

*Fast Breeder Test Reactor:  
A nuclear facility at Kalpakkam*

# Ventilation of Nuclear Facilities - AN OVERVIEW

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This article highlights experience in ventilation of nuclear facilities at IGCAR, Kalpakkam. It focuses upon the importance of ventilation in nuclear establishments. It deals with zoning concept and negative pressure once-through systems of nuclear laboratories. It describes different ventilation requirements of three major types of facilities like fume hoods, glove boxes, and hot cells.

Ventilation systems play a vital role in nuclear establishments. Nuclear establishments include facilities like atomic power stations - thermal and fast reactors, nuclear laboratories, post irradiation examination (PIE) facilities, spent fuel reprocessing plants and waste management plants. Generally, the main objective of air conditioning and ventilation systems is to control temperature, humidity and particulate matter concurrently giving air changes. In

nuclear facilities, temperature and humidity control is the same as in conventional systems. Temperature is controlled by a cooling coil while humidity is controlled by sensible heating with a control humidistat. In addition to the temperature and humidity control, the main challenge is to limit the radioactive contaminants to the prescribed level. The radioactive materials used in these nuclear facilities release alpha ( $\alpha$ ), beta ( $\beta$ ), gamma ( $\gamma$ ) rays, x-rays and neutrons, which are harmful to human

## About the Authors

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Hot cell for reprocessing of spent fuel: Typical red zone

beings. Hence, the radiation has to be confined. This is known as contamination control. Contamination control may be achieved by means of physical and dynamic barriers. The physical barrier includes concrete structures, fume hoods, glove boxes while a dynamic barrier is provided by a ventilation system with particular flow pattern and filters. Normally, negative pressure is maintained in the ventilated area of nuclear facilities to avoid proliferation of air from radioactive areas to the atmosphere in case of accidental opening of an enclosure.

### General Concepts

The ventilation system supplies fresh filtered outdoor air to working areas and also maintains temperature and relative humidity. Normally, the plant is designed on a once-through basis. Directional flow of air is maintained from areas of least contamination to that of higher contamination level. Radioactive facilities need a number of air changes to dilute the contamination level in addition to the oxygen requirement. The exhaust air should be filtered before it is discharged to the atmosphere through a stack.

Generally, the air quantity is decided by the number and size of installed radioactive containments in the facility and also dilution ventilation for radioactive contamination control. Sometimes, removal of heat from the areas plays a predominant role for calculating the fresh air quantity, similar to the conventional cooling load calculation.

The facilities intended for working under high levels of radioactivity are equipped with ventilation connections for containments like glove boxes, shielded boxes and hot cells. Lower air pressure is maintained in the containments to avoid air flow from the radioactive material to the working personnel.

Accidental conditions must be considered while designing the plant. Provision of a standby system is a must to take care of ventilation in case of breakdown of a running unit. Provision of a diesel generator set in the event of failure of the normal power supply is a prerequisite for designing air conditioning of nuclear buildings. Also, the system is to be designed to prevent the spread of fire. In the event of any fire incident in a zone, the zone is isolated by activating fire dampers.

Both dedicated and centralized air conditioning systems are in use.

### Dedicated

Individual rooms, hoods or buildings have an exhaust fan and a stack.

### Centralized

Large paired fans are installed at a central location and the rooms, hoods or buildings are connected to the fans through large exhaust ducts. For a high level radioactive plant, a centralized system is more suitable. A high stack and advanced monitoring systems, necessary for modern radioactive facility plants also favour a centralized system. The pressure balance between the different zones is easier to maintain in a centralized system, because constant pressure can be kept in the main exhaust duct. The air balance is not jeopardized by disturbances of individual fans or clogging of individual filters.

When a reduction of operating cost is to be achieved by reducing air flow during non-working hours, a centralized system is more convenient, since reduced flow can be achieved by speed regulation or by varying the number of fans in operation or by operating zonal dampers.

The operation philosophy of a radioactive zone is that the radioactive contaminants should not come out to the environment. To achieve this condition, the pressure inside the ventilated area should always be non-positive. For starting the ventilation system in such an area, the exhaust blower should be started first, followed by the supply blowers to avoid creating a positive pressure inside the area. On the other hand, for a similar reason, the supply blower should be switched off first in case of a shut down.

Since supply blowers are situated in a non-radioactive area and have 50% stand by, maintenance may be carried out by shutting down and isolating a particular system. But in the case of exhaust blowers, the blowers are installed in the downstream of the ventilation path. So, there is a chance of getting contamination. Two-stage filters are used to entrap the contaminated dust before the exhaust blowers. The exhaust blowers have 100% standby and they are physically separated from each other in separate manifolds. For maintenance of any exhaust manifold, the blower is to be shut down and radioactivity measured by health physics personnel. Based on this study, the maintenance personnel are permitted with protective clothing.

### Zoning Concept

Zoning is a very important concept for designing ventilation systems for a nuclear building. Four zones are considered for nuclear ventilation viz; red, amber, green, and white. Red zone is the core area where radioactive contamination sources are present and no access is permitted in normal course. Protective clothing is a must for working in this area.

Amber zones are areas adjacent to red zones, where there is a likelihood of contamination due to close proximity to the red areas. Here, personnel can normally work. Green zones are areas adjacent to amber areas, where no radioactive materials or contamination are present. Here, personnel can normally work

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without respiratory protection equipment.

The white zone is a non-radioactive area where probability of contamination is considered comparable to normal areas involving regular public movement. Access to these areas is free for the plant personnel. This zone is normally provided with a recirculatory AC&V system.

### Air Filtration

Inlet air is to be filtered to prevent spread of contamination borne by dust particles. Normally, a two-stage filtration system is used in the intake manifold. The filtration system reduces dust accumulation in working areas and also reduces the dust concentration on the exhaust High Efficiency Particulate Air (HEPA) filters. Otherwise, dust concentration increases pressure drop on exhaust HEPA filters and the exhaust HEPA filter will be clogged in a very short time. Fresh air intake should be positioned such that possibility of dust ingress is minimum and there is no short circuit with any exhaust system. A lawn outside the supply fan room is recommended.

Exhaust air filtration is a must to minimise release of air borne contaminants to the atmosphere. Here also, two-stage filtration is provided. HEPA filters are used finally in an exhaust system.

To avoid leakage of dust from the ducts and filter housings, the filters should come before the exhaust fans. It also helps to keep the filter housing at negative pressure. The fan is free of radioactive dust which facilitates maintenance work. The final filters should be installed in a separate room, preferably a fire proof design.

A typical flow diagram of a ventilation system is shown in Figure 1

### Fire Protection

Since nuclear buildings are vulnerable to fire hazards, certain steps are followed to prevent fire hazard/ propagation in a ventilation system.

- The ventilation system is to be constructed of fire resistant materials. Filters may be wrapped with wire mesh (screen).
- Fire dampers shall be introduced in ducts. Shut off dampers and or back-flow preventors may be used in the supply air system to prevent spreading of fire.
- Fire alarm, fire suppression equipment and dampers are to be used to restrict the fire.
- The filter bank area is to be isolated with suitable fire barriers having minimum two hours of fire rating to ensure the availability of filter banks in case of fire in an adjacent area.
- Heat/ smoke detectors are to be provided wherever fire or an explosion hazard exists.
- Fixed fire extinguishing system with an appropriate media is to be provided.
- Water for fire extinguishing system is a must, through loop distribution encircling the building. There should be two fire water pumps (1 running + 1 standby). At least one should be non-electric power driven pump. Electrically driven pump should have emergency power supply in case of normal power failure.
- Spark arrestors should be used to protect the filters from

sparks that might reach them.

### Physical Barriers

Different physical barriers are used for controlling the radioactive contamination. We shall discuss four such barriers in this article.

#### Ventilation of fume hoods

Fume hoods are used when the contamination and external exposure hazard of radioactive material being handled is low. Fume hoods are constructed of PVC, fibreglass with polyester or epoxies, MS and SS based on functional requirement. The controls for all services like power, water, gas etc. are kept outside the fume



Figure 2: Fume hood

hoods to minimize the size of the hood. Services are available inside by means of duct work/ piping. Materials are handled through openings in the fume hoods. The working personnel are protected by directional air movement (from the operator towards the material due to negative pressure inside the fume hood) through the opening. Ventilation of fume hoods is of once-through type, and air will be sucked from the laboratory area and exhausted back through a two-stage filtration system including HEPA. After the first stage filtration the exhaust air is mixed with the exhaust air coming from the rest of the areas, then passed through the area filter bank and finally released to stack. Figure 2 shows a typical fume hood.

#### Ventilation of glove boxes

A glove box is a leak tight enclosure where the radioactive material is manipulated in isolation. This manipulation is effected through gloves fixed to the ports in the walls of the box. The glove boxes are used for handling alpha ( $\alpha$ ) and beta ( $\beta$ ) emitting radioactive materials. Leak tightness of the glove box is to the tune of 1% of the box volume per hour. The material of construction is either MS or SS.

When reactive and irradiated fuel material like carbide fuel is handled in a glove box, an inert gas atmosphere of Argon gas and box pressure of 25 mm Wg (-ve) w.r.t. surrounding pressure of glove box are provided. Generally, a glove box exhaust system is designed in



Figure 3: Glove box

hoods to minimize the size of the hood. Services are available inside by means of duct work/ piping.

Materials are handled through openings in the fume hoods. The working personnel are protected by directional

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such a way that in case of rupture of the glove box, air will not come out. The suction pressure of the exhaust system is sufficient to pull out the contaminants in case of an accident. The glove boxes may be provided with a controlled atmosphere depending on the nature of material handled for processing. On the other hand, when non-radioactive material (like Sodium) is handled in a glove box, Argon gas is used (Sodium reacts with Oxygen in the air. Argon acts as an air isolator.). The inside pressure may be 25 mm Wg (+ve) w.r.t. surrounding pressure of glove box. Glove box ventilation arrangement is once through type with three stages of HEPA filtration. For safety and redundancy purpose, 100% standby arrangement is provided. Figure 3 shows a typical Glove box.

### Ventilation of shielded box

A shielded box is an air tight enclosure. The biological shield of the box is constructed from high density concrete, steel or lead. Lead is used in the form of bricks, blocks or as filling for MS fabricated casing.



Figure 4: Shielded box

Shielded boxes are used in nuclear facilities when alpha (α), beta (β), gamma (γ) and neutron activity material is being handled. Services like compressed air, vacuum, lighting, electrical power supply, instrumentation and drainage are provided through the shielding.

The inner system for the shielded box is similar to that of a glove box. The space between the containment box and shielding should be connected to a separate exhaust system so that the shielding may become a secondary containment. Figure 4 shows a shielded box.

### Ventilation of hot cells

A hot cell is an enclosure in which highly radioactive materials

are handled in isolation from the operator's environment. This enclosure is a permanent feature of any nuclear facility. There are two types of hot cells:

a) Beta (β), gamma (γ) hot cells: Used for carrying out the post irradiation examination (PIE) of irradiated oxide fuels and reprocessing of irradiated oxide fuels.

b) Alpha (α), beta (β), gamma (γ) hot cells: Used for carrying out post irradiation examination of irradiated carbide fuels. These alpha (α), beta (β), gamma (γ) hot cells are linked with stainless steel (SS) lining inside the shielded concrete cells and viewing windows are provided with a sealing glass plate. The maximum allowable leak tightness of hot cells is 0.1% of cell volume per hour.

Once-through ventilation system with inert gas atmosphere is provided for hot cells where the requirement of purity level of the inert gas atmosphere is high and volume of gas required is low. Recirculatory inert gas ventilation system is provided where inert gas volume requirement is also high.

### Supply Air Quantity

Supply air quantity required for ventilation is based on the heat to be removed.

Heat content to be removed from the ventilated space is computed.

Air quantity in m<sup>3</sup>/h may be calculated using the basic heat formula:

$$Q = m \cdot C_p \cdot \Delta t \quad (1)$$

$$\text{As } m = V \cdot \rho$$

$$\text{Therefore } Q = (V \cdot \rho) \cdot C_p \cdot \Delta t$$

Where Q = Heat content to be removed, kcal/h

V = Volume flow rate, m<sup>3</sup>/h

ρ = density of air, kg/m<sup>3</sup>

C<sub>p</sub> = specific heat of air at constant pressure, kJ/kg °C

Δt = difference in temperature, °C = (t<sub>r</sub> - t<sub>s</sub>)

Then, air changes per hour = (quantity of air in m<sup>3</sup>/h) / (room volume in m<sup>3</sup>)

### Dilution ventilation system design

The basic technique of dilution ventilation is to supply large volumes of filtered outdoor air or filtered and conditioned air to

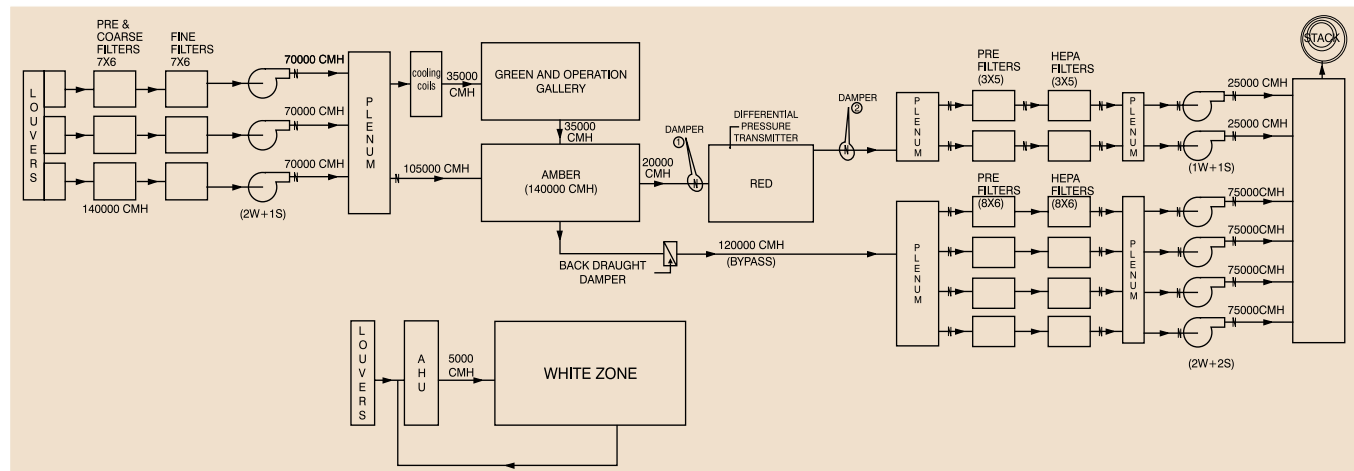


Figure 1 : A typical flow diagram of a ventilation system in nuclear facilities

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flush or dilute the air inside a working area. Dilution ventilation reduces the air borne contaminants to acceptable levels prior to reaching the breathing zone of the workers or unrestricted release to the atmosphere. Dilution ventilation is characterized in terms of volume per unit time or in air changes per hour. One air change is equal to the volume of the room. The air changes per hour for each zone of the nuclear facility are based on the Health Physics practices and experience. Relevant standards and guide lines like ICRP, IAEA and AERB are being followed in deciding the air changes per hour for nuclear facilities.

Air changes per hour (ACH) is a value representing the number of times each hour that an enclosure's total volume of air is exchanged with fresh or filtered air. For example, the ACH is about 10-15 for red zone. An air change doesn't represent a complete change of all air in the enclosure or structure. The actual percentage of an enclosure's air which is exchanged in an air change period depends on the airflow efficiency of the enclosure and the methods used to ventilate it.

Dilution ventilation is based on rate of activity generation and maximum permissible concentration in room air.

Annual limit of intake (ALI) is the maximum amount of intake of radioactivity for any radionuclide. The unit is represented as Bq.

ALI for any radionuclide is specified in ICRP guides

Radionuclide	ALI, Bq
I-131	2 x106
Pu	300

Derived Air Concentration (DAC) for any radionuclide is that concentration in air, expressed in Bq / m<sup>3</sup> which if worked in for a year would result in one ALI.

$$\text{DAC} = (\text{ALI}) / (\text{Volume of air breathed in a year at work}) \quad (2)$$

The normal breathing rate, based on reference man, is 2400 m<sup>3</sup> per year at work.

$$\text{DAC} = (\text{ALI}) / 2400$$

AERB Safety guideline on Ventilation requirement indicates that ventilation shall reduce the DAC to (1/10) of DAC in any personnel working area.

DAC based on ALI for Pu radionuclide may be derived as shown below:

$$\text{DAC} = (300 / 2400) = (0.125)$$

$$\text{DAC for Pu radionuclide is } 0.125 \text{ bq/m}^3$$

A factor of 10 is normally used on DAC to be on safe side. Hence, for Pu radionuclide, the ventilation shall reduce the concentration to (1/10) of DAC i.e. 0.0125 Bq/m<sup>3</sup>.

Air quantity required for a ventilation system may be derived by dilution ventilation method based on rate of activity generation and maximum permissible concentration in room air. In equilibrium condition, the rate of activity generation in the space is exactly equal to the rate of removal of activity.

$$G = q \times C / K \quad (3)$$

G = rate of activity generation, Bq/h

q = actual quantity of air to be exhausted, m<sup>3</sup>/h

K = Distribution coefficient to account for incomplete or

imperfect mixing, K varies from 3 to 10.

C = allowable concentration normally taken as (1/10) of DAC (e.g. 0.0125 Bq/m<sup>3</sup> for Pu)

### Conclusions

This paper presents an overview of nuclear ventilation systems. Ventilation systems in a nuclear facility are normally once-through systems. Zoning concept is used to separate the different activity areas. Directional flow of air is maintained as a dynamic barrier to the spreading of radioactivity. In addition, physical barriers like fume hood, glove box, shielded box and hot cells are used for containment of radioactivity. Accidental conditions like rupture of containment are to be thought of while designing of a ventilation system. Filtration is an important part of ventilation of nuclear facilities. On the inlet side it uses two-stage air filtration; first stage with course filters/ pre-filters followed by High Efficiency Particulate Air (HEPA) filters. Fresh air intake should be positioned such that dust is minimized and chance of contamination is reduced. Similarly, HEPA filters are used on the exhaust system to avoid ingress of contaminated dust into the atmosphere.

Supply air quantity is derived by dilution ventilation method, in addition to the conventional heat removal method. Higher quantity of the above two is taken as design value. Personal and environmental safety, controlling temperature and humidity and fire control features play a very important role in designing ventilation of nuclear buildings.

### Nomenclature

C <sub>p</sub>	specific heat (kJkg <sup>-1</sup> K <sup>-1</sup> ) at constant pressure
G	rate of activity generation (Bq m <sup>-3</sup> )
K	distribution coefficient
m	mass flow rate (kg)
q	air quantity (m <sup>3</sup> h <sup>-1</sup> )
Q	heat flow rate (kJ)
t	temperature (°C)
V	volume flow rate (m <sup>3</sup> h <sup>-1</sup> )

### Greek letters

ρ	density of air (kgm <sup>-3</sup> )
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### Subscripts

r	room air
s	supply air

### Acronyms

ACH	Air Change per Hour
AC&V	Air Conditioning and V entilation
AERB	Atomic Energy Regulatory Board
ALI	Annual Limit of Intake
DAC	Derived Air Quantity
HEPA	High Efficiency Particulate Air (filter)
IAEA	International Atomic Energy Agency
ICRP	International Commission of Radiological Protection
MS	Mild Steel
PIE	Post Irradiation Examination
PVC	Poly Vinyl Chloride
SS	Stainless Steel

