Air Conditioning and Ventilation for a Prototype Fast Breeder Reactor

An artist's impression of the Prototype Fast Breeder Reactor, Kalpakkam

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Abstract

Prototype Fast Breeder Reactor (PFBR) is a pool type, sodium cooled, 500 MWe nuclear reactor presently under construction at Kalpakkam. The air conditioning and ventilation (ACV) system for PFBR is designed to minimise the occupational and public dose of radiation. The system maintains air flow from less radioactive to more radioactive zones. To avoid the spread of contamination, radioactive exhaust air is filtered before releasing to the atmosphere through a stack. The system incorporates features for isolation of containment in case of accidental release of radioactivity. It also provides necessary air changes based on radioactivity, contamination and O_2 deficiency, or Annual Limit on Intake (ALI) and Derived Air Concentration (DAC). It maintains negative or positive pressure with respect to outside atmosphere in various buildings based on the requirement of radioactivity containment or ingress control of outside air. The ACV system is also designed to contain fire.

Introduction

ACV systems for PFBR can be broadly divided into ACV for radioactive buildings and ACV for non-radioactive buildings. In addition to the requirements of filtration, humidity and temperature control, the ventilation system for radioactive buildings is designed for controlling the spread of radioactivity during normal and accidental

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condition of the reactor. Based on radioactivity level and the source of radioactivity, radioactive buildings are divided into four zones (Zone I to Zone IV). Zone IV is the highest active zone, which contains the radioactive source, and Zone I is a non-active zone (AERB/NF/SM/O-2, 2005). In ACV system design, it is always ensured that air flow is from a lower active zone to higher active zone and there is no possibility of reverse flow.

ACV system for a non-radioactive building is mainly designed for the requirements of filtration, humidity and temperature, for proper functioning of sensitive instruments and for the comfort of personnel. Availability of the system for critical areas during normal or accidental condition is ensured by providing redundancy or other design provisions.

Rector Containment Building (RCB), Fuel Building (FB), Rad Waste Building (RWB), Steam Generator Buildings (SGBs), Liquid Waste Management Plant (LWMP) and change rooms are under radioactive category, whereas Control Building, Electrical Buildings, Diesel Generator Buildings, Service Building, Turbine Building, Switchyard Building, Raw Water Pump House, Service Water Pump House, Sea Water Pump House and Electro-chlorination Plant are non-radioactive buildings.

The design temperature and relative humidity are based on the requirements of the served systems and areas and overall plant economy. Wherever human occupancy is continuous and sensitive equipments are provided, air is conditioned to a comfortable or suitable temperature and humidity range, e.g. office rooms, Local Control Centres (LCCs), Equipment Control Centres (ECCs). Where humidity is not a criterion, an economical design is achieved by the use of washed air to take care of heat load and to maintain a dust free ambient.

For the purpose of heat load calculations, outdoor design conditions are selected based on the values of dry bulb and mean coincident wet bulb temperature that are not exceeded 1% of total hours in a year, as per Site Evaluation Report for Kalpakkam.

Dry bulb temperature = 39.2°C

Wet bulb temperature = 28.5°C

Specific Criteria for Design of ACV Systems in Nuclear Reactors

1. Air concentration of the activities in full occupancy areas should not exceed 1/10th of the derived air concentrations (DAC), obtained by dividing the annual limit on intake (ALI) values given in *International Commission on Radiological Protection-61* by 2.4×10^3.
2. Capability to prevent spread of airborne radioactive particulate material and to limit their concentration, and to ensure flow of air from low activity zones to higher activity zones.
3. Capability to circulate and exhaust sufficient air to prevent accumulation of flammable or explosive gas from components.
4. Heating and cooling ability to maintain a suitable ambient temperature range and humidity in the area serviced for assuring proper performance of equipment, and for human occupancy and access.
5. Provisions to detect the need for isolation and capability to isolate parts of the system with sufficient reliability.
6. Radioactive releases to the environment to be through appropriate filters and within specified limits during all operational states and postulated accident conditions, through a stack of appropriate height.
7. Reactor containment to be maintained under negative pressure during all operational states, so that radioactive air should not leak outside.
8. To ensure that containment isolation requirements are not defeated, ducting systems that penetrate the containment envelope to have appropriate automatic and reliable provisions to bring about containment isolation in response to signals.
9. For limiting the release of radioactivity to atmosphere, isolation devices to close at a speed which takes account of potential release hazard.
10. Habitability of control room and backup control room to be ensured during every mode of reactor operation.

ACV System for Radioactive Buildings

Among all the radioactive buildings, RCB and FB contain more radioactive sources and need special features to contain spread of radioactivity.

1. Reactor Containment Building (RCB)

RCB houses the reactor assembly, various radioactive cells and local control centres. The cells and area below the operating floor come under Zone III or Zone IV, whereas the open area above the operating floor comes under Zone II. Based on heat load and regulatory requirements, ACV system is provided with recirculation system for Zone II with two air changes per hour, and the remaining zones with once through system. RCB is maintained at negative pressure of 0.735 kPa (73.5 mm wc) with respect to the

Abbreviations

ACV ....Air Conditioning and Ventilation
AERB ....Atomic Energy Regulatory Board
AHU ....Air Handling Unit
AWU ....Air Washer Unit
ALI ....Annual Limit on Intake
BCR ....Back up Control Room
CB................................Control Building
CR................................Control Room
DAC ....Derived Air Concentration
ESF ....Emergency Safety Function
EVTP............................Ex Vessel Transfer Port
FB ....Fuel Building
FTC..............................Fuel Transfer Cell
HEPA ....High Efficiency Particulate Air
LWMP ....Liquid Waste Management Plant
LCC ....Local Control Center
PFBR ....Prototype Fast Breeder Reactor
RCB ....Reactor Containment Building
RWB ....Rad Waste Building
SGB ....Steam Generator Building
SSSB............................Spent Sub-assembly Storage Bay

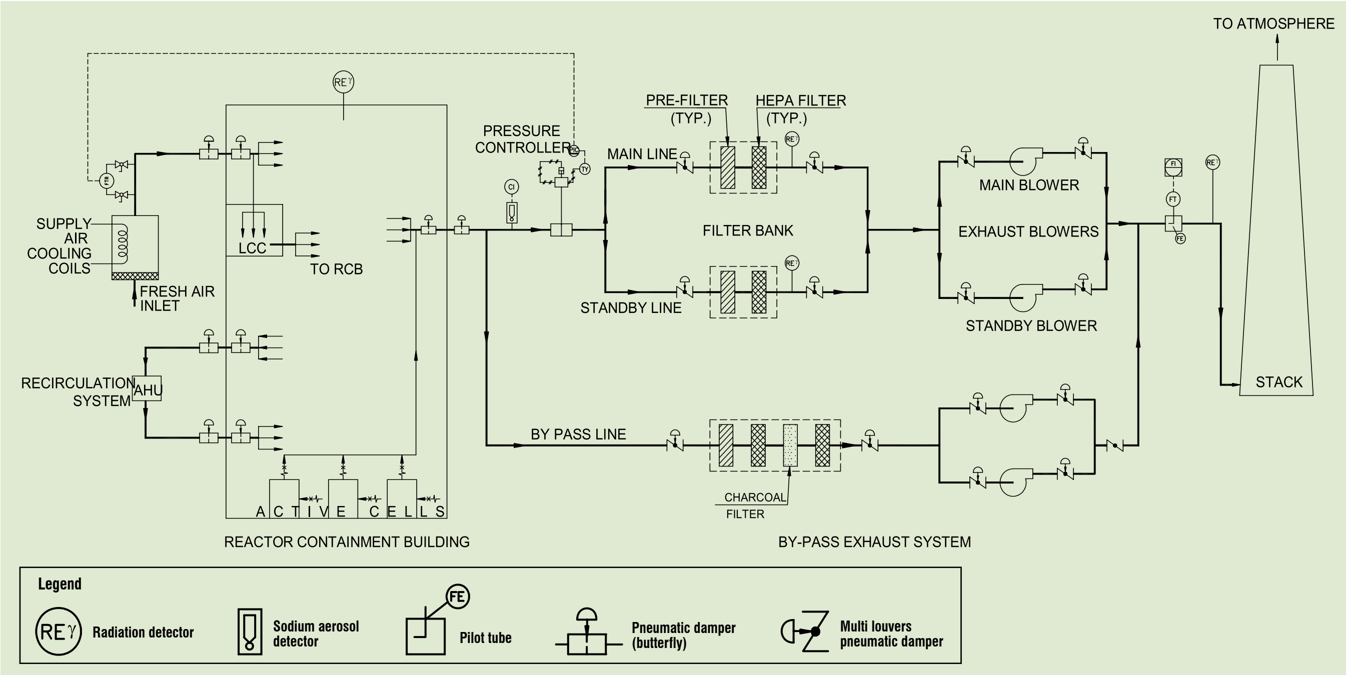

Figure 1: Schematic of air conditioning and ventilation system for reactor containment building

atmosphere to prevent leakage of RCB air outside.

Air quantities to radioactive areas or cells are provided as per AERB Criteria to meet the requirement of ALI and DAC values. Fresh air is supplied through fresh air cooling coils to all areas above and below the operating floor, around the cells and in open areas. The cells are not provided with fresh air; instead, they draw air from open areas around the cells and maintain the design temperature. Thus, air flow is maintained from low radioactive to high radioactive areas, restricting the spread of contamination to other areas. These cells are provided with air changes based on the requirements of radioactivity dilution or heat load in the cells, whichever is higher.

RCB is provided with filtered fresh air supply through cooling coils to meet the requirement of air changes, a re-circulation system with AHU to take care of internal heat loads and to maintain a temperature of 35°C and an exhaust air filtration system to filter the air before exhausting it to the atmosphere through a stack. It is ensured that the fresh air supply intake is away from smoke and fire products venting zones and free from any contaminated gas release areas.

Supply air is filtered using a bank of filters (efficiency 95% down to 5 microns particle size). Exhaust air filtration and clean up system is provided with a filter bank comprising pre-filters (efficiency 95% down to 5 microns), and HEPA filters (efficiency 99.97% down to 0.3 microns). 100% standby exhaust fans and filtration systems are provided. The exhaust is monitored for its radioactivity before releasing to atmosphere.

The Local Control Centres (LCCs), which house control equipment related to distributed control systems, are provided with fresh air supply through a cooling coil, and air flow is maintained from LCC to RCB. LCCs are maintained at slightly positive pressure with respect to RCB to prevent air ingress from RCB. They are maintained at a temperature of 24±2°C. Two air cooled ductable split units, each of 100% capacity, are provided in each LCC for redundancy. In case of off-site power failure or non availability of fresh or exhaust air system, these ductable split units come into operation. In addition, fire dampers are provided in the supply and return air paths, which close on receiving a signal from the fire alarm panel to avoid entry of sodium aerosol or combustion products.

In case of fire, the system is automatically shut off and then operated in accordance with fire fighting requirement to drive off smoke and for flushing of cells. In case there is a fire inside the cells, it is isolated by closing the dampers. Redundant filter banks of RCB exhaust system are separated by a fire barrier. RCB is provided with instrumentation and pneumatic lines for routine pressure testing and subsequent depressurization.

Pressure control

Fresh air system does not have supply air fans. Exhaust air fans create a suction effect and induce flow in RCB through various areas and cells. Pressure control is achieved by regulating the flow rate of fresh air, by adjusting the opening of the damper provided in the exhaust air duct of RCB. Fresh air flow is measured by a flow element Annubar™ in the supply air duct and differential pressure transmitter. Transmitter output is connected to the Flow Indicating Controller (FIC), which adjusts the damper opening in exhaust air duct to maintain RCB pressure at 735±100Pa below atmosphere.

(An Annubar is similar to a pitot tube used to measure the flow of gas or liquid in a pipe, which measures the difference between the static pressure and the flowing pressure of the media in the pipe. The volumetric flow is calculated from the difference,

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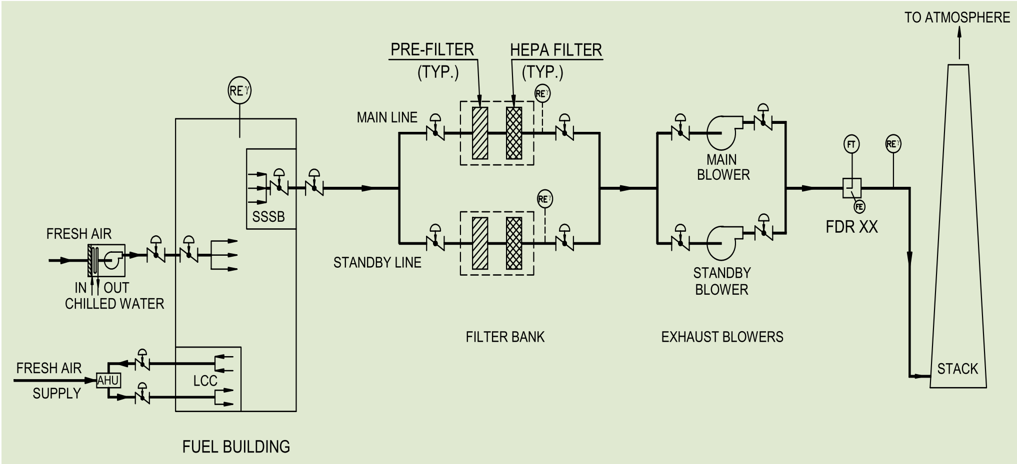

Figure 2: Schematic of air conditioning and ventilation system for Fuel Building

using Bernoulli's principle and taking into account the pipe inside diameter. An Annubar takes multiple samples across a section of a pipe or duct, and averages the differential pressures encountered accounting for variations in flow across the section.)

Containment isolation system

During the design of reactor and its safety features, the postulated events that are likely to release radioactivity to RCB are adequately addressed with redundancy provisions. In the eventuality of radioactivity exceeding the limit within RCB, it is isolated automatically. RCB isolation is initiated on the actuation of anyone of: 2 out of 3 RCB area radiation monitors, or 2 out of 3 duct radiation monitors and an alternate signal (high pressure or temperature). For isolating RCB, twelve isolation dampers (two in series in each duct) are provided to close within 10 seconds for air inlet ducts, air exhaust ducts and recirculation ducts. All dampers are pneumatic type and close in case pneumatic supply is not available, for fail safe operation. The system described below is also provided for controlled discharge from the isolated RCB.

System for controlled discharge

ACV system is designed to meet any exigency during off normal condition or any event beyond design basis. A separate bypass line is provided with a filter bank consisting of a pre-filter, a HEPA filter and a charcoal filter followed by a HEPA filter for controlled release of RCB air after isolation to restrict pressure build up or before rehabilitation of containment. During normal condition this line remains isolated and can be remote operated manually for controlled discharge, and for testing purposes. *Figure 1* shows the ACV system for RCB.

2. Fuel Building (FB)

Fuel building is situated north of RCB. The working area, i.e. Local Control Centres (LCCs) of FB are under Zone II and various active cells are under Zone III or Zone IV, while Spent Sub-assembly Storage Bay (SSSB), where spent sub assemblies are stored in DM water pool for fuel transfer, is under Zone IV. FB is provided with once through ACV system, and a temperature of 35°C is maintained using an AHU. Fresh air from the atmosphere is filtered, cooled and dehumidified and supplied to all the areas in FB. The area is maintained at slightly negative pressure of around 10Pa with respect to the surrounding Access Control passage to ensure inward air flow. Air flow is maintained from low radioactive to high radioactive areas by supplying fresh air to operating areas (based on heat loads) and exhausting it through radioactive areas to prevent spread of contamination. The operating areas i.e. radioactive cells like purification cell and spent fuel storage area are provided with enough air supply as per AERB criteria to meet the requirement of ALI and DAC values.

Exhaust air from all areas except the cells is collected over the SSSB and is exhausted mainly from spent fuel storage area and other radioactive cells, thereby limiting the spread of contamination to working areas. The supply air is filtered using filters (efficiency 95% down to 5 microns).

The exhaust air is filtered using pre-filter (efficiency 95% down to 5 microns) and HEPA filters (efficiency 99.97% down to 0.3 microns) provided in series before sending it to atmosphere through the stack. 100% standby filter banks and exhaust fans are provided. *Figure 2* shows the ACV system for FB.

Accident in Fukushima Nuclear Power Plant, Japan

In Fukushima Dai-ichi power plant, Japan, where an accident recently took place, hydrogen was produced due to metal and coolant water reactions in the reactor due to oxidation of zirconium. Hydrogen accumulation led to the explosion. In PFBR, water is not used as a coolant; hence there is no hydrogen generation. In case of any accidental situation, RCB is designed to be bottled up. As an additional safety measure, the ventilation system is designed to automatically stop to avoid any radioactivity leakage to outside.

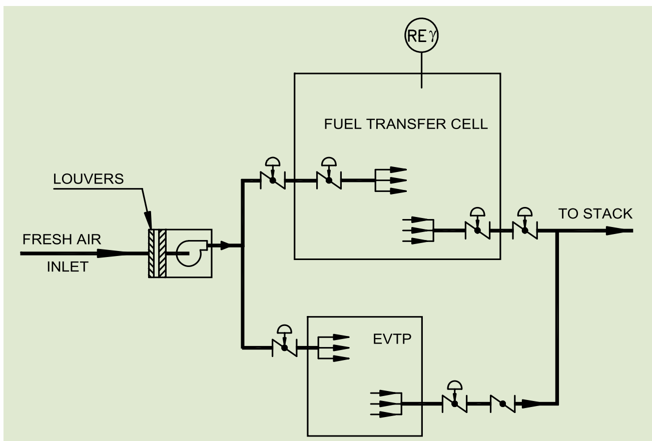

Figure 3: Schematic of ventilation for fuel transfer cells

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Fire dampers are provided in supply and exhaust ducts. They close in the event of fire in the open areas of FB.

LCC is provided with separate AHU units and maintained at a temperature of 24±2°C with one air change rate of fresh air supply.

Ventilation for cells

All the cells in FB except Fuel Transfer Cell (FTC) and Ex Vessel Transfer Port (EVTP) cell draw fresh air from the surrounding areas and exhaust is directly rooted to the exhaust system. The air quantity drawn is estimated based on minimum requirement for dilution or to maintain inside design conditions. FTC and EVTP cells are provided with a separate fresh air supply and exhaust system to flush the cell whenever personnel entry in the area is envisaged. These cells are normally filled with nitrogen. Before the entry of personnel, they are flushed with fresh air. Oxygen concentration in the cell is checked before personnel entry. *Figure 3* shows the ventilation for EVTP and FTC cells.

Both supply and exhaust ducts from the cells are provided with dampers on both sides. They remain closed when the cells are in nitrogen atmosphere. The cell dampers are opened to flush with fresh air for personnel entry.

When entry of personnel in any of the above cells or enclosure is planned, FTC ventilation system is started and dampers of the corresponding cell are opened. Exhaust from these areas is connected to FB exhaust system.

If the radioactivity level in cells is higher than the specified limit, gas inside the cells will be delayed for decay of radioactivity by retaining it in the cell and then discharging it into FB exhaust system. Provision is also made to enable the gas from the cells to be delayed in the Gaseous Effluent system. After the delay it is exhausted directly to the stack. Air inlet and exhaust to the cells are provided with fire dampers at entry. These dampers close in case a fire is detected in the cell.

3. Other Radioactive Buildings

Rad Waste Building (RWB), Steam Generator Buildings (SGBs) and Liquid Waste Management Plant (LWMP) are also radioactive buildings. All open areas of RWB and LWMP are categorized as Zone II, while active waste storage areas, exhaust filter banks in RWB and decontamination room in LWMP are categorized as Zone III. As SGB does not contain any radioactive source other than secondary sodium pipes, it is categorized in Zone II.

RWB and SGBs are provided with once through ventilation system using Air Washer Plant for fresh air and exhaust fans. Temperature inside the above buildings is maintained within 4.5°C above ambient. The exhaust air system for RWB is similar to FB system. Exhaust from SGBs is extracted through roof extractors and wall mounted fans 22m above ground level to achieve sufficient dilution of sodium aerosol. In case of fire due to sodium leakage, the ventilation system is switched off and is operated in accordance with fire fighting requirement. Fire dampers are provided for LCCs at supply and return air path which close on signal from fire alarm panel to avoid entry of sodium aerosol or combustion products.

In LWMP, an exhaust air fan creates a suction effect and induces the required flow pattern through louver and filter from atmosphere. To ensure flow from lower to higher contamination zone, the exhaust duct is routed such that contaminated air is collected only in the Decontamination Room (Zone III) and from there, through pre-filter and HEPA filter, it is exhausted to atmosphere. This also ensures that LWMP is maintained at negative pressure compared to atmosphere.

The Local Control Centre is provided with conditioned air using AHU for proper functioning of instruments by maintaining a temperature of 24±2°C. LCCs are maintained at 30Pa positive pressure with respect to building atmosphere.

ACV System for Non-radioactive Buildings

Control Room (CR), Back-up Control Room (BCR), Electrical Building, Turbine Building, Service Building and all other buildings not listed as radioactive buildings are considered as non-radioactive areas, since they do not handle or house any radioactive materials or components. These buildings are provided with recirculation type ACV system or once through washed air or direct outside air supply and exhaust system depending upon the requirement of each building.

These buildings are not provided with any exhaust air filtering system. The supply air is filtered using a bank of filters to reduce dust concentration. In non-radioactive buildings, CR and BCR are more critical to safe operation of the reactor and maintaining it in safe shut down condition.

1. Control Building (CB)

This building houses the main Control Room, computer room, handling control room, cable spreader room etc. Since the reactor operation and other safety related instrumentation and control systems are provided in control room and computer room, this is considered to be a safety related building.

A re-circulation type ACV system is provided with AHU to

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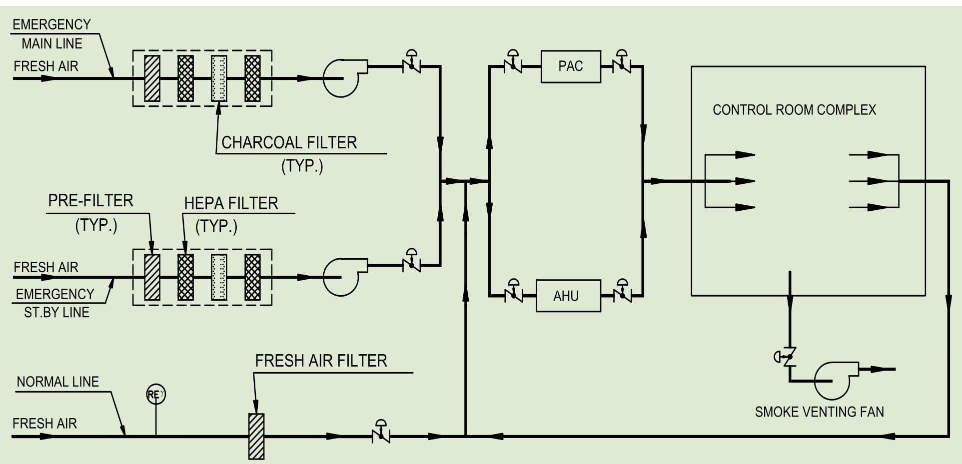

Figure 4: Schematic of ACV system for control room/ back-up control room

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maintain a temperature of 24±2°C with 50±5% RH for Control Room and Computer Room, and 24±2°C 50% RH (design) for other air conditioned areas in this building. The supply air is provided with high efficiency filter to reduce dust concentration, and this area is maintained at slightly positive pressure of 30Pa (3mm wc) above atmosphere by means of gravity dampers to prevent entry of dust particles inside CR. The gravity dampers have louvers mounted on spindles to allow the damper to open with system pressure and close under gravity.

System for emergency operation

For emergency operation (radioactive accident), CR is provided with emergency fresh air system (*IAEA safety series no. 98, 1989*). During any emergency, fresh air is inducted into the PAC room or AHU room (whichever is in operation) through a separate emergency fresh air path comprising of emergency fresh air fan, louvers, a separate bank of filters (2x100% capacity) consisting of pre-filters, HEPA filters and charcoal filter (see *Figure 4*). During external accidental conditions, like radiation and contamination outside the CR, this feature ensures habitability inside this building. A standby to this emergency fresh air path is also provided (*USNRC/ Regulatory/ Guide-1.52, March-'78*). Separate smoke venting systems are also provided to drive out the smoke, fumes, etc. in case of fire inside the CR, with blower and damper arrangements.

The fan and the smoke dampers normally remain closed and are operated manually following the extinguishing of the fire. For diversity, package air conditioners are also provided for Control and Computer Rooms. Emergency power supply is provided for ACV system in case of loss of offsite power.

2. Back-up Control Room (BCR)

BCR is a safety related non-radioactive room similar to CR. Whenever CR is unapproachable, the essential controls required for shutting down the reactor, maintaining it in shut down condition and monitoring essential plant parameters are carried out from BCR. It is also provided with ACV system similar to CB along with emergency fresh air system.

3. Other Non-radioactive Buildings

Electrical buildings, diesel generator buildings, service building, turbine building, switchyard, water treatment complex, sea water pump house, etc. are non-radioactive buildings. Electrical buildings are considered safety related. They house the power supply system for static converter panels, batteries and distribution boards. They also house sodium pump variable speed drives, and static converter panels, which are essential for reactor operation. Other buildings are non safety related.

Equipment control centre and local control centres of the above buildings are provided with a re-circulation type air conditioning and ventilation system with AHU, and a temperature of 24±2°C with 50±5% RH is maintained (*ASHRAE Handbook – Fundamentals, 1985*).

The other areas in these buildings are maintained at ambient temperature using air washer units, since they do not house any control panels or critical instruments. The battery rooms in electrical buildings and turbine building are provided with supply and

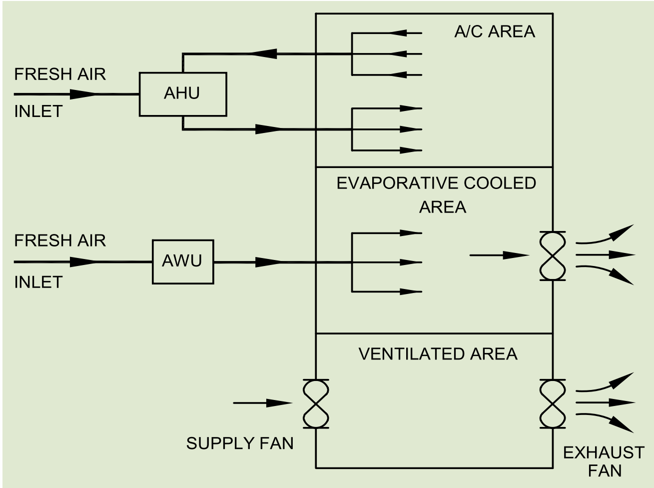

Figure 5: Schematic of ventilation for general buildings

exhaust fans and with supply air duct for filtered fresh air entry to maintain H_2 concentration within 1% by volume with 7 air changes per hour. In Argon storage area, an exhaust fan is provided to avoid spread of Argon in case of its leakage in the building.

All other buildings like water treatment complex, sea water pump house, etc. are considered to be general category buildings. They are provided with ventilation system using supply fans or wall mounted air circulators with wall mounted or roof-mounted exhaust fans, with louvers for fresh air entry. This takes care of heat loads in these buildings. *Figure 5* shows a typical ACV system for non- radioactive buildings.

Safety Provisions

For the ACV systems of RCB, FB and RWB, 100% standby exhaust fans and filter banks with necessary instruments and control logic for change-over mode are provided. Exhaust air from these buildings is monitored for its radioactivity before being released to the atmosphere through a stack, to control airborne contamination. The parts of all exhaust lines from the above buildings required for containment isolation are made of carbon steel welded ducts to avoid any leakage of radioactive air. Provision is made to test all HEPA filters in-situ for their efficiency.

The annual dose apportionment to environment though air route is 90μ Sv (sievert*). All fresh air intake points are located away from exhaust air outlets to minimise the possibility of contamination of fresh air.

In case of fire or high radioactivity inside the buildings, the ACV system of the building is shut off to avoid spread of fire, smoke or contamination to other areas. Necessary fire, smoke and radioactivity sensing detectors are provided in these buildings. Redundant filter banks of RCB, FB and RWB exhaust system are provided with isolation dampers and are separated by fire barriers. ACV system for RCB is connected to emergency power supply (Class-III) so that, during offsite power failure, the system can be

**Sievert is the derived unit of dose equivalent radiation, which quantifies the biological effects of ionizing radiation, as opposed to the absorbed dose of radiation energy which is measured in gray.*

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maintained. In case of high radioactivity inside RCB, it is bottled up by using isolation dampers, with closure time within 10 seconds, which are provided on either side of the RCB wall. During station black-out condition also, RCB is bottled up in a similar manner.

In case of non availability of chilled water and service water, the ventilation system alone is operated. All dampers have a provision for manual operation to enable their operation in case of pneumatic supply failure. Provision is made to test all dampers for leak tightness, and routine testing of all safety equipment, viz. isolation dampers, HEPA filters, fans and motors. The fan and filter rooms are provided with sufficient space and isolation dampers for maintenance of each fan and filter bank.

Control Room and Backup Control Room have two independent ACV systems. Considering the importance of CR and BCR the ACV systems for these rooms are connected to emergency power supply. For diversity, packaged air conditioners are also provided, so as to ensure operability of ACV system in case chilled water supply or AHU fails. Habitability in CR and BCR is considered important for safety of the reactor. Hence, a provision is made during accident conditions for normal fresh air supply line to AHU and PAC room to close automatically and emergency fresh air supply line to open, to maintain positive pressure of 30Pa inside CR and to provide sufficient filtered fresh air for the occupants (*IAEA Safety Series No.98, 1989*). The positive pressure is maintained by using gravity type dampers. Both CR and BCR have two independent air intake points. Quick closing isolation dampers (closure time: within 10 seconds) are provided to reduce air ingress in case outside air is contaminated. Fire dampers are provided in supply air header and exhaust air line. They are closed automatically during a fire to avoid spread of fire and smoke to other areas. EBs house the sodium pump drive system control panels, static converter panels, batteries, and distribution boards, which are essential for plant operation. Hence, to ensure the availability of ACV system, it is connected to emergency power supply system.

As mentioned above, TB and other buildings are not safety related buildings. During non-availability of offsite power supply, chilled water, compressed air or service water, the ventilation system will not function. However, battery rooms and battery charger rooms are connected to emergency power supply system and will function during offsite power failure.

Safety and Seismic Category

Various components are classified according to the role played by them in the measures to control radiological hazards. Based on the classification, their design requirements are accordingly established without compromising the overall safety objectives. This is achieved by identifying the different safety functions performed by individual components in terms of their role in achieving the safety objectives. The safety and seismic classification is carried out on the basis of AERB safety guide no. *AERB/NPP-PHWR/SG/D-1*.

Safety class

RCB isolation dampers in supply, recirculation and exhaust system and ducts forming part of containment in RCB are classified under Safety Class-2. Standby air intake system, smoke venting system and main isolation dampers of control room and back-up control room are classified under Safety Class-3. All other items like air handling units, air washer units, ducts, duct supports, dampers, filter supports in other buildings (except those connected to ESF) are classified under Non Nuclear Safety class.

Seismic category

RCB, FB, RWB, SGB, EB, SB and CB are classified under Seismic Category-1. Isolation dampers in RCB, ducts between isolation dampers in RCB wall, duct supports for all the above buildings and ducting inside RCB, filter supports and associated exhaust lines till the stack are categorized under Seismic Category-1. All other items like ducts, AHU and PAC systems, duct supports and ACV system component in other buildings, AHU, cooling coil and fans for RCB, FB and RWB are seismically un-categorized.

Fire Safety

Fire safety aspect of each building is considered as required in *AERB/ SG/ D4 Fire Protection in PHWR Based Nuclear Power Plants*.

Conclusion

The air conditioning and ventilation system meets the diverse functional requirements of different buildings of PFBR housing radioactive and non-radioactive systems, sodium circuits and conventional systems. Challenges were met in evolving the system to meet the stringent safety requirements such as zonal direction of flow, specific isolation requirements in various conditions throughout the plant, maintaining habitability even in off-normal conditions in the required areas, restricting a fire locally, minimising the radiation dose that the occupants and public are exposed to, and providing suitable ambient condition for occupants and sensitive instruments of the reactor. Sufficient redundant, diverse and failsafe features have been built in. The design of ACV system for PFBR that incorporates the above features has provided a valuable experience.

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