas Monitor

- Monitors 8 gas levels
- True Total Dissolved Combustible Gas (TDCG) output is available
  - Σ H_2, C_2H_2, C_2H_4, CO, CH_4, C_2H_6 in PPM
  - Each gas is measured at 100% of detected level.
- Total Hydrocarbons (THC) output is available
  - Σ CH_4, C_2H_2, C_2H_4, C_2H_6 in PPM
  - Each gas is measured at 100% of detected level.
- Moisture-in-oil and Oil Temperature

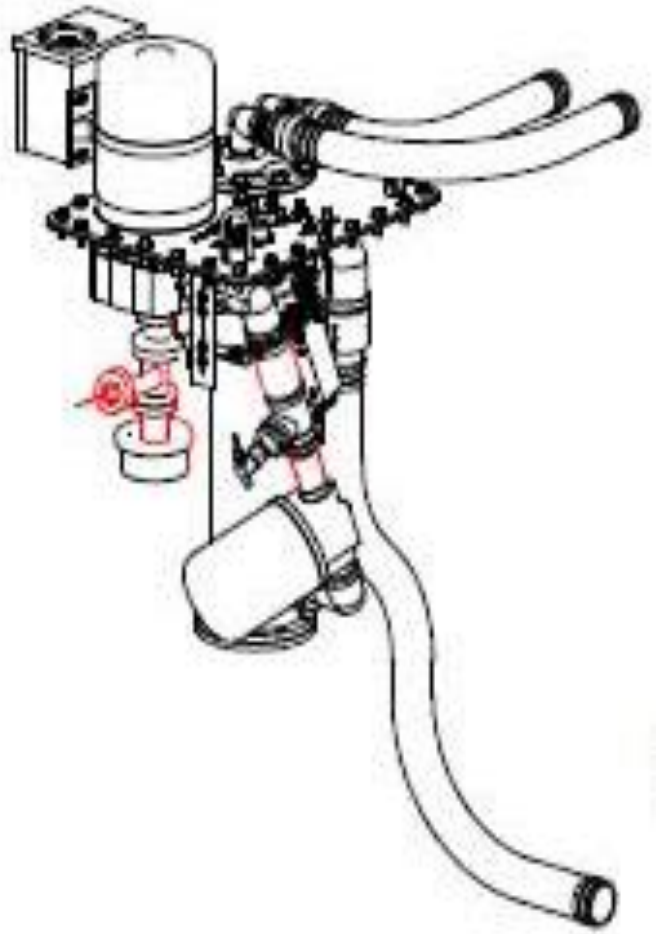
Serveron TM8 DGA

TM8 Brouchure

Safety
IEC 61010-1, IEC 61010-2-81
UL 61010-1 (2nd Edition), UL 60950-1 Clause 6.4
CSA-C22.2 No. 61010-1-04

Installation

- The modulator for Coupled Cavity Linac section 4 was selected as first deployment
- Data recorded every 4 hours
- Modified oil pump assembly allows for system to monitor oil



Collecting the Data (Manual Way)

- Proprietary data collection stores data from DGA in Microsoft SQL database
- Manufacturer software can query database and display results
  - Calculations are performed
  - Charts and Graphs are automatically generated
  - Not very portable and not designed for monitoring multi-system deployment
  - No easily read log file of which to speak
- Engineer was manually copying data and pasting into a spreadsheet
  - Desired calculations, charts, and graphs were recreated in Excel
  - Involved logging into two different servers every day (about an hour each import)
  - Collaboration not easy

Collecting Data (New Way)

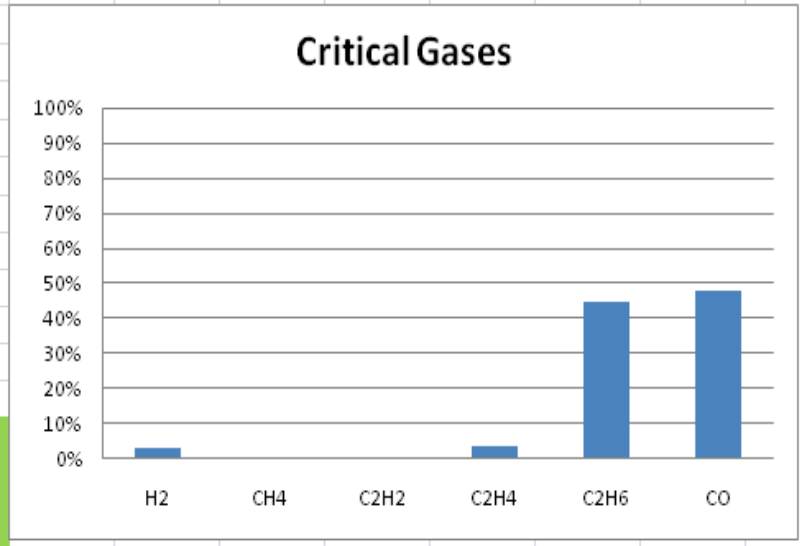
- Proprietary system still stores data in Microsoft SQL database
- Using Virtual Basic Scripting
  - Grab data and import them into a *.csv file
  - Update master spreadsheet with calculations and graphs
  - Employing formulae and filters to hide cells with bogus data
  - Publish/Update *.html page which can be accessed by anyone within defined group at any time
  - All are updated every morning before 0800
- Result is consistent, reliable, and portable data collection which can be accessed without logins and without copying data from database to spreadsheet
- Excel spreadsheet maintenance is required

Filtered Data in Actual File

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	Local Time	Sample Numbe	Sample Time	H2 - Hydrc	O2 - Oxyge	CH4 - Metl	CO - Carbc	CO2 - Carb	C2H6 - Eth	C2H4- Ethy	C2H2 - Ace	TDCG	THC	Load Guid	Ambient T	Aux
4534	4/15/15 11:00	4473	4/15/2015 16:00	0	6614.4	0	97	889	83	6.9	0	186.9	89.9	0	23.44	
4535	4/15/15 15:00	4474	4/15/2015 20:00	0	6547.5	0	96.5	900.6	82.9	6.4	0	185.8	89.3	0	23.31	
4536	4/15/15 19:00	4475	4/16/2015 0:00	0	6777.2	0	95.7	913	81.2	6.1	0	183	87.3	0	23	
4537	4/15/15 23:00	4476	4/16/2015 4:00	0	7230.7	0	92.8	923.4	82.4	5.6	1.5	182.3	89.5	0	23.13	
4538	4/16/15 3:00	4477	4/16/2015 8:00	0	7899.7	0	88.5	935.1	79.8	6	0	174.3	85.8	0	23.25	
4539	4/16/15 7:00	4478	4/16/2015 12:00	0	8270	0	86.9	929.6	81.9	6.1	0	174.9	88	0	23.13	
4540	4/16/15 11:00	4479	4/16/2015 16:00	0	8081.4	0	86.9	938.1	82.5	6.3	1.6	177.3	90.4	0	23.19	
4541	4/16/15 15:00	4480	4/16/2015 20:00	0	8103.1	0	87.4	946.7	79.3	7.3	0	174	86.6	0	23.13	
4542	4/16/15 19:00	4481	4/17/2015 0:00	0	8384.2	0	84.9	956.7	80.6	6.3	0	171.8	86.9	0	23.19	
4543	4/16/15 23:00	4482	4/17/2015 4:00	0	9486.7	0	80.7	969	79.4	6	0	166.1	85.4	0	23.63	
4544	4/17/15 3:00	4483	4/17/2015 8:00	0	9148.3	0	81.4	969.1	80	5.8	0	167.2	85.8	0	23.88	
4545	4/17/15 7:00	4484	4/17/2015 12:00	0	9144.5	0	80.2	980.1	79.9	5.5	1	166.6	86.4	0	23.56	
4546	4/17/15 11:00	4485	4/17/2015 16:00	0	9400.6	0	79.1	989.7	77.2	7.3	0	163.6	84.5	0	23.25	
4547	4/17/15 15:00	4486	4/17/2015 20:00	0	10602.4	0	76.2	1003.8	80.2	5.2	0	161.6	85.4	0	23.25	
4548	4/17/15 19:00	4487	4/18/2015 0:00	0	10302.2	0	75.6	1001.6	78.7	5.3	0	159.6	84	0	23.19	
4549	4/17/15 23:00	4488	4/18/2015 4:00	0	10546.7	0	72.6	1003.3	77	4.9	0	154.5	81.9	0	23.25	
4550	4/18/15 3:00	4489	4/18/2015 8:00	0	10870.5	0	70.2	1008.8	76.7	6.4	0	153.3	83.1	0	23.31	
4551	4/18/15 7:00	4490	4/18/2015 12:00	0	12001.2	0	70	1023.9	75.8	6.3	1.3	153.4	83.4	0	23.31	
4552	4/18/15 11:00	4491	4/18/2015 16:00	0	0	0	0	0	0	0	0	0	0	0	23.38	
4553	4/18/15 15:00	4492	4/18/2015 20:00	9.7	1596.8	0	126.1	920.6	102.4	8.2	0	246.4	110.6	0	23.63	
4554	4/18/15 19:00	4493	4/19/2015 0:00	9.1	1435.1	0	129.8	923.7	106	9.3	0	254.2	115.3	0	23.63	
4555	4/18/15 23:00	4494	4/19/2015 4:00	10	1518.4	0	133	892.4	102.5	8.9	0	254.4	111.4	0	23.25	
4556	4/19/15 3:00	4495	4/19/2015 8:00	8.1	1433.5	0	128.6	919.1	106.1	9	0	251.8	115.1	0	23.75	
4557	4/19/15 7:00	4496	4/19/2015 12:00	9.6	1428.1	0	129.1	924.6	105.5	9.7	1.2	255.1	116.4	0	23.75	
4558	4/19/15 11:00	4497	4/19/2015 16:00	9.1	1399.5	0	125.6	924.9	108.5	10	1.7	254.9	120.2	0	23.75	
4559	4/19/15 15:00	4498	4/19/2015 20:00	7.8	1349.8	0	123	901.7	107.4	9.9	0	248.1	117.3	0	23.88	
4560	4/19/15 19:00	4499	4/20/2015 0:00	9.7	1434.3	0	132	927.7	112.5	10.1	0	264.3	122.6	0	23.81	
4561	4/19/15 23:00	4500	4/20/2015 4:00	9.4	1419.4	0	130.7	923.9	112.2	11.4	0	263.7	123.6	0	23.81	
4562	4/20/15 3:00	4501	4/20/2015 8:00	9	1432.6	0	132.5	925.4	114	9.8	0	265.3	123.8	0	23.75	
4563	4/20/15 7:00	4502	4/20/2015 12:00	10.2	1431.4	0	132.6	922.9	113.3	9.3	0	265.4	122.6	0	23.81	
4564	4/20/15 11:00	4503	4/20/2015 16:00	10	1424.2	0	131.4	925.3	113.6	9.7	0	264.7	123.3	0	23.81	
4565	4/20/15 15:00	4504	4/20/2015 20:00	8.3	1399	0	128.3	926.6	117.9	10.9	0	265.4	128.8	0	23.81	
4566	4/20/15 19:00	4505	4/21/2015 0:00	6.5	1355.9	0	124.9	904.6	115.1	10.6	1.7	258.8	127.4	0	23.69	
4567	4/20/15 23:00	4506	4/21/2015 4:00	8.1	1371.7	0	125.8	918	118.4	10.4	0	262.7	128.8	0	23.75	
4568	4/21/15 3:00	4507	4/21/2015 8:00	7.7	1339.9	0	124.2	899.2	115	10	0	256.9	125	0	23.75	

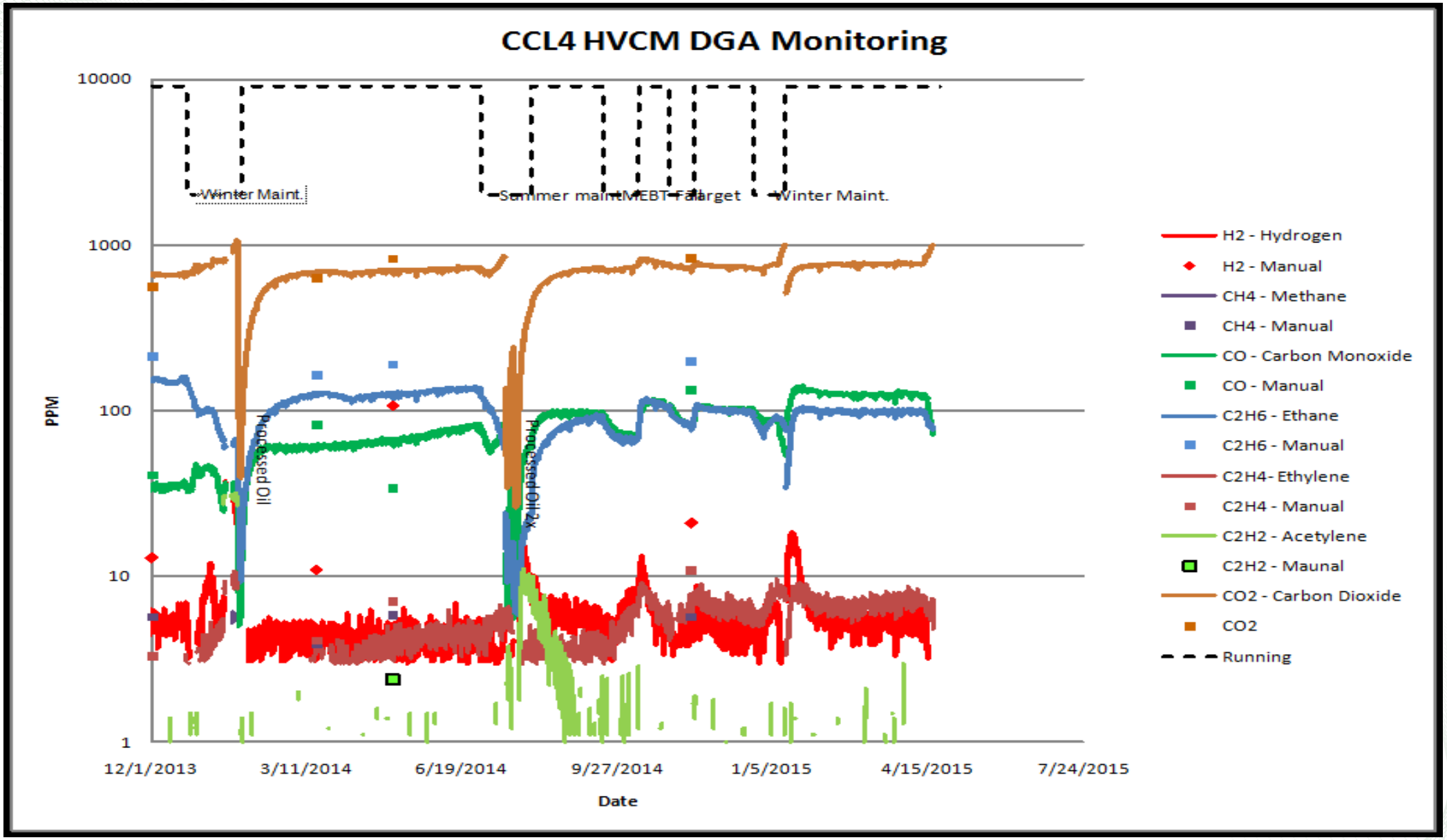
Excel Screenshots

13		are probably present. Proceed to 6.5.1 or 6.5.2.									
14	0										
15		Condition 4: TDCG exceeding this value indicates excessive decomposition. Continued operation									
16		could result in failure of the transformer. Proceed immediately and with caution per Figure 2 Step 3 and 6.5.1 or 6.5.2.									
17		**Hydrogen**	**Methane**	**Acetylene**	**Ethylene**	**Ethane**	**C Monoxide**		**C Dioxide**		
18	**Latest Data**	**H2**	**CH4**	**C2H2**	**C2H4**	**C2H6**	**CO**	**TDCG**	**CO2**		
19	4507	7.7	0	0	10	115	124.2	256.9	899.2	10	
20	4/21/15 8:00	3%	0%	0%	4%	45%	48%				
21	0	Duval %	0%	0%	100%						
22										R1	0
23	Condition 1	100	120	1	50	65	350	720	2500	R2	0
24	Condition 2	700	400	10	100	100	570	1920	4000	R3	#DIV/0!
25	Condition 3	1800	1000	35	200	150	1400	4630	10000	R4	#DIV/0!
26	Condition 4	1800	1000	35	200	150	1400	4630	10000	R5	0.086957
27										**Rogers Ratios**	
28										Low energy PD	NO
29										Hi energy PD	NO
30										Sparking low enegy	NO
31										Sparking high energy	NO
32										Thermal cellulose	NO
33										Thermal 150-300	NO
34										Thermal 300-700	NO
35										Thermal >700	NO
36											
37											

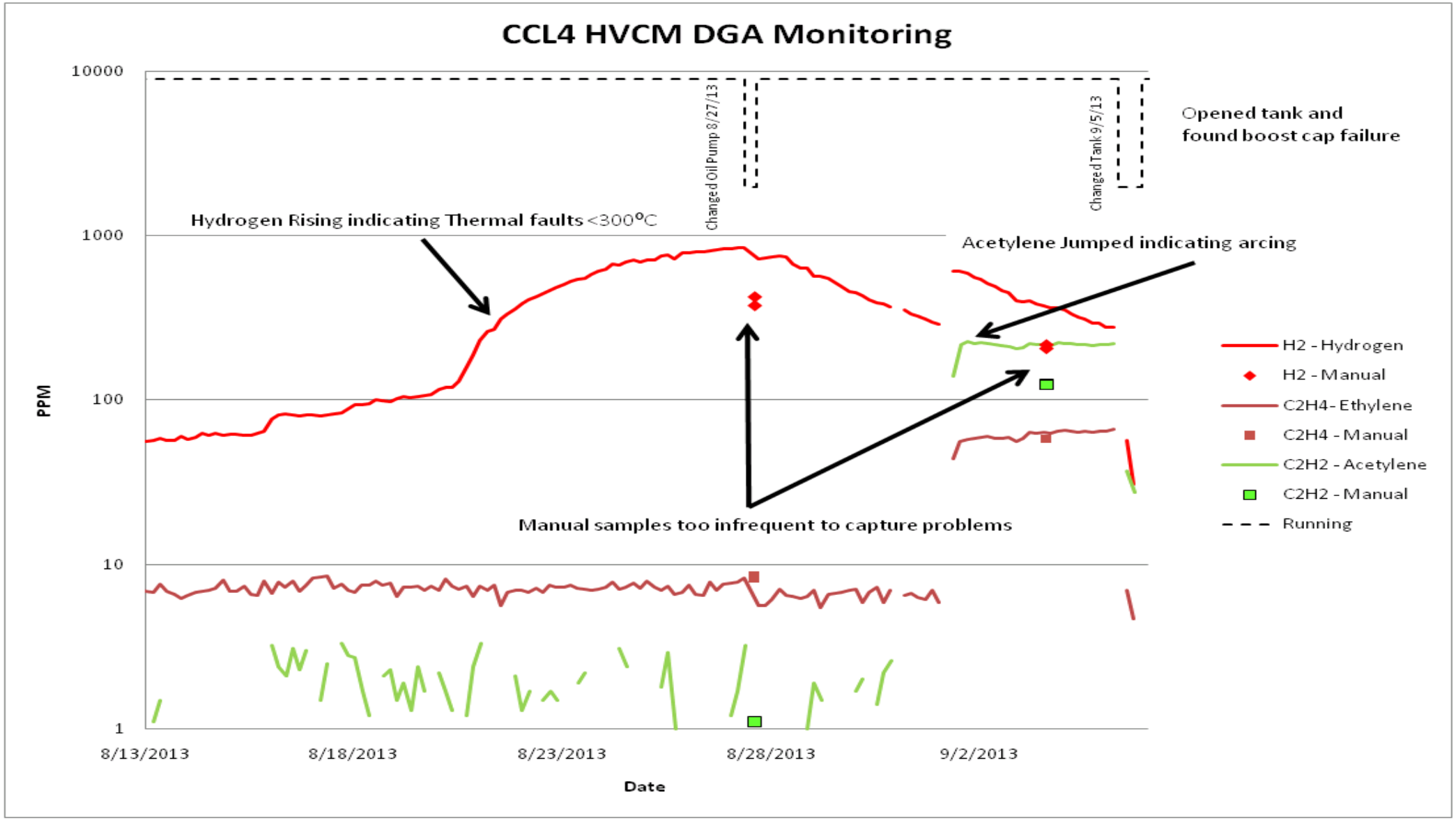


OAK RIDGE National Laboratory

Continuous Data Monitoring Available via Web Browser



Example of DGA Capturing Problem



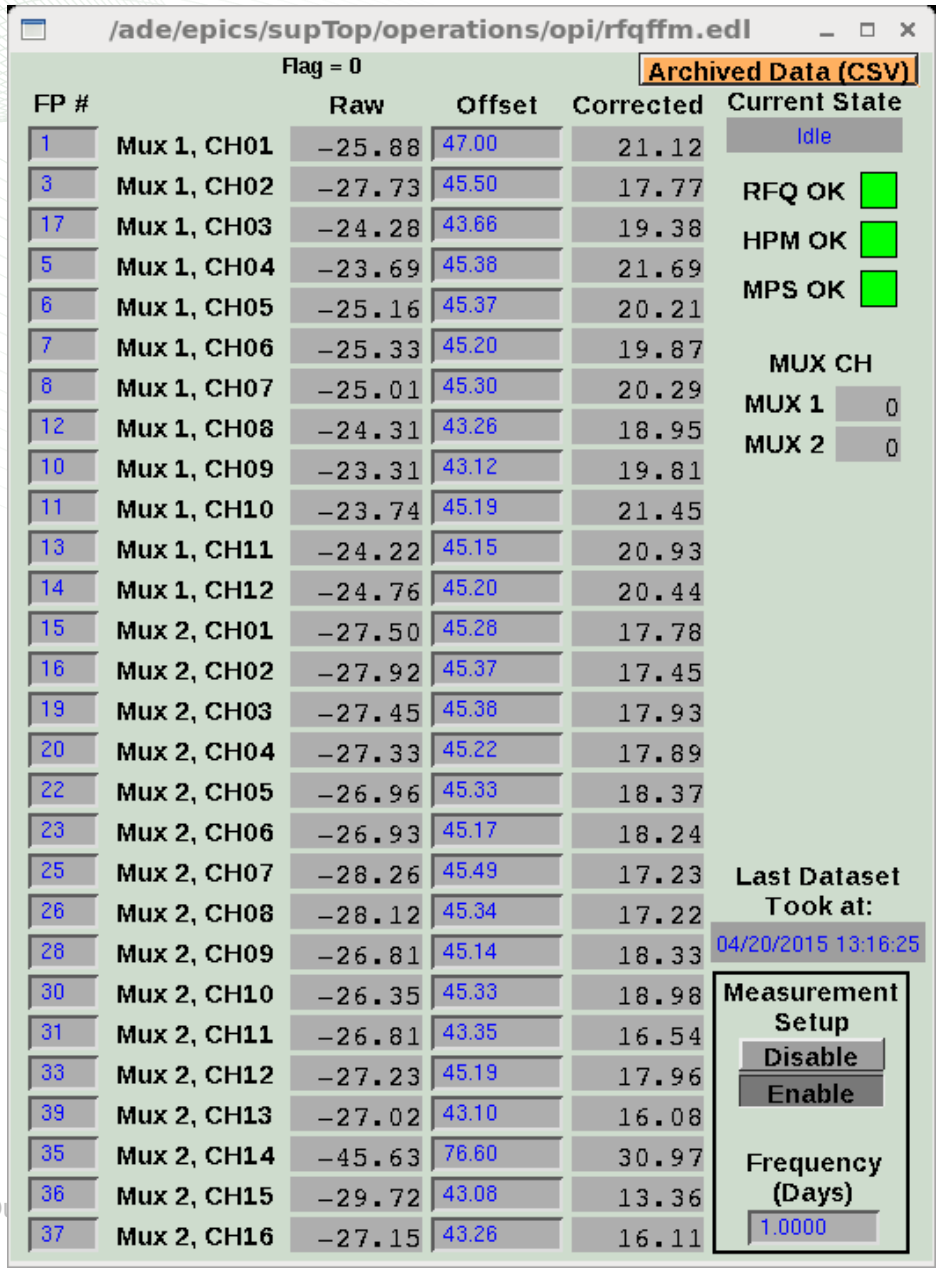
Radio Frequency Quadrupole (RFQ) Field Flatness

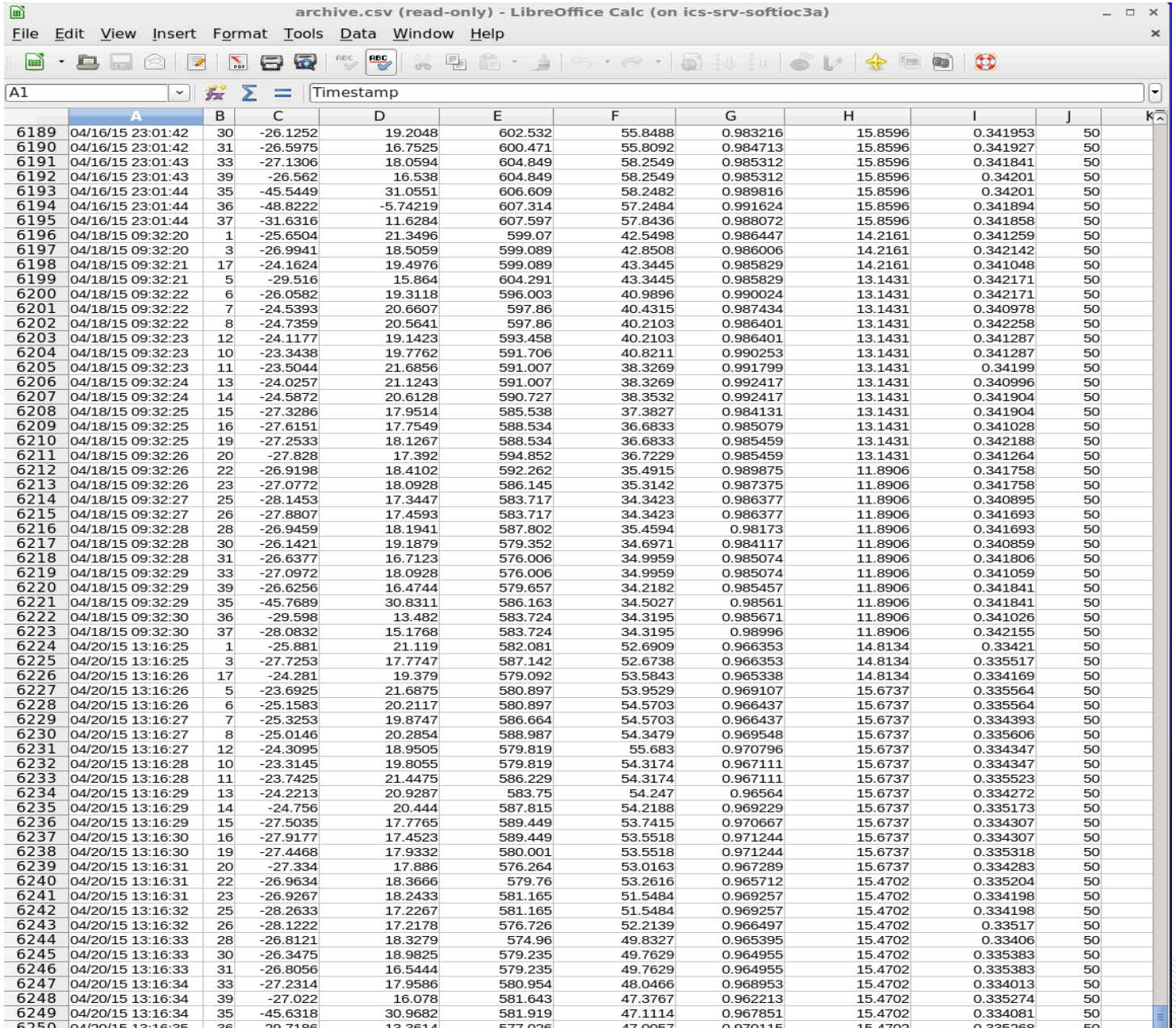
- At the SNS, our RFQ has experienced three detuning instances coming out of maintenance periods
  - All instances required retuning the cavity to operate
  - Downtime for retuning an RF cavity can measure on the order of days
- Subsequent measurements revealed significant deviation from documented field values
- An effort was initiated to characterize the RFQ field flatness under nominal operating conditions for a baseline to compare against when RFQ field and resonance error started to move

Collecting Data

- Combined use of Engineering, Physics, and Industrial Controls System (EPICS) database, Extensible Display Manager (EDM), and perl script does all the work
  - EPICS is used to control the Process Variables (PVs) needed to change the multiplexer inputs
  - EPICS also monitors readback PVs and copies readbacks into placeholder PVs
  - EDM is a Graphical User Interface (GUI) which allows the user to see the progress of the database in collecting the data and change certain variables (frequency of collection, offset values, etc.)
  - Perl is employed to grab data and append a running *.csv file which can be imported into Excel at a later date
    - *.csv file is used because appending an Excel file programmatically in Perl is not trivial
      - *.csv is text based file which can easily be appended and can be imported into Excel easily

RFQ Field Flatness Measurement Results

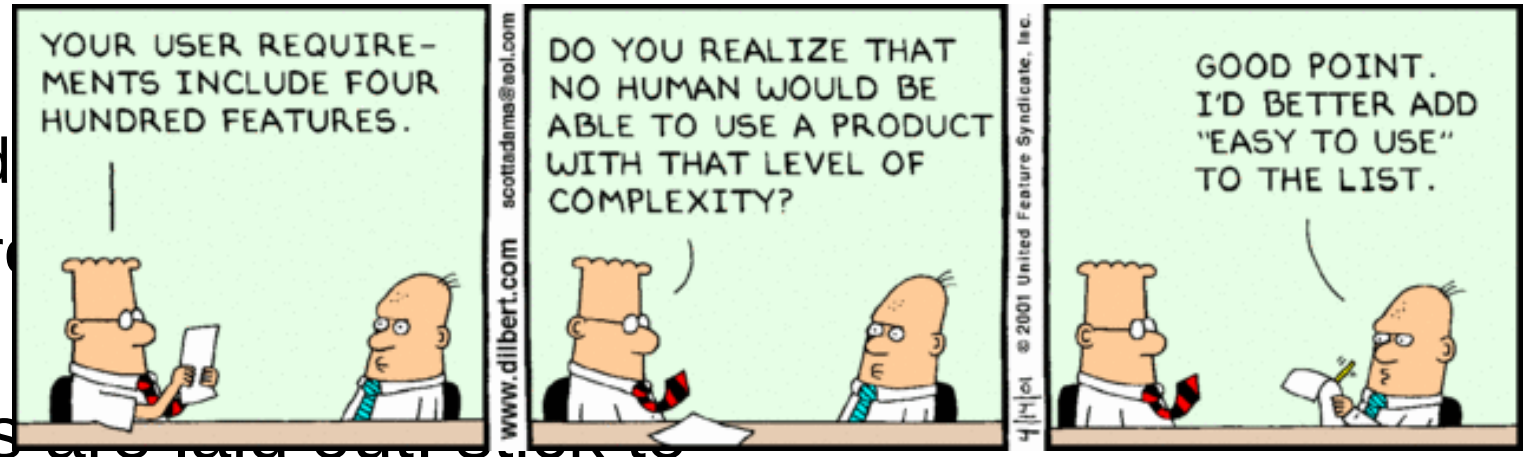




	A	B	C	D	E	F	G	H	I	J
6189	04/16/15 23:01:42	30	-26.1252	19.2048	602.532	55.8488	0.983216	15.8596	0.341953	50
6190	04/16/15 23:01:42	31	-26.5975	16.7525	600.471	55.8092	0.984713	15.8596	0.341927	50
6191	04/16/15 23:01:43	33	-27.1306	18.0594	604.849	58.2549	0.985312	15.8596	0.341841	50
6192	04/16/15 23:01:43	39	-26.562	16.538	604.849	58.2549	0.985312	15.8596	0.34201	50
6193	04/16/15 23:01:44	35	-45.5449	31.0551	606.609	58.2482	0.989816	15.8596	0.34201	50
6194	04/16/15 23:01:44	36	-48.8222	-5.74219	607.314	57.2484	0.991624	15.8596	0.341894	50
6195	04/16/15 23:01:44	37	-31.6316	11.6284	607.597	57.8436	0.988072	15.8596	0.341858	50
6196	04/18/15 09:32:20	1	-25.6504	21.3496	599.07	42.5498	0.986447	14.2161	0.341259	50
6197	04/18/15 09:32:20	3	-26.9941	18.5059	599.089	42.8508	0.986006	14.2161	0.342142	50
6198	04/18/15 09:32:21	17	-24.1624	19.4976	599.089	43.3445	0.985829	14.2161	0.341048	50
6199	04/18/15 09:32:21	5	-29.516	15.864	604.291	43.3445	0.985829	13.1431	0.342171	50
6200	04/18/15 09:32:22	6	-26.0582	19.3118	596.003	40.9896	0.990024	13.1431	0.342171	50
6201	04/18/15 09:32:22	7	-24.5393	20.6607	597.86	40.4315	0.987434	13.1431	0.340978	50
6202	04/18/15 09:32:22	8	-24.7359	20.5641	597.86	40.2103	0.986401	13.1431	0.342258	50
6203	04/18/15 09:32:23	12	-24.1177	19.1423	593.458	40.2103	0.986401	13.1431	0.341287	50
6204	04/18/15 09:32:23	10	-23.3438	19.7762	591.706	40.8211	0.990253	13.1431	0.341287	50
6205	04/18/15 09:32:23	11	-23.5044	21.6856	591.007	38.3269	0.991799	13.1431	0.34199	50
6206	04/18/15 09:32:24	13	-24.0257	21.1243	591.007	38.3269	0.992417	13.1431	0.340996	50
6207	04/18/15 09:32:24	14	-24.5872	20.6128	590.727	38.3532	0.992417	13.1431	0.341904	50
6208	04/18/15 09:32:25	15	-27.3286	17.9514	585.538	37.3827	0.984131	13.1431	0.341904	50
6209	04/18/15 09:32:25	16	-27.6151	17.7549	588.534	36.6833	0.985079	13.1431	0.341028	50
6210	04/18/15 09:32:25	19	-27.2533	18.1267	588.534	36.6833	0.985459	13.1431	0.342188	50
6211	04/18/15 09:32:26	20	-27.828	17.392	594.852	36.7229	0.985459	13.1431	0.341264	50
6212	04/18/15 09:32:26	22	-26.9198	18.4102	592.262	35.4915	0.989875	11.8906	0.341758	50
6213	04/18/15 09:32:26	23	-27.0772	18.0928	586.145	35.3142	0.987375	11.8906	0.341758	50
6214	04/18/15 09:32:27	25	-28.1453	17.3447	583.717	34.3423	0.986377	11.8906	0.340895	50
6215	04/18/15 09:32:27	26	-27.8807	17.4593	583.717	34.3423	0.986377	11.8906	0.341693	50
6216	04/18/15 09:32:28	28	-26.9459	18.1941	587.802	35.4594	0.98173	11.8906	0.341693	50
6217	04/18/15 09:32:28	30	-26.1421	19.1879	579.352	34.6971	0.984117	11.8906	0.340859	50
6218	04/18/15 09:32:28	31	-26.6377	16.7123	576.006	34.9959	0.985074	11.8906	0.341806	50
6219	04/18/15 09:32:29	33	-27.0972	18.0928	576.006	34.9959	0.985074	11.8906	0.341059	50
6220	04/18/15 09:32:29	39	-26.6256	16.4744	579.657	34.2182	0.985457	11.8906	0.341841	50
6221	04/18/15 09:32:29	35	-45.7689	30.8311	586.163	34.5027	0.98561	11.8906	0.341841	50
6222	04/18/15 09:32:30	36	-29.598	13.482	583.724	34.3195	0.985671	11.8906	0.341026	50
6223	04/18/15 09:32:30	37	-28.0832	15.1768	583.724	34.3195	0.98996	11.8906	0.342155	50
6224	04/20/15 13:16:25	1	-25.881	21.119	582.081	52.6909	0.966353	14.8134	0.33421	50
6225	04/20/15 13:16:25	3	-27.7253	17.7747	587.142	52.6738	0.966353	14.8134	0.335517	50
6226	04/20/15 13:16:26	17	-24.281	19.379	579.092	53.5843	0.965338	14.8134	0.334169	50
6227	04/20/15 13:16:26	5	-23.6925	21.6875	580.897	53.9529	0.969107	15.6737	0.335564	50
6228	04/20/15 13:16:26	6	-25.1583	20.2117	580.897	54.5703	0.966437	15.6737	0.335564	50
6229	04/20/15 13:16:27	7	-25.3253	19.8747	586.664	54.5703	0.966437	15.6737	0.334393	50
6230	04/20/15 13:16:27	8	-25.0146	20.2854	588.987	54.3479	0.969548	15.6737	0.335606	50
6231	04/20/15 13:16:27	12	-24.3095	18.9505	579.819	55.683	0.970796	15.6737	0.334347	50
6232	04/20/15 13:16:28	10	-23.3145	19.8055	579.819	54.3174	0.967111	15.6737	0.334347	50
6233	04/20/15 13:16:28	11	-23.7425	21.4475	586.229	54.3174	0.967111	15.6737	0.335523	50
6234	04/20/15 13:16:29	13	-24.2213	20.9287	583.75	54.247	0.96564	15.6737	0.334272	50
6235	04/20/15 13:16:29	14	-24.756	20.444	587.815	54.2188	0.969229	15.6737	0.335173	50
6236	04/20/15 13:16:29	15	-27.5035	17.7765	589.449	53.7415	0.970667	15.6737	0.334307	50
6237	04/20/15 13:16:30	16	-27.9177	17.4523	589.449	53.5518	0.971244	15.6737	0.334307	50
6238	04/20/15 13:16:30	19	-27.4468	17.9332	580.001	53.5518	0.971244	15.6737	0.335318	50
6239	04/20/15 13:16:31	20	-27.334	17.886	576.264	53.0163	0.967289	15.6737	0.334283	50
6240	04/20/15 13:16:31	22	-26.9634	18.3666	579.76	53.2616	0.965712	15.4702	0.335204	50
6241	04/20/15 13:16:31	23	-26.9267	18.2433	581.165	51.5484	0.969257	15.4702	0.334198	50
6242	04/20/15 13:16:32	25	-28.2633	17.2267	581.165	51.5484	0.969257	15.4702	0.334198	50
6243	04/20/15 13:16:32	26	-28.1222	17.2178	576.726	52.2139	0.966497	15.4702	0.33517	50
6244	04/20/15 13:16:33	28	-26.8121	18.3279	574.96	49.8327	0.965395	15.4702	0.33406	50
6245	04/20/15 13:16:33	30	-26.3475	18.9825	579.235	49.7629	0.964955	15.4702	0.335383	50
6246	04/20/15 13:16:33	31	-26.8056	16.5444	579.235	49.7629	0.964955	15.4702	0.335383	50
6247	04/20/15 13:16:34	33	-27.2314	17.9586	580.954	48.0466	0.968953	15.4702	0.334013	50
6248	04/20/15 13:16:34	39	-27.022	16.078	581.643	47.3767	0.962213	15.4702	0.335274	50
6249	04/20/15 13:16:34	35	-45.6318	30.9682	581.919	47.1114	0.967851	15.4702	0.334081	50

How to Implement Your Own Solution

- Requirements are key
  - Poor requirements lead
  - Also true is good requir software
- Once the requirements them
- Determine the right



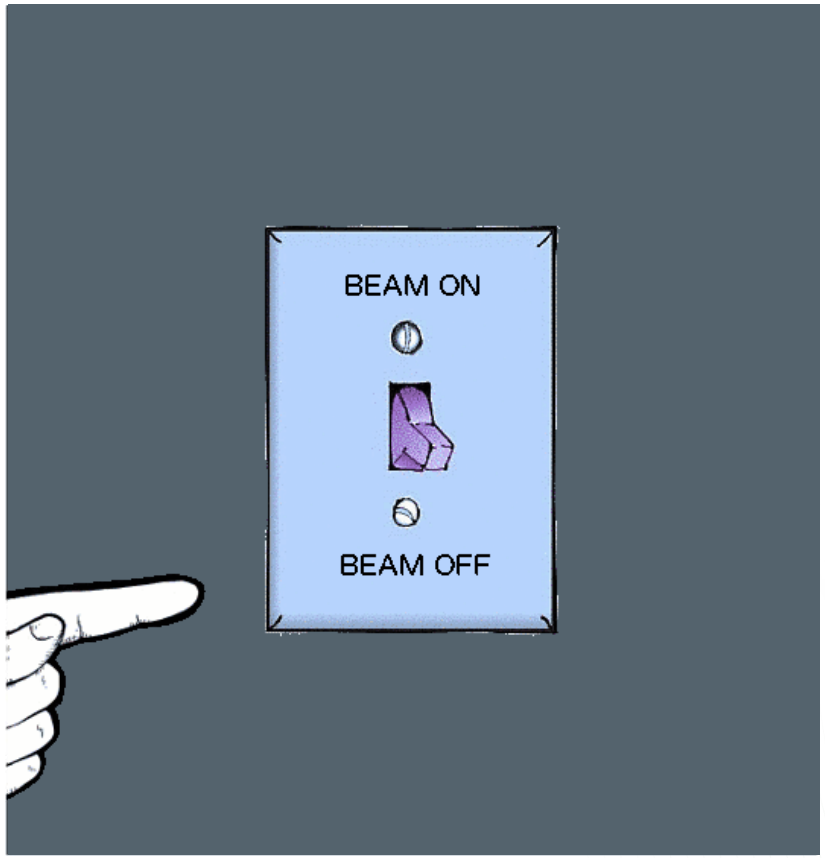
  - Database?
  - Script?
    - What language?
  - Where will the data
    - Format of the file and

Conclusion

- Software is being deployed more ubiquitously now than ever in the accelerator world for new and innovative tasks
- Benefits are numerous to using scripts and databases to help grab data in an orderly and consistent fashion
- Make sure the requirements are clearly laid out
- Be ready for customers to want more than requirements (scope creep)
- Understand that on-going maintenance will be required

That's All, Folks!

If everything is done right, reliability can be properly optimized without very much disruption to personnel time through the use of software data collection. In some ways, the goal is to make the transition to 100% reliability seem effortless; like turning on a light switch.



Why Dissolved Gas Analysis

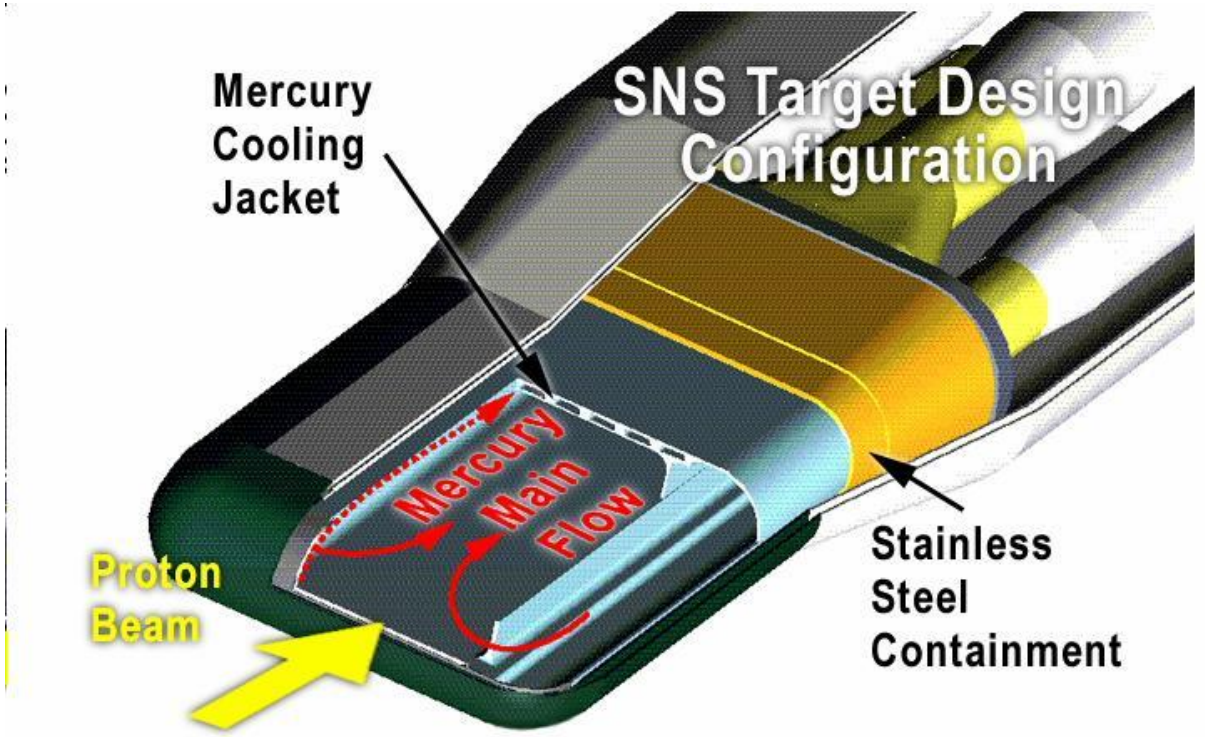
- HVCM electric insulating material breaks down due to multiple causes (Cooper Industries FR3 Insulating Oil)
- Coronal discharge under abnormal conditions in the tank heats oil and generates gases starting around 150^{o} C
  - H_2, CH_4, and C_2H_6 and eventually C_2H_4 are generated
  - There are well known “hot spots” that generate gases associated with the low temperature range inherent in the design.
- Quantity of C_2H_4 can indicate the temperature and intensity of the corona
- Acetylene (C_2H_2) is generated when the oil conducts sufficiently to allow arcs (causing a fault temperature of 700^{o} C)
- CO and CO_2 can be released during electrical cellulose insulator degradation.

DTL 3 Aftermath Pictures

Some Other Failures That the DGA Could Catch

SNS Mercury Target background

- Experience with a total of 12 Mercury Targets at SNS
- Varying lifetimes which are still being investigated
  - Lifetimes range from 1 week to 8 months
  - Some of the lifetime constraints are self-imposed as Preventative Maintenance
  - Why such a large discrepancy is still under investigation
  - Plans for improvement and plans for administrative/operational changes are underway



Target Data Retrieval Tool

- Developed to assist Engineering staff in gathering readings from the Target vessel
  - Pressure
  - Temperature
  - Flow
- Data is used to perform post mortem on failed Targets
  - Attempt is to find some diagnostic that is a direct (or indirect) prediction of failure
  - Downtime incurred from Target failure is anywhere between 7-14 days for changeout
- Data is archived and is accessible through many avenues

ARTTY (Archive Retrieval Tool To You)

- Using Perl and the Graphical Tool Kit an archive retrieval tool was created to make customized searches of archived signals
- Satisfies the requirements of the engineer to pull archived data from a particular date range at a particular interval down to 1 second
- Stores results in a *.csv file format for later retrieval