# 27th Nuclear Air Cleaning and Treatment Conference

# US Control Room Habitability Testing
# Summary and Lessons Learned

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**Abstract**

The paper presents a summary of control room inleakage testing in the US through May of 2002. The paper describes testing methods (tracer gas, component, and alternate), provides selected results from testing, highlights upcoming tests, and discusses lessons learned.

Currently, the Nuclear Regulatory Commission has four Draft Regulatory Guides (DG-1111, 1113, 1114, and 1115) and a Draft Generic Letter (GL 2002-XX) in public review. These Guides and the GL address control room habitability, but will not be discussed in this paper due to their draft status.

## Background

Control Room Habitability (CRH) describes the analysis, mechanical systems, and structures used to provide a safe environment and thus protect commercial nuclear power plant Operators and control room equipment during normal and accident conditions. The heating, ventilating, air-conditioning, pressurization, and filtration systems (HVAC) are the primary mechanical systems affected when discussing CRH. The HVAC typically consists of two systems; the control room emergency ventilation system (CREVS) and control room heating, ventilating, and air conditioning system (CRHVAC). The HVAC, when needed, performs some or all of the following functions:

- Isolation
- Pressurization
- Filtration
- Temperature control
- Ventilation
- Humidity control

At this point it is necessary to introduce some additional terminology to clearly define the various aspects discussed in this paper.

- Control Room (CR) - The plant area where the plant is controlled; typically the horseshoe area and associated panels in the immediate vicinity. This area encompasses the room(s) containing the controls and indicators necessary to safely operate and shut down the reactor and turbine plants
- CR Envelope (CRE) - The plant areas that are to remain habitable during an accident. This includes spaces such as (but not limited to) the CR, toilets, locker room, and kitchen. This is outlined by the CRB.
- CR Boundary (CRB) - The physical boundary that defines the CRE. This includes items such as the doors, walls, ducting, etc.

- CRE Integrity (CREI) - The condition whereby the CRHS are functioning to assure CRE environment is maintained and that the CRB is intact.
- CR Habitability System (CRHS) - The plant systems that help ensure CREI. This includes the CREVS and the CRHVAC.
- CR Emergency Ventilation System (CREVS) - The control room emergency ventilation system. This includes some or all of the following components: filters, pressurization fans, isolation dampers, controls, ducting.
- CR Heating Ventilating and Air Conditioning System (CRHVAC) - The heating, ventilating, and air conditioning systems that are used to maintain the CR temperature and humidity.

One of the design objectives of the CRHS is to limit Operator dose and/or exposure to toxic gases. The CRHS does this by various combinations of isolation, pressurization, and filtration. Additionally, in order to assure CREI integrity the CRB must be intact and the CRHS must be functioning properly. One input into the analyses determining dose and/or toxic gas exposure is the amount of inleakage[1] into the CRE. The specific design of the CRHS significantly influences the amount of inleakage passing through the CRB into the CRE. In the U.S., no two commercial power plants CRHS physical designs are exactly the same. Due to the many different designs, and for simplicity, this paper divides the CRE design into two groups; pressurized (Figure 1) and non-pressurized (Figure 2).

CRH received new interest in 1998 when the Nuclear Regulatory Commission (NRC), Nuclear Energy Institute (NEI), and Nuclear HVAC Utilities Issues Group (NHUG) held a CRH workshop in Washington, D. C. This workshop presented the issues facing the industry in all facets of CRH. Unfiltered inleakage (and measurement of the value) was one of the concerns brought forth by NRC at the workshop. At that point (July, 1998) eight plants had tested unfiltered inleakage using tracer gases. All eight plants had failed to demonstrate that the analysis value assumed for unfiltered inleakage could be achieved in the initial measurement. Currently 21 plants have tested their control rooms for unfiltered inleakage using a tracer gas.

## Test Data

Test results (and planned testing) are shown in **Table 1 - Control Room Testing - Available Data as of May 2002**. The data is sorted by date of initial test. This data shows all known test results for the various plants as of May 2002. A total of 24 plants have tested for unfiltered inleakage. Some plants have tested more than once and others are planning tests in the near future; therefore the table contains 31 sets of information. The majority of tests have been tracer gas tests (TGT), but testing does include alternate tests and component tests as described in NEI 99-03 Control Room Habitability Assessment Guidance[(18)]. Also a two (or more) unit plant may have either a common control room or separate control rooms. Tests could have been performed on only one control room (for a multiple unit site with separate control rooms) or for a common control room serving multiple units. Additionally plants may have performed multiple tests (different trains, different equipment line ups, etc.). All data is by plant site and only one set of test data is shown (the most conservative i.e., the largest leakage).

Summary of Table 1:

- 20 plants have tested using a tracer gas (two additional plants are planning on conducting a TGT)
- 1 plant has tested using an alternate test method[2]
- 6 plants have tested using a component test[3]
- 3 plants are planning on conducting an alternate test using multiple tracer gases (PFT)
- 3 additional plants are planning tracer gas tests

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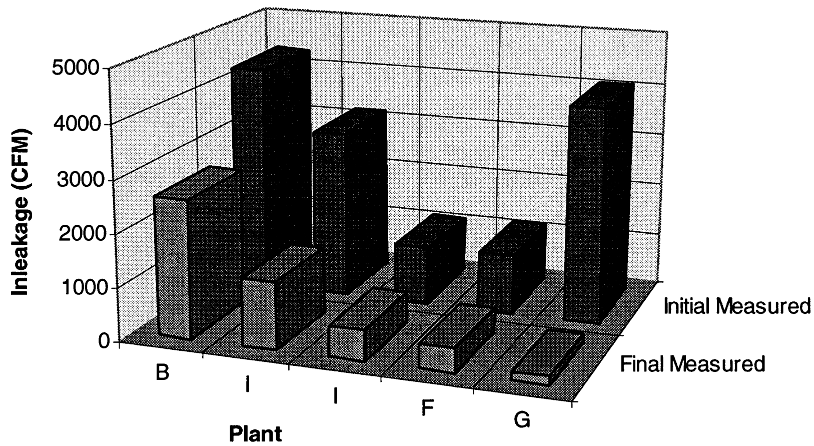
[1] **Unfiltered inleakage of airborne radiation into the CRE can have significant impact on Operator dose.**

[2] **A modified blower door test.**

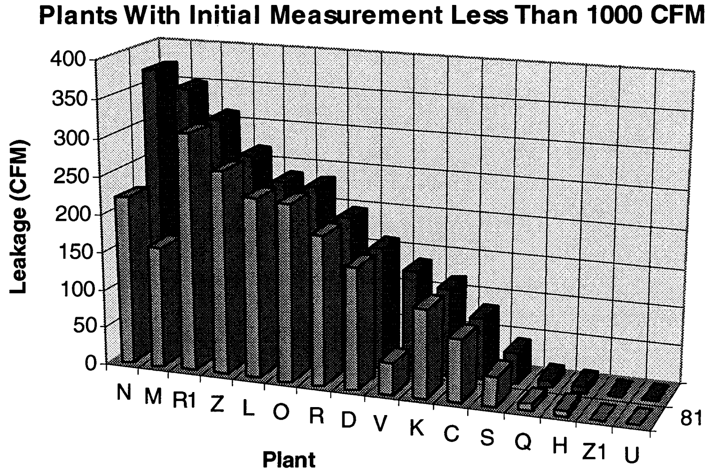
[3] **3 performed component tests per NEI 99-03; 2 performed component testing prior to development of NEI 99-03.**

Graphs of the data from Table 1 follow. These two graphs are 1) the plants with greater than 1000 CFM leakage on their initial measurement and 2) plants with less than 1000 CFM on their initial measurement. The graphs illustrate the performance of the various CRE in testing

**Graph 1**
**Plants with Initial Measurement Greater Than 1000 CFM**




**Graph 2**
**Plants With Initial Measurement Less Than 1000 CFM**




**Tracer Gas Testing**

TGT testing can be performed on both pressurized and non-pressurized CRE. There are 22 sets of data from the 20 plants that have performed TGT to date. The data in the table represents the most conservative test results. In many cases a plant tested various lineups (i.e., each train of equipment was tested and different modes of operation were tested). The most conservative data is that which yielded the highest inleakage. Some plants may have only performed one set of tests (i.e., the testing data was shown to be acceptable in dose analysis) or a second set of data was taken following maintenance/modifications to the plant. This is the reason some initial measurements are the same as the final measurements. Based on the 22 sets of plant tests (See Table 1), the average initial and final measurements were 760 CFM and 329

CFM, respectively. Some plants are still in the process of addressing unfiltered inleakage and the final measured average is expected to decrease.

The following table provides some date on averages of the test measurements:

**Table 2 - Tracer Gas Test Data Summary**

| | Initial Measurement (Average) CFM | Final Measurement (Average) CFM |
|---|---|---|
| **TGT Average (All)** | **760** | **329** |
| **TGT - Neutral Pressure** | **1080** | **653** |
| **TGT - Positive Pressure** | **640** | **207** |
| **Plants w/Initial Measurement > 1000 CFM** | **2752** | **1013** |
| **Plants w/Initial Measurement < 1000 CFM** | **174** | **123** |

Uncertainties are not included in the test results. Note that the theoretical accuracy of the tests has been shown analytically to be ± 10%(11). However, in practice, the uncertainty has been shown to be on the order of 30% to 60% for plants with low pressurization and less than 10% for plants with no pressurizing air flow (i.e., neutral)(19). For completeness , some pressurized CRE can achieve <10% uncertainty, but this is the exception rather than the rule.

Test protocols are well established when using a tracer gas to test the CRE for unfiltered inleakage. However, these protocols must be adapted to each plant on a case-by-case basis due to the many different physical designs and operating characteristics of the U.S. Plants. The protocols are based on ASTM Standard E741(28), "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution." A good discussion of the protocols can be found in Reference 11; "Control Room Envelope Unfiltered Air Inleakage Test Protocols," by Pete Lagus, Ph.D. and Richard A. Grot, Ph.D. This paper discusses the techniques and procedure for performing a TGT. The paper concludes that unfiltered inleakage can be measured to within ±10% uncertainty. This has been shown to be true for non-pressurized control rooms.

**Component Testing(17, 18, 19)**

A component test as discussed in NEI 99-03 consists of (Note that a component test can only be performed on a pressurized control room.):

- A thorough review, inspection, and walkdown of the CRE, CRHS, CREVS, CRHVAC, and CRB to identify components that may leak unfiltered air into the control room (i.e., vulnerabilities).
- A comprehensive measurement of CRE pressure across the CRB to all adjacent spaces to assure the CRE is positive to all adjacent spaces
- Measurement of the leakage of each identified component. The sum of the components' inleakage is the total inleakage.

NEI 99-03 provides guidance for reviews, walkdowns, and inspections to identify potential vulnerabilities to leakage. The major steps are:

- Identify the boundary
- Identify operating configurations
- Visual examination, differential pressure and system flow measurements
- Boundary penetrations, doors, isolation dampers inspections
- Determination of effects of other systems in the envelope
- Review of the general boundary construction

Pressure measurements (ΔP) across the CRB should be 1/8 inch W.G. (or the licensing basis value) to outside and 0.05" W.G. to adjacent areas in a building. The 1/8 inch W.G. is a typical Technical Specification requirement; while the 0.05" W.G. reflects current engineering practice in the cleanroom and healthcare industry. In the April 2001 revision of Guidelines for Construction of Hospital and Health-Care Facilities, the American Institute of Architects recommends a minimum of 0.01" W.G. ΔP (negative) for airborne infection isolation rooms, and a minimum of 0.01" W.G. ΔP (positive) for critical care areas such as intensive care and surgical rooms. In Chapter 15 of the ASHRAE HVAC Applications Handbook[22], 0.05" W.G. is noted as a widely used standard for semiconductor cleanrooms and pharmaceutical and biomanufacturing clean spaces.

There are six sets of data representing component testing. However, only three sets of data will be discussed as they were performed in accordance with NEI 99-03 and concurrent with a TGT. These test results (plants J, K, and O) indicated that a component test can accurately determine the unfiltered inleakage into the CRE. The average inleakage value for a component test is 69 CFM. The uncertainty associated with the component test is much less than that associated with a TGT. The reported uncertainty of a component test is on the order of <5%[20]. Actual field comparisons to date show that the component test yields a more accurate (plus conservative) result that a TGT for a pressurized control room[20] and can properly identify vulnerabilities to be tested. It is important to stress that the performance of a valid component test (as defined in NEI 99-03) requires a thorough assessment and walkdown of the plants leakage vulnerabilities and verification that the CRE is at a positive pressure with respect to adjacent spaces.

**Alternate Testing**

An alternate test being considered by three plants consists of a multi-tracer TGT. Brookhaven National Lab (BNL) perfluorocarbon tracer (PFT) technology has been applied to multi-tracer air inleakage and air exchange measurements for more than 20 years. This technology can be applied to a nuclear power plant CRE as an alternative test described in NEI 99-03[21]. This testing has the capability to not only quantify inleakage, but also to determine the source of inleakage. The simplest TGT inleakage test to perform at any power plant would be a single-zone test similar to the way in which the $SF_6$ TGT are currently performed. This requires the least investment in understanding the air handling systems of the plant other than that for the Control Room. This single-zone tests provides an accurate measurement of inleakage but is limited in that it does not identify leakage pathways. The PFT TGT can measure leakages for up to seven zones.

PFT TGT uses sources ranging from the size of a pencil eraser (a regular source) to the size of a large thimble (a "Mega" source) to "tag" an area. Tagging allows a specific area to be identified as a leakage source. The passive sampling tube is a glass tube about the size of a cigarette. Sampling periods of a few hours to several days or weeks of a single integrated measurement period could be made depending on the plant's need. At the end of the test, the sampling tubes are sent to BNL, and plant-specific algorithms are used to calculate the air flows between the tagged areas. The actual sampling process is transparent to plant personnel and operators, and no other measurements or operational restrictions are necessary.

Initially, a greater number of samples would be needed in order to arrive at the best representative locations for subsequent sampling tests. A review by plant personnel to review and critique suggested locations is required to reach the best distribution. At the conclusion of the first few tests, it is expected that the number of samplers can be reduced 3-fold for any necessary subsequent tests or for periodic routine testing. It does not matter whether almost all the inleakage is directly from outside or other untagged areas of the plant. If the latter is the case, then subsequent tests can be conducted in which untagged areas would be tagged to identify and quantify the leakage.

Once the number and type of PFT sources and representative sampling locations have been refined, repeat testing can be easily performed with plant personnel alone. Samplers need only be returned to BNL for analyses and the generation of a report.

## Lessons Learned

Previous information initially was concerned with the radiological dose consequences of an event[1, 2, 3, 4, 5]. This early analysis method (late 1960's early 1970's) emphasized reducing dose and increasing air filtration. However the Murphy/Campe[2] paper did recognize the proper use of the dose analysis in regards to the CRHS design, "*Much of the observed design variations are caused by differing opinions as to the degree of protection that must be provided. In some cases, one has to conclude that the dose analysis were performed after the ventilation system design had been established. Dose analyses exclusively for the sake of satisfying safety documentation requirements is not a recommended practice. Rather it should be used as a tool for system design and component selection.*" Additionally by 1975 the industry was aware of the synergistic impact adjacent HVAC systems can have ... "*The ventilation for a building (or group of buildings with interconnection of their atmospheres) must be dealt with as a whole system because the pressure gradients associated with a building require to be in a delicate balance and local areas cannot exist in isolation.*[3]" This synergistic effect was also illustrated in a paper describing the impact of a failed battery room exhaust fan upon the control room pressurizing system's ability to maintain the required differential pressures[23].

By the early 1980's (essentially after all the current CRHS designs were completed and constructed) information pertinent to today's problems began to be published[6, 7, 8, 9]. Field information concerning the lack of/condition of seals on ducting/doors is an example of what was found. ANS published a standard[7] in 1985 that provides a good overview of the design of the CRHS. However, there are no cautions about design for ducting located outside the CRE or passing through the CRE. It does recognize a 10 CFM value for ingress and egress. Duct leakage, diligence in maintenance, and lack of understanding of the requirements of CRHS system are issues that were identified in the mid-1980's. By the end of the 1980's an excellent paper on CRH was published in the American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE)[9] 1989 Transactions entitled, "Nuclear Power Station Main Control Room Habitability." This paper discusses succinctly CRH; summarizes previous information, and provides an outline of information (that is also found in NEI 99-03) concerning performing walkdowns, determining design basis, and location of vulnerabilities. Another excellent paper in discussing requirements for CRE was presented at the 25th DOE/NRC Nuclear Air Cleaning Conference (1998) entitled. "Critical Review: Historical Perspective and Evolution of Commercial Nuclear Utility Control Room Ventilation Systems[15]." This paper presents summaries of the issues, regulatory requirements, and testing solutions to the Industry.

Current information and test data illustrate the following:

- Physical CRHS design influences the amount of inleakage.
- Ducting is a major source of leakage. Ducting that traverses the CRE, for example, may leak into the CRE. Ducting serving the CRE and not totally contained within the CRB may leak and draw unfiltered air into the CRE (Figures 3, 4, 5, 6).
- Positively pressurized CRE that cannot show a positive pressure across all boundaries have a significant vulnerability to inleakage.
- Component tests (as defined in NEI 99-03) can be used to determine control room inleakage.
- 10 CFM for ingress and egress is a valid value for CRE without a vestibule entrance[15].
- Sealing of leaks is an essential part of assuring CREI

Furthermore, the current testing and efforts associated with the development of NEI 99-03 show the following:

- A breaching program for the CRB is essential
- Maintenance of the CRB and the CRHS is required
- Specifics on the type, location, and significance of components to inleakage must be identified
- Utilities are capable of testing the CRE for inleakage

Finally, NEI 99-03 is the first comprehensive document to assure CRH. The lessons learned are:

- Testing options for measuring unfiltered inleakage have been presented. Guidelines are also provided, for tests not explicitly described in NEI 99-03, to assure that an unfiltered inleakage test provides proper results.
- Testing must encompass both toxic gas and dose
- Comprehensive guidelines for assurance of control room integrity is provided, including such items as maintenance, configuration control, breaching control, procedures, and training.
- Information needs to be consolidated and packaged in an industry document available for reference (NEI 99-03 fulfills this requirement).

## Conclusion

Currently (May 2002) the U.S. commercial nuclear licensees perform testing of their CRE on an as-needed basis. Testing for the majority of the plants in the US have shown the CRE is relatively tight; though not as tight as previously believed Some plants do have significant leakage issues and this is reflected in the test data. Testing protocols are established for TGT and what is referred to as a component test. TGT protocols using PFT is being developed and may be established as of the date of this conference (September 2002). The aspects of CRH may be simple in concept however it is complicated in implementation.

## References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20. NEI Control Room Habitability Presentation to NRC, March 19, 2002
21. Multi-Tracer Control Room Air Inleakage Protocol And Simulated Primary And Extended Multi-Zone Results, A Concept Paper, Russell N. Dietz, Head Tracer Technology Center; Brookhaven National Laboratory; January 30, 2002
22. American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 1999 Handbook HVAC Applications, Chapter 15; Clean Rooms
23. Watts Bar Nuclear Plant Battery Room Exhaust Fan Failure Lessons Learned; Robert R. Campbell, PE and Sam Linginfelter, PE; Paper presented at the Summer 2002 NHUG Conference
24. NHUG Conference Presentation on Control Room Habitability Tests at Comanche Peak, presented by Michael McVean, January 2002.
25. Entergy Letter to NRC dated January 14, 2002; Submittal of Tracer Gas Test Results
26. NHUG Conference Presentation on Indian Point 2 Tracer Gas Testing, presented by Michael Faggioli, August 2002
27. Advisory Committee on Reactors Safeguards; Severe Accident Management Subcommittee (ACRS) Meeting on Main Control Room Habitability, September 17, 1999; presentation of Prairie Island Tracer Gas Test Results
28. ASTM Standard E741, "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution."

***Table 1 - Control Room Testing[4]***
***Available Data as of May 2002***

| Plant | CR Room Pressure[5] | Initial Measurement | Final Measurement[6] | Location of greatest unfiltered inleakage | Notes | Year of Test | Test Type[7] |
|---|---|---|---|---|---|---|---|
| A | + | Planned | NA | NA | | 2003 | T |
| B | + | Planned | NA | NA | | 2003 | T |
| C | Neutral | Planned | NA | NA | | 2002 | PFT |
| D | + | Planned | NA | NA | | 2002 | T |
| E | Bottled Air | Planned | NA | NA | | 2002 | PFT |
| F | + | Planned | NA | NA | | 2002 | PFT |
| G | + | 134 | 40 | Fan shaft | Reanalysis | 2001 | T |
| H | + | 0 | 0 | NA | Radiation Mode | 2001 | T |
| I | Neutral | 267 | 267 | Dampers | Toxic Gas Mode | 2001 | T |
| J | + | 40 | 40 | Ducting | Component test was the more conservative value | 2001 | TC |
| K | + | 0 | 0 | NA | Tracer/component test results were complimentary | 2001 | TC |
| L | + | 196 | 196 | Ducting | Pressurized mode for dose | 2001 | T |
| M | + | 312 | 312 | Ducting | Toxic Gas | 2001 | T |
| N | Neutral | 116 | 116 | Ducting/Walls | | 2001 | T |
| O | + | <10 | <10 | Ducting | Tracer/component test results were complimentary | 2001 | TC |
| P | + | 82 | 82 | Unknown | | 2000 | T |
| Q | + | 1089 | 589 | Ducting/Walls | Reanalysis in progress | 2000 | T |
| R | + | 233 | 233 | Unknown | | 2000 | T |
| S | + | Not Available | Not Available | Outside | Sealing/Reanalysis in progress | 1999 | T |
| T | + | 160 | 160 | Drains/Dampers | Reanalysis of Dose Calc | 1999 | T |
| U | + | 8 | 8 | Ducting | Reanalysis of Dose Calc | 1999 | T |
| V | + | 440 | 81 | Penetrations/Walls | Reanalysis of Dose Calc | 1998 | T |
| W | + | 4056 | 162 | Ducting/Walls | | 1998 | T |
| X | + | 3181 | 1256 | Ducting /Walls | | 1998 | T |
| Y | + | 236 | 236 | Doors/Walls | Reanalysis in progress | 1998 | T |
| Z | Neutral | 349 | 160 | Ducting/Dampers | | 1998 | T |
| AA | Neutral | 4300 | 2600 | Ducting/Walls | | 1997 | T |
| AB | Neutral | 1135 | 460 | Ducting/Walls | | 1997 | T |
| AC | + | 372 | 222 | Ducting | | 1997 | T |
| AD | + | <10 | <10 | Ducting | | 1995 | C[8] |
| AE | + | 2300 | 2300 | Ducting | | 1992 | A |
| AF | + | 300 | 300 | Ducting/walls | | 1992 | C[9] |
| AG | + | 51 | 51 | Ducting | | 1980 | C[10] |

[4] Multiple testing occurred at some plants. The reported results are those tests that are the maximum results measured (for conservatism). Additionally some repeated tests within two years and this test is shown as a separate entry. Individual plant identification is not made as much of the above data has not been published. This allows publication of data without compromising the anonymity of the plant. References 20, 27, 26, 25, 24, 16, 14, 13, and 10 along with correspondence from individual plants was used to develop the table.

[5] For positive pressure control rooms the design pressures vary from slightly positive (no value) to ¼ inch W.G. positive pressure. Actual measured pressures vary from slightly positive (no measurement of slightly positive) to 1 inch W.G.

[6] Where Initial test was only test performed; the initial and final test measurements are the same.

[7] A - alternate; T - Tracer gas; C - Component; PFT - using different tracer. For plants with TC in this column performed a concurrent component test and tracer gas test.

[8] Did not use NEI 99-03 as a guide as test was performed prior to issuance of NEI 99-03.

[9] Did not use NEI 99-03 as a guide as test was performed prior to issuance of NEI 99-03. However, it did use tracer gas techniques to measure the component inleakge. Previously this test was identified incorrectly as an integrated TGT. See reference 10.

[10] Did not use NEI 99-03 as a guide as test was performed prior to issuance of NEI 99-03.

## Typical Recirculation Control Room HVAC System

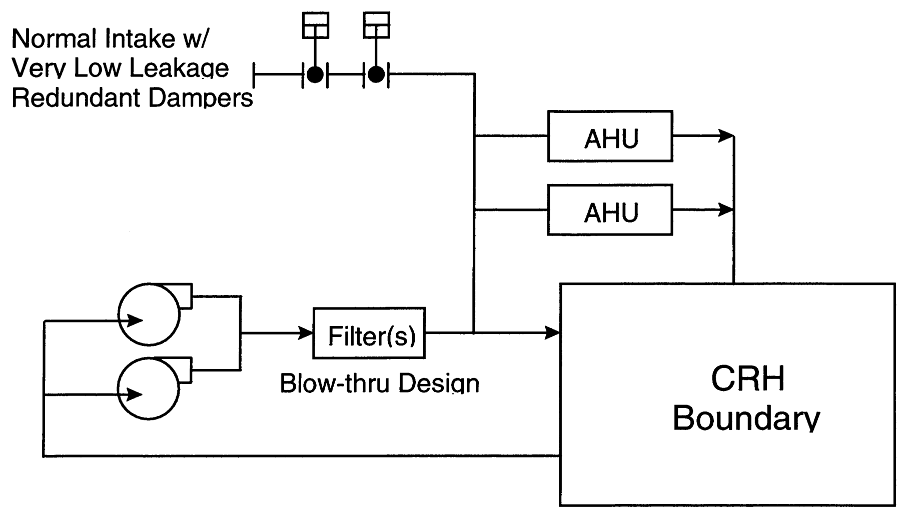


Figure 2

## Typical Pressurized & Recirculation Control Room HVAC System

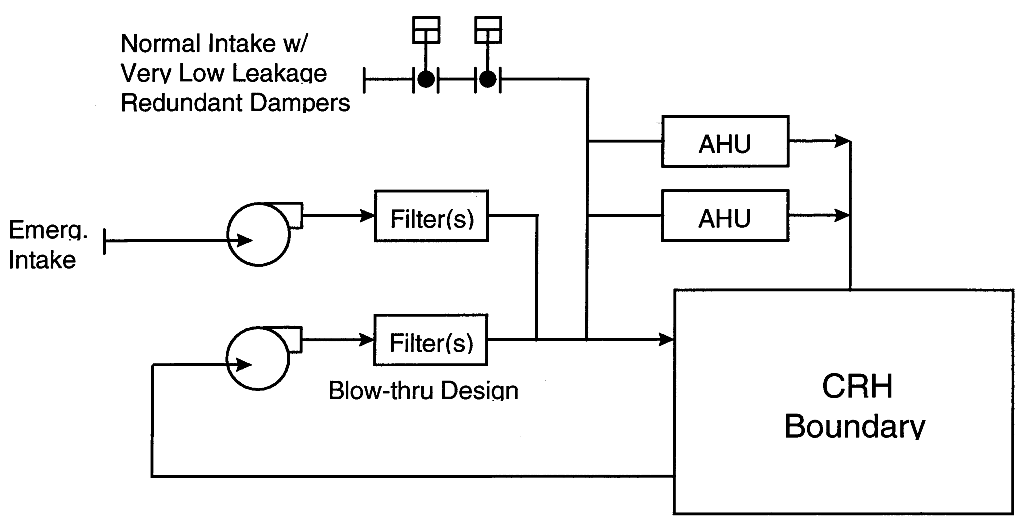


Figure 1

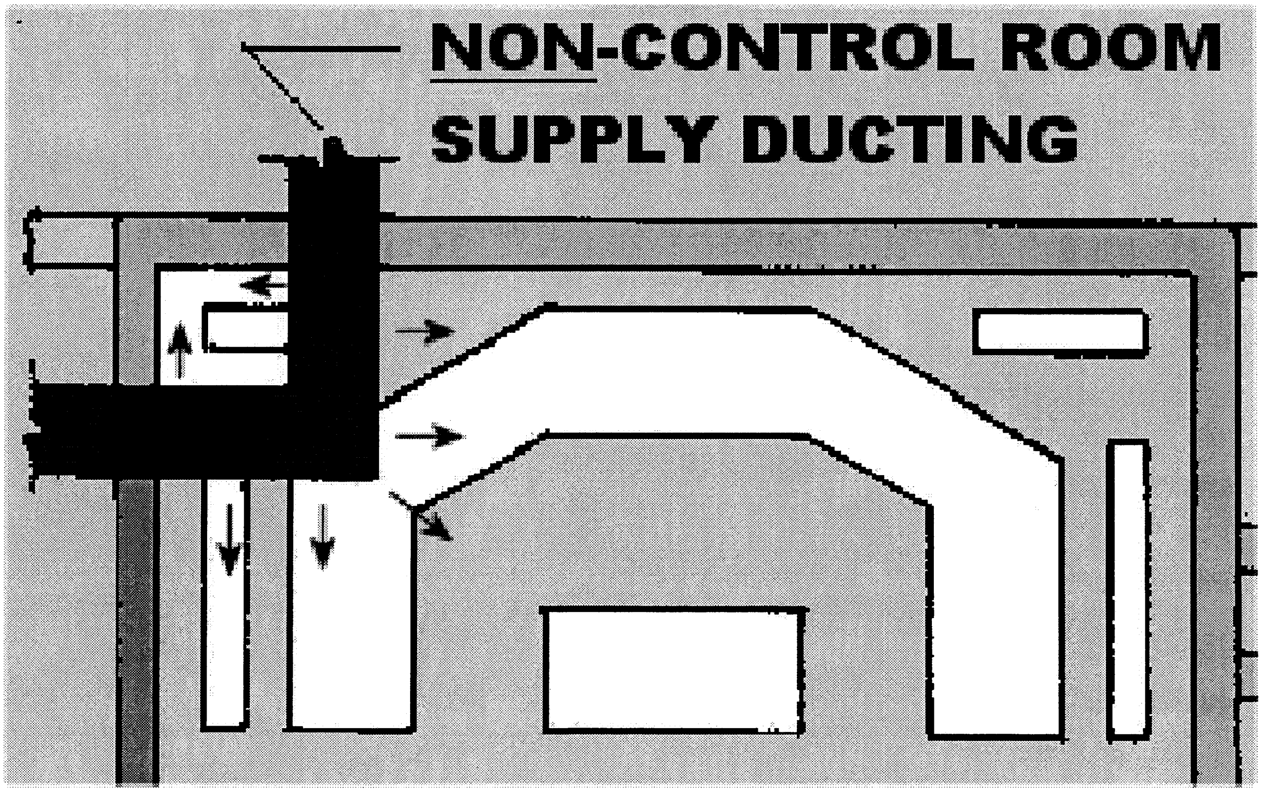


Figure 5 - Duct Leaking Into CRE

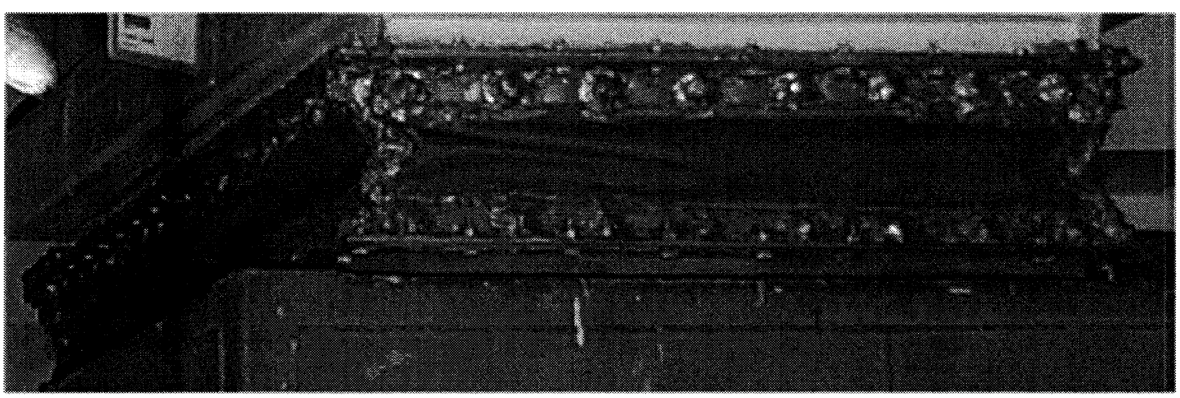

Figure 4 - Example of Potential Leak Point (flexible connection)

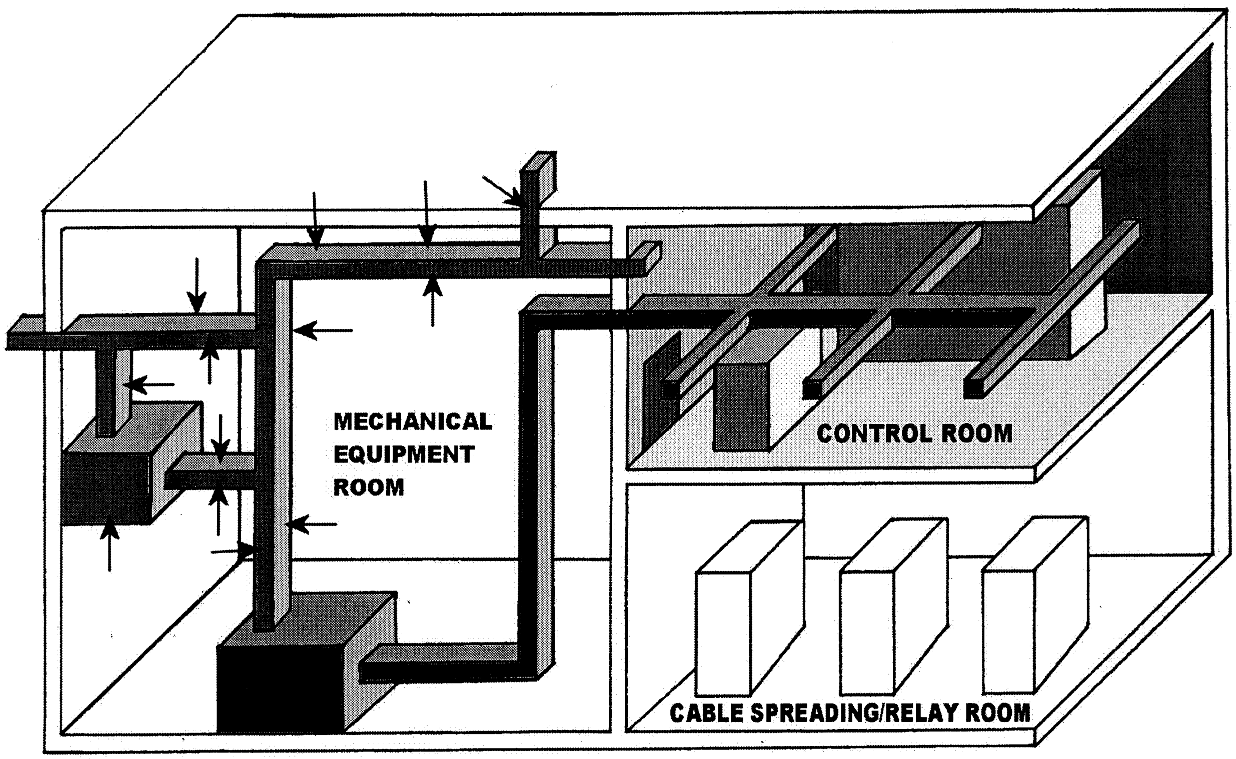


Figure 6 - Example of Leak Points Outside CRE

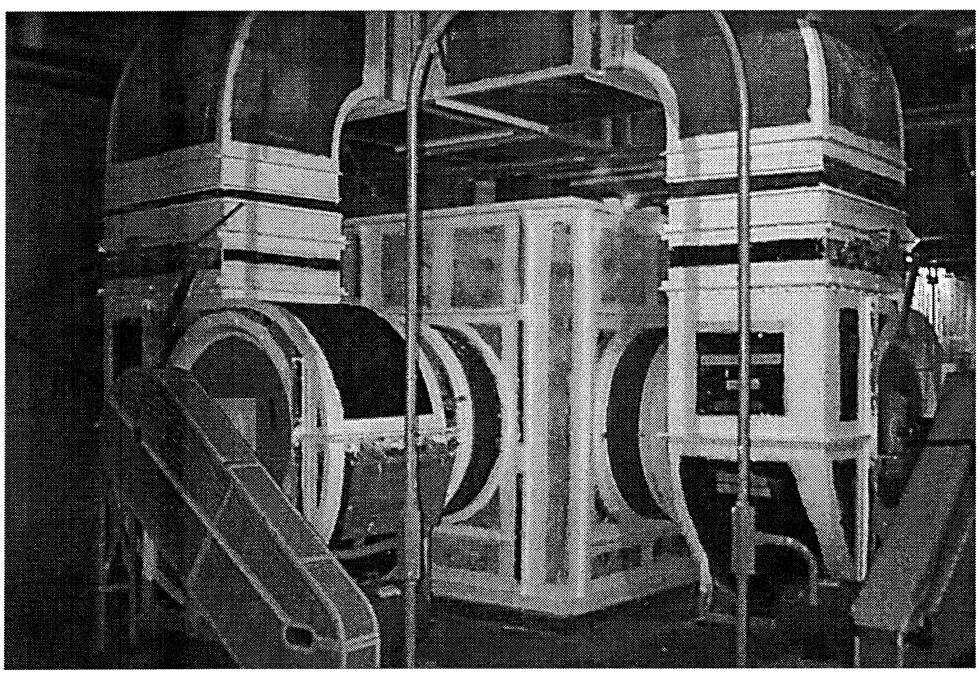

Figure 3 - Example of Sealing Ducts and Fans