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The Effect of Boundary Breech on Measured Inleakage

P. L. Lagus, Ph.D., CIH
Lagus Applied Technology, Inc.
Escondido, CA

J. A. Carlson, P.E.
Omaha Public Power District
Fort Calhoun Station
Blair, NE

Regulatory Guide 1.196 briefly addresses breech control as a part of overall Control Room Habitability. Often the question arises as to how large a breech can be tolerated in a Control Room Envelope boundary without compromising the radiological habitability assumptions regarding inleakage.

In a radiological emergency the CREEVS pressurizes the CRE with filtered air. At Fort Calhoun Station, the CREEVS is located primarily outside the CRE. Even so, the measured air inleakage values are statistically indistinguishable from a zero value.

As part of a periodic tracer gas inleakage test required under TSTF 448, Fort Calhoun Station investigated the effect of an approximate 100 in^2 breech in the Control Room Envelope. Differential pressure of the CRE relative to surrounding areas was measured during testing with and without the above breech.

In the breeched CRE test, the differential pressures relative to surrounding locations dropped to lower values than in the non-breech test and in some cases actually became negative with respect to the CRE. However, the measured inleakage remained statistically indistinguishable from a zero value.

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1.0 Introduction

Regulatory Guide 1.196 briefly addresses breech control as a part of overall Control Room habitability. NEI99-03 [1] and the NHUG Control Room Habitability Guide [2] provide information and guidance on breech control.

Often the question arises as to how large a breech can be tolerated in a Control Room Envelope (CRE) boundary without compromising the radiological habitability assumptions regarding inleakage. This question is sometimes answered by reliance on a calculation based on flow through a sharp edged orifice possessing a given area. To ensure that the differential pressure within the CRE never drops below a certain value (often taken as 1/8 in. w.g.) the maximum size of a permissible breech can be calculated.

At Fort Calhoun Station (FCS) a unique opportunity was provided to investigate the effect of breech opening on inleakage during routine tracer gas inleakage testing that was required as part of the TSTF 448 process. Two concentration buildup/steady state tracer gas inleakage tests were undertaken on different days with the same CREEVS train operating in order to investigate the effect of an approximate 100 in^2 breech in the Control Room Envelope. Differential pressure of the CRE relative to surrounding areas was measured also during testing with and without the breech.

In both tests the measured inleakage was a statistically zero value. In the breeched case, the differential pressures relative to surrounding locations dropped to lower values than in the non-breech test and in some cases actually became negative with respect to the CRE.

2.0 Tracer Gas Ventilation Measurements

Tracer gases have been used to measure the air infiltration and ventilation characteristics of buildings for over 40 years. Tracer gas techniques are successfully used in other areas of ventilation engineering and industrial hygiene to provide accurate characterization of HVAC performance under actual operating conditions [3,4].

Within the nuclear power community, tracer gas techniques have been used since the early 1980's to measure airflow patterns, to investigate health and safety monitor locations, as well as to understand potential gaseous radioactive contaminant migration within selected buildings [5,6]. In the past fifteen years tracer gas measurements designed to measure inleakage (either total or unfiltered) into a nuclear power plant control room have been accepted by the NRC.

Regulatory Guide 1.197 and Generic Letter 2003-01 on Control Room Envelope Habitability both explicitly assert that tracer gas testing is an acceptable method to characterize Control Room Envelope inleakage. In these documents, the NRC has denoted tracer gas testing as Integrated Inleakage Testing since the test itself measures the overall inleakage into the CRE.

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TSTF 448 (Revision 3) was adopted by the NRC in 2007. Amongst many allowable plant and Tech Spec modifications, this document mandates a boundary control program for any plant that adopts the TSTF and further requires a CRE inleakage test every six years.

3.0 Air Inleakage Measurements

Like the majority of nuclear power plants in the US, Fort Calhoun Station pressurizes the CRE with filtered air during a radiological emergency. The CRE encompasses two floors and possesses a volume of 100,000 ft^2. Unlike some plants, at Fort Calhoun the CREEVS is located primarily outside the CRE. A P&ID of the CREEVS is provided in Figure 1. An isometric drawing of the CRE is presented in Figure 2.

To satisfy the requirements imposed by adoption of TSTF 448, a number of tracer gas inleakage tests were undertaken at FCS in January of 2010. The tracer gas was sulfur hexafluoride (SF6)--a gas that has been used for most of the inleakage tests within the US. Sample analysis was by means of two gas analyzers that were optimized for detection of SF6.

In particular, two tests were performed with the A-Train CREEVS pressurizing the CRE. In one test, access to the CRE was restricted, the CREEVS was actuated and an ASTM E741 concentration buildup/steady state tracer gas test was initiated. Pressurization flow rates were simultaneously measured using the principles contained in ASTM Standard E2029.

In a second test, access to the CRE was again restricted, the same CREEVS train was actuated and a tracer gas inleakage and makeup flow rate test was initiated. However, in this test an access door to the CRE was propped open to produce a boundary breech with an area of 94.7 in^2 (0.061 m^2).

For completeness, a single test was also undertaken with the B-Train CREEVS operating in the pressurization mode.

A limited number of mixing fans were used in the CRE as previous experience in other nuclear power plant Control Room Envelopes has shown that ventilation flows into well ventilated rooms are sufficient to mix tracer over the time interval that elapsed prior to initiation of sampling. Portable box fans were placed in the doorway to the MCR restroom, the landing to the Mezzanine, the Mezzanine, the door way between the Air Handler Room and the Computer Room, and the northwest corner of the Computer Room.

In each of the tests, upon attaining concentration equilibrium, seven sets of makeup flow rate concentration measurements were obtained over an approximate one hour interval. For each data set, five distinct sample concentrations on two perpendicular axes of the pressurization duct were obtained using a specially configured pump/manifold system.

Simultaneously, seven measurements of the mean concentration leaving the CRE via the CREEVS were also obtained.

In addition five sets of concentration data consisting of samples from 15 spatially separate points throughout the CRE were also obtained primarily to demonstrate that good tracer gas mixing had been achieved for the test. The standard deviation of the mean concentration was 0.7% and 0.9% respectively for the two A-Train tests indicating that the tracer gas mixing within the CRE was excellent.

Basic conservation of mass considerations provide the following equation for the measurement of inleakage [7,8]:

$$L_{inleak} = L_{tot} - L_{m/u} \qquad (1)$$

where L_{inleak} is the amount of inleakage, L_{tot} represents the total air inflow into the CRE and $L_{m/u}$ is the amount of makeup air. By measuring the total inflow into the CRE as well as the makeup (pressurization) air flow simultaneously using a constant tracer gas injection rate, one can re-write equation (1) as

$$L_{inleak} = S \bullet \left[\left(1/\langle C_{DS} \rangle \right) - \left(1/\langle C_{m/u} \rangle \right) \right] \qquad (2)$$

Where S is the tracer gas injection rate, $\langle C_{DS} \rangle$ is the average concentration at the most downstream point (in static pressure sense) of the CREEVS, and $\langle C_{m/u} \rangle$ is the average concentration of the makeup flow rate. Note that this equation is valid ONLY when concentration equilibrium has been achieved.

The measured makeup (pressurization air) flow rates and the measured inleakage values for all three inleakage tests are provided in Table 1.

The measurement uncertainty of each air inleakage measurement or duct flow rate measurement was calculated using the prescription provided in ANSI/ASME Standard PTC 19.1-1985 (Reaffirmed 1990) “Measurement Uncertainty”. This value represents a 95% confidence limit. The mathematical analysis is based upon equation (2) for the concentration buildup/steady state test.

3.0 Statistical Comparison of Mean Values

Note that in Table 1, the inleakage value for the three tests is denoted as “statistically zero value”. In the context of inleakage measurements, if the mean values of C_{DS} and $C_{m/u}$ are statistically indistinguishable, then according to equation (2) the inleakage is indistinguishable from a zero value.

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It is notoriously difficult (and as a practical matter in a tracer gas test it is essentially impossible) to measure an actual zero value. However, there does exist a statistical method to determine if a zero value for inleakage is consistent with a measured data set.

If we assume that the measured data are normally distributed about their mean values then it is possible to use a statistical test to determine whether the means of C_{DS} and $C_{m/u}$ are indistinguishable.

To proceed define:

$$S_p = \left(\frac{(n_{m/u} - 1)S_{m/u}^2 + (n_{DS} - 1)S_{DS}^2}{n_{m/u} + n_{DS} - 2} \right)^{0.5} \quad (3)$$

and,

$$t = \frac{\bar{x}_{m/u} - \bar{x}_{DS}}{\left(S_p \left[\left(\frac{1}{n_{m/u}} \right) + \left(\frac{1}{n_{DS}} \right) \right]^{0.5} \right)} \quad (4)$$

where: Sp = pooled standard deviation
Sm/u = standard deviation of makeup flow mean concentration
S_{DS} = standard deviation of DS point (total flowrate) mean concentration
t = Student's t statistic
$n_{m/u}$ = number of observations in makeup concentration data set
n_{DS} = number of observations in DS concentration data set
df = degrees of freedom (equal to $n_{m/u} + n_{DS} - 2$)
$\bar{x}_{m/u}$ = mean of makeup flowrate concentration values
$\bar{x}_{DS}$ = mean of total flowrate concentration values

The measured concentration values for the makeup flow rate and the total inflow in the two A-Train pressurization tests are provided in Table 2.

Using equations (3) and (4) one can calculate a t statistic (called t_{Calc} in Table 3) for each tracer gas test data set. If the value of this t statistic (t_{Calc}) exceeds the 95% confidence value of the Student t for the appropriate degrees of freedom, the difference in the means is statistically significant at the 95% confidence value. Stated another way, if the t value calculated using equation (4) is less than the 95% Student t value (called $t_{Student}$ in Table 3) for the number of degrees of freedom, the mean values are indistinguishable [9].

From Table 3 it can be seen that t_{Calc} is not greater that $t_{Student}$, for either test (at the 95 % confidence level). This implies that the mean values are indistinguishable. If the values are <u>not</u> different, then the measured inleakage using equation (2) is <u>*indistinguishable*</u> from a zero value.

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Thus it can be asserted as in Table 1 that the inleakage for either test is “Statistically Indistinguishable from zero value”.

4.0 Differential Pressure Measurements

During each tracer gas air inleakage test, differential pressure between the MCR and various surrounding rooms were measured. Differential pressures were measured using two Setra Model 370 Digital Barometers.

Initially, both barometers were placed next to each other on the floor of the MCR and the units were “zeroed”. One unit (the mobile unit) was then moved to various locations and the pressure values noted at timed intervals. The indicated pressure values of the unit remaining (the stationary unit) were also recorded at timed intervals. The mobile unit was then returned to the stationary unit and both readings were again noted. This allowed a correction to be made for drift between the responses of the two units.

Differential pressures were then calculated between the various locations by differencing the drift corrected values of the two digital barometers. In some cases, elevation corrections were made to the readings of the mobile barometer to ensure that the differential pressure relative to the floor of the MCR was obtained.

Table 4 provides the measured differential pressures for the two A-Train air inleakage tests. A positive value for differential pressure implies that the Main Control Room is at a higher pressure than the measurement location. A bar graph data plot for each test is provided in Figure 3.

It is apparent from Figure 3 that the breech size was sufficient to severely decrease the differential pressure of the MCR to the surrounding areas and, in the case of the differential to the outside, to reduce it to essentially a zero value.

5.0 Conclusions and Discussion

For the inleakage testing at FCS, the fact that the inleakage did not increase when the boundary was subjected to a significant breech is not entirely unexpected since the negative differential pressure portions of the CREEVS that are outside the CRE boundary exhibited no inleakage with either CREEVS train operating.

However, as can be seen specifically from the testing at Fort Calhoun and more generally from a consideration of the effect of increased CRE boundary opening in the CRE differential pressure relationships, so long as the CRE maintains a positive pressure with respect to surrounding areas, one does not expect increased inleakage through the CRE boundary. An increase in leakage area will result *only* in a concomitant decrease in the level of positive differential pressure. As can be seen from Figure 3, at a sufficiently large opening, the differential pressure completely disappears.

At Fort Calhoun, one can infer that the actual CRE boundary is sufficiently well sealed that even though the differential pressure was reduced to essentially zero, the value of inleakage was unchanged.

It is well established that inleakage occurs in the negative differential portions of the CREEVS and not through the physical CRE boundary for CREs which maintain a positive differential pressure with respect to the surrounding areas. Thus, any increase in CRE openings (or increase in leakage area) results in a lower differential pressure with respect to surrounding areas. So long as this value remains positive, inleakage through the CRE boundary does not occur.

It is important to note that both SRP 6.4 and TSTF 448 rely on maintaining a positive differential pressure between the CRE and the surrounding areas as a measure of CRE boundary integrity. TSTF 448 actually requires differential pressure to be trended on a periodic basis.

One can use trending of the differential pressure to indicate the general condition of openings (leakage areas or breeches) in the CRE boundary, but so long as the differential pressure remains positive, no information regarding increased inleakage in the CREEVS can be gleaned from any changes in the CRE boundary pressure relationships.

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6.0 References

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Table 1

Fort Calhoun Generating Station CRE Inleakage Testing

Item	Value *
A CREEVS Makeup Flow rate	771 +/- 30 SCFM**
CRE Inleakage w/A-Train	Statistically Indistinguishable from zero value
A CREEVS Makeup Flow rate w/Breach	781 +/- 27 SCFM**
CRE Inleakage w/A-Train & Breach	Statistically Indistinguishable from zero value
B CREEVS Makeup Flow rate	677 +/- 29 SCFM**
CRE Inleakage w/B Train	Statistically Indistinguishable from zero value

* SCFM referenced to 70 Deg F and 14.7 psia

** Mean of seven measurements

Table 2

Mean Concentration Values for Two Inleakage Tests

NO BREECH		WITH BREECH	
Makeup Concentration (ppb)	CRE Return Concentration (ppb)	Makeup Concentration (ppb)	CRE Return Concentration (ppb)
31.34	29.8	30.60	30.2
30.64	30.3	30.42	31.5
31.16	31.0	30.32	30.0
30.96	31.0	30.28	31.0
31.20	30.9	30.34	30.8
31.50	31.0	30.10	30.0
31.10	30.8	30.46	31.0

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Table 3

Statistical Test of Makeup and CRE Return Concentration

CREEVS	Mean Makeup Conc (ppb)	Mean Return Conc (ppb)	t_{Calc}	$t_{Student}$	Distinct ?
A-Train	31.14	30.66	2.259	2.447	No
A-Train w/Breech	30.36	30.53	0.743	2.447	No

Table 4

FCS Differential Pressures Relative to MCR
(A-Train CREEVS Operating)
(in. w.g.)

STATION	No Breech	With Breech
TURBINE BLDG @ 1036	0.242	0.050
ROOM 81 @ 1036	0.186	-0.018
CABLE SPRD RM @ 1025	0.225	0.033
AUX BLDG @ 1025	0.392	0.137
OS TURBINE BLDG @ 1036	0.228	-0.002

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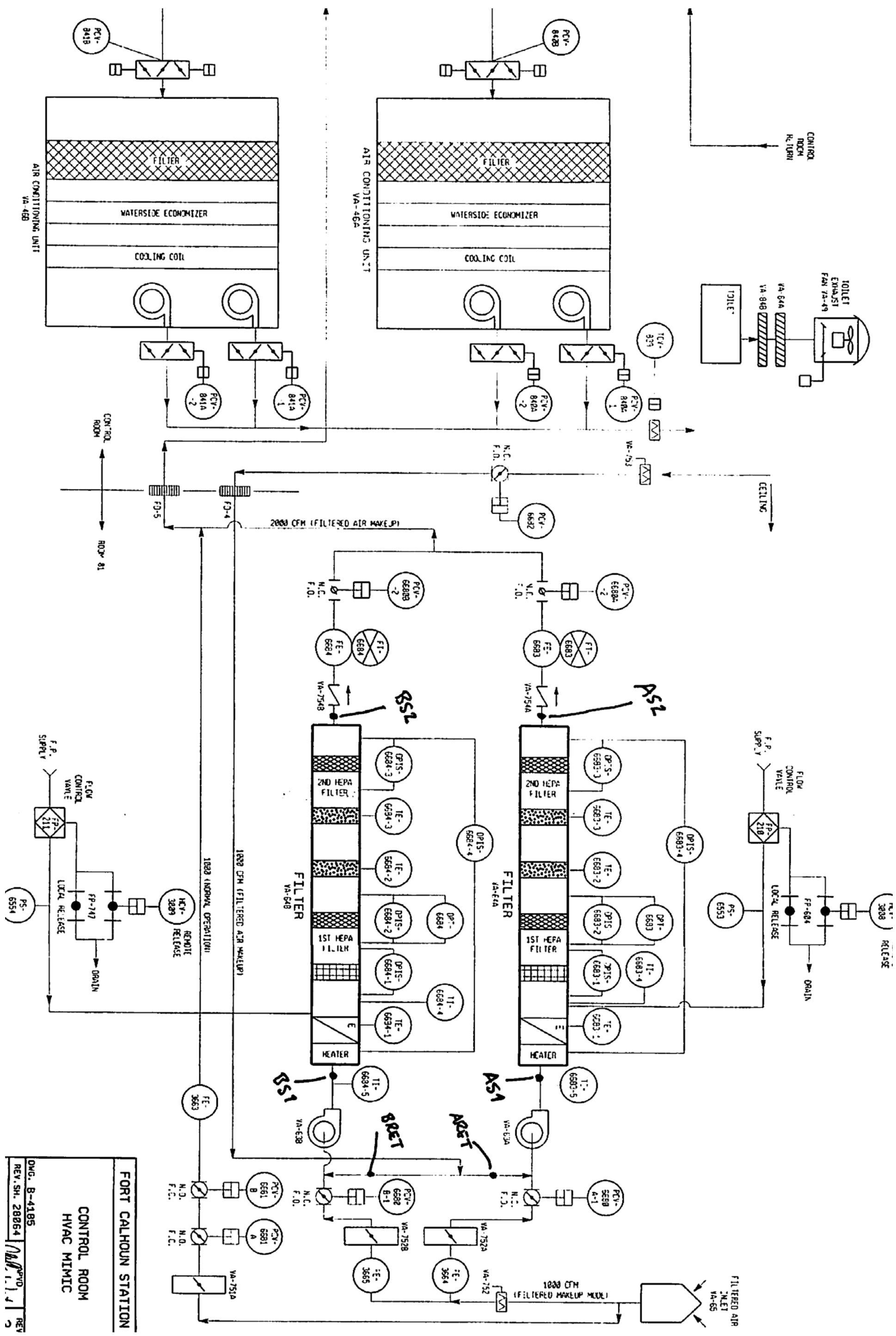

Figure 1. P&ID of Fort Calhoun CREEVS

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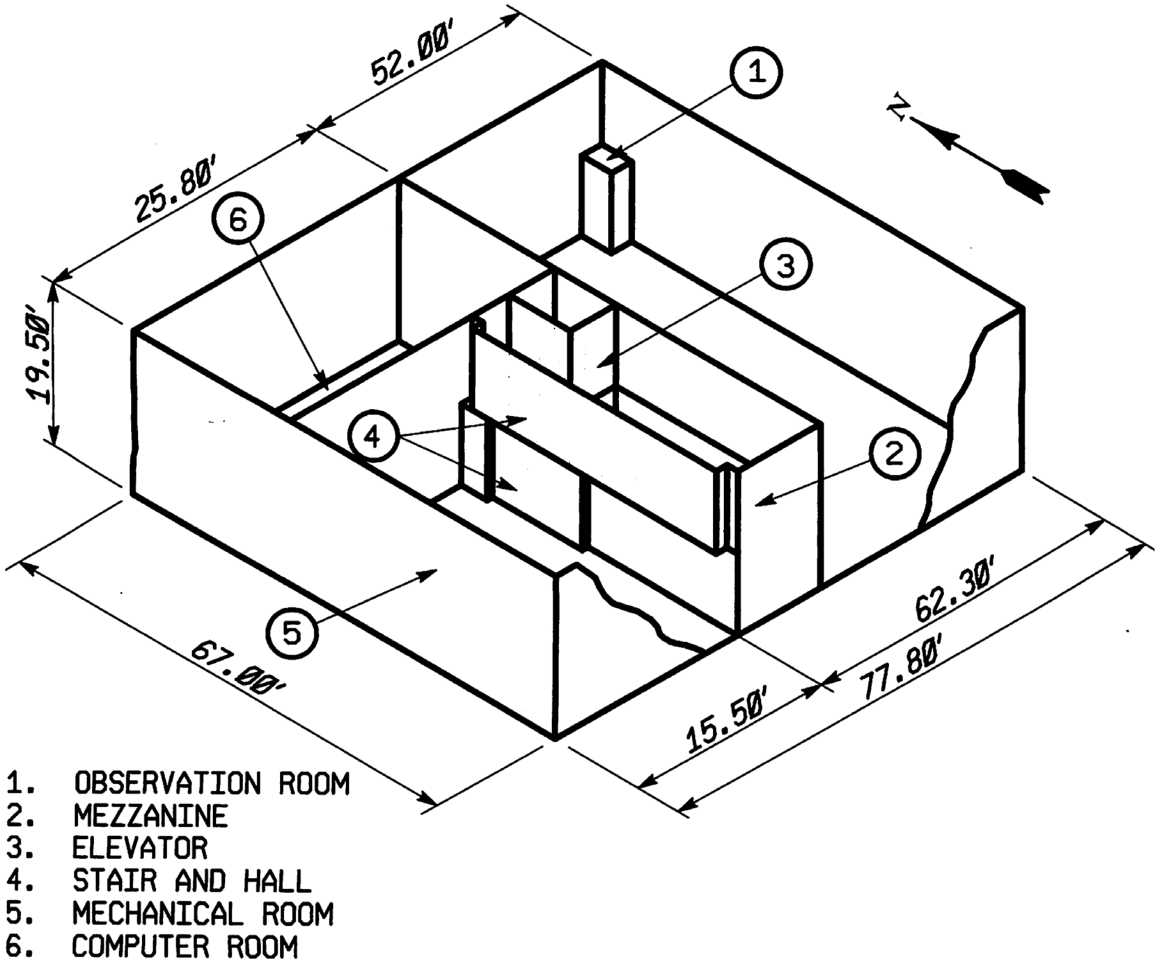

Figure 2. Control Room Envelope at Fort Calhoun Station.

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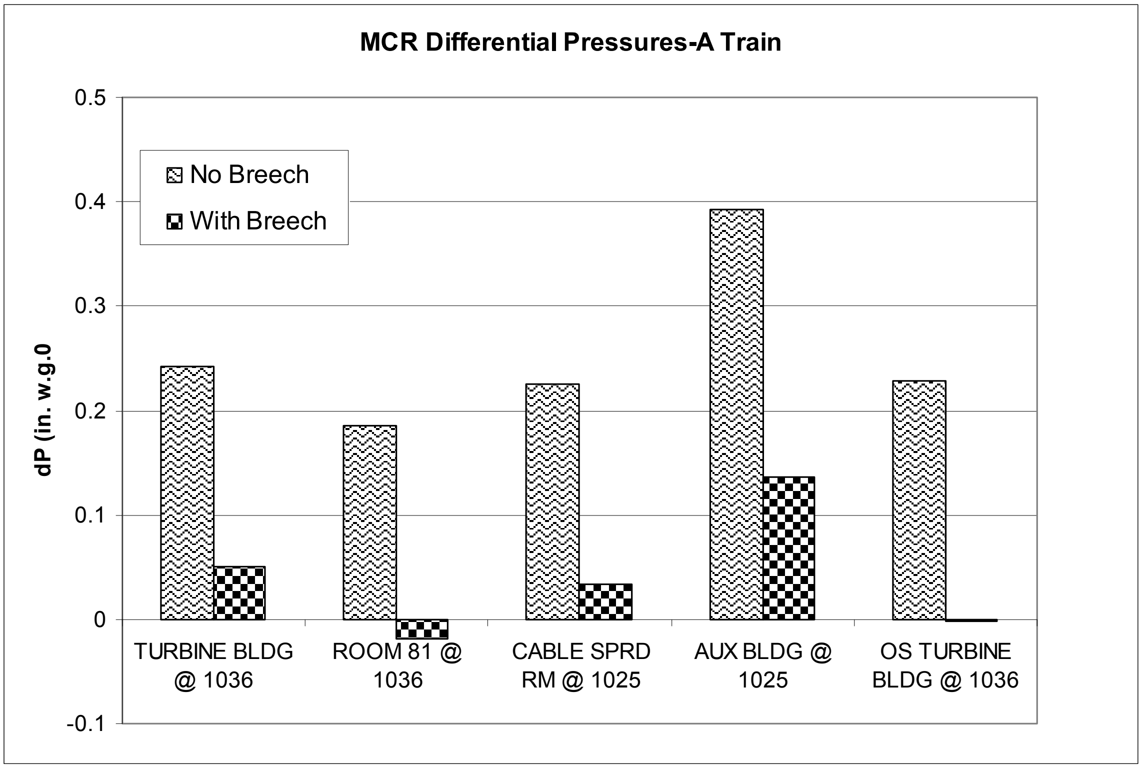

Figure 3. Differential Pressures for two Inleakage Tests

The Effect of Boundary Breech on Measured Inleakage

P. L. Lagus, Ph.D., CIH
Lagus Applied Technology, Inc.
Escondido, CA

J. A. Carlson, P.E.
Omaha Public Power District
Fort Calhoun Station
Blair, NE

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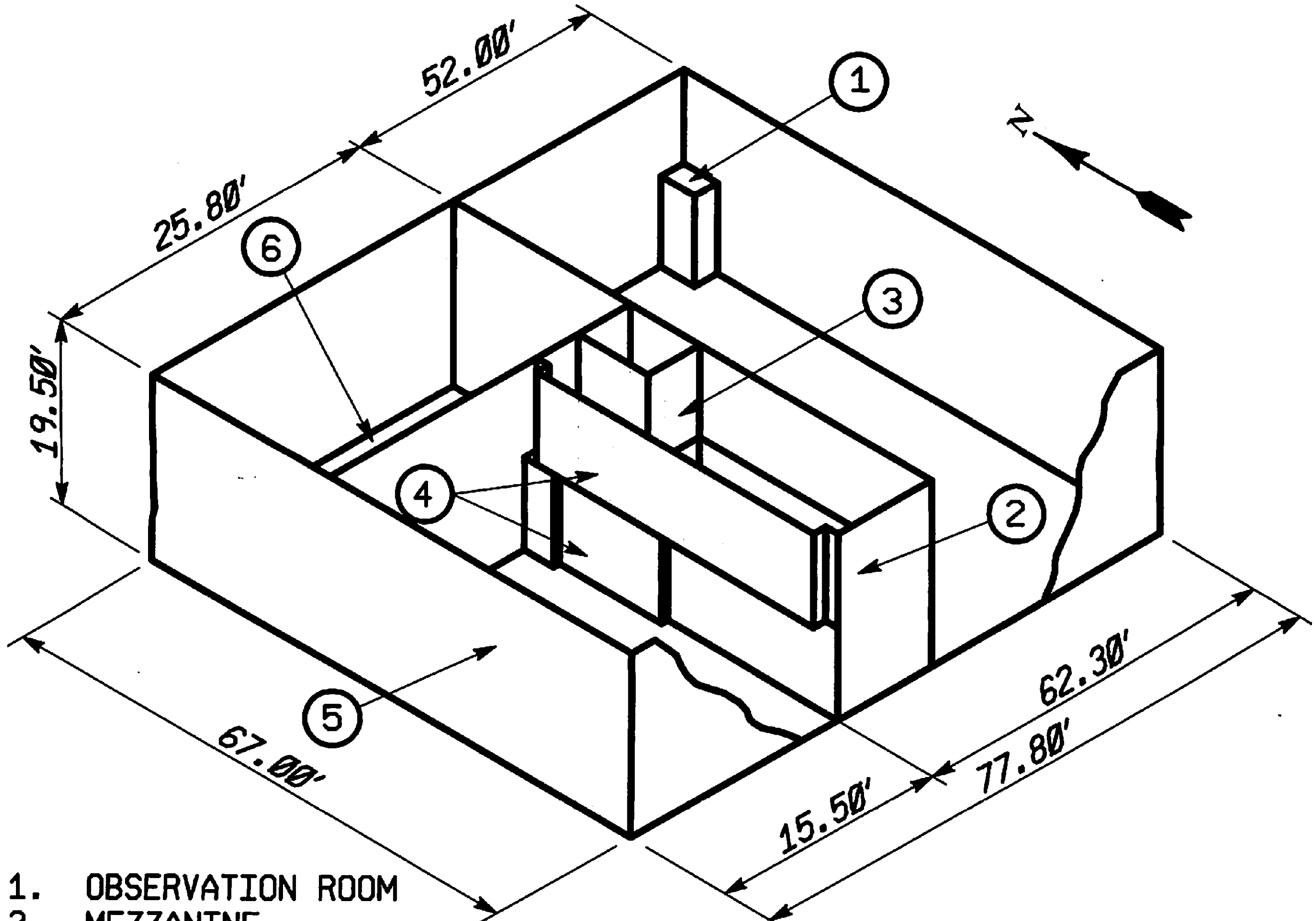
The Ft. Calhoun CRE

- Ft. Calhoun Station is operated by OPPD and located in Blair, Nebraska
- Single Unit PWR
- Two Storey CRE with Volume of 100,000 Ft^3
- The present control room configuration was established by a modification implemented in 1985
- Since 1985 the boundary has been maintained and controlled using plant procedures.

The Ft. Calhoun CRE
(Cont'd)

- Redundant CREEVS are located adjacent to, but outside of, the CRE
- CRE pressurizes upon emergency signal
- CREEVS provides filtered pressurization air
- Inleakage testing in 1999 disclosed a low, but non-zero, inleakage



1. OBSERVATION ROOM
2. MEZZANINE
3. ELEVATOR
4. STAIR AND HALL
5. MECHANICAL ROOM
6. COMPUTER ROOM

Inleakage Testing

- In January 2010, tracer gas inleakage testing performed for both A Train and B Train CREEVS
  - Inleakage measured per ASTM E741
    - Makeup flow rate measured per ASTM E2029
- An additional inleakage test with deliberate breech was undertaken with A Train operating
  - Breech by propping 2nd access door open (94.7 inch^2)
- Differential pressure between CRE and surrounding areas was measured during each test

Results

SYSTEM	Value
A CREEVS Makeup Flow rate	771 +/- 30 SCFM
CRE Inleakage w/A-Train	Statistically Indistinguishable from zero value
A CREEVS Makeup Flow rate w/Breach	781 +/- 27 SCFM
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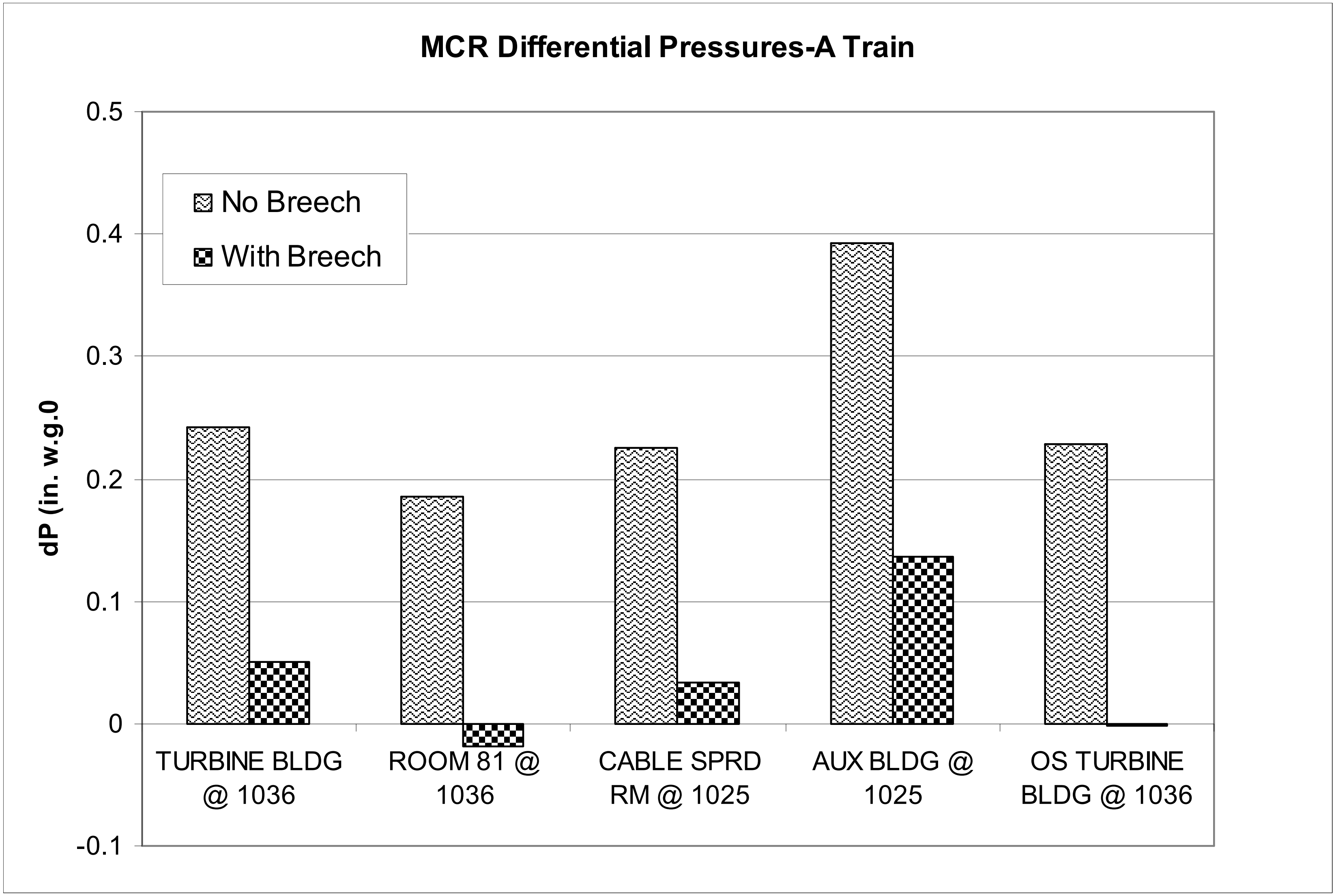
MCR Differential Pressures-A Train
No Breech
With Breech
dP (in. w.g.0
0.5
0.4
0.3
0.2
0.1
0
-0.1
TURBINE BLDG @ 1036
ROOM 81 @ 1036
CABLE SPRD RM @ 1025
AUX BLDG @ 1025
OS TURBINE BLDG @ 1036

What does "Statistically Indistinguishable from a Zero Value" mean?

As Total Inleakage Value Approaches the Makeup Flow Value

THE INLEAKAGE RATE APPROACHES ZERO

(RECALL THAT)

$$L_{inleak} = L_{tot} - L_{m/u}$$

What happens when the inleakage is near zero?

- Real data tend to oscillate about the “true” value
- For very low inleakage rates one can get negative values (Assuming that valid test is performed)
- PTC 19.1 breaks down with negative values
- Possible causes of negative inleakage values
  - Random experimental variation
  - Incomplete tracer mixing within CRE
  - Poor location or design of flow rate measurement
  - Measurement error or Calibration error in gas analysis equipment

How to handle very small positive or negative inleakage values?

- Calculate means and standard deviations of makeup and total inflow
- Calculate pooled standard deviation & t Statistic
- If calculated value of t Statistic exceeds the 95 % confidence limit for the appropriate degrees of freedom, then means are statistically distinct
- If not, the inleakage is statistically indistinguishable from zero

Statistical Argument Based on the Student t Distribution

- The t Statistic acts like a normal distribution but is a function of the number of degrees of freedom
- Useful for data sets of less than 30 points
- Provides a defensible statistical argument for a "zero inleakage value"
- Allows uncertainty of small positive and negative inleakage values to be evaluated

Pooled Standard Deviation

$$S_p = \left(\frac{(n_{m/u} - 1)S_{m/u}^2 + (n_{Ret} - 1)S_{Ret}^2}{n_{m/u} + n_{Ret} - 2} \right)^{0.5}$$

t Statistic for Comparison Of Means

$$t = \frac{\bar{x}_{m/u} - \bar{x}_{Ret}}{\left(S_p \left[\left(\frac{1}{n_{m/u}} \right) + \left(\frac{1}{n_{Ret}} \right) \right]^{0.5} \right)}$$

Statistical Test of Makeup and CRE Return Concentration

CREEVS	Mean Makeup Conc (ppb)	Mean Return Conc (ppb)	t_{Calc}	$t_{Student}$	Distinct ?
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Comments

- A Control Room Habitability Program (CRHP) was established in 2009 utilizing existing plant procedures
  - Standard Technical Specifications were adopted.
- Language provided in the CRHP allows a potential failure of the dP surveillance to be evaluated.
  - This is not indicative of a control room envelope boundary failure which is an LCO

Observations

- **Both SRP 6.4 and TSTF 448 rely on maintaining a positive differential pressure between the CRE and the surrounding areas as a measure of CRE boundary integrity**
  - **TSTF 448 actually requires differential pressure to be trended on a periodic basis**
- **For a positive dP CRE boundary, inleakage occurs in the negative dP portions of the CREEVS**
  - **A decrease in CRE dP does *not* imply an increased inleakage**
- **Trending the positive dP does not provide any indication of a change in inleakage for a pressurized CRE**

Conclusions

- B Train inleakage was also "statistically indistinguishable from a zero value"
- Measured inleakage is well below allowable inleakage value of 38 SCFM
- At FCS, the CRE boundary is well sealed
  - Even though the differential pressure was reduced to essentially zero the inleakage was unchanged
- The boundary control program has done an excellent job of preserving the integrity of the CRE boundary

  Results from 1999 and 2010 confirm that the system has not degraded over the intervening interval