

Ventilation of Glove Boxes in Nuclear Applications

Glove boxes in a nuclear facility in Kalpakkam

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Abstract

A glove box is a leak tight enclosure where the radioactive material is manipulated in isolation. This manipulation is effected through gloves fixed to ports in the walls of the box. Glove box ventilation system is designed in such a way that a negative pressure is always maintained inside to avoid spillage of radioactive contaminants into the operating area. The suction pressure of the exhaust system is sufficient to pull the contaminants in case of rupture of gloves.

Introduction

Ventilation system plays a vital role in nuclear establishments. The radioactive materials used in nuclear facilities release alpha (α), beta (β) and gamma (γ) rays, x-rays and neutrons, which are to be confined since they are harmful to human beings. The main challenge of the ventilation system is to limit the radioactive contaminants within the prescribed limits, in addition to the general objective to control temperature, humidity and particulate matter. This contamination control may be achieved by means of physical and dynamic barriers. The physical barrier is achieved by some structures, while a dynamic barrier is provided by the ventilation system with particular flow patterns and filters. Normally, negative pressure

is maintained in the ventilated area of nuclear facilities to avoid proliferation of air from a radioactive area to an operating area in case of accidental opening of the enclosure. The areas are divided into four zones based on their radioactive potential. These zones, in the ascending order of their radioactive potential, are:

- White
- Yellow
- Amber and
- Red

Pressure gradients are maintained to allow the flow of air

About the Authors

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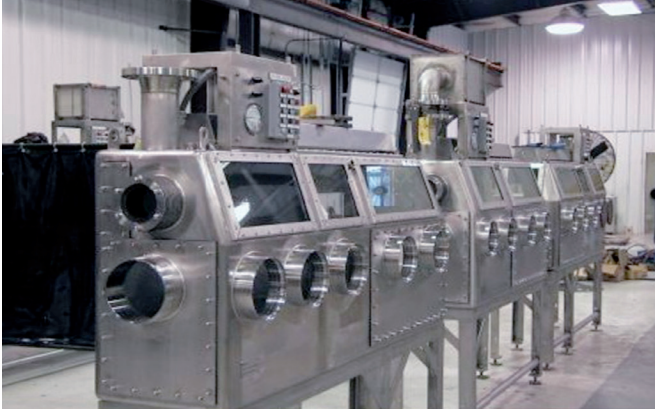


Figure 1: Glove Boxes

from a low radioactive zone to a higher radioactive zone. Flow reversal is not permitted.

A glove box is a containment to handle hazardous materials through gloves fixed on the ports of walls without getting exposed to the material. Glove boxes are used in different industries like nuclear, pharmaceutical, biological, microelectronics etc. A typical glove box is shown in Figure 1. In the nuclear industry, the glove box serves as the primary containment for manipulating radioactive material, though it may be used to handle chemicals, hazardous materials and air sensitive materials. The building acts as the secondary containment.

Ventilation is the heart of the glove box system. It acts as a dynamic barrier. A negative pressure is kept inside the glove box to avoid contamination of the operator.

Description of Glove Box

The glove box is generally made of sheet metal with transparent glass windows. It is equipped with flexible gloves for manipulation of materials and monitoring performance of operations inside the enclosure from the uncontaminated outside environment. The glove boxes have other service connections like piping and electricity as required. They may have inert gas atmosphere based on the process requirement.

Glove boxes generally have several common characteristics.

- The depth of the glove boxes is governed by the "arm reach". If the depth requirement is high, access is provided from both the sides.
- They contain viewing windows.
- Glove ports are usually available in multiples of two at various locations in the glove box walls.
- Remote handling systems are provided, if required.
- Nuclear glove boxes are generally kept at a negative pressure of 25 mm water gauge.
- HEPA filters are used. Material and HEPA filter transfers between glove box interiors and exteriors are commonly made through a bagging port.
- Transfer of material from one glove box to other may be achieved through rapid transfer ports (RTP).
- Powders are handled inside another container.

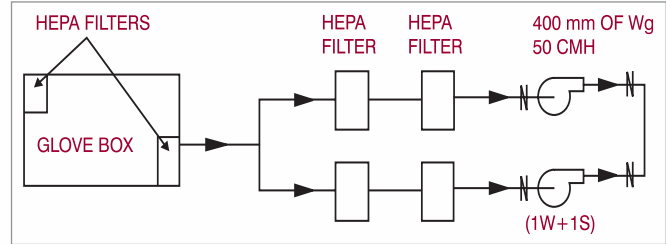


Figure 2: Typical glove box ventilation system

Three important points are to be considered for nuclear glove box design. They are;

Shielding from radiation

In the nuclear glove boxes, proper shielding is used to avoid radioactive exposure. The shielding is generally made of lead, concrete or special glass.

Criticality consideration

Criticality is a concern for glove box design. Care must be taken in providing proper shape of the container. Water entry and drain must be designed properly. The buildup of fissile material on the exhaust HEPA filters should be considered during design.

Seismic qualification

The glove boxes are designed for maintaining structural integrity and/ or operational requirement in case of a seismic event of designed magnitude. Specially, the seismic qualification of exhaust manifold is very important.

Glove Box Ventilation

A glove box is an air tight container. A once through ventilation system minimizes the possibility of accidental release of airborne radioactive material while working with radioactive material. It is under negative pressure since the exhaust blower draws air from the glove box. Inlet filters work as a controlled leakage path from the secondary containment (laboratory or operating area) and help to regulate the negative pressure. Exhaust filters are used to remove contamination from the exhaust air. The air is finally discharged through a stack after monitoring. Figure 2 shows a typical scheme of glove box ventilation.

The system is designed in such a way that in case of an accidental rupture/ removal of gloves, air flow is maintained from the room to the glove box through the port with a minimum velocity of 30m/min to prevent proliferation of contamination. This is an inherent safety feature provided in a glove box ventilation system. Proper instrumentation is provided to indicate inlet/exhaust filter blockage and loss of pressure/confinement. Audio alarm is provided to indicate the deviation of pressure from design limits. The ventilation system also removes heat generated by the process.

The air change rate is an important consideration for all glove boxes. For normal operations, flow rate is based on the dilution of radioactive contamination and heat dissipation. When exposed radioactive material is handled inside a glove box, the box becomes the primary confinement.

Glove boxes must be protected against excessive pressure or vacuum. Each glove box containing service connections or internal equipment, whose malfunction might cause a pressure surge, should be equipped for proper pressure relief. The filter and ductwork should be designed to take care of sudden increase of flow. Proper annunciation is also provided to alert the operator.

Blowers

The exhaust blower is used to provide air flow and negative pressure in a glove box. Blower material is decided based on the nature of exhaust gas (Glove Box Off Gas – GBOG). Exhaust manifolds are normally made of stainless steel and dedicated for glove box. Similar types of GBOG ducts join together before the exhaust blower, and finally join the laboratory area exhaust duct near the stack. The off gases are more contaminated than the area exhaust air, and care is taken in the design to avoid backflow from glove box to the laboratory in case of failure of area exhaust blower.

The blower has to take care of the sudden pressure difference caused by quick insertion and removal of arms into and out of gloves. This is called “pressure recovery”. Presently, variable frequency drives are being used to take care of pressure variations and clogging of filters.

Blowers are normally located at a distant place to avoid noise and vibration. Redundancy is planned in blowers since the system is related to safety. Generally, the system is designed with 100% standby blowers. Exhaust blowers are also backed by DG power (Class III supply) with automatic change over. In case of extremely important systems, a diesel engine operated third exhaust blower is provided. The blowers are located after dedicated pre and HEPA filter assembly to avoid contamination to the fan room and release of contaminated air to the atmosphere.

Filters

Filtration is very important in glove box ventilation systems. The system normally takes air from the secondary containment through a HEPA filter, which is an integral part of the glove box to ensure air that is free of airborne contaminants. It also serves three other useful functions:

- Extending the service life of the exhaust filters by protecting them from atmospheric dirt loading.
- Preventing the spread of contamination from the glove box to the room in the event of a glove box pressure reversal.
- Providing overpressure relief.

All the HEPA filters have pre-filters to reduce loading. Similarly,

an exhaust HEPA filter is also provided in the glove box. Additional exhaust HEPA filters are provided in front of blowers (after the exhaust duct) to filter the air. The maximum airflow rate from the glove box determines the required capacity of the filters and the size of the equipment for the entire downstream portion of the ventilation system. Supply blower is generally not used, to avoid pressurization in case of failure in the exhaust manifold. Air is taken in through inlet filter from the laboratory.

Replacement of filters

The glove box design should prevent back flow of contamination from the glove box or exhaust manifold to the operating area. Replacement of filter should be easy and safe. Changing a glove box filter is difficult because it must be performed through a glove port with limited operator movement. The most common method is explained in *Figure 3*. A new cartridge filter displaces the spent filter as it is pushed through. The old filter and spacer are displaced inside the glove box.

Bagging ports are used on glove boxes for multiple purposes such as transferring materials and equipment and removing the waste generated during operations. These ports are also used to transfer new or spent filters. Bagging ports are normally cylindrical and sized to take care of filter changing. *Figure 4* explains filter changing through the bagging port.

Off Gas Dilution

The basic technique of dilution ventilation is to supply filtered outdoor air (or filtered and conditioned air) to flush or dilute air inside the working area. Dilution ventilation reduces the air borne contaminants or smoke to acceptable levels. Dilution ventilation is characterized in terms of volume per unit time or in air changes per hour (ACH). 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 on experience. Relevant standards and guidelines like ICRP, IAEA and AERB are being followed in deciding the air changes

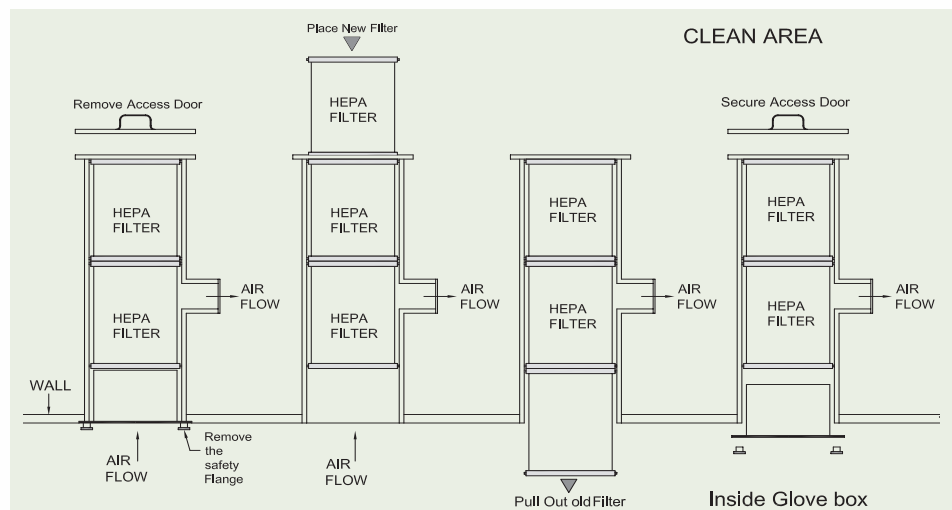


Figure 3: Replacement of filter

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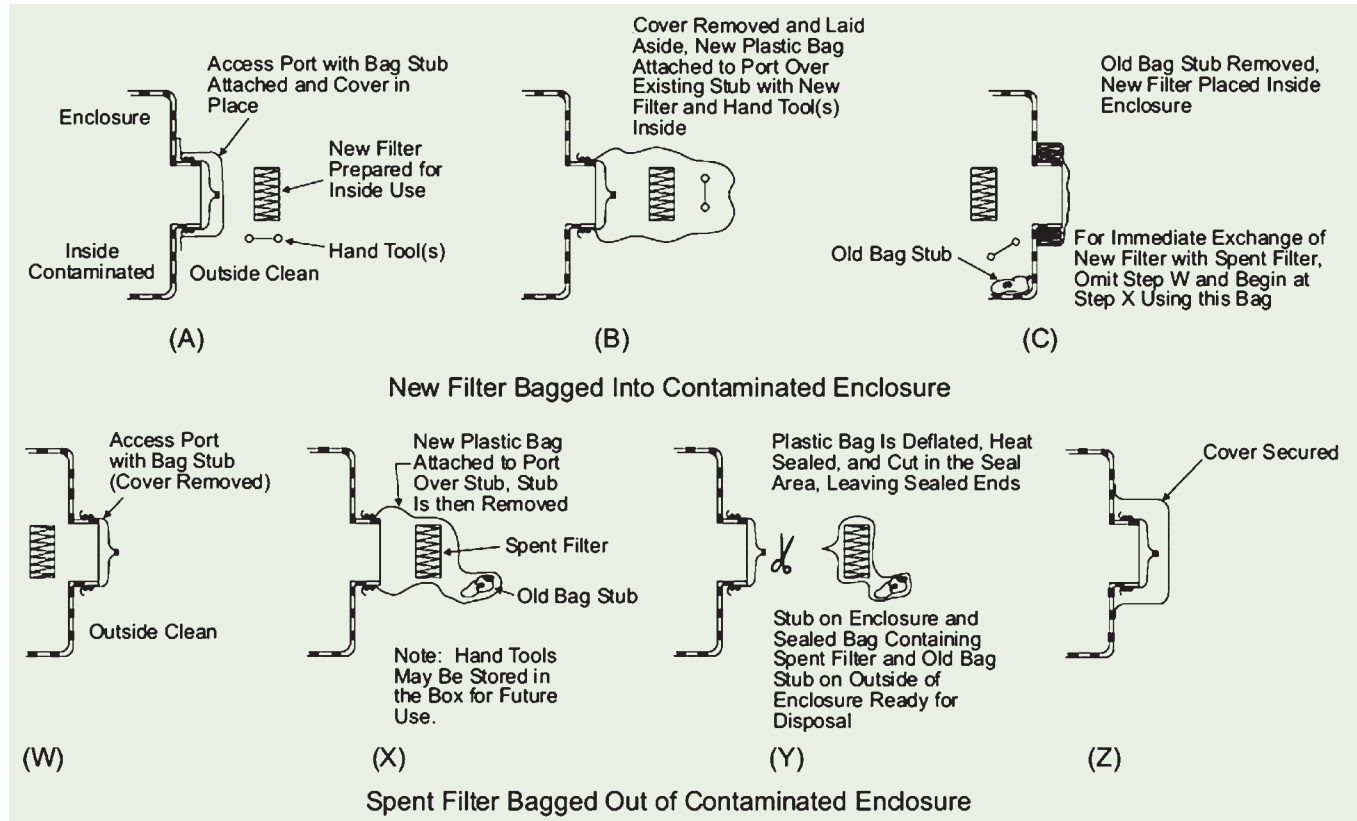


Figure 4: Filter change through bagging port

per hour for nuclear facilities.

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, ACH is about 10-15 for the red zone of ventilation. An air change does not 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. A high air exchange rate is often required to dilute fumes generated in an air-ventilated glove box. When evolved gases, vapors, and particles are not flammable, toxic, or corrosive, a flow rate sufficient to maintain a negative pressure is employed. However, when fumes or vapors are hazardous, a higher ventilation rate is necessary. The maximum generation rate of hazardous substances must be determined to establish the minimum airflow rates needed for dilution. The following equations can be used to determine minimum safe airflow rates.

$$Q = R.S \times 106/L$$

where:

Q = required dilution flow rate

R = contaminant generation rate

S = safety factor (4 to 10 is suggested, depending on volatility, flash-point temperature, degree of mixing, and risk)

L = limit value of contaminant, volume parts per million (vpm) [using threshold limit value (TLV) for toxic vapors and lower explosive limit (LEL) for combustible vapors].

Heat Load

The air flow rate is designed by considering the heat load to be removed. The temperature inside the glove box may be higher than the laboratory, but it must be within the limit the operator can withstand.

Air quantity in m³/h may be calculated using the basic heat formula:

$$H = m \cdot C_p \cdot \Delta t$$

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

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

where

H = Heat content to be removed, kcal/h

V = Volume flow rate, m³/h

ρ = density of air, kg/m³

C_p = specific heat of air at constant pressure, kJ/kg °C

Δt = difference in temperature, °C = (t_r - t_s)

Then, air changes per hour = (quantity of air in m³/h) / (room volume in m³)

Conclusion

This article presents an overview of glove box ventilation system. Ventilation system in a glove box is a once through system. Glove box is considered in the red zone as per zoning concept. The pressure inside the nuclear glove box is always

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kept negative with respect to the operating area. Directional flow of air is maintained from the glove box to exhaust to avoid the spread of radioactivity. Accidental conditions like rupture of the glove box are to be thought of while designing a ventilation system. Filtration is an important part of a glove box ventilation system. On the inlet side it uses two stage air filtration; first stage with coarse filters/ pre-filters followed by High Efficiency Particulate Air (HEPA) filters. Fresh air intake should be from the adjacent operating area. Similarly, pre-filter and HEPA filter are used in the exhaust system before the exhaust blower to avoid ingress of contaminated dust in the atmosphere.

The supply air quantity is derived by dilution ventilation method in addition to the conventional heat removal method. The higher of these two quantities is taken as the design value.

The glove box ventilation system must be capable of reliable performance to assure safe operation without exposure to airborne contamination to the operators and the environment.

Nomenclature

C_p	Specific heat at constant pressure
H	Heat flow rate
L	Limit value of contaminant
m	Mass flow rate
Q	Required dilution flow rate
R	Contaminant generation rate
S	Safety factor

t	Temperature
V	volume flow rate

Greek letters

ρ	density of air (kgm^{-3})
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Acronyms

ACH	Air Change per Hour
AC&V	Air conditioning and ventilation
AERB	Atomic Energy Regulatory Board
DG	Diesel Generator
GBOG	Glove Box Off Gas
TLV	Threshold limit value
LEL	Lower explosive limit
HEPA	High Efficiency Particulate Air (filter)
IAEA	International Atomic Energy Agency
ICRP	International Commission of Radiological Protection

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