High Equilibrium Time CREEVS Inleakage Measurements

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CRE Inleakage

- TSTF 448 refers to Reg Guide 1.197 which specifies ASTM E741 Tracer Gas Test to measure CRE Inleakage
  - Concentration Decay
  - Constant Injection
- No guidance in E741 on repeatability of tracer gas test
- Two Previous Published Studies:
  - Recirculation CREEVS for 4 tests in one plant. Inleakage standard deviation of 3%.
  - Pressurization CREEVS for two plants, 6 tests each. Inleakage standard deviation of 21% and 17%.

ASTM Standard E741

- Use Tracer Gas Techniques to Measure Total Air Inflow
  - Based on Conservation of Mass
- Standard describes two distinct tracer gas tests that can be used to measure inleakage
  - Constant Injection Test
    - Most useful for Pressurization CREEVS
  - Concentration Decay Test
    - Most useful for Recirculation CREEVS

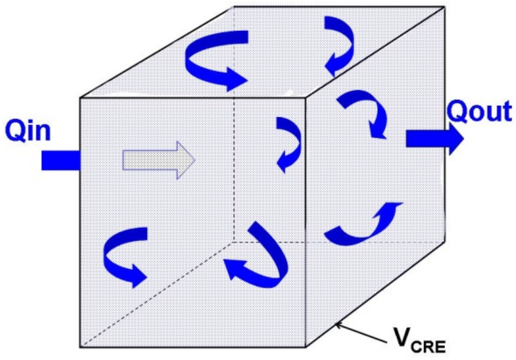
Inleakage

Inleakage is the difference between the total amount of air flowing into the CRE and the air supplied by the CREEVS to the CRE

$$Q_{inleak} = Q_{tot} - Q_{mu}$$

Concentration Decay Test

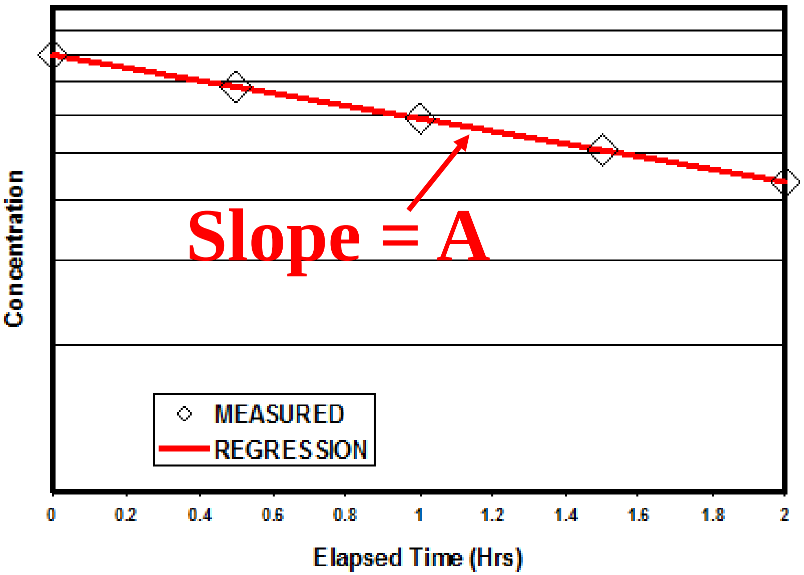
1) Inject tracer and thoroughly mix in the volume



2) Measure mean concentration as function of time

Time (Hrs)	Mean Concentration
0.0	C0
0.5	C1
1.0	C2
1.5	C3
2.0	C4

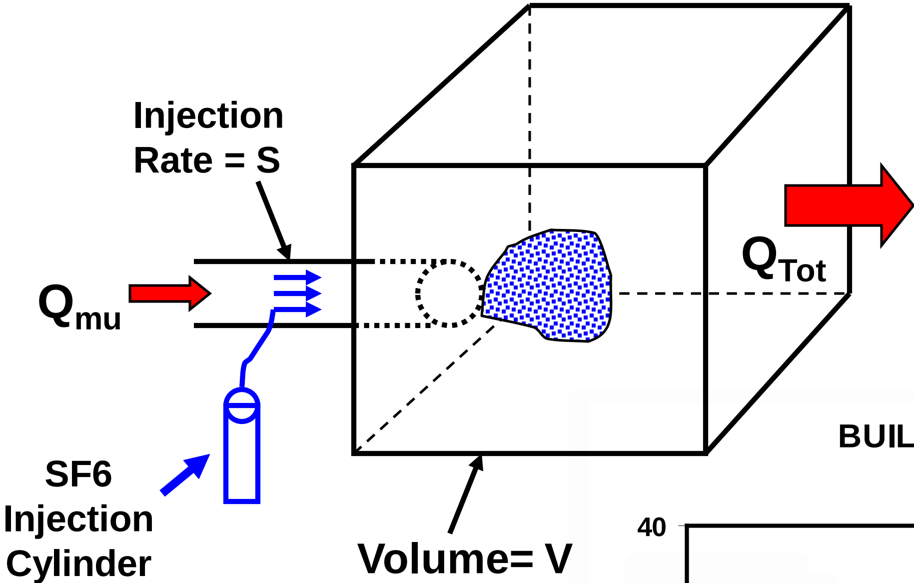
3) Plot concentration vs time and calculate slope by regression.



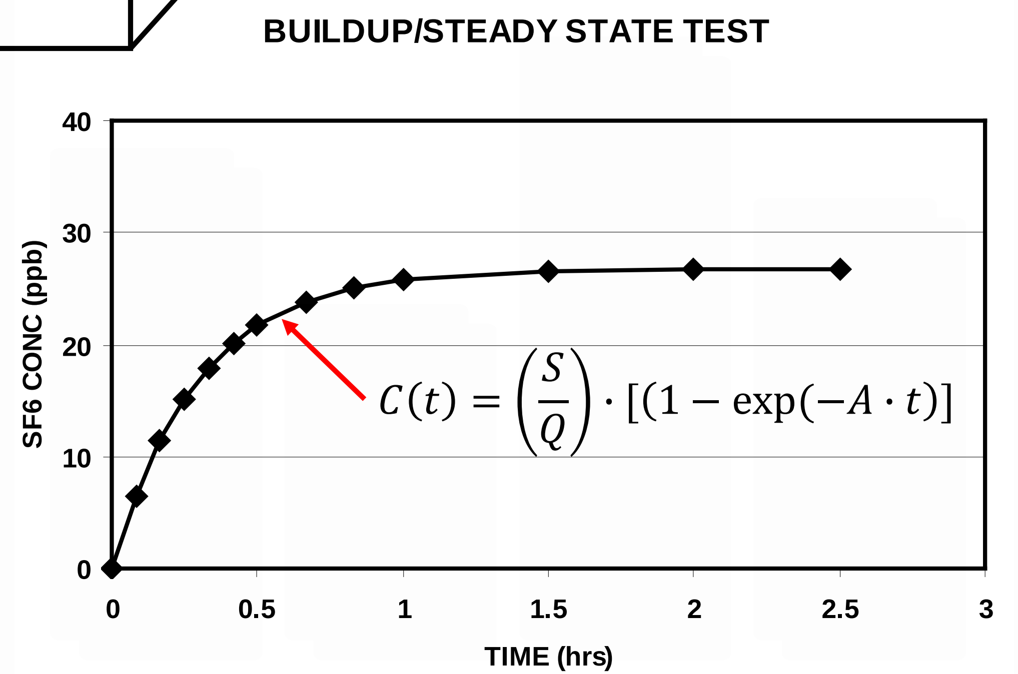
4) Multiply slope (A) by volume to determine Total Inflow

$$Q_{tot} = A \cdot V$$

Constant Injection Test



1. Inject SF6 at Constant Rate
2. Mix SF6 throughout Volume
3. Measure concentration in Volume

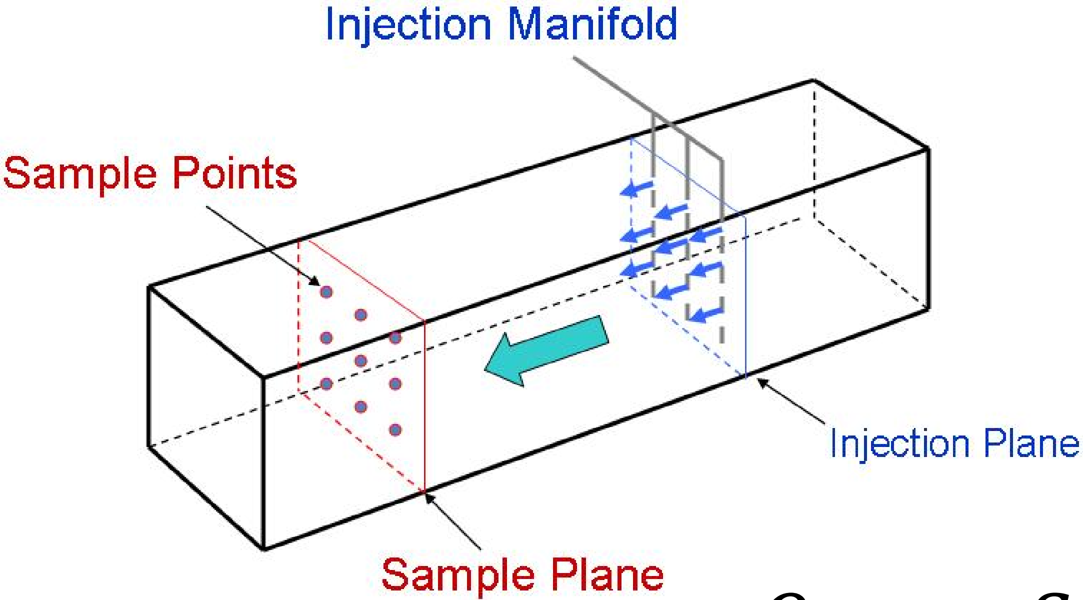


4. At equilibrium, calculate Total Inflow

$$Q_{tot} = S/C_{eq}$$

Tracer Gas Flow Rate Measurement

(ASTM E2029)



$$Q_{mu} = S/C_{av}$$

Makeup Flow/Concentration Decay Test

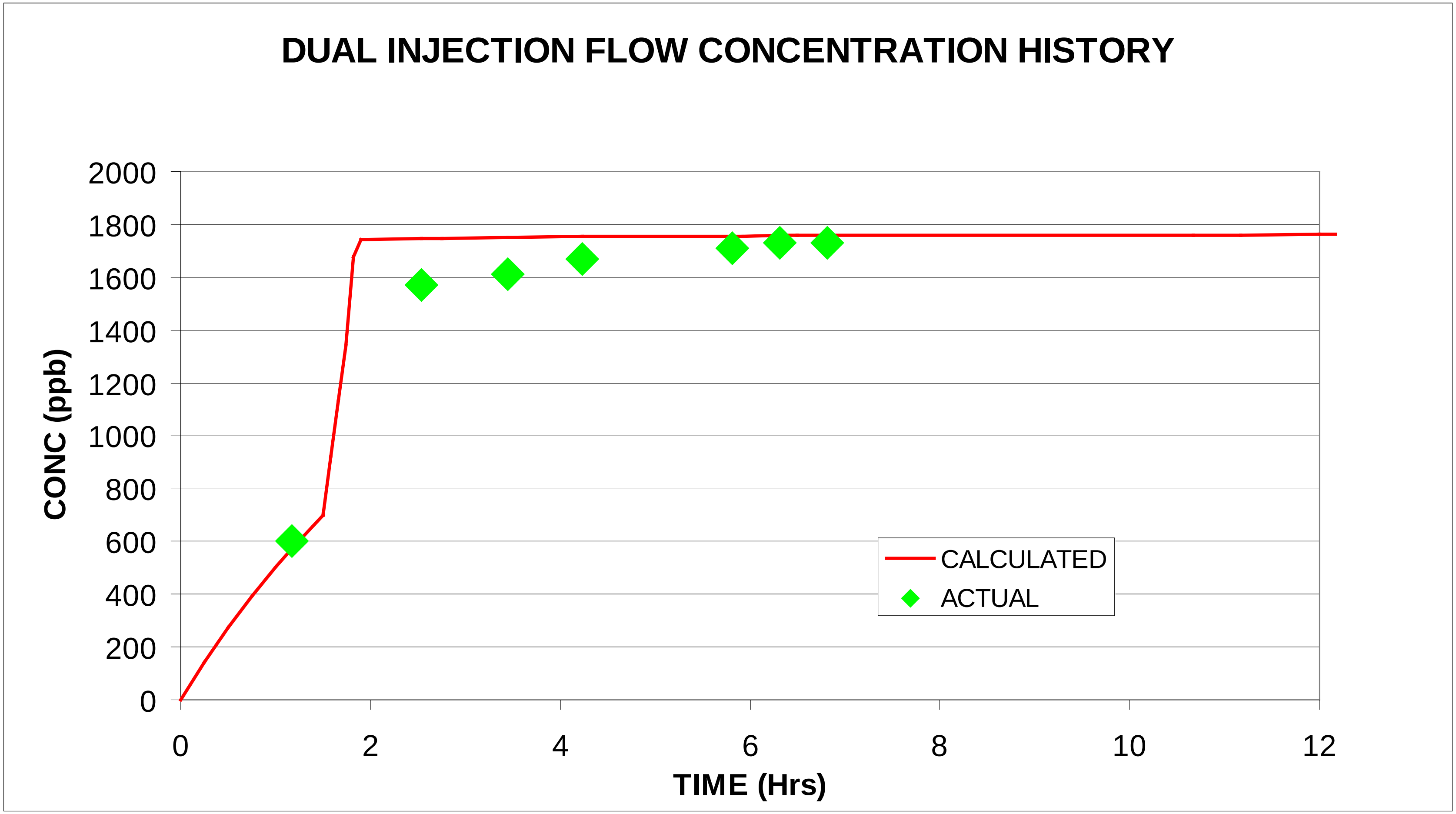
- The typical Constant Injection test requires a LONG equilibrium time for low A plants
- The "Boost" technique described in ASTM 741 helps but still may not be enough
- Inleakage can be measured by using ASTM 741 (Decay) and ASTM E2029 (Make-up Flowrate)
- This study: three plants, one BWR and two PWRs
- Two or three cycles of ASTM E741/E2029 inleakage tests performed over 6 to 12 year periods

Equilibrium Times for Four Plants

Wait Time	Equilibrium %	Plant A (Hr)	Plant 1 (Hr)	Plant 2 (Hr)	Plant 3 (Hr)
3/A	95.0	9.5	10.0	13.3	16.6
4/A	98.2	12.6	14.9	19.8	24.8
5/A	99.3	15.8	20.7	27.6	34.5

The Importance of Equilibrium

Plant A



The Importance of Equilibrium Cont.

- ASTM suggests taking 3/A as an approximate equilibrium value to determine total inflow
- For Plant A, using 3/A (95%) as opposed to 5/A (99%) would have resulted in a reportable inleakage value 70% higher than actual and a failed test
- For a Concentration Buildup/Steady State test, using values that are not at true equilibrium will always *overestimate* inleakage

Inleakage Calculations

For High Equilibrium Time Tests,

1. Q_{tot} is measured via ASTM E741 (Decay):

$$Q_{tot} = A \cdot V$$

2. Q_{mu} is measured via ASTM E2029:

$$Q_{mu} = S/C_{av}$$

3. Then:

$$Q_{inleak} = Q_{tot} - Q_{mu}$$

ANSI/ASME Standard PTC 19.1 "Measurement Uncertainty"

- Combines both Bias or Systematic Uncertainties of the measurement equipment with Random Uncertainties of the actual measured data

- Provides Confidence Limits (Chosen as 95%)

- Substitutes a calculational format for subjective "engineering judgment" uncertainty analysis

ANSI/ASME Root Sum Square Uncertainty, Urss, is given by

$$U_{rss} = \pm\left[(B)^2 + (t_{95} \bullet S)^2\right]^{1/2}$$

- B = Systematic Uncertainties (Bias) in Measurement Apparatus
- S = Random Uncertainties in Measured data
- t_{95} = Student's "t" distribution value

Analyzer & Equipment Uncertainties

ITEM		UNCERTAINTY
Gas Chromatograph		
	Repeatability	1-3% of value
	Drift	< 2% of value
Calibration Gas		
	> 1ppm	1% of value
	1 ppm – 0.1 ppb	2% of value
Mass Flow Controller		1% of full scale
Tracer Injection Gas		1% of value

Measurement Uncertainty

- For an individual test that is difficult or expensive to repeat would like an uncertainty estimate
  - Standard deviation is meaningless for a single test
- Can use ANSI/ASME root sum square (U_{rss}) value to define a confidence interval
- If the measured value of inleakage is I, a 95 % confidence interval (C) means that if one repeats the test 100 times, then for 95 of those times the value of inleakage will satisfy the following equation

$$I-C < I < I+C$$

Mean Inleakage

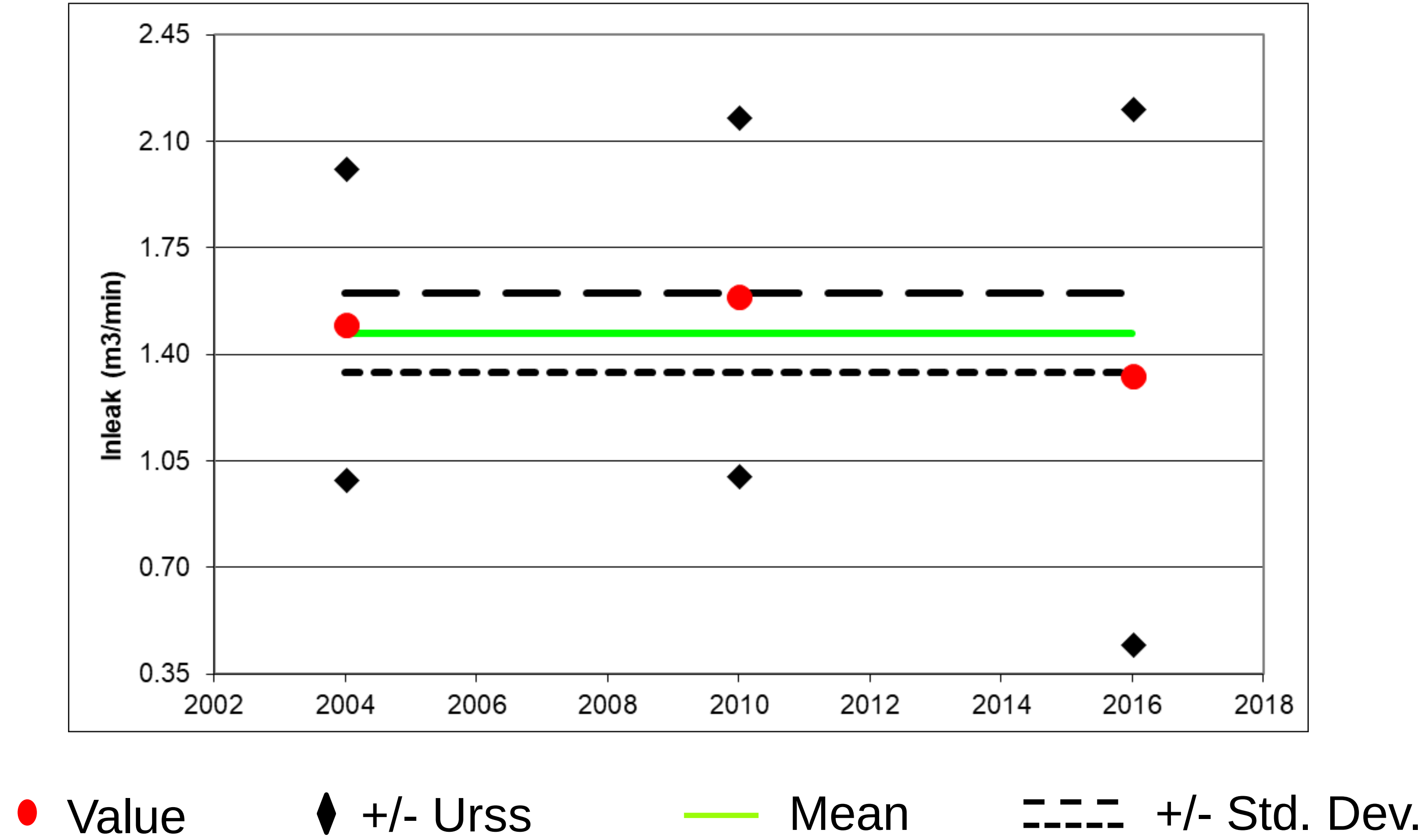
	m3/min		CFM	
	Inleakage	Std. Dev.	Inleakage	Std. Dev.
Plant 1	1.47	0.13	52	4.6
Plant 2	20.14	1.81	711	64
Plant 3	1.72	0.26	61	9.1

Major Assumption

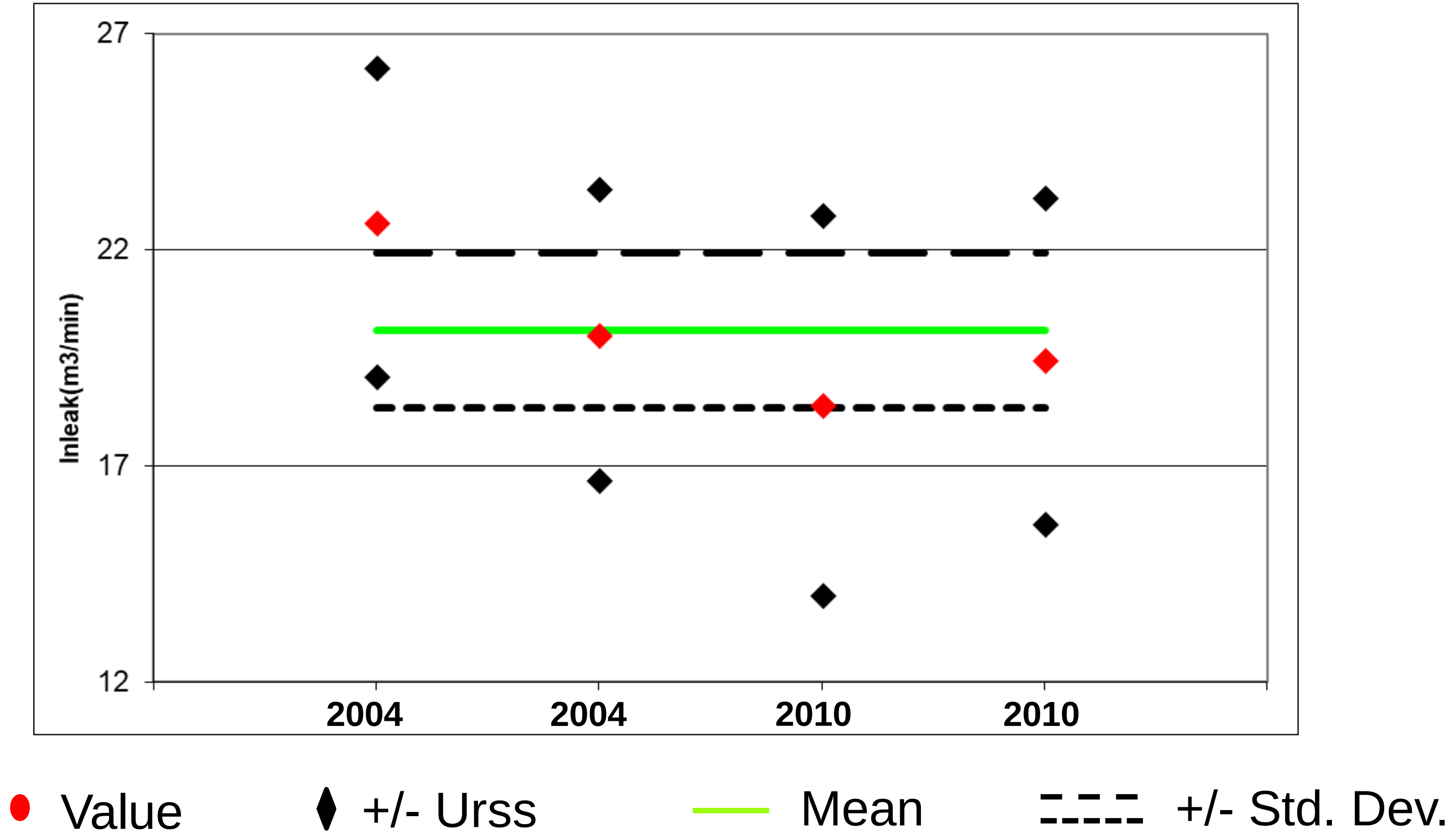
The mean and std. dev. are valid for evaluation of the *technique* only if the CRE boundary and the operation of the CREEVS plus the surrounding HVAC systems are (*approximately) the same* from test to test

- Plant 2 inleakage tests were repeated in 2017 with a measured inleakage increase of >200%
- Plant 3 A Train inleakage test in 2011 resulted in a value ~300% higher than the other 3 tests

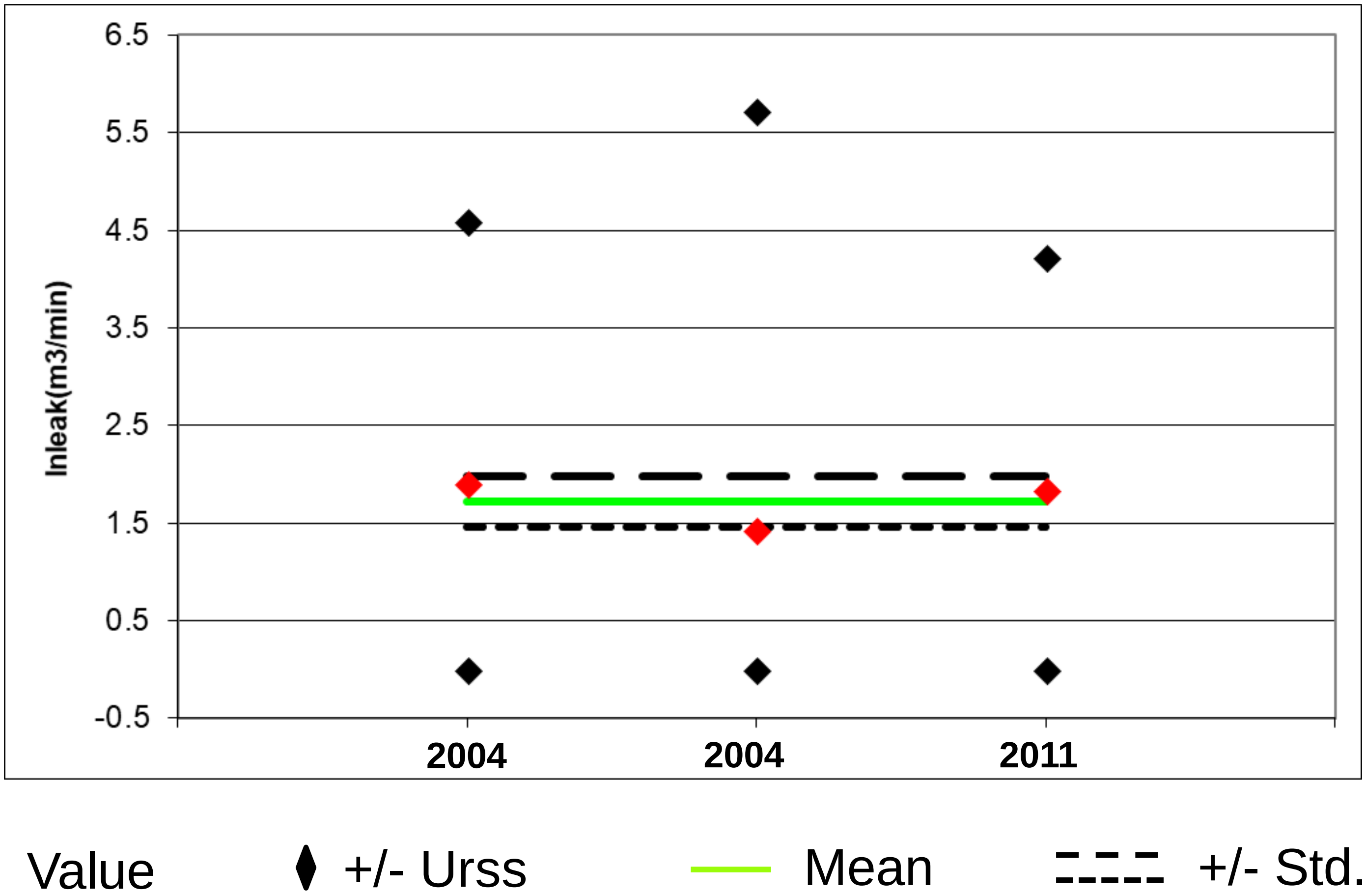
Plant 1 Test Urss Compared to Combined Standard Deviation



Plant 2 Test Urss Compared to Combined Standard Deviation



Plant 3 Test Urss Compared to Combined Standard Deviation



Conclusions

- Makeup Flowrate/Conc. Decay test can be performed over one shift, typically <8hrs.
- Multi-year inleakage measurements for Makeup Flow / Conc. Decay tests are repeatable. Standard deviations ranged from 9% (Plants 1 &2) to 15% (Plant 3).
- Similar standard deviations as compared to Constant Injection tests (17%-21%).
- PTC 19.1 uncertainty analysis is necessary for a *single measurement* but maybe be overly conservative.
  - Plant 1 U_{rss} averaged approximately 50%
  - Plant 2 U_{rss} averaged approximately 20%
  - Plant 3 U_{rss} averaged approximately 200%