SESSION 14

VENTILATION SYSTEMS

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DEVELOPMENT OF A COMPUTER DESIGN SYSTEM FOR HVAC

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Abstract

The development of a computer design system for HVAC (Heating, Ventilating and Air Conditioning) system is presented in this paper. It supports the air conditioning design for a nuclear power plant and a reprocessing plant. This system integrates various computer design systems which were developed separately for the various design phases of HVAC. The purposes include centralizing the HVAC data, optimizing design, and reducing the designing time. The centralized HVAC data are managed by a DBMS (Data Base Management System). The DBMS separates the computer design system into a calculation module and the data. So, the design system can be expanded easily in the future.

I. Introduction

In the last 10 years computers have been applied intensively in the design, engineering, manufacturing and construction of nuclear power plants and they have contributed greatly to the increased productivity of the Mitsubishi Nuclear Group in its nuclear power plant work. In most cases, these systems have been developed separately and utilized independently. Recently, the requirements for nuclear power plants have become more strict with regard to safety, reliability and economy. So, we have started to integrate various systems and to upgrade them.

In this paper, we have described the integrated computer design system for HVAC, which is one part of these systems. The HVAC system for a general nuclear power plant consists of more than 20 systems. So, the cost of the design, engineering, and manufacturing is high and it is related to many of the plant systems. And its design has been modified many times with the progress made during the engineering step, because the HVAC system is dependent on the designing of the other systems. Especially, concerning a reprocessing plant in Japan, which we are constructing, the scale is greater than that of the former LWR (Light Water Reactor) and the initial cost of the HVAC system accounts for a large part of the plant cost. So we must maintain the economy of the system scale in order to reduce the cost. Therefore, we started development to integrate various computer systems for the HVAC system. The purposes include centralizing the HVAC data, optimizing design with improving engineering precision, estimating the amount of materials early, and reducing the design period by creating various tables and drawings automatically. In other words, we started the development of computer systems which support systematic design and engineering, precise and rapid work management.

II. System Configutation

The concept for the integrated system is represented in Figure 2.1. This system covers all aspects of the HVAC system from basic design through field construction. And it has a centralized data base as its core, as well as various subsystems, almost all of which have been developed separately and have been upgraded to be able to use the data base. The subsystems are as follows:

1. The application programs for design tools

   They have been upgraded to use the data base and have been used for some kind of calculations defining the HVAC system specifications.

2. The dialog interface program

   It is for retrieving, deleting, and updating the centralized data.

3. The three dimensional modeling system

   It is for layout design of equipment, ducts, cable trays, concrete, and components.

The hardware for this system is a large host computer. It dose not include the three dimensional modeling system, for which the hardware is an engineering workstation for high-speed graphics processing.

System Features

Features of this system are as follows.

1. Covering all aspects from basic design through detailed design

   This system supports each phase of design, for example, calculating air flow rate, calculating specifications for equipment, estimating material accounts, making specification sheets for order, and estimating ability of trial operation, and so forth.

2. Centralized data base includes almost all data for design

   Centralized data base system manages almost all the data for each design phase. Therefore, problems which occur when the data is shifted from a basic design to a detailed one, could be reduced.

3. Isolating programs and data

   Design tool programs are divided into modules by function, and physical data is isolated from the design tool programs by the DBMS. Therefore we can easily revise and expand the system.

4. Using the three dimension model

   We used a three dimensional solid model for design, so we can easily design the layout.

System Flow

Figure 2.2 shows the flow of the system design. We designed the system in the following order.

1. Basic Design Phase

   (a) The HVAC system configuration is entered into the data base, based on the equipment layout.

   (b) The room specifications are calculated from the data that was entered using the air flow rate calculation program.

(c) The routes for the ducts are set based on the HVAC system configuration, and the layouts of the ducts and equipment are adjusted with the three dimensional plant model. Then the result is translated and put into the data base by the interface program.

(d) Pressure drops in every system are calculated from the duct routes. And the room specifications for the fans and air conditioning units are set by the equipment specifications calculation program.

2. Manufacturing and Construction Phase

   - The amount of material is estimated by the duct material accounting program.
   - The specification sheets for the requisitions are made by the specification sheet making program.
   - The system diagrams are made by the system diagram drawing program using the duct route data.

3. Trial Operation Phase

   - We adjust the damper opening rate with the damper opening rate adjustment program.

In the later chapters, we will describe the subsystems in detail.

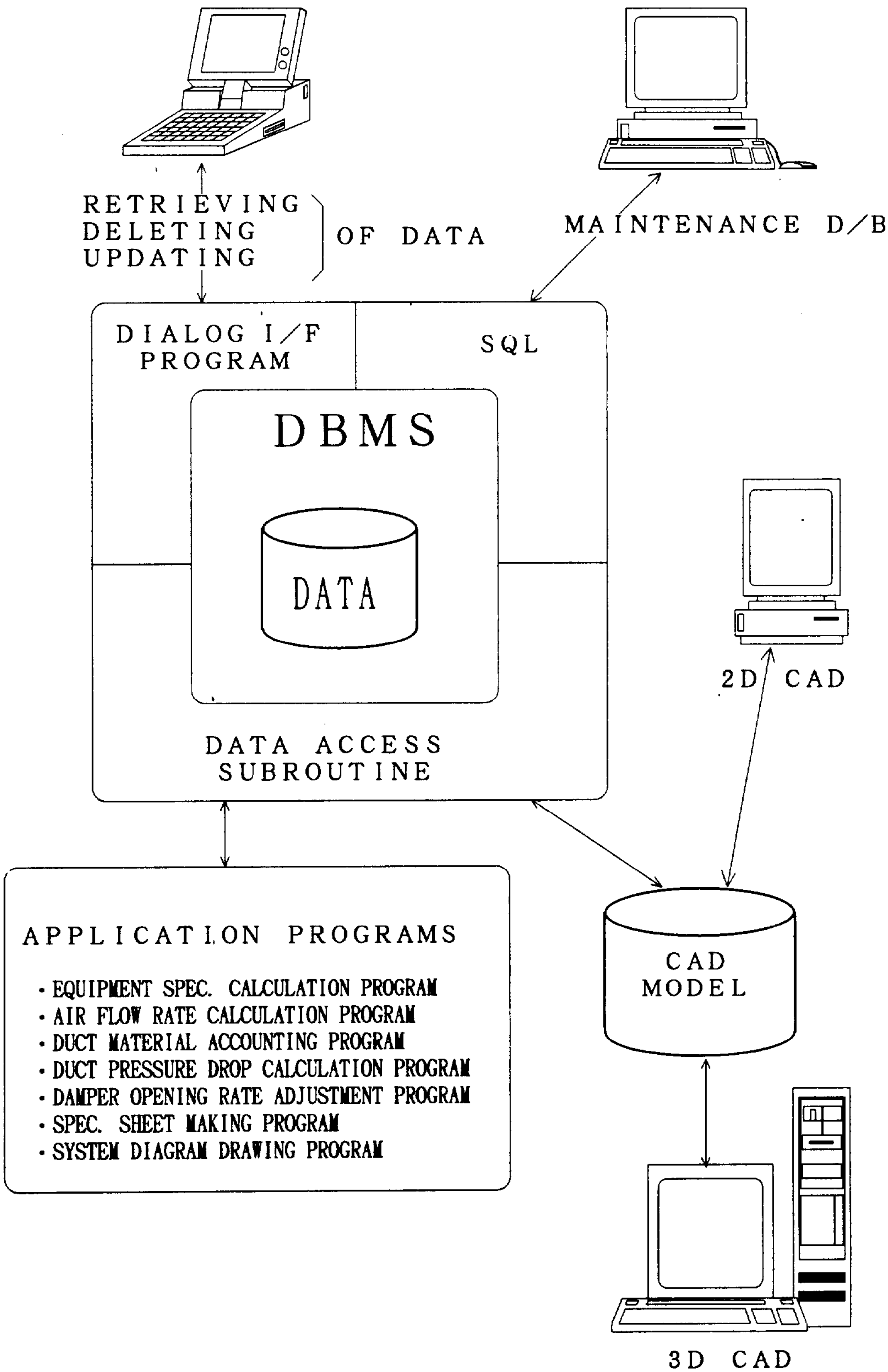

Figure 2.1 System Concept

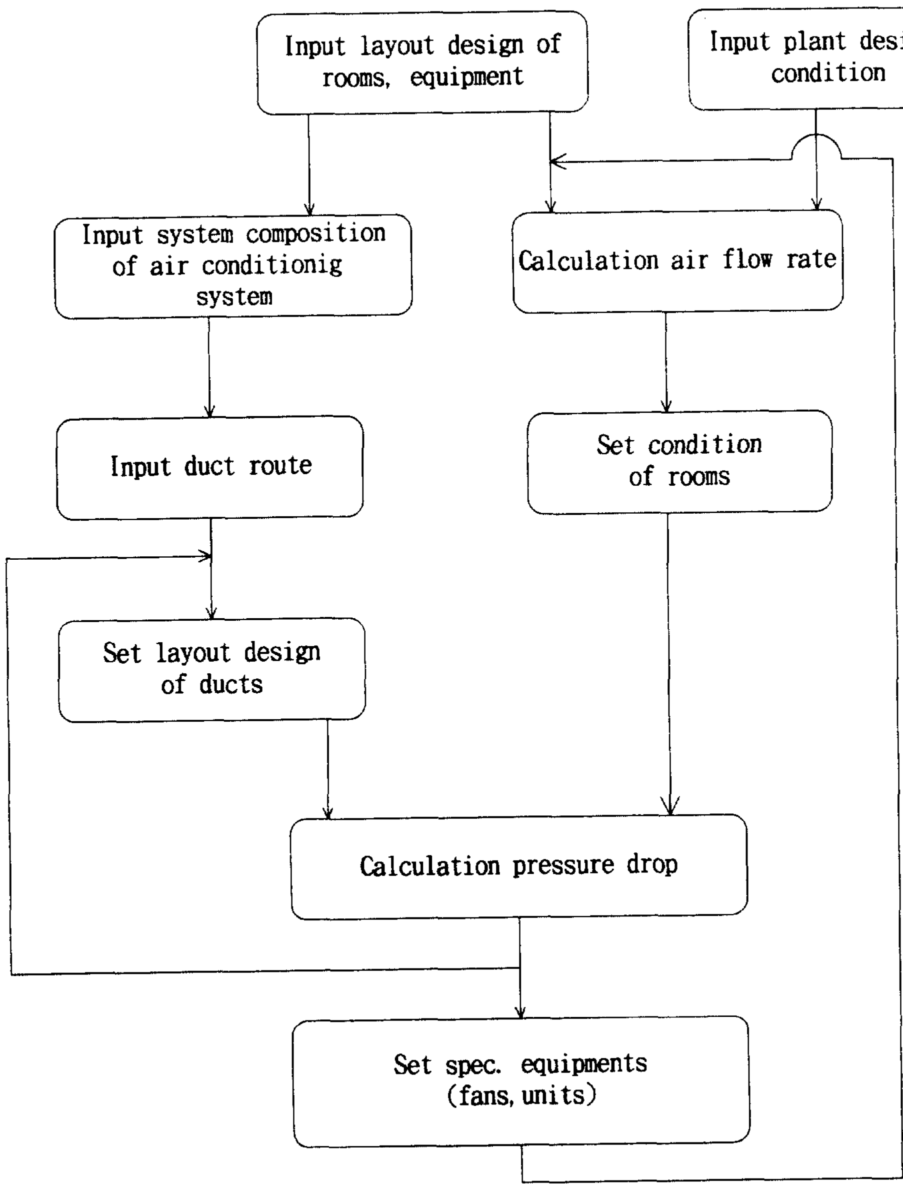

Figure 2.2 Design flow chart

III. Data Base System

The HVAC data are centralized by the data base system. This system consists of a relational data base. Because a relational data base can be expanded easily, we will add operation records data and repair records data to the data base in the future.

Data Base Tables

This system contains the following tables:

1. Design condition data

   It includes the basic plant conditions, for example, temperature, and humidity of the intake air at the site.

2. System data

   It includes common design conditions for each system, for example, system composition and the method of air conditioning.

3. Room condition data

   It includes the area, the volume, the temperature setting, the radiating account, the air flow rate, and so forth under various conditions. (For example, during operation or the plant maintenance)

4. Equipment specification data (for fans)

   It includes the static pressure, the air flow rate, the temperature, the setting location, and so forth of the fans.

5. Equipment specification data (for air conditioning units)

   It includes the flow rate, the specifications for the filters, the volume of heating or cooling, and so forth of the air conditioning units.

6. Equipment specification data (for motor units)

   It includes the power, the voltage, the frequency, and so forth of the motor units.

7. Duct line specification data

   It includes the routes and the specifications for the ducts.

Data Base Interface

The DBMS manages these data and acts as a connection between the data and the subsystems, so the subsystems are independent of the physical construction of the data. Therefore, we can easily expand the system.

The methods for accessing the data base are as follows:

1. Data access subroutines

   The subroutines connect the application programs and the interface program with the three dimensional model.

2. Dialog interface program

   The dialog interface program is used for retrieving, deleting, and updating the data by the computer terminals, so it is easy to control the data base.

3. SQL

   SQL is used for informal access and basic maintenance of the data base.

The data reliability has been kept high, because we restrict the access methods to the data base-which include the previously mentioned methods only. So, the data cannot be destroyed easily if an application program contains bugs. So many people can develop some types of application programs to be used for design tools, which carry out some kind of calculations defining the HVAC specifications.

IV. Application Program

The application programs, in Figure 2.1, act as the design tools, which are used for some kind of calculation using the data base and the results are registered in the data base. We developed seven types of application programs which are as follows.

1. Equipment specification calculation program: It is for calculation of specifications for a piece of equipment (fan, cooling coil, etc.).
2. Air flow rate calculation program: It is for calculation of the air flow rate in each room.
3. Duct material account program: It is for estimating the duct material account for every kind of duct and making the estimation lists.
4. Duct pressure drop calculation program: It is for calculation of a drop in duct pressure between a piece of equipment and the end of a duct.
5. Damper opening rate adjustment program: It is for calculation of the damper opening rate which adjusts the pressure drop balance in various duct routes.
6. Specification sheet making program: It is for making specification sheets from the data base.
7. System diagram drawing program: It is for drawing various system diagrams automatically, which show the system composition plainly as well as various system engineering specifications.

Each program is described in detail in the following section.

(1) Equipment Specification Calculation Program

It is for calculation of various equipment specifications. The kinds of equipment which are supported by this program are described bellow.

1. Filter

   The air flow rate and the number of filter elements are estimated. The subject rooms are derived from the duct specification data base, and the air flow rate is estimated by adding the air flow rates in the rooms.

2. Fan

   The axis power of the motor is estimated from the pressure drop, which itself is estimated by the duct pressure drop calculation program, along with the designed flow rate, which is estimated in the same way as the filter.

3. Cooling coil

   The air flow rate, the cooling load, and the amount of cooling water for the cooling coil are estimated. The cooling load is estimated from the difference in the enthalpy of both sides of the coil. The enthalpy of the exit point of the coil is assumed to be constant. And the entrance enthalpy is estimated from the intake air and the returned air conditions. The amount of cooling water is estimated on the condition that the efficiency of the coil is assumed to be constant.

4. Heating coil

   The air flow rate, the heating load, and the amount of heating water(steam) are estimated in the same way as the cooling coil.

5. Humidifier

   The air flow rate and the amount of steam needed for humidifying are estimated.

The temperature of the exit point for every piece of equipment is estimated from its specification and the air temperature of the entrance point. The condition data which are used for calculation are registered in the data base and the results of the calculations are registered in the equipment data base.

(2) Air Flow Rate Calculation Program

The planning of the air flow rate for each room is completed by this program. It selects the higher air flow rate needed for cooling and ventilation. The input parameters for this program are geometric conditions, temperature, humidity, heat radiation, supplied air temperature, and the number of ventilations. The parameters are registered in the data base and the results of this program are registered in the data base.

(3) Duct Material Account Program

This program estimates the material account (the number of parts, weights, and so on) of the duct system for each duct accessory. The results are used for cost accounting.

(4) Duct Pressure Drop Calculation Program

This program estimates the duct pressure drop between a fan and an exhaust or an intake. It contains many kinds of pressure drop coefficients in table form, so the calculation result is precise. Therefore, we can check duct size carefully and optimize it.

(5) Damper Opening Rate Adjustment Program

This program estimates the damper opening rate which adjusts the pressure drop balance in the various duct routes. Resistance is needed to adjust the pressure drop imbalance and the planning air flow rate. Therefore we have to adjust the damper opening rate to create this resistance. At first, we estimate the pressure drop imbalance. And then the damper opening rate is calculated from the air flow rate and the imbalance.

(6) Specification Sheet Making Program

This program makes specification sheets using the data base. It supports the editing function, which is used for adding and replacing the sheet data. Sheets can be output for all the equipment.

(7) System Diagram Drawing Program

This program draws system diagrams automatically, which show the system engineering specifications clearly. The kinds of system drawings are listed bellow.

1. Earthquake-proof area system diagram
2. Highest temperature and pressure area system diagram
3. Duct specifications area system diagram
4. Thermal insulation setting area system diagram

V. Three Dimensional Model

The three dimensional model consists of the concrete building data, the components data, the piping data, the cable tray data, and the duct data. We use this model for the layout design. This is one of the most important points for the HVAC design. And the results are put in the data base by the interface program and are used for the duct material accounting, making specification sheets, and drawing system diagrams. Also, we are now trying to translate the data into a two dimensional graphic design system from the model for making various drawings.

The hardware for this modeling system is an engineering workstation for high-speed graphics processing. The engineering workstation is connected with the large host computer, which acts as the hardware for the data base system, by the ethernet LAN (Local Area Network).

VI. Conclusion

The features of an efficient HVAC design system using the centralized data base was presented. By applying a part of this system to the FBR(Fast Breeder Reactor), 'MONJU', the cost of design and of functional testing at the site have been reduced by about 30 percent. Now, it has been applied to a reprocessing plant. Also the DBMS separates the program into the calculation module and the data, so the design system can be expanded easily. In the future, not only an engineering design data base, but also a system operation records data base, and a repair records data base will be constructed. Following these, this system will be upgraded to an optimizing design system and an efficient repair system by referring to these data bases.

DISCUSSION

MIYAZAKI: First, what is the interface between your program for HVAC with the other disciplines? Secondly, what are the duct optimization objectives, what optimization method for duct sizing is used? Also are you using T-method duct design from the ASHRAE 1989 Handbook?

TSAL: In answer to your first question, a 3-D-engineering model (by CAD system). Second, for reducing the quantity of the duct material, reducing the duct size except the duct of the maximum pressure drop. Thirdly, no, we do not use that method.

CHIPULI S: I would like to know whether this HVAC design computer program for Nuclear Facilities is based on the ALARA criteria. I mean from low radiation areas to high radiation areas?

MIYAZAKI: The computer program does not have this system yet. At this moment, designers can check the above situation based on calculations.

BERGMAN: Have you confirmed the accuracy of the computer code with experimental measurements?

MIYAZAKI: Not yet. We are applying this system to a reprocessing plant that is under design now.

DESIGN AND CHARACTERISTICS OF ANNULUS VENTILATION AND HVAC SYSTEM FOR PROTOTYPE FBR MONJU

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Abstract

The MONJU annulus ventilation system keeps the annulus below a pressure of -15 mmAq as a secondary containment during reactor operation to assure -6 mmAq even in the case of accident. To minimize release of radioactive substances, the system adopts a charcoal filter with a thickness of 20 cm whose efficiency of iodine removal is over 99 %. Rooms for components containing radioactive sodium are maintained in a nitrogen atmosphere during ordinary operation by the inert gas cooling system, and form gastight cells for which atmospheric leakage is designed to achieve below 100 %vol/day at a pressure differential of 100mmAq. Design specifications of annulus ventilation and HVAC system are determined by experimental data and computer analyses for the accident. Function and performance of the annulus ventilation and HVAC system have been confirmed by pre-operational tests.

I . Introduction

MONJU is a 280MWe prototype fast breeder reactor, which was completed in its construction in April 1991, and pre-operational tests are now underway. The plant is a loop-type consisting of three primary and secondary sodium loops, and is equipped with a reactor containment vessel. A sectional view of main building is shown in Figure 1. The reactor and the primary sodium loops are located in the reactor containment vessel surrounded by the outer shield building. An annular part which exists between the reactor containment vessel and the outer shield building is held at a slightly negative pressure during reactor operation to prevent radioactive substances from dispersing. Areas where components containing radioactive sodium are installed are kept in a nitrogen atmosphere to suppress sodium combustion in the event of sodium spill. This paper describes design features and results of pre-operational tests for the annulus ventilation and HVAC system of MONJU.

II . Outline of HVAC Systems of MONJU

HVAC systems of MONJU are composed of twenty-two systems shown in Table 1, and are designed in accordance with the design criteria by the authorities and the following principles.

R/B : Reactor building
A/B : Reactor auxiliary building
T/B : Turbine building
D/B : Diesel building
M/B : Maintenance & waste disposal building

1 Turbine generator
2 Steam generator
3 Intermediate heat exchanger
4 Reactor vessel
5 Operating floor
6 Ex-vessel fuel strage tank
7 Ex-vessel fuel transfer machine
8 Maintenance area
9 Annulus

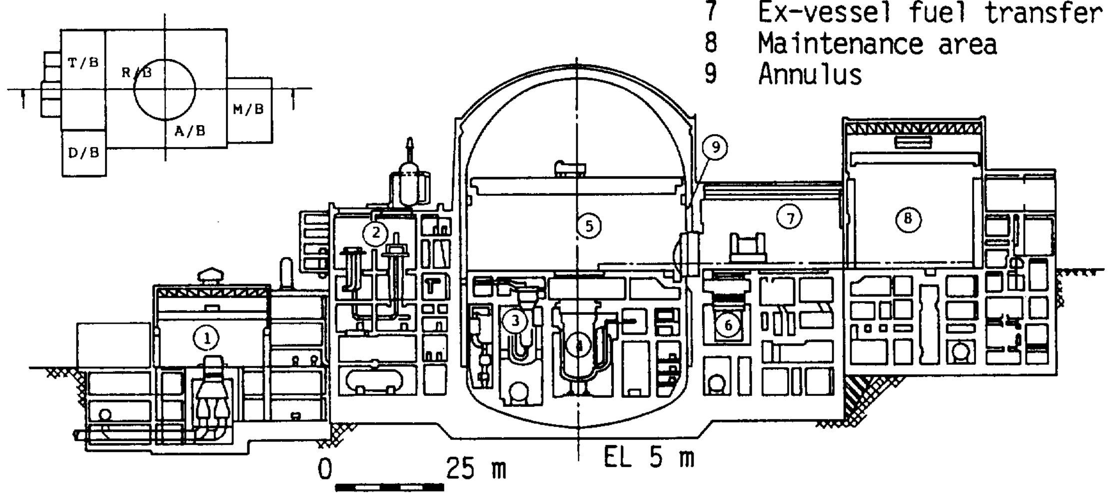


Figure 1 Sectional view of main building

(1) HVAC systems shall be classified into radiation controlled and non-controlled areas, and separated into several systems in each area by functional demands of facilities.
(2) Fresh air flow shall be from clean areas to radioactive contaminated areas, and exhaust air shall be filtrated by HEPA or charcoal filters.
(3) Ventilating capability shall be enough to remove the heat evolved from components or to supply the fresh air required by design guidelines.
(4) Gastight cells shall be constructed for rooms where components containing radioactive sodium are installed, and kept in a nitrogen atmosphere during ordinary operation. At maintenance, these cells shall be ventilated from nitrogen to air.
(5) In the event of accident, the annulus kept in a negative pressure shall gather radioactive substances leaked from the reactor containment vessel and lead them to a vent stack after filtration to minimize radiation doses of the neighbouring public.
(6) In the event of accident, an air handling system for main control room shall isolate the room from the outer field and select a recirculation mode through the charcoal filter to protect operators from internal radiation doses.
(7) HVAC systems shall equip ducts with fire dampers to prevent a fire from spreading, if necessary.

MONJU employs sodium as coolant and the sodium spill is a design basis accident, therefore (4) and (5) are key features of HVAC systems of MONJU.

Table 1 HVAC Systems of MONJU

Classsification	Building	Division of HVAC System	Temp.[℃]	Remark
Radiation Controlled Areas	R/B	Annulus Ventilation System	—	A1
		C/V Ventilation System	—	
		C/V Air Recirculation System	10 ~ 40	
		Reactor Cavity Inert Gas Cooling System	≦ 55	S1
		PHTS Cells Inert Gas Cooling System (pl.)	≦ 55	S1
	A/B	Fuel Handling Facility Room Inert Gas Cooling System	≦ 55	S1
		Fuel Handling Facility Area Ventilation System	10 ~ 40	
		Fuel Transfer Machine Passageway Air Cleaning System	—	A1
		Controlled Access Area Air Handling System	21 ± 5	
	M/B	M/B Ventilation System	10 ~ 40	
Non-controlled Areas	A/B	Main Control Room Air Handling System	21 ± 5	A2
		A/B Ventilation System	5 ~ 40	
		Steam Generator Area Ventilation System (pl.)	≦ 55	S2
		Secondary Maintenance System Room Ventilation System	≦ 55	S2
		Electric Equipment Room Air Handling System I	5 ~ 40	
		Electric Equipment Room Air Handling System II	5 ~ 40	
		Electric Equipment Room Air Handling System III	5 ~ 40	
		EVST Cooling System Area Ventilation System (pl.)	≦ 55	S2
	T/B	T/B Ventilation System	5 ~ 40	
	D/B	D/B Electric Equipment Room Ventilation System	5 ~ 40	
		Diesel Generator Room Ventilation System	5 ~ 45	
		D/B Ventilation System	5 ~ 40	

R/B:Reactor Building, A/B:Reactor Auxiliary Building, M/B:Maintenance & Waste Disposal Building,
T/B:Turbine Building, D/B:Diesel Building, PHTS:Primary Heat Transfer System,
EVST:Ex-vessel Fuel Storage Tank, pl.:Three systems exsist for ABC loops,
S1:HVAC for radioactive sodium area, S2:HVAC for non-radioactive sodium area,
A1:HVAC for minimizing radioactive mateials in accident,
A2:HVAC for protecting operaters from radiation doses

III. Annulus Ventilation System

A. Design Features

The annulus ventilation system is provided to maintain a slightly negative pressure in the annulus by modulating exhaust and recirculation air, and to remove radioactive materials leaking from the reactor containment vessel(C/V) to reduce radiation doses to the general public in the case of accident. This system includes two fans of 100 percent capacity and two filter units connected by ducts to each fan. Exhaust is all filtrated by a medium and a HEPA or a charcoal filters, and returned to the annulus with partial discharge through the vent stack. A flow diagram of the system is shown in Figure 2. During normal plant operation, the exhaust from the annulus is led to a HEPA filter unit and through a bypass line of a charcoal filter unit and partially discharged to keep the negative pressure in the annulus. In the event of sodium spill accident, the flow line is changed to the charcoal filter line and the radioactive substances leaking from the C/V are gathered in the the annulus and captured by the HEPA and charcoal filters.

The annulus ventilation system is one of the engineering safety systems for the plant and has the following characteristics.

(1) Redundancy and independency

Single failure of active components is considered in the system design. Then, two independent and individual lines are provided for redundancy and independency. During normal plant operation, one line is working while the other remains in standby. In the case of accident, the C/V isolation signal would make two lines work automatically, and operators would confirm the operating condition, then stop one of the lines.

(2) Consideration of loss of off-site power supply

Electric power is connected to the emergency power supply, considering loss of off-site power. Each electric line of the systems is connected to a different unit of the emergency diesel generator.

(3) Keeping of negative pressure in the annulus

The negative pressure of -6 mmAq[1] should be kept in normal operation and accident as a secondary reactor containment system. A credit value of the negative pressure in the annulus is determined less than -15 mmAq, since pressure rising would be occurred by temperature elevation of 15℃/h in the event of sodium spill accident and by a time lag below ten seconds in the case of diesel generator starting.

(4) Cleaning of radioactive substances

Radioactive substances are removed as much as possible to decrease the potential of public exposure risk. The HEPA filer is designed to the U.S. regulatory guide, and its efficiency is more than 99 % for removal of 0.7μm particles. The charcoal filter employs a bed type with a thickness of 20 cm considering a span of life time and filtrating efficiency. The efficiency is more than 99 % of iodine absorption, which is rather high compared with LWR plants.

(5) Consideration of sodium aerosol

The charcoal filter is protected against sodium aerosol which would be produced at the sodium spill accident. The HEPA filter unit is arranged in upstream of the charcoal filter unit. The HEPA

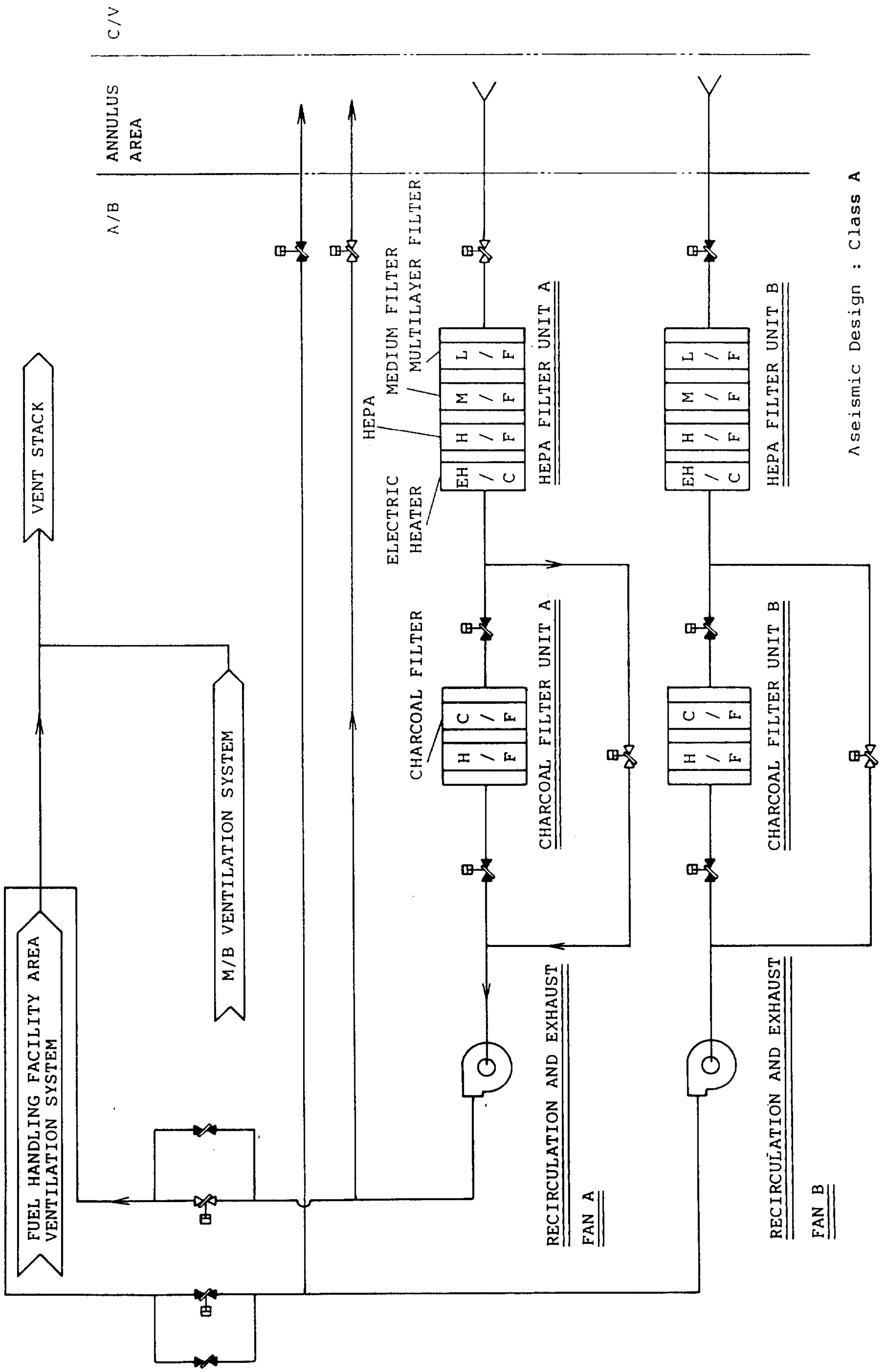


Figure 2 Flow diagram of the annulus ventilation system

filter unit is composed of a multilayer filter(L/F), a medium-efficiency filter(M/F) and a HEPA filter. The L/F is for sodium aerosol and consists of five layers which have a lot of openings to avoid blocking by absorbing the sodium aerosol.

B. Analysis and Experimental Data for Design

1. Analysis for Flow Rate

In order to determine flow rates of the annulus ventilation system, several cases were analyzed by using the parameters of C/V leakage rates, decrease of sodium aerosol caused by plate-out phenomenon, recirculating flow rates and release passes of radioactive materials. The exhaust flow rate through the vent stack is 20 m^3/min to keep the negative pressure in the annulus. The limit of radiation doses to the general public is set a twenty-fifth times as small as the LWR's criteria. Since this plant is the first prototype FBR plant in Japan, more conservative value was selected. Figure 3 shows one of analytical

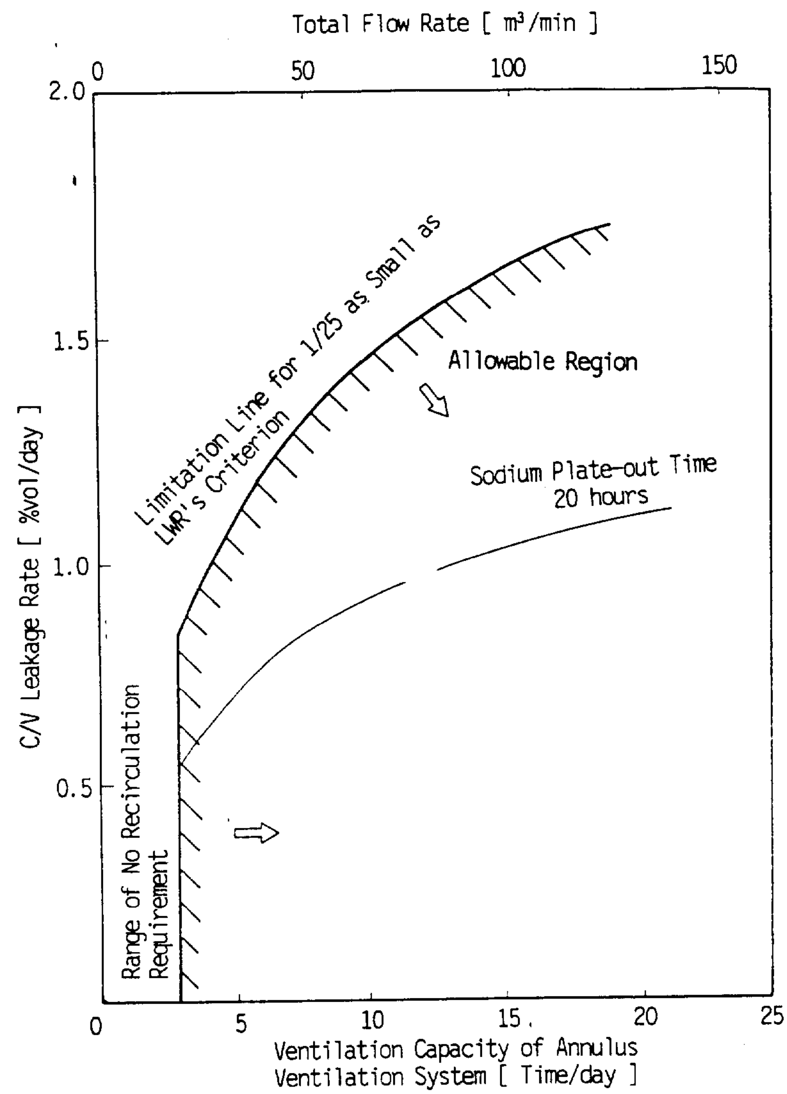


Figure 3 Ventilation capacity required for the annulus ventilation system by safety analysis

results. A thick line represents the criterion for ventilation capacity, while a thin line represents more conservative estimation fixing the sodium plate-out time in 20 hours. The C/V design leakage rate is 1 %vol/day in MONJU. If the total flow rate is over 100 m^3/min under the exhaust flow rate of 20 m^3/min, the amount of radioactive materials is significantly decreased. Based on this result, the rates of recirculating and total flow were determined as 100m^3/min and 120 m^3/min respectively.

2. Filtration of Sodium Aerosol

There is a possibility that the sodium aerosol would occur and leak into the annulus in the event of sodium spill accident. The multilayer type air filter was developed in order to protect the function of HEPA filter from clogging[2]. The sodium aerosol would be filtrated by the multilayer filter, the medium-efficiency filter and the HEPA filter in series. Table 2 shows the specification of multilayer filter and Figure 4 shows the data for the relation between amount of sodium collection and pressure drop. The number of layers for the filter is determined based on the calculation of an amount of sodium aerosol occurrence and an allowable pressure drop of the system.

Table 2 Specifications of multilayer filter

Items	Specifications
Material	High-Silicate Glassfiber Mat
Thickness	6 mm
Diameter of hole	20 mm
Opening percentage of holes	20.4 %
Number of layers	5

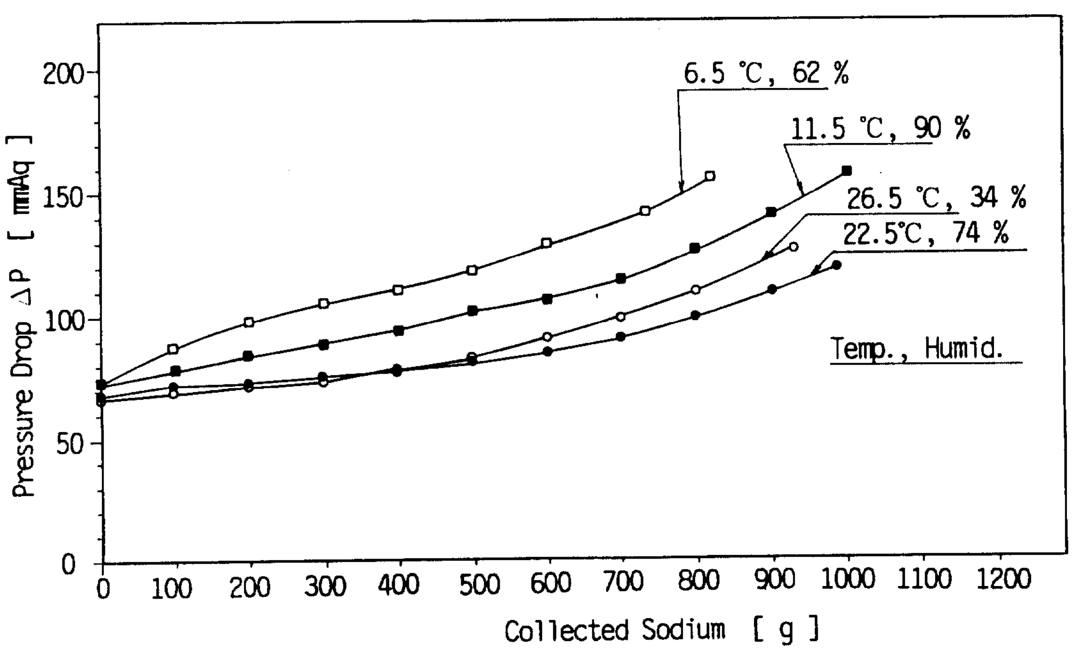


Figure 4 Changes of pressure drop during loading of sodium aerosol [2]

3. Confirmation of Charcoal Filter Efficiency

Efficiency of the charcoal filter was confirmed by a laboratory test before filling up the units. The test was carried out by using ten small cartridges — 5 cm in diameter and 1 cm in thickness — , and pre-heating was treated for twelve hours to obtain the uniform temperature and humidity. Figure 5 shows a result of iodine absorption test that the filter of 6 centimeters is thick enough to obtain the required filtrating efficiency, though the thickness of filter bed is 20 cm.

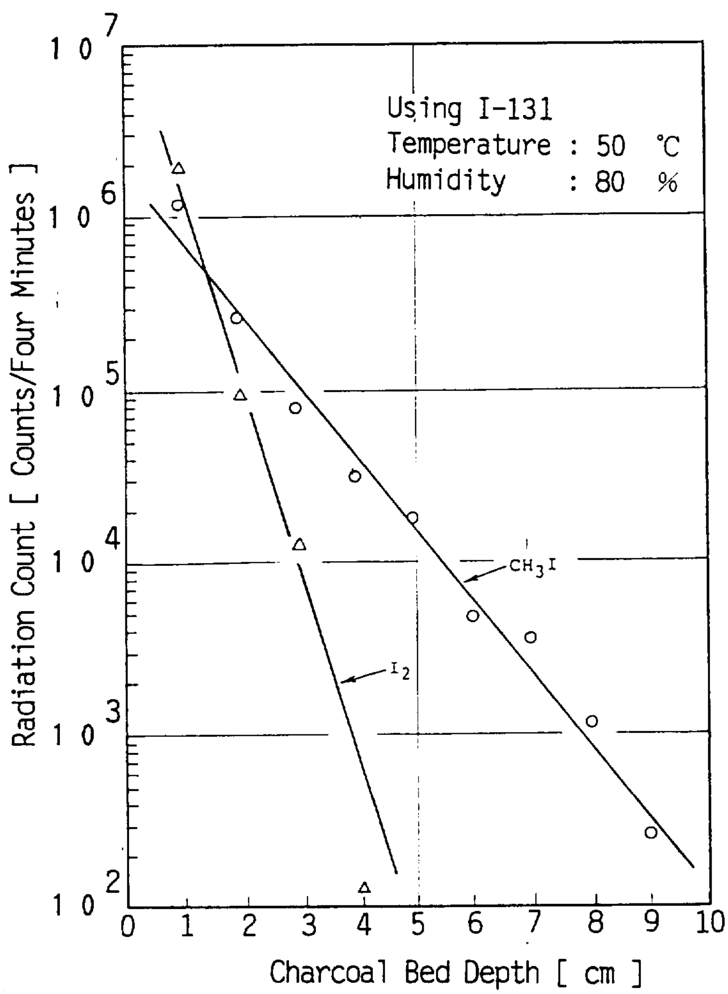


Figure 5 Efficiency of charcoal filter

4. Safety Analysis

The accident analyses for design basis accidents and hypothetical accidents were conducted to verify that the public radiation dose would be under a certain level. The analyses were performed by using the appropriate values which gave some margins to the size of crack opening of pipings, contents of iodine in the reactor vessel, transfer quantity of iodine to the reactor containment vessel, decline of aerosol caused by plate-out and others according to circumstances. For the annulus ventilation system, the analysis assumed 99 % or 95 % of the charcoal filter efficiency, 0.83 of the recirculation ratio, 120 m^3/min of the total flow rate and 1.0 %vol/day of the C/V leakage rate. The analytical results showed that radiation doses to the general public would be sufficiently low compared with the criteria.

C. Results of Pre-operational Tests

The function test of fans, the interlocking and alarm tests, the air flow rate test, the negative pressure test and the filter efficiency test were carried out to confirm the performance of the system. The filter efficiency test was conducted for the HEPA filter unit and the charcoal filter unit at the plant site in addition to the factory tests. The results of both filter units were quite satisfied with the requirements as shown in table 3.

Table 3 Results of filter efficiency tests

	Factory Test		Plant site Test	
	Requirement	Result	Requirement	Result
HEPA	≧ 99 % *1	99.99 %	≧ 99 % *2	99.99 %
Charcoal	≧ 99 %	99.99 %	≧ 99 %	99.99 %

*1 : 0.3 μm particles , *2 : 0.7 μm particles

There are a lot of penetration through the annulus. The penetration of the reactor containment vessel(C/V) is strictly controlled by the C/V leakage test, while penetration of the outer shield building is loosely gastight. Leakage from the penetration of the outer shield wall was checked at a slightly negative pressure from inside and outside of the annulus before the negative pressure test. The negative pressure reached -70 mmAq at the exhaust flow rate of 15 m^3/min.

The flow rates of recirculating and total flows are maintained with the values used in the safety analysis in any conditions except for the plant maintenance. At this point, it is necessary to consider that back-pressure from the vent stack affects the exhaust flow rate of the annulus ventilation system, since the exhaust line is connected to the vent stack with the other systems. The influence of other systems against the exhaust flow rate was measured at the air flow rate test by various operational conditions. The flow rates of the annulus ventilation system were adjusted by controlling damper openings to

Table 4 Pressure and exhaust flow rate of the system

Condition	Pressure	Exhaust flow
Design Value	≦ - 15 mmAq	≦ 20 m^3/min
With Other Systems Operation	Approximately - 21 mmAq	Approximately 8 m^3/min
Without Other Systems Operation	Approximately - 46 mmAq	Approximately 12 m^3/min

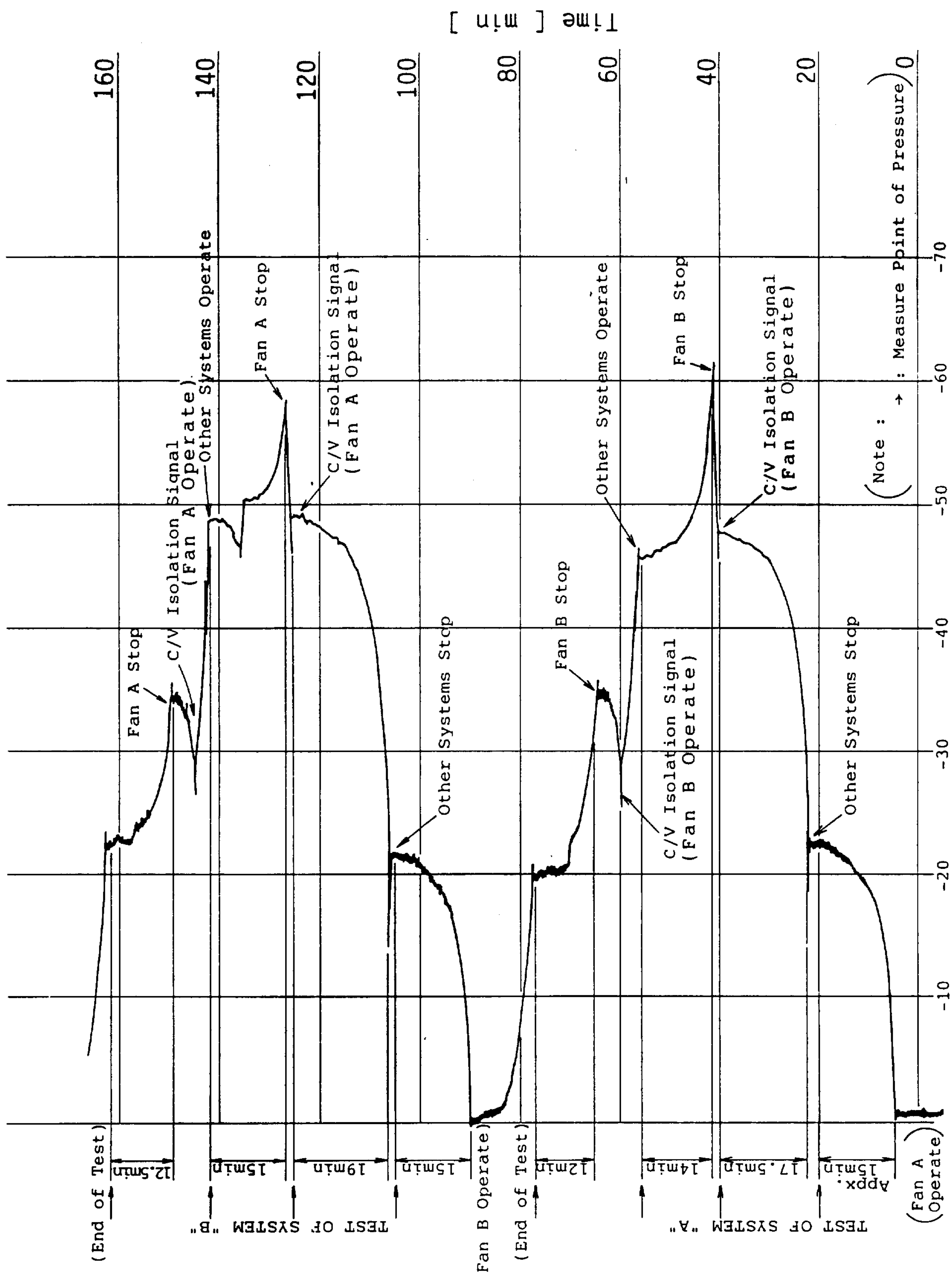


Figure 6 Recorder chart of the annulus negative pressure test

meet with the flow rates used in the safety analyses and the negative pressure required for the annulus, considering the back-pressure from the vent stack. Table 4 and Figure 6 show the fluctuation of pressure and exhaust flow rate affected by operational conditions.

IV. HVAC Systems for Primary Sodium Areas

A. Design Features

The sodium spill accident is considered in the design of the areas for components containing radioactive sodium such as the reactor vessel, the primary cooling loops and the ex-vessel fuel storage tank. HVAC systems for these areas have the following characteristics.

Rooms of these areas are lined with steel liners as shown in Figure 7 and form gastight cells. The atmospheric leakage rate of the cells is limited below 100 %vol/day in-leakage or out-leakage at a pressure differential of 100 mmAq. During ordinary operation, the cells are kept in a nitrogen atmosphere — oxygen concentration below 3 %vol — and are maintained at a slightly positive pressure to prevent air intrusion. At maintenance of the components, the cells are ventilated from nitrogen to air. In the event of sodium spill, the accident signal trips HVAC system, and then the liners and ducts of HVAC confine radioactive materials inside the cell boundary. HVAC systems, except the accident areas, can be re-started to cool the interior concrete and components, if necessary.

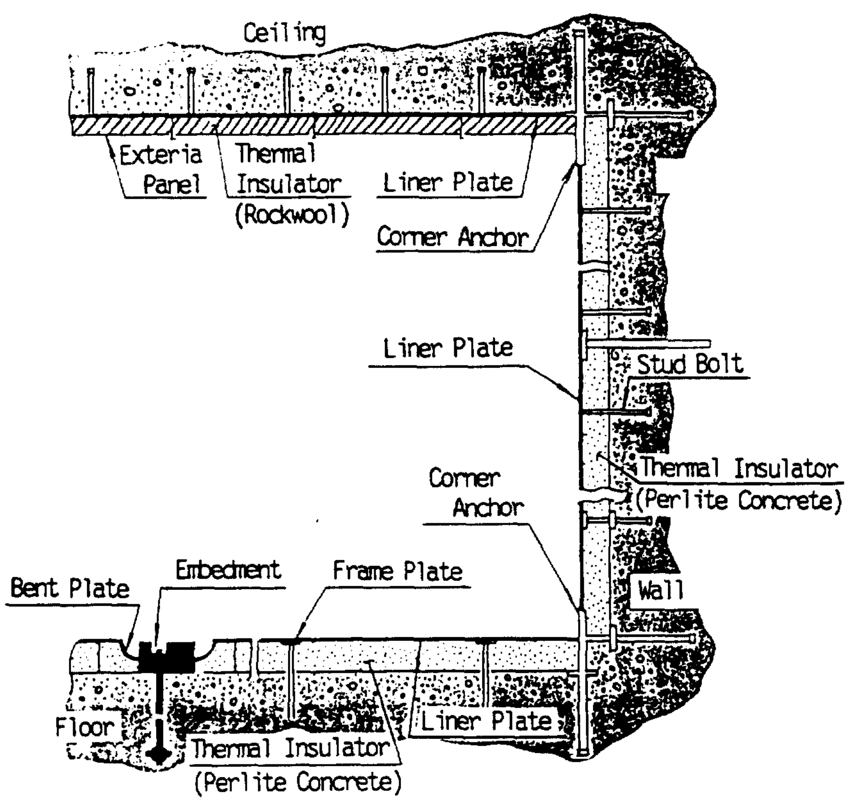
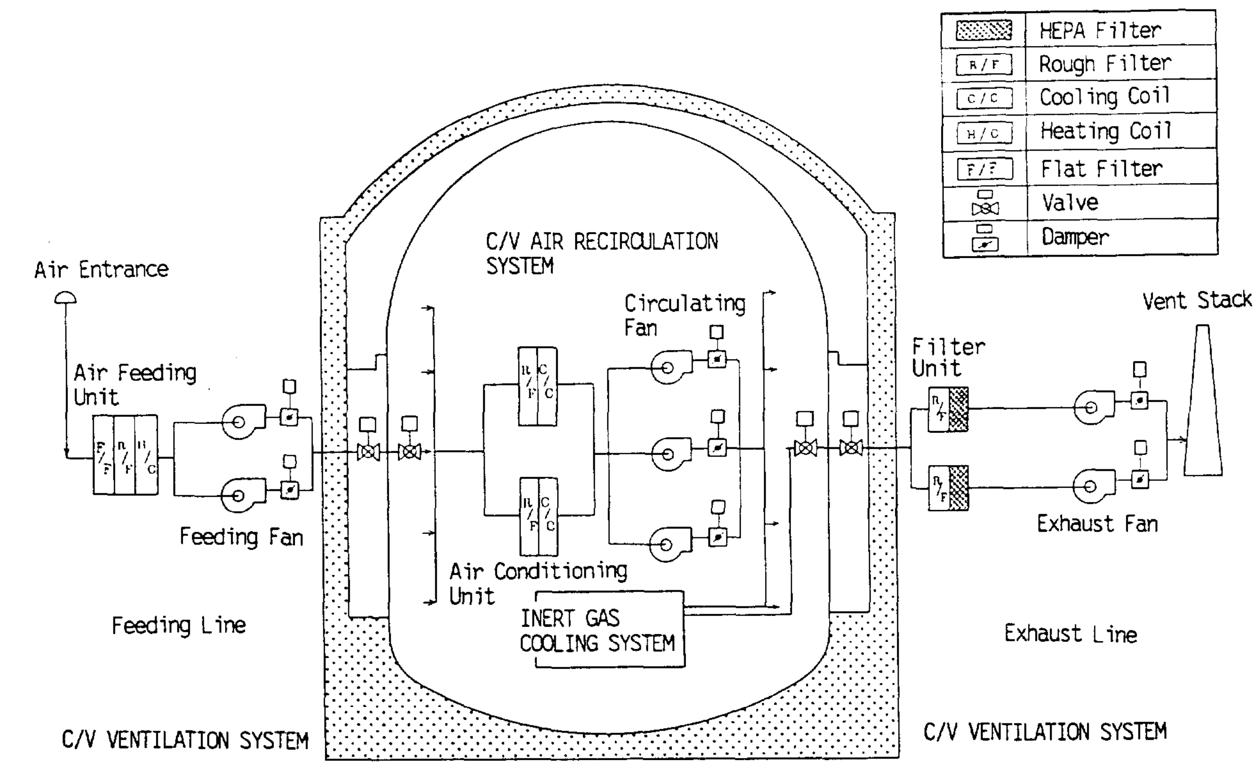


Figure 7 Structure of cell liners[3]
(Fixed type)



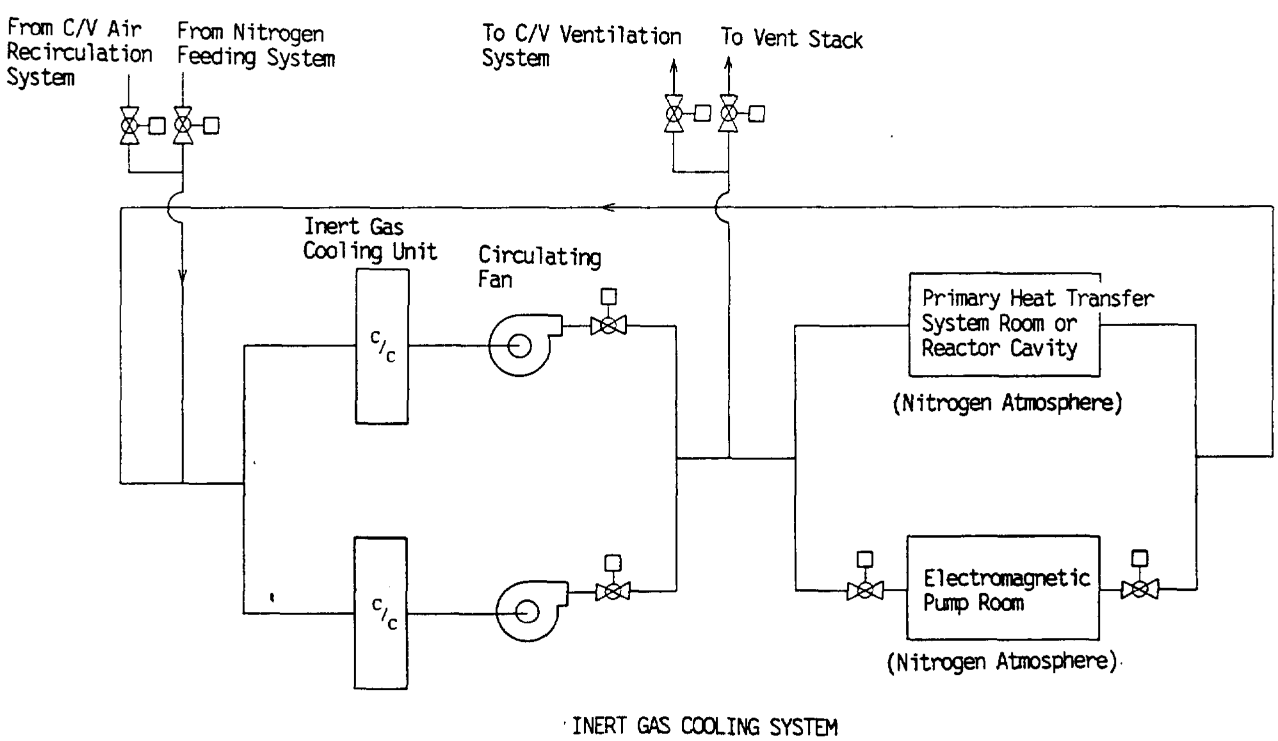


Figure 8 Explanation diagram of the HVAC system for the C/V

As shown in Table 1, HVAC system for the reactor containment vessel(C/V) is composed of a C/V ventilation system, a C/V air recirculation system, a reactor cavity inert gas cooling system and a PHTS(primary heat transfer system) cells inert gas cooling system. The C/V ventilation system feeds fresh air to the C/V and exhausts contaminated air through HEPA filter when personnel enters the C/V. The C/V air recirculation system controls the temperature of the air area in the C/V within 10 ~ 40 ℃, and is equipped with a rough filter and cooling coil. The inert gas cooling systems for these gastight cells of the reactor cavity and PHTS cells keep them nitrogen atmosphere and temperature below 55℃. Pressure adjustment in the cell is performed by monitoring the pressure differential(Δ P) between the cell and the operating floor in the C/V. When Δ P decreases under 10 mmAq, the inert gas cooling system feeds nitrogen gas to the cell up to 20 mmAq. The C/V operating floor pressure is also controlled by a differential from the atmospheric pressure out of the C/V. In the event of sodium spill, the C/V isolation signal trips the system and closes lines connected to electromagnetic-pump rooms so as not to damage the pump by thermal effect. When personnel enter the primary heat transfer system rooms for maintenance, the inert gas cooling system is switched to the C/V ventilation system and the rooms are purged from nitrogen to air. Figure 8 shows an explanation diagram of the HVAC systems for the C/V.

B. Analysis for Design

Computer analysis was necessary for estimating design specifications of HVAC systems of MONJU. For the sodium component areas, sodium spill accidents were analyzed by computer programs of SOFIRE-MII and SPRAY-II which were developed and modified on the bases of experimental data[(4)(5)]. SOFIRE-MII can deal with sodium pool fire, and can calculate atmospheric temperature and pressure. This program let a combustion rate of sodium be determined by the quantity of atmospheric gases approaching the sodium surface and concentration of oxygen. Thermal transfer models are of convection and radiation between the sodium surface and the atmospheric gases, of convection between the gases and the liners, and of conduction in the structural materials. SPRAY-II can deal with sodium spray combustion, and can calculate atmospheric temperature and pressure. This program let a combustion rate of sodium be derived from the oxygen concentration and the humidity, and the quantity of sodium vapour from the drops moving into combustion regions. Thermal transfer models are of convection and radiation between the sodium drops and the combustion region, of convection of the gases between the combustion region and the spray region, of radiation from the combustion region to the walls, of transfer of the gases between the spray region and the atmosphere, of convection from the atmospheric gases outside of the spray to the walls, of convection of the atmospheric gases close to the surface of the sodium pool, of conduction from the sodium pool to the floor, and of conduction in the structural materials.

Figure 9 shows a analytical result of the primary cooling room in the case of sodium spill from hot leg piping. Analytical assumptions severer than the actual accident were taken to get more credible results. Sodium would leak from the slit with length of 1/2D and width of 1/2t, where D and t were a diameter and a thickness of the pipe respectively. The atmospheric leakage rate of 100 %vol/day was assumed at the pressure differential of 100 mmAq. Initial oxygen concentration in the cell was presumed 3 %vol in the analysis to cover the design value of 2 %vol. Reaction between sodium and oxygen was considered as $2Na + O_2 \rightarrow Na_2 + O_2$ + 435 kJ/mol. Receiving these analytical data, design specifications of the HVAC systems and the cell liners were discussed and estimated. In this way, the cell boundaries of HVAC systems were designed to endure against a pressure of 98 kPa and a temperature of 300℃ respectively.

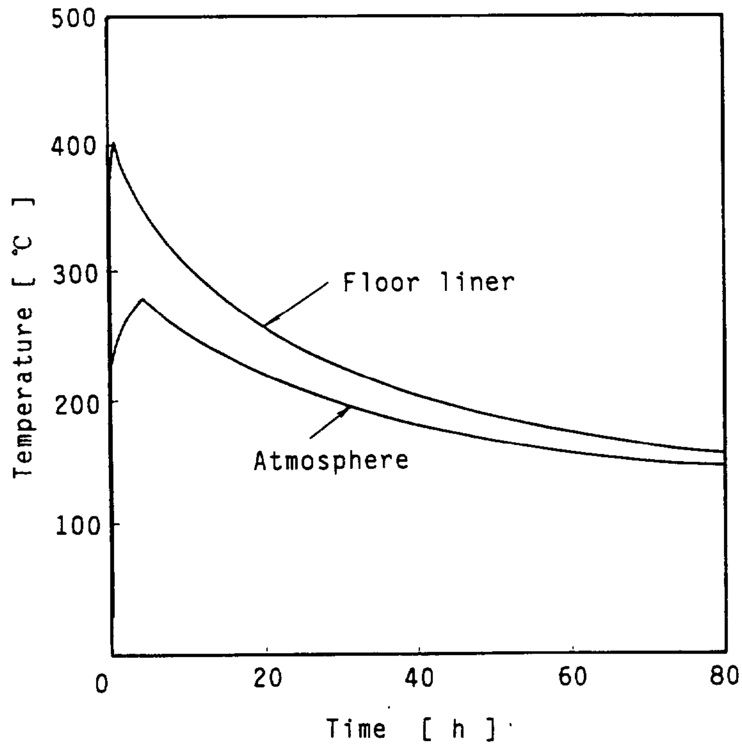


Figure 9 Transition of temperature in a lowermost room at the sodium spill from hot leg piping

C. Results of Pre-operational Tests

The function test of fans, the interlocking and alarm tests, the air flow test, the filter efficiency test and the temperature measurement test were carried out for the HVAC systems at the pre-operational test stage. In addition, the atmospheric leakage rate test and the atmospheric gas purging test have been conducted for the gastight cells and the inert gas cooling systems.

The total area of approximately 12,000 m² is lined with steel plates to form the gastight cells, for which the allowable leakage rate is 100 %vol/day out-leakage or in-leakage at the pressure differential of 100 mmAq. To achieve acceptable gastightness, much quality control work was applied to materials, welders and welding methods. All welding lines were non-destructively examined by visual inspection, vacuum box inspection and liquid penetrant inspection. Then ducts and units of the inert gas cooling systems were examined by soap bubble test. Table 5 shows the results of atmospheric leakage rate test for 24 hours. Owing to the strict quality control, the cells obtained good gastightness of less than one-hundredth compared with the design allowance. Results were sufficiently contented with the value of 1 %vol/day which is a design target to reduce the nitrogen leakage from the cell.

Table 5 Results of atmospheric leakage rate test for 24 hours[3]

Area	Design	Volume	Test Results
R/B-A	100 %vol/day at 100 mmAq	4,180 m³	0.49 %vol/day
R/B-B & R/C		8,040 m³	0.14 %vol/day
R/B-C		3,960 m³	0.46 %vol/day
A/B-E		3,730 m³	0.40 %vol/day

R/B : Reactor building, R/C : Reactor cavity,
A/B : Reactor auxiliary building, -A.-B.-C.-E : Cell division

With regard to substitution of nitrogen for air in the cells, the inert gas cooling systems can adopt both a batch method and a continuous flowing method. The batch method means that exhaust is done after pressurization and repeated, while the continuous flowing method means that continuous feed and exhaust are carried out until density of oxygen is below 2 %vol. Either method is to be selected according to the exhaust line condition of the HVAC systems. The continuous flowing method is superior in shortening of the ventilating time, while infe-

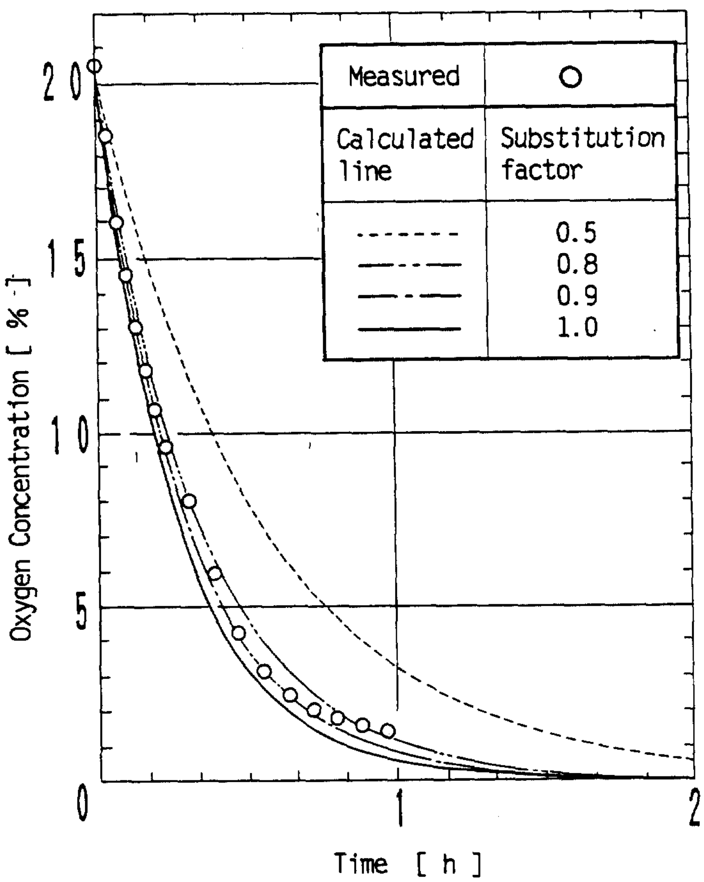


Figure 10 A result of atmospheric gas purging test by the continuous flow method for the fuel handling facility inert gas system

rior in consuming nitrogen gas. Moreover, the continuous flowing method is easier to operate than the batch method. The amount of nitrogen gas required for ventilation depends on a substitution factor, though the factor is rather hard to predict by calculation. The substitution factor means S in the following equation.

$$D = (D_0 - D_I)\, e^{-Sqt/V} + D_I \qquad (1)$$

D : Oxygen Density in Cell, D_0 : Initial Oxygen Density in Cell
D_I : Oxygen Density of Inlet Gas, S : Substitution Factor
q : Inlet Gas Flow Rate, t : Time, V : Volume of Cell

At an economical point of view, a large substitution factor is preferable because it makes ventilating time shorter and consuming nitrogen gas smaller. Figure 10 shows a result of atmospheric gas purging test by the continuous flowing method for the fuel handling facility inert gas cooling system. The concentration of oxygen in the cell decreased sharply and the substitution factor of approximately 0.9 was obtained. The value of 0.9 by the continuous flowing method is so large that the batch method is unnecessary to use for saving the nitrogen gas.

V. Conclusions

MONJU is the first prototype FBR in Japan which employs sodium as coolant. The sodium spill is a design basis accident and is also considered in the design of HVAC systems of MONJU. The characteristics and performances of the HVAC systems can be summarized as follows.

(1) The annulus is a gastight structure as a secondary reactor containment and is kept in a negative pressure less than -15 mmAq by the annulus ventilation system during reactor operation.

(2) Caused by the back-pressure from the vent stack, the exhaust line of the annulus ventilation system is difficult to maintain the required negative pressure and exhaust flow ratio. However, the negative pressure and exhaust flow ratio have been confirmed to meet the design values by controlling damper openings based on the pre-operational test data.

(3) To minimize release of radioactive substances, the annulus ventilation system is equipped with the bed type charcoal filter having a thickness of 20 cm, and its efficiency of over 99 % was confirmed by the laboratory and the pre-operational tests.

(4) Sodium spill accident is considered in the design of the annulus ventilation system, and the multilayer filter is provided in the filter unit to prevent sodium aerosol from clogging the HEPA filter.

(5) Rooms for components containing radioactive sodium are lined with steel plates to form gastight cells, and are kept in a low oxygen atmosphere less than 3 %vol to suppress sodium combustion by the HVAC systems.

(6) The leakage rates from the cells have achieved less than 1 %vol /day at a pressure differential of 100 mmAq, which is sufficiently low compared with the design value of 100 %vol/day.

(7) Substitution factor of approximately 0.9 has been obtained by the atmospheric gas purging test of the EVST rooms from air to nitrogen.

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DISCUSSION

PORCO: What is the filtering medium for multilayer filters and what are the loading characteristics for the sodium aerosol?

FUJIMORI: The filtering medium for the 5-layer multilayer filter is made from high-silica glass fiber. The multilayer filter has some holes to avoid plugging by the sodium aerosol. Detailed information has been provided at the 19th DOE/NRC Air Cleaning Conference.

MODERN TECHNOLOGY TOOLS FOR IMPROVEMENT OF NPP RELIABILITY

-CASE STUDY OF NPP FILTRATION SYSTEMS VALIDATION-

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Abstract

The relationship which describes influence of ageing, relative humidity and organic poisons on the adsorption quality of coconut charcoal has been established. On the basis of the established relationship the computer program, for easy calculations of the reliable operation time of the adsorbent media in the charcoal filters of any single nuclear air cleaning system, was proposed. The program enables determination the life time of charcoal filters in the standard cases of working regime or in a real time.

Introduction and Scope

During normal working regime of NPP or possibly an unlikely event, as reactor accident, the certain amount of radioactive materials will be released to the containment atmosphere and become airborne and potentially dangerous for the environment. Among these radioactive materials iodine is the most important nuclide due to the volatility of its compounds and great radiological effects. Activated charcoal, as the adsorbent media, arranged in filters either as the absorber cells (Type II) or as the sorbers (Type III)[(1)] is used for trapping radioiodine released during these events, as well as during the normal operation of a reactor. These makes charcoal filters the most responsible component of an nuclear air-cleaning system in the view of environmental protection from gaseous and volatile effluents during normal and accidental operation of NPP. At the same time carbon looses its adsorption properties due to ageing, poisoning, oxidation of the surface, humidity and the temperature of air. For prediction of the reliability of filter media or carbon filter systems complete relations between the adsorption quality of carbon and influence of the poisons have to be known.

The first such relationship was made only for ageing.[2] In the literature exist a lot of experimental data of influence of water and other poisons on adsorption quality of carbon[3-12] and on the basis of these experimental results we have made the relationship which connect the influence of "all poisons" (ageing, humidity and air borne organic compounds) on adsrpption quality of carbon.[13]

The aim of this work is to establish, on the basis of this relationship,[13] the numerical simulation model for prediction of the life time of the filter media and filter systems as a function of the time from the last in-service inspection and laboratory control of carbon adsorption parameters and known parameters of air stream (T^0C, RH, content of poisons) obtained in NPP in the meantime.

The numerical model will enable construction of computer program for easy and fast calculation of the life time of carbon in Nuclear Air Treatment Systems (NATS).

Principle

A brief statement of the construction procedure of the dependence of life time of carbons on all poisons concentration is given here while the details are available elsewhere.[13]

The studies of adsorption on active carbon have shown,[14,15] that its external surface is negligible but is permeated by micropores-pores, whose diameter range is believed to be between 5-20 Å. The adsorption of volatile iodine compounds take place in these pores, and at the same time is seriously thwarted by a competitive interaction of water and air borne organic compounds adsorption, which might easily turn into insufficient decontamination degree of carbon.

In the literature, the experimental data of organic poisons diameters can not be found. In this work, we consider the possibility to calculate these diameters using the charge density calculations established by Bader et al.[17,18] They concluded that in general over 95% of molecular charge lies within the 0.02 contour, so that the dimensions of this contour may provide a useful theoretical measure of molecular size. To be consistent we have also calculated the diameter of water molecule.

To find a complete relation of adsorption capacity of carbon, it is necessary to consider separately the effects on adsorption capacity of carbon for each of the poisons.

Influence of ageing

The relationship for ageing:[2]

$$\log K = \log K_0 - 0.3 \times 10^{-8} N - 1.3 \times 10^{-3} t \qquad (1)$$

where: t-age of charcoal in weeks; K_0-initial performance index of the trap; K-performance index after time t; N-number of air changes to which the trap is exposed from the start of in-service life.

Influence of water

Relative humidity appears to be a very important parameter in reduction of the adsorption capacity of carbon. The quantity of adsorbed water on carbon depends on its concentration in air, which is proportional to vapor pressure of water on given temperature and relative humidity.

On the basis of these experimental results[3-8] the following relationship was established:[13]

$$\log K = \log K_0 - A t p_w \qquad (2)$$

where: A is the constant depending on kind of carbon, for coconut carbon $A=5.9 \times 10^{-5}$; p_w is the vapor pressure of water on the given temperature and relative humidity (mm Hg).

Influence of air borne organic compounds

Aliphatic and aromatic organic compounds were detected on the charcoal taken from NPP in-service filters,[6,9] and experimental results[6,9] show that the adsorption of aliphatic organic compounds (nonane to tetradecane) and xylene on charcoal cause fastest decrease of K factor.

The diameter of these compounds calculated by Bader[16,17] charge density values is from 7.1 Å for nonane to 8.1 Å for tetradecane, so that all of them can be adsorbed in micropores of carbon.

Investigation of adsorption of aliphatic organic compounds on active carbon showed that nonane is adsorbed on micropores of carbon stronger than other compounds and disable their adsorption.[15,10,11] For this reason nonane was chosen as the representative organic molecule for calculation of the influence of organic poisons, and the following relationship has been established:[13]

$$\log K = \log K_0 - BtC_pp_p \qquad (3)$$

where: B is the constant depending on the kind of carbon, for coconut carbon it is 0.226; C_p is the concentration of organic compounds in air stream; p_p is vapor pressure of nonane, representative compound, on given temperature; t is the time in weeks.

Influence of all poisons

Influence of aging and all poisons (humidity and air borne organic compounds) on adsorption quality for coconut carbon can be presented by one equation having in mind next assumptions:
- concentration of water in air stream is proportional to vapor pressure on given temperature and relative humidity,
- air borne organic can all be represented as nonane.

Equations (1-3) give the final relationship:[13]

$$\log K = \log K_0 - 0.3\text{x}10^{-8}N - 1.3\text{x}10^{-3}t - 5.9\text{x}10^{-5}tp_w - 0.226tC_pp_p \qquad (4)$$

where: K - index of performance after time t; K_0 - index of performance of the trap obtained by the last laboratory control; N - number of air changes; t - time in weeks; p_w - vapor pressure of water on the temperature and relative humidity of considered case; C_p -concentration of air borne organic compounds; p_p - vapor pressure of nonane at the temperature of considered case.

Life time of carbon under various conditions

Equation (4) can be rearranged so that the validity time of carbon filter, in normal regime or from the beginning of accident or incident, can be simply calculated . The term $0.3\text{x}10^{-8}N$, in equation (4), is too small comparing with the others and can be neglected, so the expression for t can be presented as:[13]

$$t = \frac{\log K_0 - \log K}{1.3\text{x}10^{-3} - 5.9\text{x}10^{-5}p_w - 0.226C_pp_p} \quad \text{(weeks)} \qquad (5)$$

The equation (5) can be now used as the basis for a computer program.

Description of CarbExp Computer Program

In the literature we find only in the paper of W.P.Freeman and J.C.Enneking[12] that the computer program was used for calculation of the amount of evaporated solvents in NATS.

According to the equation 5 presented above, a computer program CarbExp was made, in order to enable quick prediction of filter media life time. CarbExp is user friendly, written in high level language and therefore highly portable.

Program user can input the relevant parameters either through the interactive dialogue, or in the text file. The results obtained are presented in the table form for various values of K-factor. Every table entry contains results for four working regimes of NPP characterized by specific temperature, relative humidity and concentration of poisons. Parameters for four characteristic working regimes can be redefined for any particular case. Parameters assumed in this paper are:

NORMAL OPERATION	-> $T=25^0C$; RH=40%; $c_p=0.0001\%$
FIRST INCIDENT	-> $T=80^0C$; RH=70%; $c_p=0.0015\%$
SECOND INCIDENT	-> $T=90^0C$; RH=95%; $c_p=0.0015\%$
ACCIDENTAL SITUATION	-> $T=60^0C$; RH=98%; $c_p=0.0020\%$

The presented life time values of filter media validity can be durations in hours or absolute dates computed relatively to the moment of filter installation.

Example given in Table 1. shows entire dialogue with input parameters and obtained results.

Special feature of the program makes possible the examination of the specific situation which can occur during normal operation. The value of temperature, relative humidity and concentration of poisons for the specific situation must be given, as well as its duration in hours. Two successive values of Ko at the beginning and at the end of the specific situation are computed, and table entries for K-factor between those values are filled in with *. An example for such a case is presented in the Table 2.

Finally, if computed Ko is less than critical value of K, denoted as Kc, the table is not presented, and the operator is instructed to change the carbon immediately, as shown in the Table 3.

Conclusion

The results obtained by equation (5), Tables 1 - 3, also show that the equation is promising for quick prediction of validity time of carbon filters in many various situations. If it is accepted that the carbon filter is the most sensitive component of the filtration unit of air cleaning system in NPP, the usage of the equation (5) may contribute in bringing a relevant decision, from the control room of the NPP,about the reliability of filter systems working time, in the normal, incidental and accidental situations. With CarbExp application a regular maintenance plan for carbon filters could be improved, the final result being the impact on improvement of reliability of the NPP.

Further development of CarbExp will lead to NATSExp (Nuclear Air Treatment System Expert) development as a complete expert system for filtration system validation, which will include reciprocal influence and mutual impact of all exchangeable components of filtration unit and may become a regular working tool for predicting the filtration system performance.

Acknowledgment

The authors thank Dr. D.Lj.Vuckovic for helpful discussions. The work is partly supported by the Republic Serbia Science Foundation.

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Table 1.

CarbExp **Bgd, 1992.**

CARBON FILTER VALIDATION PROGRAM

```
Enter the name of the system >VA 441 PLM01
Enter the time of carbon exchange:
--Year-->1992
--Month->7
--Day--->16
--Hour-->16
Time after last exchange is   0.00 weeks.
Enter the initial producer value of K-factor (Kp) >17
Enter the number of air changes per week (B) >2520
Enter the range for user K-factor:
--Max-->17
--Min-->10
Enter the value of increment between K values in table >1
Do You want Standard cases table or Your case table (S/Y) >S
Do You want absolute Dates or durations in Hours (D/H) >D
```

LIFE TIME OF THE FILTER MEDIA
FOR THE VARIOUS VALUES OF K-FACTOR

Values for system VA 441 PLM01: Current date is: 16-07-1992 17h

K	NORMAL OPERATION	FIRST INCIDENT	SECOND INCIDENT	ACCIDENTAL SITUATION
17.000	16-07-1992 16h	16-07-1992 16h	16-07-1992 16h	16-07-1992 16h
16.000	18-10-1992 19h	21-07-1992 04h	19-07-1992 09h	24-07-1992 12h
15.000	27-01-1993 00h	26-07-1992 00h	22-07-1992 07h	01-08-1992 22h
14.000	14-05-1993 03h	31-07-1992 04h	25-07-1992 09h	10-08-1992 21h
13.000	06-09-1993 05h	05-08-1992 17h	28-07-1992 17h	20-08-1992 12h
12.000	08-01-1994 12h	11-08-1992 17h	01-08-1992 08h	30-08-1992 21h
11.000	23-05-1994 15h	18-08-1992 05h	05-08-1992 06h	11-09-1992 05h
10.000	18-10-1994 15h	25-08-1992 09h	09-08-1992 13h	23-09-1992 14h

Table 2.

CarbExp **Bgd, 1992.**

CARBON FILTER VALIDATION PROGRAM

```
Enter the name of the system >VA 441 PLM01
Enter the time of carbon exchange:
--Year-->1992
--Month->6
--Day--->16
--Hour-->17
Time after last exchange is   4.29 weeks.
Enter the initial producer value of K-factor (Kp) >17
Enter the initial concentration of poissons (Cpo) >0.0001
Enter the number of air changes per week (B) >2520
Enter the range for user K-factor:
--Max-->17
--Min-->5
Enter the value of increment between K values in table >1
Do You want Standard cases table or Your case table (S/Y) >Y
Do You want absolute Dates or durations in Hours (D/H) >D
Enter Your value of temperature in C degrees (T) >90
Enter Your value of humidity in % (RH) >98
Enter Your value of concentration of poissons (Cp) >0.015
Enter the value of critical K factor (Kc) >8
Enter the time of the begining of abnormal situation:
--Year-->1992
--Month->7
--Day--->16
--Hour-->17
Duration of normal operation was   4.29 weeks.
Enter duration time of abnormal situation in hours (Ta) >15
```

Table2. cont.

LIFE TIME OF THE FILTER MEDIA
FOR VARIOUS VALUES OF K-FACTOR AFTER SPECIFIC SITUATION

Values for system VA 441 PLM01 First Ko: 16.673 Second Ko:15.358

K	NORMAL OPERATION	FIRST INCIDENT	SECOND INCIDENT	ACCIDENTAL SITUATION
17.000	17-06-1992 06h	15-07-1992 22h	16-07-1992 12h	14-07-1992 20h
16.000	****************	****************	****************	****************
15.000	22-08-1992 23h	19-07-1992 02h	18-07-1992 09h	20-07-1992 09h
14.000	08-12-1992 02h	24-07-1992 06h	21-07-1992 12h	29-07-1992 08h
13.000	02-04-1993 04h	29-07-1992 19h	24-07-1992 20h	07-08-1992 23h
12.000	04-08-1993 11h	04-08-1992 19h	28-07-1992 10h	18-08-1992 09h
11.000	17-12-1993 14h	11-08-1992 07h	01-08-1992 08h	29-08-1992 16h
10.000	14-05-1994 14h	18-08-1992 10h	05-08-1992 15h	11-09-1992 01h
9.000	25-10-1994 05h	26-08-1992 08h	10-08-1992 09h	24-09-1992 17h
8.000	26-04-1995 03h	04-09-1992 03h	15-08-1992 16h	10-10-1992 01h
7.000	19-11-1995 11h	14-09-1992 03h	21-08-1992 16h	27-10-1992 09h
6.000	15-07-1996 20h	25-09-1992 16h	28-08-1992 15h	16-11-1992 09h
5.000	24-04-1997 23h	09-10-1992 07h	05-09-1992 20h	10-12-1992 02h

Table 3.

CarbExp **Bgd, 1992.**

CARBON FILTER VALIDATION PROGRAM

```
Enter the name of the system >VA 441 PLM01
Enter the time of carbon exchange:
--Year-->1989
--Month->6
--Day--->16
--Hour-->17
Time after last exchange is 160.86 weeks.
Enter the initial producer value of K-factor (Kp) >17
Enter the initial concentration of poissons (Cpo) >0.0001
Enter the number of air changes per week (B) >2520
Enter the range for user K-factor:
--Max-->17
--Min-->8
Enter the value of increment between K values in table >1
Do You want Standard cases table or Your case table (S/Y) >Y
Do You want absolute Dates or durations in Hours (D/H) >D
Enter Your value of temperature in C degrees (T) >90
Enter Your value of humidity in % (RH) >98
Enter Your value of concentration of poissons (Cp) >0.015
Enter the value of critical K factor (Kc) >8
Enter the time of the begining of abnormal situation:
--Year-->1992
--Month->7
--Day--->16
--Hour-->17
Duration of normal operation was 160.86 weeks.
Enter duration time of abnormal situation in hours (Ta) >15
```

Evaluated K is: 7.562

EXCHANGE CARBON IMMEDIATELLY !!!

HEATER SELECTION CRITERIA FOR ENGINEERED SAFETY FEATURES ATMOSPHERE FILTRATION SYSTEMS

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Abstract

U.S. nuclear power plants incorporate engineered safety features atmosphere filtration systems (ESFAFS) in their design as a means of limiting radiation exposure to individuals in the event of a design basis radiological accident. These systems typically utilize heaters to limit the relative humidity of the filtered air to 70 percent or less in order to obtain the desired level of efficiency from the charcoal adsorbers. ANSI/ASME N509 requires that these heaters be sized to reduce the maximum expected relative humidity of the airstream to approximately 70 percent at the system design flowrate. However, in some cases the criteria used to select these heaters may not consider the worst case conditions that could occur both during and following a design basis accident. Degraded electrical system voltage, airflow variations, and accident condition heat loads are significant factors in the heater selection process that are commonly overlooked.

The Vogtle Electric Generating Plant ESFAFS heaters were originally selected without considering these worst case conditions. As a result, several systems were found to have insufficient heater capacity to maintain the previously assumed humidity levels and filtration efficiency. To compensate for the undersized heaters, the Technical Specifications and accident analysis were revised to reflect the potential impact of increased relative humidity on the charcoal adsorber filtration performance.

I. Introduction

The ESFAFS at the Vogtle Electric Generating Plant* are designed to perform two major functions in the event of a design basis radiological accident:

1. Limit the radiation exposure to individuals located offsite to within the guidelines established in 10 CFR 100.[1]
2. Limit the radiation exposure to operating personnel located in the control room to within the limits established in 10 CFR 50, Appendix A, GDC 19.[2]

To ensure that the ESFAFS can remove the required level of radioactive iodine from the filtered air, the activated charcoal adsorbers are conservatively designed to be consistent with the decontamination efficiencies and laboratory test requirements given in Table 2 of Regulatory Guide 1.52.[3] Plant Vogtle's 4-inch deep charcoal adsorbers are assigned a decontamination efficiency of 99.0 percent with a corresponding laboratory test criteria of 99.8 percent, based on a system with the relative humidity (RH) controlled to 70 percent or less. The assigned decontamination values are then used in the plant accident analysis to verify conformance with the radiation exposure criteria.

To verify that the ESFAFS maintain the assigned efficiencies, periodic surveillance tests are performed in accordance with ANSI/ASME N510-1980[4] and the plant Technical Specifications.[5] These surveillance tests verify, among other functions, that the heaters dissipate specific power levels in accordance with the project specifications. The Plant Vogtle Technical Specifications require that the heater power dissipation be verified within a specific kilowatt (kW) range (i.e., kW ± kW). These values were originally derived on the basis of heat transfer calculations, performed in accordance with Section 5.5.1 of ANSI/ASME N509-1980,[6] to ensure that the maximum expected RH of the entering air is reduced to approximately 70 percent at the system design flowrate.

Although the calculation method used to size the ESFAFS heaters included the design air flowrate and assumed 100-percent RH entering air, the following plant design basis conditions were not considered in the selection process:

- Degraded electrical distribution system voltage under design basis accident conditions.
- Maximum system air flowrate allowed by the Technical Specifications.
- Accident condition heat loads (maximum inlet temperature).

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* Westinghouse 4-loop PWR operated by Georgia Power Company

II. Criteria Discussion

Electrical Distribution System Degraded Voltage

Degraded voltage is a factor that should be considered within the context of a specific electrical distribution system design. The Plant Vogtle electrical distribution system design criteria require that the safety-related loads on the 480 Vac distribution system provide rated performance at 460 volts ± 10 percent. Therefore, the ESFAFS heaters that are supplied power from the 480 Vac distribution system should be sized to function with the minimum design voltage (414 Vac). However, the ESFAFS heaters were originally sized without consideration of degraded voltage and were purchased to provide the required heat dissipation at a nominal 480 volts. Per ANSI/IEEE Standard 141,[7] "The energy input and, therefore, the heat output of resistance heaters varies approximately as the square of the impressed voltage". Therefore, when the minimum design voltage available is considered, the output of the heater would be reduced as follows:

$$kW_{MINIMUM} = \left(\frac{Voltage_{MINIMUM}}{Voltage_{RATED}}\right)^2 \times kW_{RATED} \tag{1}$$

Where: Heater resistance is constant and the power factor is 1.0

Maximum System Air Flowrate

Air flowrate above the system nominal design values should also be considered in the ESFAFS heater selection process. The Plant Vogtle Technical Specification surveillance tests require that the ESFAFS design flowrate be verified within ± 10 percent on a periodic basis, which is consistent with the Standard Technical Specifications for Westinghouse Plants[8] and Section 8.3.1 of ANSI/ASME N510-1980. This flow tolerance allows the design airflow to be verified under actual field conditions at the minimum and maximum filter pressure drop. Since the maximum allowable mass flowrate results in maximum required heater capacity, the Technical Specification upper limit (nominal design flow + 10 percent) should be used in the heater sizing calculations.

Maximum Inlet Temperature

Another factor that is commonly overlooked in ESFAFS heater selection is the maximum inlet temperature combined with the worst case humidity. Some of the calculations for the Plant Vogtle ESFAFS failed to account for the elevated temperatures that may be experienced during accident conditions. For example, the fuel handling building post-accident filtration system heater calculations assumed the entering air temperature to be at the minimum normal conditions (60°F). However, the postulated accident conditions could result in inlet temperatures in excess of 100°F. Although the impact of inlet temperature variations on required heater capacity is relatively small when compared to degraded voltage and increased air flow, it is a criterion that should be considered in the overall heater selection process.

III. System Analysis

When combined, the additional criteria can have a significant impact on the ESFAFS heater selection process. The following analysis of a Plant Vogtle ESFAFS demonstrates the combined effect that the worst case conditions can have on heater size requirements:

System Name: Piping Penetration Area Filtration and Exhaust System (PPAFES)

1. Original Specification Design Parameters

Heater Voltage:	480 Vac
System Flowrate:	16,000 ft^3/min
Inlet Air Temp:	104°F
Inlet Air RH:	100%
Humidity Control (RH):	70%

Required Heater Capacity Based on Original Design Parameters

$$q = m_a(h_2 - h_1) \quad \text{(9)} \qquad (2)$$

where: q = required sensible heat input (Btu/hr)
m_a = mass flowrate of dry air (lb/hr)
h_1 = entering coil enthalpy *
h_2 = leaving coil enthalpy *

* Btu/lb dry air and associated moisture

$$q = \left(\frac{0.06525\ \text{lb}}{\text{ft}^3} \times \frac{16,000\ \text{ft}^3}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}}\right)\left(\frac{82.6\ \text{Btu}}{\text{lb}} - \frac{79.4\ \text{Btu}}{\text{lb}}\right)$$

q = 200,448 Btu/hr

Required Heater Capacity = 58.7 kW

2. Revised Criteria Design Parameters

Heater Voltage:	414 Vac	(460 -10%)
System Flowrate:	17,050 ft^3/min	(Tech Spec + 10%)
Inlet Air Temp:	168°F	(Accident Heat Loads)
Inlet Air RH:	100%	(Steam Environment)
Humidity Control (RH):	70%	

Required Heater Capacity Based on Revised Criteria

$$q = \left(\frac{0.03855\ \text{lb}}{\text{ft}^3} \times \frac{17,050\ \text{ft}^3}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}}\right)\left(\frac{502.7\ \text{Btu}}{\text{lb}} - \frac{496.0\ \text{Btu}}{\text{lb}}\right)$$

q = 264,226 Btu/hr

Required Heater Capacity = 77.4 kW

The actual heater specified and installed in the Vogtle PPAFES is rated for 80 kW at 480 Vac. This specified value was used as the basis for the Technical Specification surveillance test acceptance criterion of 80 ± 4 kW. However, the Technical Specification did not specify the voltage that the acceptance criterion was based upon. When the specified heater capacity is adjusted to compensate for the nominal design voltage (460 Vac), the actual heater capacity is reduced to 73.5 kW. When the heater is further derated to the minimum design voltage (414 Vac), the actual heater capacity is reduced to 59.5 kW. This indicates that the PPAFES specified heater is deficient by approximately 18 kW when the minimum voltage capacity (59.5 kW) is compared with the revised criteria required capacity (77.4 kW). A properly specified heater for this system would require a minimum rating of 95.6 kW at 460 Vac in order to provide the required 77.4 kW heat dissipation under the worst case accident conditions to maintain 70 percent relative humidity.

A complete analysis of all Plant Vogtle ESFAFS was conducted to verify heater performance with the revised criteria. This analysis included the PPAFES, the Control Room Emergency Filtration System (CREFS), and the Fuel Handling Building Post Accident Filtration System (FHBPAFS). The results of this analysis, as shown in Table 1, indicated that only the CREFS had sufficient capacity to limit the filtered air to 70 percent RH or less. Since no credit was originally taken for the FHBPAFS operation in the plant accident analysis, the immediate operability concerns were focused on the PPAFES. To address this problem, the system was evaluated based on the actual field conditions obtained by Technical Specification surveillance tests.

Table 1

System	Specified Heater Capacity (480 Vac)	Minimum Voltage Capacity (414 Vac)	Revised Criteria Required Capacity	Revised Criteria Relative Humidity
CREFS	118 kW	87.8 kW	74.0 kW	≤ 70%
PPAFES	80 kW	59.5 kW	77.4 kW	74.1%
FHBPAFS	20 kW	14.9 kW	24.9 kW	80.4%

These tests revealed that the actual system flow was not at the maximum Technical Specification allowable value, and that the calculated voltage drop would not reach the design criteria minimum 414 Vac. When the actual test conditions were considered, the air entering the charcoal absorbers was shown to be controlled below the 70 percent RH limit.

The Nuclear Regulatory Commission (NRC) granted Plant Vogtle a temporary waiver of compliance from the Technical Specification surveillance requirement of verifying a specific heater kW, based on the systems ability to meet the 70 percent RH criterion under the actual test conditions. However, since there was very little safety margin remaining under the test conditions, a commitment was made to consider plant modifications that would increase the margin between the actual heater power and the power required to fulfill the heater design function.

IV. Corrective Actions

In order to provide the PPAFES and the FHBPAFS with additional heater capacity safety margin, the following options were evaluated:

1. Physically modify the heaters and/or the electrical supply system to increase the heater output.
2. Revise the acceptance criteria used to perform the ESFAFS charcoal laboratory testing and the credited decontamination efficiency used in the plant accident analysis.

The first option, although it would clearly provide additional margin by increasing the power output, was by far the most expensive option, considering the safety qualification requirements of the ESFAFS heaters. In addition, a physical modification would be the least desirable from a plant operation standpoint. Therefore, the second option was chosen on the basis that a revision to the plants operating license:

- Was less expensive.
- Involved no physical plant modifications.
- Maintained doses within radiation exposure guidelines.

To implement option two, the charcoal laboratory test conditions were revised from 70 to 95 percent RH to more accurately reflect the reduced capacity humidity control available from the heaters. By increasing the lab test criteria to 95 percent RH, the system would be consistent with the test conditions recommended by ASTM Standard D3803-1989.[10] In addition, the 95 percent RH test condition is generally accepted in the nuclear industry for systems without heaters.[11]

To account for the reduced charcoal efficiency associated with the increased RH conditions, the laboratory test acceptance criteria and the assigned decontamination efficiency were revised to be consistent with Regulatory Guide 1.52 for a system designed to operate inside primary containment (i.e., uncontrolled RH) as indicated in Table 2. The revised values also conform with the recommended safety margin for systems without heaters.[3,11]

Table 2

Regulatory Guide 1.52 Parameter (Organic Iodide)	Old Value	New Value
Lab Test Penetration Criteria	0.2%	10.0%
Accident Analysis Penetration	1.0%	70.0%
Safety Margin	5	7

Accident Analysis Review

To determine the impact of the revised filter efficiencies on the previously calculated radiation dose rates, a new analysis was performed using the new decontamination values. A preliminary analysis indicated that the new decontamination values would result in unacceptably high radiation dose rates if the previous analysis radiation source term assumptions were used. However, a review of these assumptions revealed excessive conservatism in the amount of Emergency Core Cooling System (ECCS) recirculation loop leakage assumed in the Auxiliary Building area served by the PPAFES. The new calculations were performed with a significant reduction in the assumed ECCS leakage and, therefore, a substantially reduced radiation source term. The revised filter conditions in conjunction with the revised radiation source term assumption resulted in an overall reduction of the calculated offsite and control room radiation dose rates.

Technical Specification Changes

The following revisions were made to the Plant Vogtle Technical Specifications to reflect the new ESFAFS surveillance test requirements and provide a basis for the changes:

1. The CREFS heater surveillance test criterion was revised to reflect the lower heat dissipation needed to maintain the original 70 percent RH requirement. The previous test value of 118 kW ± 6 kW was changed to a minimum of 95 kW. The bases to this Technical Specification were revised to clarify that the verification of heater power dissipation for surveillance testing is referenced to 460 volts. This revision will provide verification that sufficient capacity is available under design bases accident conditions to meet the 70 percent relative humidity criterion without being overly restrictive. The charcoal laboratory test conditions remained at 70 percent relative humidity with an efficiency of 99.8 percent.

2. The PPAFES heater surveillance test criterion was revised from 80 kW ± 4 kW to a minimum of 65 kW. The Technical Specification bases were revised to clarify that the heater surveillance test is referenced to 460 volts. The bases were also revised to indicate that since no credit was taken for heater performance in the dose analysis, the heaters would remain in place to provide defense-in-depth. The charcoal lab test conditions were changed from 99.8 percent efficient at 70 percent relative humidity to 90.0 percent efficient at 95 percent relative humidity.

3. The FHBPAFS heater surveillance test criterion was revised from 20 kW ± 2 kW to a minimum of 16 kW. The bases to this Technical Specification currently reflect that no credit is taken for system operation in the safety analysis, and the system remains in place for defense-in-depth. The Technical Specification bases were revised to clarify that the heater surveillance test is referenced to 460 volts. The charcoal lab test conditions were changed from 99.8 percent efficient at 70 percent relative humidity to 90.0 percent efficient at 95 percent relative humidity.

V. Summary

ESF atmosphere filtration systems are designed to operate during accident conditions that can significantly affect the systems heater performance and thus filtration efficiency. In addition to assuming the maximum inlet air relative humidity, the heater selection criteria should also consider the following design basis accident conditions:

- Degraded electrical distribution system voltage.
- Highest allowable system flowrate.
- Accident condition heat loads (maximum inlet temperature).

When the heater selection process fails to consider these design basis accident conditions, the ESFAFS heater may not provide the required performance needed to maintain the filtration efficiency assumed in the plant accident analysis. When an existing system is found to have insufficient heater capacity to maintain the previously assumed filtration efficiency, several options to correct the deficiency are available:

1. Physically modify the heaters and/or the electrical distribution system to increase heater output.
2. Revise the charcoal filter efficiencies to be consistent with the increased relative humidity.

If deficient heaters and/or the electrical distribution system are not modified to increase heater capacity, the credited adsorber decontamination efficiency and charcoal laboratory testing criteria must be revised to reflect the potentially increased relative humidity. A new radiation dose analysis is then required to verify that the revised filter efficiency will not increase dose rates in excess of the established radiation exposure criteria.

References

1. Code of Federal Regulations, Title 10 - Energy, Part 100, "Reactor Site Criteria", (1991).

2. Code of Federal Regulations, Title 10 - Energy, Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants", Criterion Number 19 - "Control Room", (1991).

3. U.S. Nuclear Regulatory Commission, "Design, Testing, and Maintenance Criteria for Post Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants", Regulatory Guide 1.52, Revision 2 (1978).

4. The American Society of Mechanical Engineers, "Testing of Nuclear Air-Cleaning Systems", ANSI/ASME N510 (1980).

5. Vogtle Electric Generating Plant Units 1 & 2 Technical Specifications, Docket Nos. 50-424 & 50-425, Appendix A to License Nos. NPF-68 and NPF-81.

6. The American Society of Mechanical Engineers, "Nuclear Power Plant Air Cleaning Units and Components", ANSI/ASME N509 (1980).

7. The Institute of Electrical and Electronics Engineers, IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants, ANSI/IEEE Standard 141 (1986).

8. U.S. Nuclear Regulatory Commission, "Standard Technical Specifications for Westinghouse Pressurized Water Reactors", NUREG-0542, Revision 4 (1981).

9. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, "ASHRAE Handbook - 1981 Fundamentals."

10. American Society for Testing and Materials, "Standard Test Method for Nuclear-Grade Activated Carbon", ASTM D 3803 (1989).

11. Hayes, J.H., "Changes in adsorber testing as a result of NRC generic information." Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0116, CONF-900813, Vol. 2, pp. 607-625 (1990).

DISCUSSION

PORCO: 1) Was your radioiodine lab test velocity increased by 10% to simulate worst case? (40fpm +10%) Was your system (i.e., HEPA filter & charcoal adsorbers) designed for worst case (17,050 cfm vs 16,000)?

HAYES, T: 1) The lab test velocity was not increased. 2) Yes, the system filters remained within the design flowrate limits when the worst case conditions were considered.

WEIDLER: Did you revise your charcoal test method to be consistent with the new system conditions?

HAYES, T: Yes, we included a reference to the 1989 version of ASTM D3803 in our Tech. Spec revision at the NRC's request. We had no problems committing to the new test standard since we were already testing to the more stringent requirements based on the INEL study.

CONTROL ROOM INLEAKAGE TESTING USING TRACER GASES AT ZION GENERATING STATION

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Abstract

In order to assess the amount of air inleakage into the Control Room Envelope at Zion Generating Station (ZGS), a series of tracer gas tests using sulfur hexafluoride (SF_6) were performed on the Control Room ventilation system (PV system) and the Computer Room/Miscellaneous Area ventilation system (OV system) during February, 1991. Two redundant trains, denoted A and B comprise the PV system. Inleakage was measured for each train. An OV supply duct passes through the Control Room Envelope. Leakage from this duct into the Control Room would constitute air leakage into the Control Room Envelope and hence any potential leakage had to be quantified. Each test attempted to measure the contribution (if any) of a particular section of PV return duct or OV supply duct to the total air inleakage into the Control Room.

I. INTRODUCTION

A series of tracer gas tests were performed during February 1991 in order to quantitatively investigate the amount of air leakage into the Control Room Envelope at ZGS. Each test attempted to measure the contribution of a particular section of Control Room Ventilation System (PV) return or Computer and Miscellaneous System (OV) supply duct to the total air leakage into the Control Room Envelope. Figure 1 schematically illustrates the physical relationship of the PV ducting to the various levels within the plant. Note that much of the PV system return duct work is located outside the Control Room Envelope. Thus, inleakage into this portion is of potential concern in studies of Control Room Habitability. Figure 2 provides a schematic view of the OV duct work passing through the Control Room Envelope.

Testing was performed either by creating a homogeneous volume of tracer gas surrounding a run of return duct passing through one of the rooms shown in Figure 1 and sampling within the duct for the presence of tracer gas, or by injecting tracer at a constant rate into a run of duct and sampling within the volume surrounding the duct for the presence or absence of tracer gas.

The electronegative gas, Sulfur Hexafluoride (SF_6), was used as a tracer. This gas is generally recognized as non-toxic, non-reactive, and inert. Since it is easily detectable in minute quantities by means of electron capture gas chromatography, SF_6 is an ideal tracer gas for ventilation system performance investigations. Analytical sensitivity to this gas ranged from 10 parts per million to approximately 50 parts per trillion. Thus, for reasonable injection concentrations, dilutions on the order of 10,000 were easily measured. All tracer gas measurements were performed by means of gas chromatographic instrumentation manufactured for field use.

The testing of both the PV and OV systems was complicated by the existence of flow communication between the PV and OV air handling units both of which are located in the HVAC Equipment Room. Any leakage of air, and hence tracer, from the positive pressure section of the PV system would ultimately be picked up by the PV return and circulated through the PV system. In addition, during the OV system testing, tracer leakage out of the positive pressure portion of the OV system communicated with the negative pressure portion of the PV system which then circulated additional tracer to the Control Room. Thus extreme care had to be exercised in the performance of these tests.

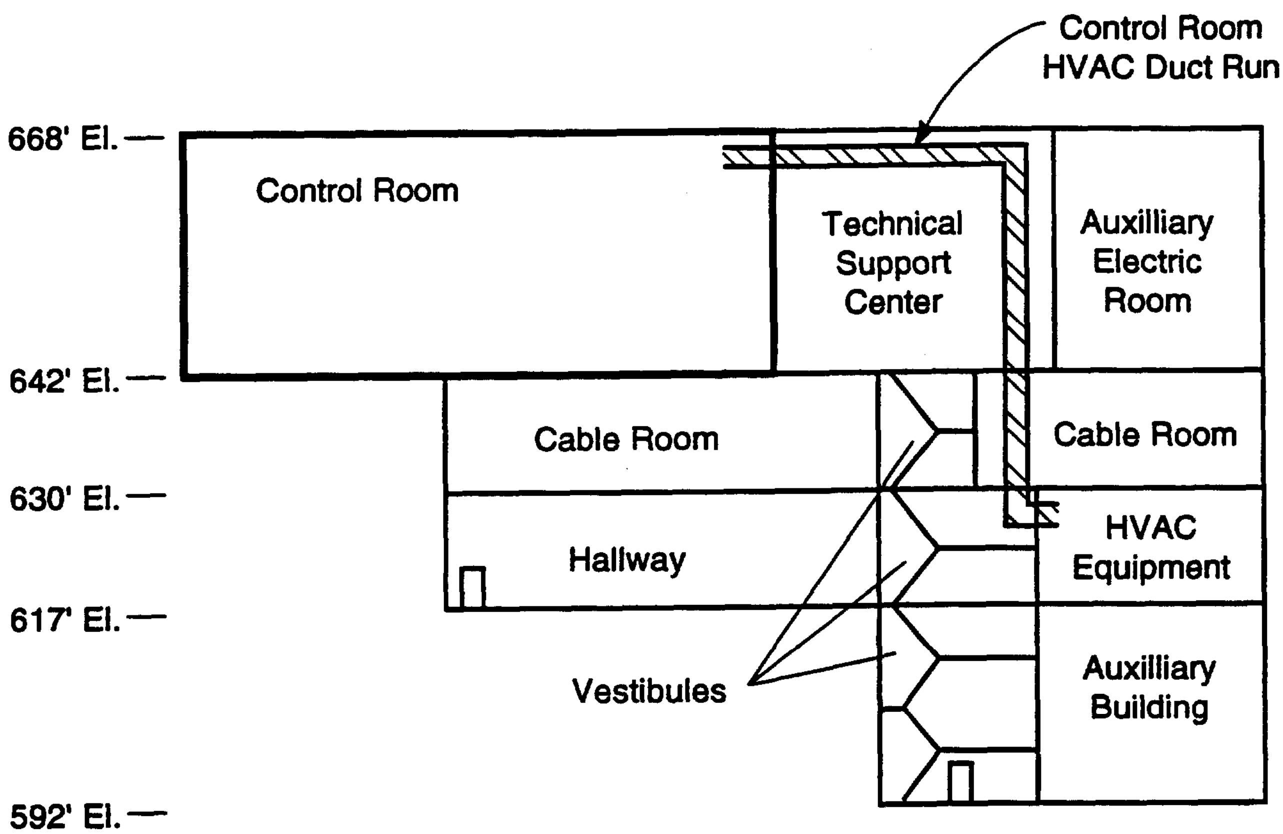

Figure 1. PV Duct runs through plant.

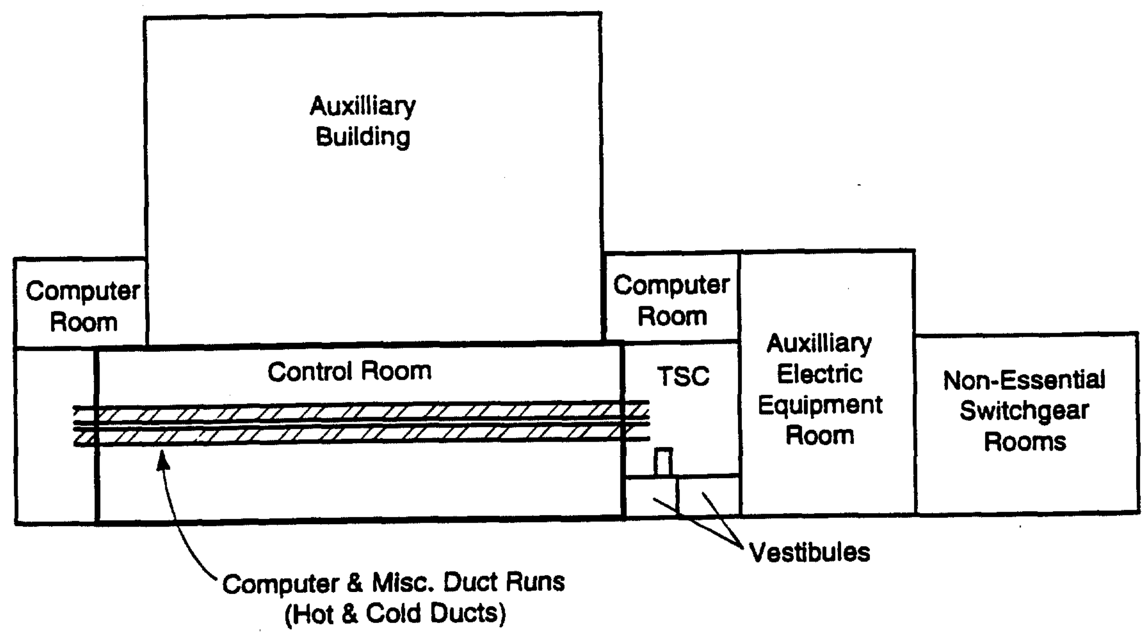

Figure 2. Schematic view of OV duct through Control Room Envelope.

II. TRACER GAS TESTING

The use of a tracer gas(es) to investigate the flow, migration and dispersion of potentially harmful, noxious, or toxic gases and vapors is well established within the industrial hygiene, indoor air quality, and ventilation engineering communities (1,2,3). During the last few years tracer testing results specific to concerns within the nuclear industry have appeared in the literature (4,5). In simplest terms, tracer gas testing provides a means to document the actual performance of an operating ventilation system by tagging and unambiguously tracing one or more ventilation induced flows. This is done by introducing easily measurable, inert, non-toxic, non-reactive gases that are not part of the common industrial background.

The theoretical interpretation and experimental detail necessary to undertake tracer gas testing of complex ventilation systems is provided in the five prior references and will not be discussed further. Application of the principles of mass conservation to tracer injection and tracer measurement conditions allows quantitative information to be obtained on the performance of actual operating ventilation systems.

III. CONTROL ROOM INLEAKAGE TESTING

In order to characterize the amount of inleakage into the Control Room Envelope tracer gas tests were undertaken on six different segments of the Control Room ventilation system. Each test attempted to measure the contribution of a particular section of PV return or OV supply duct to the total air leakage into the Control Room Envelope. With the exception of the OV supply duct test, two tests were performed for each section of duct work--one with the A Train operating and one with the B Train operating. In each test, tracer gas samples were obtained by means of penetrations through access doors in the supply and return ducts located in the Cable Spreading Room.

As a part of each of these tests the PV system supply and return flow rates were measured in the supply and return ducts passing through the Cable Spreading Room using a hot wire anemometer. Duct flow data were taken immediately prior to the initiation of each tracer test. Also, before each test the pressures within the Control Room and the Auxiliary Building were also recorded. These are provided in Table 1.

In the following, the testing on the various portions of the PV return or OV supply ducting is described. A simplified schematic of the Control Room PV system is provided in Figure 3. For convenience, each test sequence is described individually. Inleakage data obtained during each sequence is provided for those portions of ductwork where testing was possible.

IV. HVAC EQUIPMENT ROOM DUCT INLEAKAGE

The negative pressure section of PV duct within the HVAC Equipment Room was tested. Tracer was injected over a 2 minute period at multiple locations within the HVAC Equipment Room. A number of portable fans were used to mix the tracer to assist in homogenizing the tracer concentration. Concentrations were measured at 5 locations within the HVAC Equipment Room. By measuring the average concentration of tracer within the room as well as the tracer concentration within the supply and return ducts it is possible to calculate the inleakage into the PV system using a mass balance equation. Figure 4 illustrates the flow paths for the PV inleakage test.

Table 2 provides measured tracer concentration data and calculated inleakage rates. As can be seen the A Train data at 5, 6, 7, and 8 minutes yield an approximately constant inleakage rate. One can see a similar trend in measurements for the B Train. Thus, for both the A and B Train tests, the data from 5, 6, 7, and 8 minutes have been averaged to provide an estimate of the inleakage. Data obtained at later times were inconsistent due to flow communication between the PV and the OV system.

V. PURGE PLENUM INLEAKAGE

The PV/OV normal outside air intake duct was tested. For each test a tracer gas concentration was established within the Purge Plenum surrounding the PV return duct. Two fans were located within the plenum to ensure adequate mixing. Gas samples within the plenum were obtained by means of a recirculating pump. This allowed samples to be obtained from within the plenum without having to enter it and possibly alter the tracer concentration.

During an initial test, the tracer concentrations obtained in the PV supply and return ducts were much higher than expected implying the existence of a very high inleakage rate into the section PV return duct located within the purge plenum. It was also observed that the concentration within the Purge Plenum itself decayed rapidly

TABLE 1

Pressure Measured During Testing

Test	Auxiliary Bldg Delta P	Control Room Delta P
TSC-A	-0.125	+0.10
TSC-B	-0.250	+0.05
Vestibule-A	-0.35	+0.05
Vestibule-B	-0.25	+0.025
HVAC-A	-0.10	+0.125
HVAC-B	-0.20	+0.07
Purge Rm-A	-0.15	+0.25
Purge Rm-B	-0.15	+0.10
CS Rm-A	-0.35	+0.10
CS Rm-B	-0.30	+0.05
OV CR Flow	-0.10	+0.15

Pressures in Inches of Water Gauge with Respect to Atmosphere

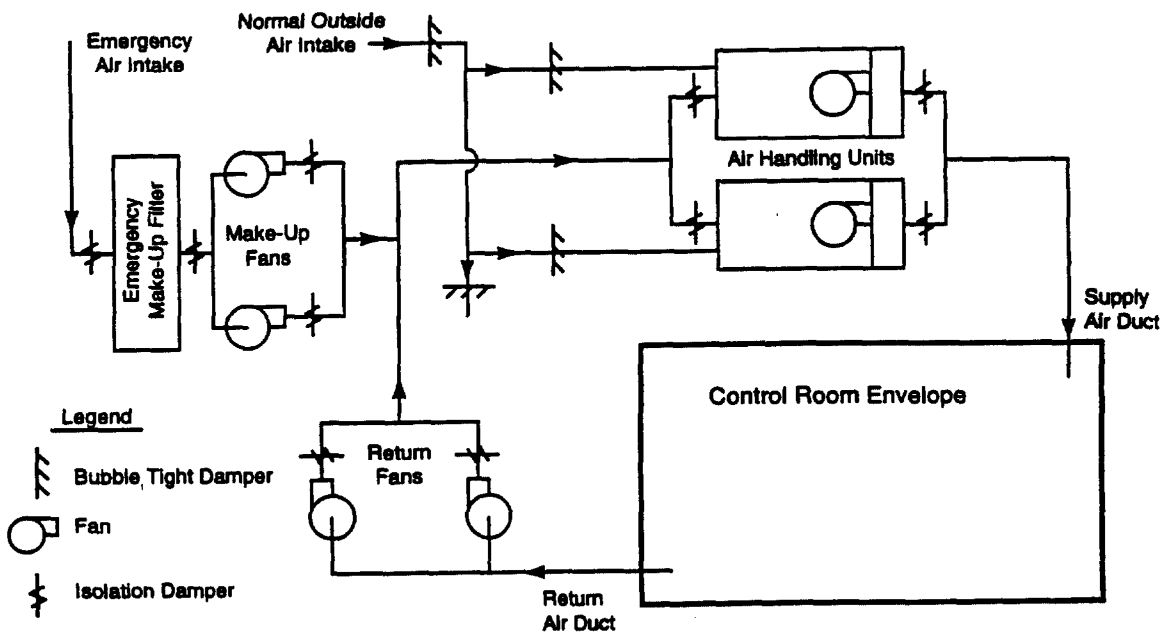

Figure 3. Schematic of Control Room PV system.

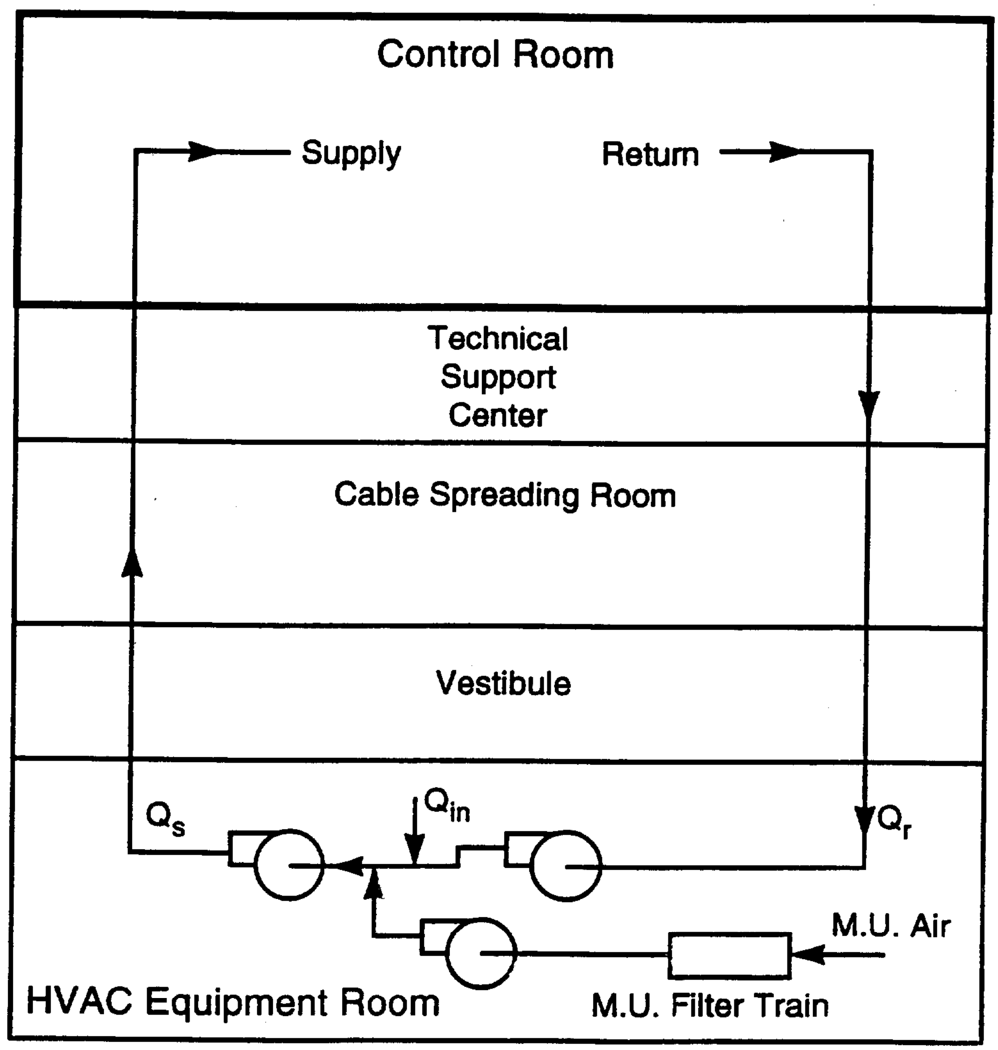

Figure 4. Flow Paths for PV Inleakage Test

TABLE 2

HVAC Equipment Room
PV Duct Inleakage

A Train

Time	Room Conc. (ppb)	Supply Conc. (ppt)	Return Conc. (ppt)	Flow (CFM)
5	30.0	500	92	153
6	28.3	460	92	147
7	26.7	460	118	147
8	25.2	480	120	164

Inleakage Estimate = 153 ± 11 CFM

B Train

Time	Room Conc. (ppb)	Supply Conc. (ppt)	Return Conc. (ppt)	Flow (CFM)
5	35.3	410	32	112
6	31.3	435	67	125
7	27.8	410	90	124
8	24.7	375	140	122

Inleakage Estimate = 121 ± 9 CFM

TABLE 3

Purge Plenum Duct Leakage

A Train

Purge Plenum Conc. (ppb)	PV Supply Conc. (ppt)	PV Return Conc. (ppt)	Inleakage (CFM)
640	520	225	5.5

B Train

Purge Plenum Conc. (ppb)	PV Supply Conc. (ppt)	PV Return Conc. (ppt)	Inleakage (CFM)
550	670	400	6.5

TABLE 4

OV System Leakage into Control Room

Time (min)	Average CR Conc. (ppb)	PV Supply Conc. (ppb)	PV Return Conc. (ppb)	OV Supply Conc. (ppm)	Control Room Inleak (CFM)
15	38.0	12.5	25.0	3.0	115
20	56.3	24.0	27.0	3.0	134

OV System Leakage = 124 $\pm$ 10 CFM

Measured Make-up Flow = 1700 CFM
Measured PV Return Leakage = 153
Total Infiltration Leakage =1853

again implying a very high leakage rate. Additional investigation was undertaken at which time it was discovered that a substantial unsealed penetration existed between the Purge Plenum and the HVAC Equipment Room where the PV duct passed through the HVAC Equipment Room wall. This opening was approximately 2 inches wide and at least 48 inches high. Subsequent testing demonstrated that substantial tracer migrated through this opening almost immediately upon initiation of a test.

Because of this substantial inleakage it was felt that only the "first arrival" measurement of supply and return concentration could provide a realistic estimate of the inleakage in this section of PV duct. Data for both tests are provided in Table 3. These values represent a crude estimate due to the fact that the rapidly increasing tracer concentration within the HVAC Equipment Room affected the measured concentrations within the supply and return duct due to inleakage. However, the estimate is probably good to within a factor of 2.

VI. OV DUCT LEAKAGE INTO CONTROL ROOM ENVELOPE

The OV system positive pressure duct passing through the Control Room Envelope was tested. For this test, tracer gas was injected into the OV supply duct immediately upstream of the A OV supply fan within the HVAC Equipment Room. Two different tests were undertaken. The first was undertaken to establish the existence of any possible leakage from the OV system into the Control Room without regard for quantifying the amount of leakage. This test was performed by injecting tracer into the OV supply duct and sampling by means of a battery operated pulse pump to fill 5 liter Mylar sample bags. The pump was connected to a stainless steel sample wand. This wand was passed over one joint of the OV duct at a time during which a sample bag was filled. The finding of tracer in several these bags demonstrated the existence of OV duct leakage into the main Control Room and necessitated a second OV system test.

For the second test a number of fans were used to mix any tracer gas entering the Control Room Envelope. Tracer was injected into the OV supply duct at a constant rate and air samples were obtained at three locations within the Control Room as well as from the PV supply duct, the PV return duct, and the OV Supply Duct immediately upstream of the OV supply fan. The OV system A Train was chosen for testing due to its evidencing higher static pressure. This test was limited in time due to the discovery of substantial external flow communication between the OV and the PV air handling units which are both located within the HVAC Equipment Room. This external flow communication resulted in the PV system supplying tracer to the Control Room along with the OV system. This occurred by means of PV return system inleakage picking up and then circulating tracer leaked into the HVAC Equipment Room by the OV supply system. Accordingly, the tracer concentrations within the PV supply and return ducts were monitored with an eye toward terminating the test when this flow communication occurred.

Tracer concentration data along with OV leakage into the Control Room are provided in Table 4. The tracer concentration data were analyzed as follows. For this test both the make-up flow rate (by measurement at the emergency make-up filter unit) and the inleakage rate (from the PV test) are known. As such these comprise the total infiltration or dilution air. Now, since the volume of the Control Room is also known, it is possible to calculate an inleakage rate into the Control Room even though the tracer concentration is not in steady state. So long as the Control Room can be considered a well mixed zone, it is possible to use the mass conservation equation to calculate an inleakage rate.

As can be seen, the data points at 15 minutes and 20 minutes are approximately equal. Accordingly, these two values provide an estimate of the OV supply duct leakage into the Control Room. The scatter in these two numbers also provides an estimate of the uncertainty in the measurement.

VII. VESTIBULE PV RETURN INLEAKAGE

The negative pressure PV duct in the vestibule outside the HVAC Equipment Room was tested by erecting temporary visqueen tent around the ductwork. Tracer was injected into the visqueen tent and mixed for 5 minutes by shaking the walls of the tent. After an initial test determined that samples from different locations within the tent gave similar concentration decay rates, samples were drawn at a single location within the tent as well as from the PV supply duct, the PV return duct, and within the HVAC Equipment Room itself. The tracer concentration data obtained from samples within the supply and return duct could not be interpreted in terms of a duct inleakage since it was demonstrated that substantial tracer gas leakage (and hence, flow from the tent) occurred into the HVAC Equipment Room almost immediately upon initiation of the test. Accordingly for this test, the best that could be done was to estimate the total inleakage by assuming that the decay in tracer concentration within the vestibule tent was totally due to inleakage into the PV return duct within this tent. Using the concepts embodied in the tracer dilution measurement technique (ASTM Standard E741) concentration decay rates and leak rates shown in Table 5 were obtained.

VIII. TSC DUCT INLEAKAGE

The negative pressure PV duct in the vertical chase up to and including the duct in the ceiling of the TSC was tested. For this test tracer gas was released within a temporary visqueen tent which surrounded the PV return ductwork within the TSC. Tracer gas concentration was sampled from the tent as well as from the PV supply and return ducts. An initial test disclosed unreasonably high inleakage rates.

Upon investigation a substantial leakage from the tented volume within TSC into the Cable Spreading Room and thence into the HVAC Equipment Room was discovered. Hence, it was not possible to perform a meaningful inleakage test on this portion of duct work.

IX. CABLE SPREADING ROOM INLEAKAGE

The negative pressure PV duct located in the Cable Spreading Room was tested. at the access door portion of the duct. A small visqueen tent was erected around the access door. Tracer was injected into this tent and homogenized by oscillating the tent wall. Tracer concentrations were measured in the tent and in the return duct. The resulting data were analyzed as a concentration decay test as per ASTM E741. Results for both the A and B Train are shown in Table 6.

X CONCLUSIONS

It should be noted that the testing of both the OV and PV system were complicated by the existence of external flow communication between the PV and the OV system within the HVAC Equipment Room. The ability to take early time discrete samples in the supply and return ducts allowed data to be obtained which were consistent.

Table 7 provides a summary of the total inleakage into the Control Room Envelope as a result of the PV return system and the OV supply system. The significance of these data is that they represent *measured* inleakage rates which can be used in Control Room Habitability analyses in place of engineering assumptions. To our knowledge these are the first published data on Control Room Envelope Inleakage rates obtained under actual operating conditions.

Note that the measurements provided in Table 7 do not include an estimate for leakage of the duct run extending from the floor of the TSC to the ceiling of the TSC, as duct leakage in this run could not be measured due to floor leakage between the TSC and the Cable Spreading Room.

Based on the magnitude of the measured inleakage rates enhanced maintenance was undertaken in order to reduce inleakage into the Control Room Envelope. Additional tracer testing is planned to document any reduction of inleakage achieved by the enhanced maintenance. This maintenance effort is ongoing.

XI. REFERENCES

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TABLE 5

Leakage of Vestibule Portion of PV Return Duct

A Train

Time (min.)	Concentration (ppb)
10	14
13	3.55
16	1.52
19	0.85

I = 18.5 ACH

Inleak = I x VOL

= 15.4 CFM

B Train

Time (min.)	Concentration (ppb)
9	65
12	28.5
15	14
18	7.7

I = 14.2 ACH

Inleak = I x VOL

= 12 CFM

TABLE 6

Cable Spreading Room Duct Leakage

Train	Enclosure Conc. (ppb)	Return Duct Conc. (ppt)	Return Duct Flowrate (CFM)	Inleakage Rate (CFM)
A	650	75	8999	1.04
B	1900	263	8791	1.2

TABLE 7

Total Unfiltered Leakage

Source	A Train Inleakage (CFM)	B Train Inleakage (CFM)
TSC	N.M.	N.M.
Cable Spread Access Door	1	1.2
HVAC Equipment Room	153	121
Purge Plenum	5.5	6.5
Vestibule	15.4	12
OV Leakage	124	124
Total Unfiltered Inleakage	299*	265*

* Rounded to Nearest Whole Number

N.M.--not measured

DISCUSSION

WEIDLER: That was a pretty high leak rate that you found. What did the utility do to repair the leaks after you found them?

LAGUS: All of the access doors and other closures were regasketed, number one, and number two, many of them were then sealed with an elastomeric sealer. After the doors were sealed, a change in procedure was instituted so that when the doors needed to be opened for access, you would have to break this nice seal. Then it was required that they be resealed. Joints in the ductwork were sealed with an appropriate sealer. All of the expansion boots, both supply and return on the A and the B trains, were replaced with new material and then sealed with elastomeric compounds because every one exhibited a greater or lesser degree of in-leakage.

WEIDLER: Was there a retest?

LAGUS: Yes, there was a retest and the results were much, much better than 50% by the time everything was done. There was a significant improvement across the board by undertaking this preventive maintenance activity.

PARKER, W.: I am wondering how your results compare to any assumptions that you might have made?

DUBOIS: The focus of the paper is not on that work, we were working with the NRC. We just wanted to give our test results. We reduced leakage to gain a greater tolerance.

MILATOVIC: Prior to this test, were these gaskets maintained as required. Was the leakage due to aging? Did you find the leakage by a test, without previous knowledge of it?

DUBOIS: The gaskets on these parts were installed prior to TMI. We have replace the doors and we have upgraded the doors on our air handling units. It sounds like the gaskets were leaking badly but we found the bigger leaks in the expansion boots. That was a major contributing factor. We used smoke pencils to identify where the leakage was; basically, by following air currents. Any area that we could get to with smoke pencils, we tested. When we found a leak, we repaired it. We had replaced gaskets after the first test, but I was not satisfied with the gasket replacement. The doors in the air handling units are not the bulkhead type, so we decided to use the elastomeric sealant on them also.

MILATOVIC: The reason I asked is because from my experience these gaskets only last 3 to 5 years. They have to be replaced whether you open the door or not and that is why it is so important for the safety of your handling units. When you install gaskets, you have to design them for the particular door, otherwise you are just wasting your time, leakage will occur.

DUBOIS: I agree to that.