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Nuclear facilities — Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors

Installations nucléaires — Critères pour la conception et l'exploitation des systèmes de ventilation des installations nucléaires autres que les réacteurs nucléaires

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17873 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Introduction

This International Standard applies to all types of nuclear installations other than primary containment envelopes of nuclear power plants or certain categories of research reactors.

The installations concerned are particle accelerators, radiation generators, fusion machines, research and examination laboratories and, more generally, all types of nuclear fuel cycle installations (e.g. enrichment plants, nuclear fuel fabrication and examination laboratories, plutonium-handling facilities, reprocessing plants, radioactive waste treatment stations, radioactive waste storage facilities, etc).

It can also be applied to the primary containment envelope of research reactors, where only low pressure can occur during accident scenarios, as well as to auxiliary rooms of nuclear power plants.

Specific features associated with the containment envelope of nuclear power plants or certain categories of research reactors will be developed in another International Standard.

Nuclear facilities — Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors

1 Scope

This International Standard specifies the applicable requirements concerning the design and use of ventilation systems in nuclear installations such as hot cells, nuclear fuel fabrication and examination laboratories, plutonium-handling facilities, reprocessing plants, enrichment facilities, nuclear-waste treatment stations, storage facilities, etc.

The purpose of ventilation and containment systems is to and ensure safety functions and protect workers, public and environment against the spread of radioactive contamination resulting from the operational processes of these installations.

This International Standard does not apply to the containment envelope of nuclear power plants and some research reactors where high pressure can occur during accident scenarios. It does apply to auxiliary rooms of these facilities.

The requirements for the design and use of ventilation systems that ensure safety functions in nuclear reactors will be developed in another International Standard.

2 Normative references

The following Standards contain provisions that, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2889, *General principles for sampling airborne radioactive materials*

ISO 10648-2, *Containment enclosures — Part 2: Classification according to leak tightness and associated checking methods*

ISO 11933-4, *Components for containment enclosures — Part 4: Ventilation and gas-cleaning systems such as filters, traps, safety and regulation valves, control and protection devices*

ICRP 60, 1990, Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP, 21, (1-3), Pergamon Press, Oxford (1991)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
aerosol
solid particles and liquid droplets of all dimensions in suspension in a gaseous fluid

3.2
air-change rate
ratio between the ventilation air-flow rate of a containment enclosure or a compartment, during normal operating conditions, and the volume of this containment enclosure or compartment

3.3
air conditioning
arrangements allowing the sustainment of a controlled atmosphere (temperature, humidity, pressure, dust levels, gas content, etc.) in a closed volume

3.4
barrier
structural element, which defines the physical limits of a volume with a particular radiological environment and which prevents or limits releases of radioactive substances from this volume

EXAMPLE Containment enclosure, shielded cell, filters.

3.5
balancing damper
control valve
adjustable device inserted in an aerodynamic duct allowing balancing of the fluid flow and/or the pressure of the fluid during plant operation

3.6
cell
or shielded enclosure
term generally used to designate an enclosure equipped with a shielding structure, of fairly large dimensions, possibly leaktight

See **containment enclosure** (3.9).

3.7
containment
confinement
arrangement allowing users to maintain separate environments inside and outside an enclosure, blocking the movement between them of process materials and substances resulting from physical and chemical reactions which are potentially harmful to workers, the external environment, or to the handled products

See **containment enclosure** (3.9) or **barrier** (3.4).

NOTE The word “confinement” is used in several IAEA documents to mean the function of confining radioactive or toxic products whereas “containment” is used to mean the physical barrier that achieves the objective of confinement, i.e. a confined area.

3.8
containment compartment
CC
compartment of which the walls (or the nearest walls of a volume that includes one or several fire compartments) are able to contain radioactive substances that would be generated by any plausible fire that could break out in one of the fire compartments included

NOTE It is often more practicable to limit the spread of a fire by fire-resistant walls, and to prevent the spread of contamination in the adjacent volumes.

3.9
containment enclosure
enclosure designed to prevent either the leakage of products contained in the pertinent internal environment into the external environment, or the penetration of substances from the external environment into the internal environment, or both simultaneously

NOTE This is a generic term used to designate all kinds of enclosures, including glove boxes, leaktight enclosures and shielded cells equipped with remotely operated devices.

3.10
containment system
system constituted by a coherent set of physical barriers and/or auxiliary dynamic systems intended to confine radioactive substances in order to ensure the safety of the workers and the public and the protection of the environment

3.11
contamination
presence of radioactive substances on or in a material or a human body or any place where they are undesirable or could be harmful

3.12
decontamination factor
measure of the efficiency achieved by a filtration system and corresponding to the ratio of the radiological contents of the inlet and outlet of the filtration system

3.13
discharge stack
duct (usually vertical) at the termination of the ventilation system, from which the air is discharged to atmosphere

3.14
dynamic confinement
action allowing, by maintaining a preferential air-flow circulation, the limitation of back-flow between two areas or between the inside and outside of an enclosure, in order to prevent radioactive substances being released from a given physical volume

3.15
filter
conventional term used to designate a device intended to trap solid or liquid particles suspended in gases or fluids or to trap gases themselves

NOTE A particle filter consists of a filtering medium, generally made of a porous or fibrous material (i.e. glass fiber or paper) fixed within a frame or casing. During the manufacturing process, the filter is mounted in a leaktight manner in this frame, using a lute. Gas filters are generally found in physical or chemical process units where the primary aim is to trap certain gases.

3.16
fire compartment
FC
reference volume delimited by construction elements for which fire resistance has been chosen according to the plausible fire that could break out within this volume or penetrate into it

3.17
fire damper
fire blocking valve
device which is designed to prevent, generally by automatic action under specified conditions, the ingress of fire through a duct or through the walls of a room

3.18
fire load
heat energy that could be released by the complete combustion of the whole combustible contents of a volume, including the surfaces of the walls, partitions, floors and ceilings

3.19
gas cleaning
action (sometimes called “scrubbing”) that consists of decreasing the content of undesirable constituents in a fluid

NOTE Aerosol **filtration** and iodine **trapping** are examples of gas cleaning.

3.20
iodine trap
scrubbing device, usually based on activated carbon, intended to remove volatile radioactive components such as radioactive iodine from the air or the ventilation gases

3.21
negative pressure or depression
pressure difference between the pressure of a given volume, which is maintained lower than the pressure in a reference volume or the external ambient pressure

3.22
negative pressure system
regulated ventilation system, which ensures a negative pressure between the ventilated area and an adjoining zone or the external ambient pressure

3.23
prefilter
filter fitted upstream of the main air filters to minimize, by removal of large particles, the dust burden on the latter

3.24
pressure drop
pressure loss in an air stream due to its passing through a section of ductwork, or a filter or fittings

3.25
process ventilation system
ventilation system that deals specifically with the active gases and aerosols arising within process equipment (such as reaction vessels, piping networks, evaporators and furnaces) but excludes the ventilation of the containment enclosures in which such equipment is generally located (e.g. hot cells, glove boxes, fume cupboards or high-radioactivity plant rooms)

3.26
safety flow rate
flow rate that guarantees air flow through any occasional or accidental opening, sufficient to either limit the back-flow of contamination (radioactive or other) from the working volume, or to avoid the pollution of products handled within the working volume

3.27
ventilation
organization of air-flow patterns within an installation

NOTE Two systems are commonly used:

— ventilation in series: ventilation of successive premises by transfer of air from one to the next;

— ventilation in parallel: ventilation by distinct networks or premises or group of premises presenting the same radiological hazard. Utilised also to indicate that the totality of blowing and extraction circuits of each particular volume is directly connected to the general network (in contrast to ventilation in series).

3.28
ventilation duct
envelope, generally of rectangular or circular section, allowing air or gas flow to pass through

3.29
ventilation system
totality of network components, such as ducts, fans, filter units and other equipment, that ensures ventilation and gas-cleaning functions as defined in the present document

4 Functions ensured by the ventilation system

The ventilation of nuclear facilities enables the improvement of the safety of the workers, general public and environment and/or if necessary, the protection of the products to be handled. It plays a role of

— safety, by contributing to keep the workers, the general public and the environment free of contamination, and

— protection of the equipment and the handled products (and thus indirectly safety), by maintaining the internal atmosphere in a state (temperature, humidity, physical and chemical properties) compatible with the proposed operational materials and process conditions.

Ventilation ensures the following functions.

a) **Confinement**, by acting in a dynamic manner in order to counteract any defects in the leaktightness of the static containment constituted by the walls of the relevant enclosures. In this case, the “dynamic” confinement ensured by the ventilation systems has two aspects.

   — Between items of equipment, enclosures (or cells) and rooms of the same building (i.e. internal dynamic confinement), the ventilation ensures a hierarchy of pressure in order to impose a circulation of air from volumes with a low potential hazard of radioactive contamination to volumes with a high potential of radioactive contamination hazard. Dynamic confinement is also able to circumscribe, to process and to control the contamination as close as possible to its source, complementing the other systems provided to protect the operators from the hazards of ionizing radiation.

   — At the interface with the environment (i.e. external dynamic confinement), the ventilation system maintains a significant depression within controlled areas with a high potential radioactive contamination, in order to avoid uncontrolled releases as well as to direct the gaseous effluents towards identified release points, and to enable, if required, cleaning (purification) and monitoring the gases discharged.

b) **Purification** (or gas cleaning) by conveying the collected gases, including any dust, aerosols and volatile components, towards defined and controlled points for collection, processing and elimination where possible (by using filters, traps, etc.).

c) **Monitoring** of the installation, by organizing air flows in such a manner as to allow meaningful measurements in order to detect and to limit any spread of radioactive components during normal as well as abnormal conditions, including fire events. Ventilation systems, with or without surveillance monitoring, can also contribute to the improvement of some radiological measures inside rooms by helping to control the background level of natural radioactivity (radon).

d) **Cleaning** of the atmosphere of the enclosure or room, by renewing the volumes of air within it, in order to minimise the risks associated with the corresponding atmosphere (for example, the elimination of any gas necessary to make credible an explosion hazard).

e) **Conditioning** of the atmosphere of the enclosures or the rooms, to obtain the optimum functioning of machines or to improve the safety of some otherwise hazardous operations (for example, the maintaining of ambient conditions compatible with the proper functioning of equipment).

f) **Comfort**, by ensuring processing (heating or refreshing) of the air, regulation of the temperature and the relative humidity of the atmosphere of the rooms, in order to maintain the climatic conditions to suit the work that the personnel have to undertake.

The first five functions are safety functions.

The achievement of optimal climatic conditions is indirectly a safety function, because “human risks”, which could be caused by inadequately regulated climatic conditions, are then substantially reduced.

5 Safety aspects of ventilation systems

5.1 General principles

Ventilation systems shall be able to ensure the safety and protection functions defined in the previous clause, in all normal operation and maintenance conditions of the enclosures. Ventilation systems shall ensure some of these functions, based upon a safety assessment, during abnormal operating conditions, maintenance operations, exceptional interventions or accidental situations that are to be defined case by case.

Before beginning any ventilation design, a hazard assessment shall be made so that design safety principles and actual targets will be adequately defined. Subclause 5.2 provides an outline of the hazard assessment process as it relates to ventilation design.

In addition, designers of ventilation systems for nuclear installations also have to comply with all national legislation and with any more stringent safety requirements specified by the national regulatory authority.

5.2 Risk assessment procedure

The design of an appropriate ventilation system requires preliminary analyses, taking into account:

a) radiological hazards arising from the materials and operations which lead to the need for ventilation of the enclosures and rooms containing dangerous substances, including:

   — the permitted levels of air and surface contamination within the building, and the air monitoring requirements, leading to a classification of the area regarding the contamination hazard, as defined in 8.1.1;

   — the risk of radiological exposure, leading to the classification of radioactive areas in accordance with the definitions proposed by ICRP 60[1)];

b) an adequate margin between the authorized discharge limits and the anticipated actual discharges resulting from the ventilation system as a whole, as well as the air-cleaning requirements prior to these discharges;

c) non-radiological hazards related to the processes and equipment implemented in the volumes which have to be ventilated (e.g. catastrophic rupture of containment caused by some mechanical failure, abrupt variation of pressure, explosion, fire, corrosion, condensation);

d) hazards of external origin to which the enclosures and the ventilation system itself can be exposed (e.g. fire, floods, external explosion, earthquakes, wind and extreme temperatures);

e) possible temporary unavailability of the fluids or energy supply needed for the correct functioning of the ventilation system.

For each consideration, a risk assessment shall be carried out using the safety analysis methodology where the risk is defined as the combination of the consequences of the event and its estimated frequency. An alternative deterministic approach may also be carried out, based on incidental or accidental envelope situations. It is important not to exclude some scenarios combining internal and external hazards (e.g. strong wind and some other event leading to the dispersion of radioactive contamination inside the building). In any case, the associated loads on the system shall be described in the safety report, according to the safety assessment policy of the organisation(s) concerned.

1) ICRP: International Commission on Radiological Protection.

Other factors which should be taken into account, when designing ventilation systems, include the following.

— There is a need to minimize, as far as reasonably practicable, the level of contamination in the workroom air.

— For protection of the environment, it is now conventional practice to design nuclear- process plant systems so as to minimize radioactive waste arising and radioactive releases (liquid and gaseous) as far as practicable. Thus attention must be paid to the whole-life considerations of waste streams produced by operational, maintenance and decommissioning activities (consumable seals, filters, swabs; contaminated fluids from lubrication, cleaning, off-gas scrubbing, etc.). It is also usual practice to minimize the quantity of high-activity waste instead of conventional waste, or low-activity waste. In particular, contaminated filters, being of low density, are very expensive to store or dispose of as radioactive waste. Consideration shall be given to the use of self-cleaning or cleanable filters, cyclone filtration etc., or filter compaction techniques.

— The design of an enclosure, through which air is exhausted via ductwork, filters, fans and a stack to the outside atmosphere, must take into account the pressure, temperature, humidity and other variations to be tolerated by each component, in an appropriate range of operational and fault conditions.

— Comfortable working conditions must be provided for operational and maintenance staff.

It arises from the foregoing that certain general safety principles shall be followed when designing ventilation systems for radioactive premises, as listed below:

1) The total air flow through the system, from inlet to discharge into the atmosphere, shall be minimized, while still achieving the necessary function.

2) The air-flow magnitude and air-flow patterns in the working environment must be adequate to give the occupants protection against airborne contamination, with a view to obtaining doses “As Low As Reasonably Practicable”.

3) Sufficient fresh air must be provided to ensure acceptable industrial hygiene conditions in the spaces that are normally occupied.

4) Filtration systems are recommended for the air inlets to reduce firstly, the quantity of dust and impurities burdening extract filters and hence prolong their lifetime and secondly, the back-flow of contaminant products through the inlet circuits in case of failure of the ventilation systems.

5) Physical containments (e.g. total enclosures) are the most effective means for minimizing radioactive releases and for protecting the product to be handled. Ventilation provides a supportive role to this physical containment by ensuring an adequate air circulation between different containment areas.

6) The system shall provide a sufficient inward air velocity through unavoidable or accidental openings in containment barriers to limit the egress of particulate, aerosol and vapour contamination as far as is reasonably practicable.

7) The air flows shall, as far as reasonably practicable, be adequate for both the normal conditions and the potential accident conditions.

8) The systems shall incorporate optimum energy efficiency (e.g. heat reclamation from exhaust air), but this must not compromise the containment and safety requirements.

6 Principles of containment of radioactive material

6.1 General requirements

The basic principle with regard to the prevention of the spread of the radioactive material is:

— in normal situations, to limit the release of radioactive material outside the facility (with regard to the regulatory authorization), but also to maintain a level of contamination as low as is reasonably achievable inside the facility;

— in accidental situations, to limit to acceptable levels the radiological consequences for the environment, for personnel directly involved in the operations leading to the spread of radioactive contamination, for other operators in the same facility and for the general public.

The application of this principle leads to the provision of different containment systems between the environment and the radioactive substances. Each containment system and the associated devices are designed to suit the risks they are intended to control. The goal will be to maintain, in any case, the functionality of at least one stage of effective filtration between the contaminated areas and the environment under all circumstances, including accident situations, such as fire or explosion.

Attention must be paid to designing protection for personnel in charge of operations that may lead to the spread of radioactive contamination, as well as additional protection for personnel in adjacent areas.

In nuclear facilities, generally several containment systems are distinguished. Each containment system can be made of (see Figure 1):

— one or several static containment barriers;

— complemented if necessary, by means of dynamic systems, consisting of a specific ventilation system and appropriate air-cleaning devices.

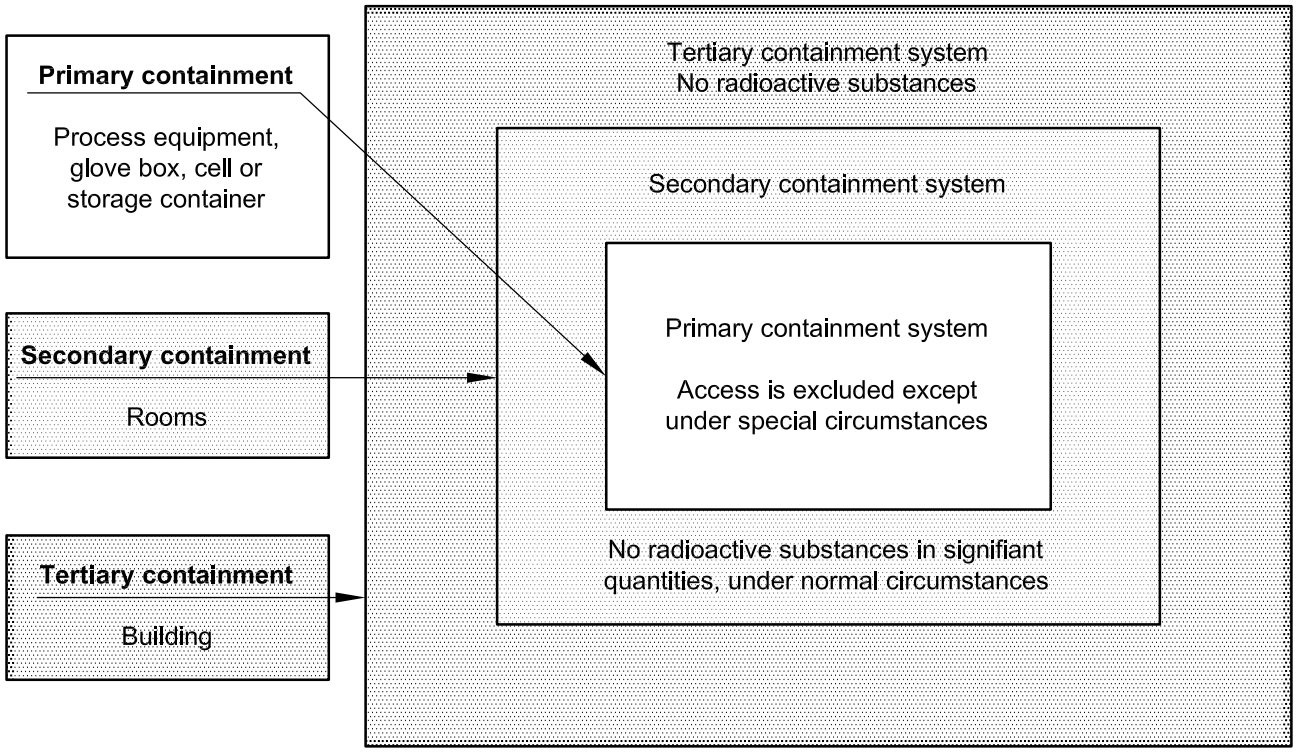


Figure 1 — Schematic drawing of a three-containment system

6.1.1 Primary containment system

The goal of the “primary containment system” is to prevent the release of radioactive substances to the accessible working areas and the environment.

In cases involving materials in gaseous, liquid or solid form, the primary containment system includes the process equipment, piping, vessels, glove boxes, cell or storage containers and containment enclosures, etc, complemented by their associated ventilation equipment including off-gas collecting and treatment systems. When the continuity of the static barrier constituting the first containment system is not ensured in all normal operating and maintenance conditions, the designer is recommended to complement it by appropriate dynamic or static means, to minimize the spread of radioactive contamination in the adjoining working areas. This is especially true in the case of glove boxes used for handling radioactive powders, which require the installation of various service penetrations such as ventilation ducts, fluid, gas or electricity supplies, transfer devices for the introduction of objects or waste evacuation, observation and manipulation means and so on.

For this purpose, the internal volume of the primary containment enclosure shall be maintained by the associated ventilation system at a lower pressure than that of the accessible adjoining working area. Where it is important to maintain a high purity special working atmosphere in the hot cell, an interspace could be provided at a depression with respect to both the working area and the operator areas, to maintain the high purity of the working area and to facilitate checking for leaks by monitoring the purge gas of the interspace. In this case, a special extraction system shall be installed on the interspace with its own filtration equipment.

6.1.2 Secondary containment system

The goal of the “secondary containment system” is to prevent the release of radioactive contamination from the secondary containment system to areas accessible to non-authorized radiological workers, the general public and the environment, in circonstances, accidental or not, for which the primary containment could no longer be ensured.

The secondary containment includes the structure of the rooms enclosing the primary containment volumes and their associated ventilation systems: room walls, ducts of the associated ventilation networks, filters installed on these ducts or on the containment walls, etc.

The design of the secondary containment system has to take into account the maximum quantity of radioactive substances that are present in a dispersible form inside the primary containment, the quality of the containment barrier(s) and the possible consequences of the hazards introduced by the industrial process(es) being implemented.

6.1.3 Tertiary containment system

The goal of the “tertiary containment system” is to prevent the release of radioactive contamination outside the whole building in case of failure of the two previous containment systems and to provide, to an appropriate standard, the protection of the general public and the environment. It includes the building and the associated ventilation and air-conditioning system.

The third containment system shall be installed when necessary to satisfy safety requirements for installations with high hazard potential. It is generally recommended in installations presenting a high potential of radioactive releases or where highly radiotoxic substances are handled (e.g. plutonium).

Table 1 summarises the constitution of the different containment systems.

Table 1 — Typical examples of static containment systems

Type	Material form	
	Solid	Liquid and gas
Primary containment	Glove box, container, fuel cladding, cell, containment enclosure and associated ventilation networks	Equipment, piping, vessel, cell, containment enclosure and their associated process and/or enclosure ventilation networks
Secondary containment	Adjoining room(s) and associated ventilation networks	Adjoining room(s) and associated ventilation networks
Tertiary containment (if required)	Building, building-ventilation network	Building, building ventilation network

6.1.4 Additional remarks concerning static containment

In this International Standard, those parts of the plants, building structure and equipment provided specifically to limit the release of radioactive and toxic substances, whether in the form of gas, aerosols or vapours, will be referred to as the containment. Total enclosures, fume cupboards and the rooms in which these are housed are all examples of containment.

A leaktight containment is the most effective way to prevent release of particulate and gaseous substances. However in practice, perfect leaktightness is not possible and, as some openings in the containment are necessary to allow access by operators, transfer of materials and equipment, etc., and also as structural gaps will occur, a depression between each containment barrier is usually maintained to create an inward flow of air to minimize leakage.

The degree of containment for the particular plant, including the number of barriers required, must be determined by a risk assessment, taking into account the design safety principles for the project. For this, the following factors shall be considered: severity and likely frequency of potential accidents, quantity of radioactivity present, radio-toxicity and potential dispersability (gas, liquid, solid) of the pertinent materials.

Where there are multiple barriers, the first will often be provided by a total enclosure in which the radioactive substance is contained. This may be a containment enclosure or a glove box. An additional confinement may be required to prevent the release of radioactive material to the workplace or environment. This may be an integral part of the structure of the building which shall totally surround the inner containment, and must remain effective under the postulated accident conditions. This additional confinement is often necessary in order to give adequate protection to the workers, particularly where substances of high toxicity are involved.

Different approaches to the principles of compartmentation for both containment and contamination control must be adopted to solve the various problems, which arise in the facility. However, the foregoing is intended to indicate the underlying principles on which containment is based. For a particular project, the designer of the ventilation system for the radioactive areas shall seek to understand the operational requirement(s) of the various areas requiring ventilation, because air-flow patterns within them and from one area to the next are an essential safeguard. The ultimate purpose is to minimize the escape of radioactive substances into occupied workrooms and to the environment.

6.1.5 Dynamic confinement

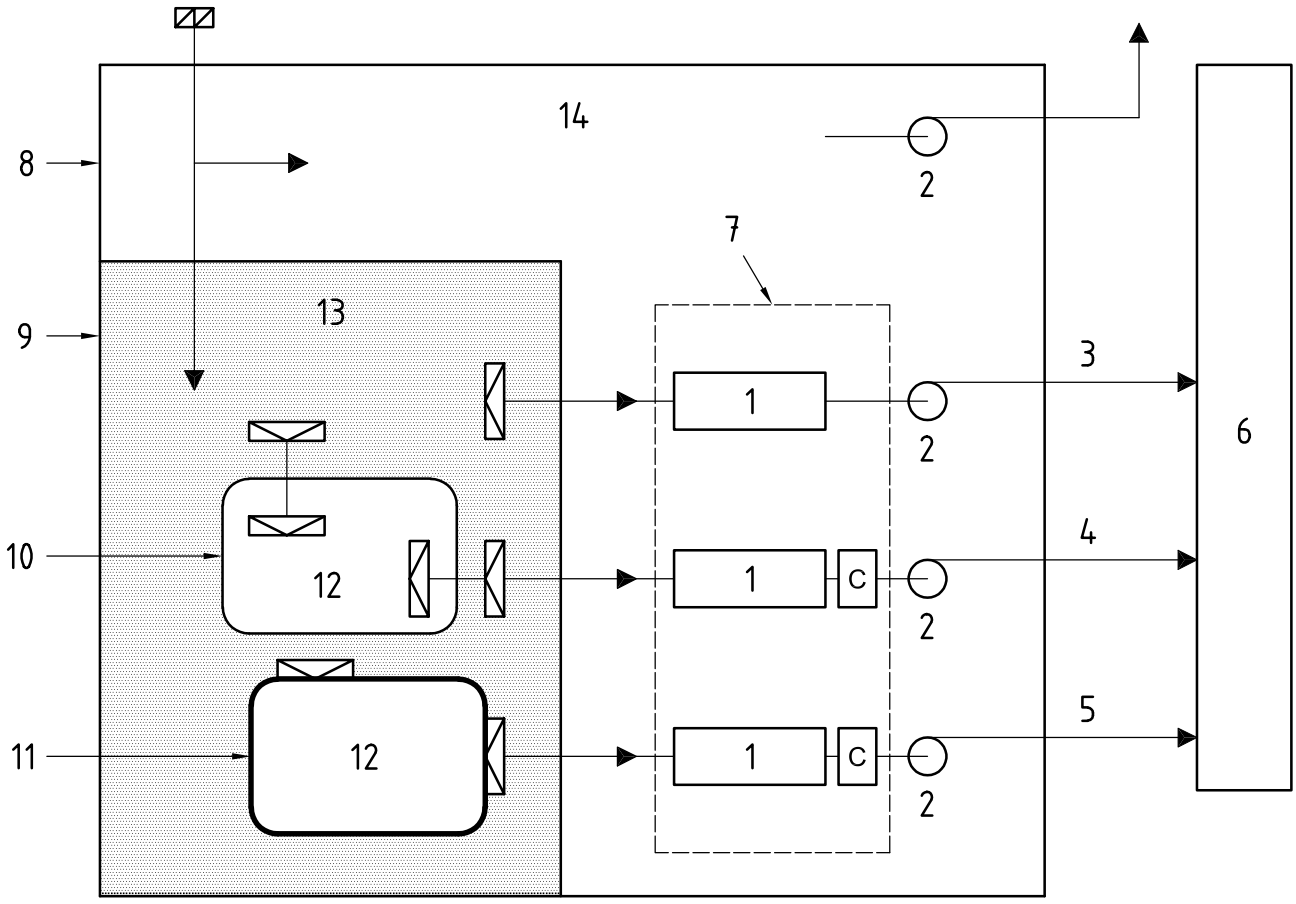
Dynamic confinement complements static containment. It is based on a series of negative pressure differentials. The system shall be designed so that the pressure is lowest in the areas where the radioactive substances are contained (process equipment or glove boxes or cells), so that if a leak occurs, except in certain circumstances[2)], the air flow goes from the low contamination to the high contamination area.

2) As described in 6.1.1, for the case of special working atmospheres, sometimes a purged interspace volume will have the lowest pressure, which must then be exhausted via a dedicated filtration system.

Such dynamic confinement is provided primarily by the ventilation system, described in Clause 8, which includes at least one and preferably two HEPA filters[3)] at the exhaust to avoid the release of radioactive material to the surrounding environment. The number of filtration stages are indicated in 8.2.3 (see also Annex B).

In new installations, air transfer between minimally contaminated areas and highly contaminated areas shall be limited as far as possible and realized using appropriately dimensioned inlet and outlet ventilation networks. Where such transfers could not be avoided, a filtration unit must be installed in these transfer lines whose efficiency is as large as practicable, and at least equal to the ratio between the potential airborne contaminations of the respective areas.

The ventilation system for any radioactive area is a major component for maintaining confinement of the radioactive material within it. Figure 2 below illustrates a typical radiological facility in this context.



Key

1	last filtration stage	6	stack	11	shielded cell
2	extraction fan	7	filtration room	12	primary containment
3	high-depression extraction line	8	building	13	secondary containment
4	low-depression extraction line	9	contaminated area	14	tertiary containment
5	glove-box extraction line	10	glove box		

Pre-filter (Coarse filter) HEPA filter C Chemical scrubber (optional)

Figure 2 — Schematic diagram of a possible ventilation system

3) The definition of HEPA filters is given in Annex C.

6.2 Specific requirements associated with containment systems

In addition to the previous general principles, the following specific requirements shall be met:

a) classify and consider the optimisation of the arrangement of the different equipment, enclosures, rooms and the associated ventilation systems according to the hazard potential and the risk of radioactive material escape;

b) provide separate ventilation extraction networks, which allow the designer to vary the reliability of each one (redundancy, choice of equipment, quality of construction, reliability of electrical supply, etc.) to suit the potential risk for each different type of exhaust flow (extraction from process equipment areas, containment enclosures, occupied rooms of the building);

c) achieve and sustain a hierarchy of pressure levels between zones presenting different radioactive contamination-dispersion hazards, according to design criteria that take into account the influence of the different physical factors that govern the regime of the ventilation and its control;

d) equip the ventilation systems with appropriate monitoring and control devices in order to guarantee the required behaviour throughout the projected lifetime of the plant;

e) equip ducts of the extraction networks with appropriate contamination-monitoring devices, which facilitate the monitoring of the transported air according to the level of risk of the corresponding rooms;

f) provide continuity of the containment barriers by systems of airlock chambers, or by taking special precautions during normal and occasional openings:

   — by ensuring some minimum air velocity to limit back-flow (turbulent distribution) and thermal convection;

   — by arranging an air speed as homogeneous as possible in the openings;

g) improve some radiological protection measures in the areas routinely accessible to operators, by reducing the natural radioactivity present (mainly radon).

Various operating regimes of the ventilation systems corresponding to the different operating characteristics may be considered. These regimes shall be listed with adequate precision and the values of associated functional parameters shall be specified.

An examination of the various failure possibilities of the equipment, particularly any leading to the modification of the hierarchy of pressures or excessive pressure differences, must be undertaken and measures will be taken to limit, if necessary, the likelihood or frequency of such incidents and their consequences.

For this purpose, some provisions shall be made, namely:

— maintaining the extraction flow of equipment, enclosures or rooms which are potentially more contaminated, rather than the extraction flows of rooms which are less contaminated;

— in case of failure of one of the extraction systems, to maintain the air circulation and the pressure differentials by automatically stopping the corresponding inlet air system and, if appropriate, the ventilation systems of the adjoining rooms;

— establishing a range of limiting control values allowing the operation of equipment such as regulating valves, shut-off valves or safety devices to prevent overpressure in the exhaust ventilation network during disturbances of the general ventilation system;

— avoiding, as far as possible, booster fans in the design of new nuclear facilities.

6.3 Additional arrangements to limit the risk of spread of radioactive contamination

Ventilation systems must not generate any unnecessary additional risks and shall be designed in order to limit the spread of radioactive substances inside the installation. For this purpose:

a) the location of ventilation ducts shall be considered with a view to limiting the radiological exposure and possible spread of radioactive substances inside the rooms that they cross;

b) all ducts, filtering and air-cleaning devices used shall have the appropriate specified leaktightness in accordance with ISO 10648-2;

c) points of release and intake will be chosen in order to avoid possibilities of local recycling of discharges from the installation, or the discharges produced by another installation, and to limit their impact on the environment;

d) filtering and air-cleaning devices shall be designed in order to limit the volume of wastes that they will produce. If the possibility of replacement of filtering and air-cleaning devices in the design of ventilation systems is considered, their replacement shall be capable of being undertaken without the risk of spread of radioactive contamination and without the risk of excessive exposure of the workers during the operation. If necessary, remote-handling means will be provided;

e) if excessive overpressure or underpressure could occur which could destroy the static containment, the equipment or leaktight enclosures shall be supplied with devices able to act as safety valves connected to dedicated extraction and/or gas-cleaning (scrubbing) systems;

f) the nature of materials employed for the construction of ventilation systems shall be selected according to the intended function, noting especially the behaviour regarding resistance to corrosion, radiation, ease of decontamination, vibration, heating and mechanical effects due to pressure variations.

6.4 Air-cleaning devices

Air-cleaning (or scrubbing) devices shall be designed and constructed, if needed, in such a way that they suitably resist the various stresses of predictable mechanical loadings, transient or periodic, and especially any chemical attack by corrosive gases or transported vapours.

During the design stage, there will also be taken into consideration the necessity of installation of devices that allow the isolation of parts of the air-cleaning system, in order to facilitate interventions without disrupting either the confinement function or the air cleaning.

These devices shall be designed to suit the predictable chemical forms of nuclides to be filtered, such as HEPA filters for aerosols, iodine traps for iodine gases, detritiation systems for tritium, gas absorber or gas washing for chemicals or radioactive components of gaseous form. The efficiency of these devices must be controlled periodically and compared to the reference values defined during the safety analysis stage. Injection and take-off devices, as well as measurement, points shall be implemented upstream and downstream of the filters in order to test each type of filter *in situ*. Pressure-drop measurement devices shall be implemented and periodically checked as part of the formal maintenance schedule.

7 Principles of prevention of other risks

7.1 Prevention of risks linked to releases of heat, gas or toxic vapours

The purpose of the ventilation, with regard to such risks, is to ensure the evacuation of the heat, gases or harmful vapours emitted by the process or by the product handled or stored. The implied safety functions are the conditioning and the renewal of the atmosphere, ensuring the avoidance of creation of any “dead areas” inside the defined volumes. These functions can be ensured by open or closed ventilation networks. It will be necessary to analyze these risks and to specify the reliability of the systems concerned and their control devices to suit the consequences of possible accidents.

Special attention shall be paid to controlling the release of radioactive gases and vapours into the rooms and/or the environment. This may require the introduction of appropriate equipment such as scrubbers, chemical traps (e.g. iodine traps, tritium treatment stations) and noble-gas delay systems. Examples of this type of equipment are described in ISO 11933-4.

In addition, ventilation systems shall be designed in order to prevent the accumulation of explosive atmospheres, inert gases or toxic gases where these could pose particular hazards. Some ventilation systems will have to accommodate the air flow associated with cooling the process plant. These objectives can be achieved by appropriate selection of air-change rate, depending on the specific safety analysis.

7.2 Prevention of risks linked to deposition of matter in ventilation ducts

In order to avoid the deposition of radioactive products, flammable matter, corrosives or toxic material in ventilation ducts, the following preventive measures are recommended:

— installation of appropriate air-cleaning or filtering devices as near as possible to the source points, except when especially justified;

— adoption of an air velocity inside the ducts sufficient to entrain the predicted particles;

— separation of ventilation duct networks to avoid cross-contamination;

— choice of layout, form and nature of material of construction of ventilation ducts, reducing as much as possible the retention of matter and facilitating their cleaning, where appropriate.

7.3 Prevention of fire hazard

7.3.1 Compartmentation

To inhibit the spreading of a fire, the best prevention rule consists of creating fire compartments (FC), inside the building or the rooms. The aim of these compartments is both to limit the propagation of fire and smoke beyond these compartments, due to pressure phenomena and thermal loads induced by the fire, and to contain internal fires within pre-defined volumes for a sufficient period to facilitate intervention for extinguishing the fire, and to protect these compartments against possible external fires.

When the consequences of a fire occurring inside a fire compartment containing radioactive substances lead to a significant risk of release of contamination affecting the radiologically exposed workers, the general public or the environment, additional containment compartments (CC) shall be defined in order to limit these consequences.

The walls constituting both of these compartments, i.e. the fire compartment and the containment compartment, shall, in new installations, be separated wherever possible.

7.3.2 Fire compartments

Fire compartments shall fulfil the following requirements.

— The walls and the material of construction of a fire compartment shall be designed to resist penetration by the maximum fire which may occur inside or immediately outside the compartment, for the duration corresponding to the worst-case fire prediction. The design must also take into account the constraints due to maximal pressure and temperature induced by the possible fire, especially when the containment is only ensured by means of static barriers during the fire.

— A fire compartment can include one or several rooms, the choice depending on safety considerations (including the necessity of avoiding common mode failure) and on the possibilities for extinguishing the fire (duration, accessibility, etc.).

— When fire compartments are to contain radioactive substances such that a possible fire leads to significant consequences for the environment and the general public, designers are strongly recommended to avoid making the fire compartment walls common with those of the external building structures. It is preferable to insert between these walls some room, or group of rooms, with specific ventilation networks equipped with HEPA filtration. To facilitate the early detection of fires and hence prevent any compromise of the barriers defining the fire compartments containing radioactive substances, specific measures shall be taken to detect these fires by external means (doors equipped with fireproof windows, visual-detection systems, TV cameras, etc.).

In the case of fire compartments containing radioactive substances, the associated ventilation systems shall fulfil the following basic principles:

— relevant information (e.g. on temperature, pressure, presence of smoke) shall be continuously available to allow the operation of the ventilation system in an appropriate way, in order to control smoke, hot gases and dust using whatever means were identified for this purpose in the plant safety case and design provisions;

— the ventilation must be capable of being isolated in order to prevent, on the one hand, the propagation of the fire along the normal extraction network, and on the other hand, the limitation of the air contribution to the fire source;

— the functioning of the extraction network and the air-cleaning system will be maintained in order to

  — ensure the control of the dynamic confinement, as long as possible during and after the possible fires,

  — minimize the potential for creation of explosive atmosphere within the containment areas or rooms,

  — limit the release of the radioactive substances to the rooms where personnel are intended to remain, and

  — protect the last filtration level from chemical and heat attack in order to avoid uncontrolled releases into the environment (to maximize protection of the general public), namely in case of risk of loss of the last filtration level.

The operation of the ventilation system in the case of a fire has to be carried out according to the findings of a suitable safety study and respect the recommendations given in 9.6. To fulfil these principles, the following measures shall be taken:

a) The fire resistance of the boundaries of the fire compartments must be maintained by the installation of suitably positioned fire dampers within the associated ventilation ducts. The control devices of these fire dampers must be protected against the effects of the fire.

b) The extraction circuit designed to be used during a fire shall take into account the following considerations.

  — The first level of filtration, where it exists, shall be designed in order to avoid clogging or developing a loss of efficiency too rapidly. Its destruction shall not necessitate the interruption of the extraction ventilation. Its clogging shall not rapidly lead to a reduction of the extraction air-flow rates to such an extent that a significant positive pressure excursion might arise, or the dynamic confinement becomes ineffective.

  — The last level of filtration shall be designed in order to guarantee its functioning and its efficiency throughout the duration of the fire (by dilution of the gaseous effluents for example).

c) The ventilation ducts and their connection flanges, etc. shall be leaktight and must be designed to resist breaching by sources of heat and corrosive particles which could be dispersed into the rooms they serve or cross. If it cannot be avoided that ducts cross other fire compartments, these ducts must be fire resistant to at least the standard of the walls of the fire compartments that they cross.

d) The admission ducts to a fire compartment could be equipped, if necessary, with one filtering stage, located as near as possible to the wall of the compartment and upstream of a suitable fire-resistant isolation valve or a fire damper in the admission line.

e) Transfer of air between fire compartments, or from fire and containment compartments to other rooms, must be made impossible in new installations. Air-conditioning systems shall accordingly meet the same requirements.

f) The calculation of releases in the event of a fire will have to be undertaken taking into account the leak rate of the fire compartment.

It arises from the foregoing that certain general safety principles shall be followed when designing fire compartments, namely:

1) Design the system to keep the size and number of all penetrations in the associated barriers to a minimum.

2) Normally, where a ventilation duct penetrates a fire barrier, fit a fire damper with the same standard of fire resistance as that required by the wall through which it passes.

3) Test and certify fire dampers and barriers by an approved authority in accordance with a nationally recognized standard. The designer should ensure that the fire damper is installed in the manner in which it was tested.

4) During operation, carry out periodic tests of fire dampers, according to approved procedures. It is necessary to be able to test the correct operation of each damper by closing and opening it, either at the damper or from a remote control point. A positive indication of successful operation shall be included, for example by use of limit switches. Multiple-use dampers should be resettable without having to gain access into the duct.

5) Adapt the materials of construction of fire dampers for the likely environment within the duct. Care needs to be taken in the presence of acid and other reactive vapours, which may cause long-term corrosion. Fire dampers with intumescent materials are not recommended unless the initiation temperature of the intumescent material is well below the maximum permitted operation temperature of the associated HEPA filters.

6) Depending on individual circumstances, some of the fire dampers may need to be resettable from a safe location, e.g. a control room. The need for this capability will be dependent on factors like ease of access to the damper location, likely local environment in the vicinity of the fire, and the importance of the damper in the overall fire-control philosophy (see 9.6.2).

7) Use, with caution, automatically initiated closure of fire dampers within certain ductwork systems, because the associated pressure excursions could breach the rooms containment.

7.3.3 Containment compartments

When a fire in a fire compartment containing radioactive substances would lead to unacceptable consequences for the workers, the general public and the environment, the limitation of the spread of contamination is realized via containment compartments.

For that purpose, containment compartments shall fulfil the following requirements.

— The limits of the containment compartment are constituted by the walls of the room, or the group of rooms including the fire compartment(s) concerned. Access and inspection of the walls of the containment compartment and of the associated fire compartments shall be possible from both sides;

— The barrier of the containment compartment shall be designed to retain the effluents produced, including those emanating from the walls of the associated fire compartments.

— In the region where a containment compartment wall constitutes an integral part of the structure of the external building wall, or constitutes the limit of volumes having specific ventilation networks not equipped with HEPA filtration systems, the containment enclosure shall be entirely free of penetrations;

— In order to limit the risk of spread of radioactive contamination within the facility, and to facilitate interventions and subsequent decontamination, the boundary of the containment compartment shall be located as near as practicable to the associated fire compartments;

— In order not to break the confinement of radioactive substances, the accessibility to containment compartments for intervention shall be achieved via an appropriate ventilated airlock chamber.

The ventilation philosophy of containment compartments shall permit the control of the smoke and radioactive particles that would escape from the associated fire compartment(s) and contain them appropriately in the event of a fire. The ventilation systems of the rooms constituting the containment compartment shall be dimensioned according to the leak rates induced by these fire compartments, as well as to the temperature and pressure predicted to be reached in these volumes.

During the total duration of a fire, the containment compartment shall, wherever possible, be maintained in depression, when compared to the adjoining rooms or the atmospheric pressure.

7.4 Consideration of external hazards

The design of the plant shall account for consideration of a variety of external hazards, with a view to preventing or minimizing the release to the environment of radioactive material, and to maintaining the principal safety functions defined in Clause 4.

External events to be considered in the design of containment systems are those events resulting from human activities in the vicinity of the plant, as well as natural hazards, which may challenge the integrity and functions of the containment systems.

All relevant external events shall be evaluated to determine the possible effects, establish the safety systems needed for prevention or mitigation, and assist in designing the systems to mitigate the expected effects.

Some examples of external hazards are:

— aircraft crash;

— explosion of a combustible fluid container;

— earthquake;

— strong winds;

— flood;

— external missile impact;

— extreme temperature (high and low).

The objective is to maintain at least one effective containment system between the radioactive substances and the environment for any plausible risks during the projected lifetime of the plant. For that purpose, containment systems shall be designed in such a way that external events do not lead to unacceptable consequences for the general public and the environment.

In order to mitigate the consequences of these hazards, preference should generally be given to designing the necessary protection features into the static containment barriers rather than the dynamic confinement systems.

The role of ventilation systems in maintaining the other safety functions shall be assessed and the chosen design shall reflect the reliability required for these systems.

8 Methodology for dimensioning ventilation systems

8.1 Classification of the installation into working areas

The areas in which work on radioactive materials takes place shall be classified according to the degree of radioactive hazard they contain. The classification is usually set according to the direct radiation (external exposure), and the potential level of surface contamination and/or airborne contamination (internal exposure).

8.1.1 Containment-area classification

In order to optimize the ventilation system, the installation shall be divided into separate areas with regard to the risk of spread of radioactive contamination. For this purpose, a classification into containment areas, according to the normal or foreseeable accidental risk of spreading of contamination, shall be defined in accordance with the respective national safety authorities.

Different systems of classification are used around the world. Most of them use a four-grade subdivision, called in the text below C1, C2, C3 and C4 zones. The definitions of these four zones are given in Table 2. Annex A gives an example of such a system of classification.

All these systems, defined on the basis of a safety analysis, are a convenient “shorthand” by which the broad division of areas may be referred to in operational and design discussions, but shall not be taken as an absolute definition. In a particular case, the designers shall use the descriptions of such areas as a guide, but shall ask the client to specify what additions or modifications are appropriate.

Table 2 — Usual classification of containment areas

Class	Expected normal and/or occasional contamination
C1	Means a clean area free from normal radioactive contamination, whether surface or airborne. Only in exceptional situations, a low contamination level can be accepted.
C2	Means an area that is substantially clean during normal operation. Only in exceptional circumstances, resulting from an incident or accident situation, is a medium level of surface or airborne contamination acceptable, so appropriate provisions must be made for its control.
C3	Means an area in which some surface contamination could be present but it is normally free from airborne contamination. In some cases, resulting from an incident or accident situation, there will be a potential for surface or airborne contamination at a level higher than in C2 areas, so that suitable provisions must be made for its control.
C4	Means an area in which permanent, as well as occasional, contamination levels are so high that there is normally no access permitted for personnel, except with appropriate protective equipment.

Some examples of classifications are given as follows:

— non-contaminated change rooms are classified C1;

— mechanical process cells presenting a high level of permanent radioactive contamination are generally classified as C3 or C4;

— mechanical process cells presenting a low level of accidental radioactive contamination are generally classified as C2 or C3;

— chemical process cells, according to their level of toxicity and whether or not permanent contamination is expected to be present, are generally classified as C2 to C4.

For each of these classes, there shall be appropriate ventilation architecture and a specific air-cleaning system. Basic considerations for the constitution of these systems will be given in 8.2.

Where a containment-area classification is used, care shall be taken to meet the following safety principles:

a) The various areas must be maintained at different atmospheric pressure levels; areas with the highest atmospheric contamination levels must be maintained at the greatest depressions with respect to the ambient pressure in the adjoining areas. In these adjoining areas, the potential contamination level may be considered to be so low that is not necessary to hold the area under depression with respect to the external environment.

b) In the event of accidental breaches in the structural barriers segregating areas of different levels of contamination, the ventilation systems must be capable of maintaining sufficient air flow in a preferential direction through the adventitious openings to limit back diffusion of the more highly contaminated atmosphere into the lower contaminated atmosphere of the adjoining area.

c) The enclosure structure around the C4 area housing a radioactive process will be the first containment barrier and will have an integrity and leaktightness appropriate to the contained activity. Further containment barriers will be provided by the surrounding area boundary structures (C3, C2 or C1 areas) as required by the plant hazard analysis, and the depressions and flows will be at levels consistent with the defined containment quality. In some cases, e.g. accident conditions, the levels of depressions, and inward-leakage flows will need to be increased and this will require appropriate ventilation provision (e.g. operation in only an extract mode).

d) It may be necessary, on a short-term basis, to change the classification of some areas, or portions of areas, for example due to specific operational or maintenance requirements. In the case of permanent areas including maintenance facilities that are associated with enclosure structures, these areas might be normally classified as C2 or C3. When certain maintenance activities are being carried out, these areas may need to be classified as C4. Where such are identified, the ventilation system must be designed to meet the requirements of the higher classification.

8.1.2 Classification into radiological areas

In the event of a radiation exposure hazard (internal and external exposure), a complementary classification of the installation into radiological zones shall be made, according to the ICRP recommendations. The following radiological area designations are used if needed: unrestricted areas, supervised, controlled and forbidden areas.

Definitions of these different radiological areas are given in national regulations. They can overlap with the previous containment-area classification, but care shall be taken in both these classifications to avoid incompatibility (e.g. a C4 class can only be a forbidden area, etc.). The overall classification system used must comply with the pertinent national regulations.

8.2 Requirements concerning basic ventilation parameters

8.2.1 Static containment

Static containment is ensured by different means: the walls of the building, the walls of the rooms containing radioactive substances, and/or the envelope of the process.

The quality of its design, and especially its degree of leaktightness, which is chosen according to the potential risk presented by the installation, has a consequential influence on all the functions attributed to the ventilation systems that are associated with it, in particular the dynamic function.

Following the same principles, it is generally true that good leaktightness of a building or room can only be favourable for the overall safety of the installation, if failure of the dynamic confinement is considered possible.

The dimensioning and the overall design of ventilation installations must begin with an order of magnitude estimate of the leak rates of the buildings and of the rooms, according to the local most severe climatic conditions (wind, snow, temperature, etc.).

8.2.2 Dynamic confinement

8.2.2.1 Normal functioning

In order to ensure the adequacy of this function for all operational regimes of the installation, criteria shall be defined during the design stage, taking into account the influence of several factors including:

a) the speed of the wind on building façades (with adventitious or temporary openings) as well as air intakes for the ventilation;

b) the differences of temperature between rooms, as well as between given rooms and the exterior;

c) the various predictable disturbances of short duration, such as the opening of airlock chambers or alterations of operational regimes of the ventilation systems;

d) the uncertainties linked to the functioning of the ventilation systems and their regulation namely:

— the precision of the measurement devices according to their location with respect to bends, etc.;

— the differences induced by the response time of the monitoring and regulation devices;

— the drift of the functional characteristics of some components of the ventilation network (ageing, clogging, degradation, etc.).

8.2.2.2 Depressions

Depressions between areas are necessary to create the required inflow of air through permanent or accidental openings of not less than specified average velocity during normal and abnormal conditions. Depressions are maintained by means of balancing dampers, valves, and fan-speed regulators, etc. The inlet and extract systems must be balanced to maintain the required depressions in the areas.

For indication, examples of usual values of depressions are given in Table 3.

Table 3 — Guide to depression values

Nature of room or area	Depression value [a]	Containment class
Non-controlled rooms or areas free from contamination	Atmospheric pressure or small overpressure	Unclassified
Supervised areas with low levels of surface or airborne contamination	Less than 60 Pa	C1
C1 should be uncontaminated in normal operations		
Controlled areas with moderate levels of surface or airborne contamination	80 to 100 Pa	C2
Controlled areas with high levels of surface or airborne contamination	120 to 140 Pa	C3
Controlled areas with very high levels of surface or airborne contamination	220 to 300 Pa	C4
Areas which are not accessible except under specific circumstances		

[a] Compared to the reference pressure.

The depressions required to create the specified velocities given in 8.2.2.3 can be very small and not easily measurable. Where it is required to measure and/or alarm loss of flow, it is usually necessary to enhance these depressions, a value of between 60 and 100 Pa being usually sufficient for this purpose.

The differential pressure between adjacent areas with different classification shall be chosen to suit particular conditions but, in any case, it should be at least 40 Pa.

It should be noted, however, that larger depressions might be required for glove boxes or containment enclosures. In certain circumstances, for example, where the effects of wind loading and thermal convection have to be considered, it may be necessary to enhance depressions.

8.2.2.3 Air velocities between areas

Ventilation systems can be used in some cases to ensure dynamic confinement between two areas presenting different risks of spread of radioactive contamination, when they are connected:

— either by occasional openings necessary for operation (doors, traps, front faces of fume cupboards, etc.);

— or by incidental or accidental openings (rupture of a circuit or a transfer system, etc.).

a) In the first case, minimal air velocities at the openings have been advanced in the past, namely 0,5 $m \cdot s^{-1}$ for all type of contaminants, except for plutonium 238 and tritium for which respective air velocities of 1 m·s and 1,5 $m \cdot s^{-1}$ have been recommended (see also ISO 11933-4). It should be noted that, when openings are of a large cross-section, these values lead to air-flow rates substantially higher than the normal air-flow rates necessary for ensuring a correct dynamic confinement for the room considered. In this case, the overall air-flow rate shall be chosen to ensure nevertheless a minimal air circulation through the openings.

   Consequently each situation has to be studied case by case, according to the potential risk of contamination and (indirectly) the containment-area classification of the room, the design of its ventilation system, the influence of heat sources, the number and position of measurement points, etc. In many cases, the use of a ventilated airlock-chamber should represent a satisfactory alternative solution for ensuring a complementary dynamic confinement.

b) For accidental or off-normal openings which have been taken into account during dimensioning of the installation, the consequences of back-flow of contaminants present a more serious situation because the openings are generally located at the interface between the process and the operating room, and hence constitute a potential breach of the containment barrier.

   Here again, alternative solutions have to be studied case by case, according to the geometry of the opening and the corresponding risk (e.g. direct contamination, fire, explosion). When identified potential openings have the form of a thin edge (or extremities), a configuration profiled in the form of a tunnel can be arranged to suppress turbulence and entrained contamination at the end of the opening. Consequently, this allows the reduction of the values of the recommended air velocities referred to above [8.2.2.3 a)] and accordingly also the air-flow rate of the overall ventilation system, while still ensuring an equivalent protection level.

   Correspondingly, for the particular problem of achieving dynamic confinement at incidental or accidental openings, it currently proves rather difficult to provide very precise recommendations. Because of the characteristics presented by each installation, every case has to be examined separately and validated, if necessary, by an experimental study.

8.2.3 Basic air pattern and clean-up systems

The functions attributed to the system of ventilation and the classification of rooms according to the risk of contamination lead to the definition of a hierarchy of ventilation networks.

a) According to the risks induced by the nature of the effluents transported.

b) According to the following parameters:

- required reliability (redundancy, quality of construction, electricity supply, etc.);
- number of regimes of functioning required for the particular objectives of operation;
- saving of energy (electricity, heating, etc.);
- safety requirements (redundancy of the ventilation and or air-cleaning systems, energy supply, permanency of ventilation and filtration functions, etc.);
- operation and installation constraints (decontamination, dismantling).

This overall study shall include the nominal regimes of functioning of the different types of ventilation networks, as well as the totality of the transitory regimes following an incident or accident in the installation, in order to guarantee, in all cases, a secure state of the installation.

In addition, the analysis has to take into account the following considerations.

8.2.3.1 C1 areas shall normally not be filtered. Appropriate air treatment shall be foreseen only when the corresponding rooms are occupied by workers or contain electric or electronic material. The extract air can be exhausted locally without filtration.

8.2.3.2 Air shall enter the building through industrial grade filters to reduce the quantity of dust and impurities in the inlet air, which would otherwise find its way to the HEPA filters in the extraction network. The air may be treated to maintain the designed environmental conditions. Where deemed necessary by the safety case for the plant, inlets to C2 areas shall be equipped with HEPA filtration to protect against possible back diffusion of contamination due to loss of extract flow from the C2 areas.

8.2.3.3 Within the building, air flows shall be from areas of lowest potential contamination to those of highest contamination (i.e. from C1 to C2 areas and so on). Air velocities through breaches in the containment barriers shall be sufficient to prevent unacceptable back-flow of contaminated aerosols into the lower contaminated atmosphere of the adjoining area. Where shown to be necessary, as a result of hazard assessment, air-flow paths shall be through a filtration unit between areas of different classification.

Consideration shall be given to supplying air adjoining to the operator work station, in order to direct the flow from the operator location to the extraction points where radioactive contamination will potentially be released.

8.2.3.4 In general, air is extracted from the C2 areas via ductwork to the discharge duct or stack, although some may exhaust via any C3/C4 areas present. The number and type of filters in series in the duct system from the various areas, prior to the discharge point, will be determined as a result of hazard assessment. The recommended extraction system includes, as a minimum, one HEPA filtration stage.

8.2.3.5 Air in C3 areas is likely to be sufficiently contaminated to require one more HEPA filtration stage in the discharge line than a C2 area would have. The need for additional treatment on the ground of potential accident releases will need to be considered as part of the plant hazard assessment. It shall be noted, in this context, that the level of activity in relation to operator access is not directly relevant to the need for discharge filtration; this latter requirement arises more from the need to keep discharges ALARP (As Low As Reasonably Practicable). Where deemed necessary by the safety case for the plant, inlets to C3 areas shall be equipped with HEPA filtration to protect against possible back diffusion of contamination due to loss of extract flow from the C3 areas.

8.2.3.6 Containments for C4 areas, such as glove boxes, shielded cells, etc. which contain loose radioactive materials, a very small proportion of which is airborne at any time, require special consideration. The activity extracted from these facilities will be directly proportional to both the airborne contamination concentration and the extract air-flow rate. As a general rule, several HEPA filtration stages are recommended to provide the necessary clean up for these extracts.

8.2.3.7 Complementary requirements concerning the extraction lines of rooms or cells classified C4 or C3 shall be fulfilled, when a risk of significant filter deposits of radioactive material exists. The discharge of air or

gases from these areas will include a local filtration with a single or a double HEPA filtration stage, the first of which may need to be equipped with shielding against gamma radiation. Another filtration stage, which is generally located in a more remote central filtration room, constitutes the last cleaning stage before release into the environment, typically via a general stack.

8.2.3.8 Specific air-cleaning systems shall be implemented in the case of a significant inventory of nuclides for which HEPA filters are not efficient (e.g. iodine, tritium, gaseous ruthenium).

8.2.4 Classification into ventilation types

In addition to the classification into containment-area classes, and in accordance with the previous requirements, a classification into types of ventilation can be established, which permits the definition of the principle rules for the general design and equipment specific to the different ventilation networks.

Annex B gives an example of such a classification, which is based on the normal as well as the potential accident contamination levels. This annex is not a requirement but only a guide, comprising suggestions that may be modified according to the safety analysis of the particular plant.

8.2.5 Optimization of air changes

The number of air changes will be determined by the conventional ventilation requirements necessary to cater for fresh air, removal of odours, potential asphyxiants, vapours and heat, etc. In addition, the air-change rates may be determined by the radiological requirement to maintain correct depression and air flows between areas, and to allow efficient air monitoring where this is required.

The calculation of ventilation air-change rates for areas, containment enclosures and rooms needs four iterative steps:

a) Estimation of the typical air-flow rate according to the classification of the working areas (radiological areas, containment areas).

b) Consideration of the specific risks.

c) Study of the containment function.

d) Maintainance of the climatic and hygienic conditions.

The first two steps are directly dependant on the nature of the principles and operating conditions of the process implemented. The last two steps take into account the design and the construction of the building.

8.2.5.1 First step

This allows the definition of a minimal air-change rate, taking into account the air-conditioning requirement of the ambient atmosphere in normal and accidental conditions. For accident situations, the following operational conditions should be considered:

— principles of intervention;

— methods of intervention (permanent or temporary);

— conditions for return to the normal operating state (duration of immobilization, acceptable contamination level, etc.).

As a guide, the conventionally adopted air-change rates are given in Table 4.

Table 4 — Guide to air-change rates

Compartment	Typical air changes per hour	Containment class
Changing rooms, air locks	4 to 5	C1, C2 or C3
Normally clean air corridor	1 to 2	C2
Normally non-active rooms	1 to 2	C2
Controlled areas of medium potential hazard	2	C2
Maintenance areas to primary containment of risk process plants	1 to 5	C3
Controlled area of high potential hazard	5 to 10	C3
Maintenance areas to primary containment of high-risk process plants	10	C3
Primary containment (glove box, containment enclosure or shielded cell)	1 to 30 (depending entirely on process, volume of the containment enclosure and on hazard)	C4

8.2.5.2 Second step

Consideration of the following hazards and the specific constraints such as:

— explosive and inflammable gases, for example H_2;

— presence of radioactive gases (e.g. tritium) or toxic liquids;

— thermal constraints due to the process, etc.;

has to be made in evaluating the required air-change rate of the room. This evaluation necessitates a particular study, which may lead to increasing the air-change rates from the values indicated in Table 4.

8.2.5.3 Third step

In order to ensure the dynamic confinement of the room, i.e. to maintain the necessary depression, the leak rate of the room is determined according to the characteristics of construction, operational requirements (occasional openings) and foreseen accidental conditions threatening the containment.

Depending on the relative values of the inventoried leak flow rates, it is advisable to verify that the air flows transported by the ventilation (mainly the admission and transfer air-flow rates) remain sufficient to guarantee the confinement. In cases where the exhaust air flows necessary to compensate the predicted leak flow rates appear to be excessive, a cost optimization study shall be undertaken, balancing the cost of the ventilation against the cost of improvement of the leaktightness of the room, while achieving the required degree of safety of the overall installation.

8.2.5.4 Fourth step

This step consists of making an inventory of the thermal loadings and associated air-flow rates (contributions, losses, etc.) in order to determine the necessary air-flow rate required to maintain the climatic conditions of the room.

The study has to be undertaken for both the normal and likely off-normal functioning of the installation. It will take into account:

— the influence of the location of the rooms;

— the possibilities of air transfer or of recycling, respecting the application of the principles defined in the diagrams given in 6.2 or in Annex B;

— the uncertainties linked to the functioning of the ventilation system.

This optimization could require several iterations. In practice, the methodology consists of:

— analysis of the results obtained in steps 1, 2 and 3;

— retention of the maximal air-flow rate derived from these steps;

— use of this air-flow rate in the calculations of step 4.

The air-flow rate thus obtained (the maximum air-flow rate resulting from the four steps) will constitute the air-flow rate taken into account for dimensioning the ventilation system.

8.2.5.5 Remarks

In establishing the air-change rates, the following requirements shall be fulfilled.

a) C1 areas, by their definition, are free from contamination, and generally do not require special consideration other than to maintain a correct air circulation toward the surrounding C2 areas. This does not preclude the use of ventilation in these areas, as determined by the normal building mechanical service requirements.

b) In those areas which have a potential for airborne activity, increasing the air-change rate may not result in a significant reduction of airborne activity levels local to the operator. Excessive flow rates shall be avoided, since they can cause levitation of contamination and hence increased airborne activity levels. However, increased flow can reduce the average concentration in the area as a whole. Distribution of the clean air at the operator level is important.

   The air-flow rates into C2 areas may include a proportion induced from the C1 volumes or the exterior. In certain circumstances, subject to hazard assessment and by agreement with the responsible safety authority, a significant fraction of the air-change rate may be obtained by recirculating the air within the areas or transferring air from different areas. In areas having a potential for high contamination, the air must be filtered through HEPA filtration before recirculating or transferring.

c) The air-change rate shall be the lowest rate possible which fulfils the requirements of the area.

d) The aim of the design must be to optimise the air-flow patterns and the air-change rates so as minimize the contamination levels in the air to which the operators are exposed.

8.2.6 Additional requirements

8.2.6.1 Transfer

In order to limit the volume of air used, the possibility of transferring air from one area to another while respecting the containment principles given in 5.1 shall be considered, for instance, by installing on the transfer lines, medium high efficiency or HEPA filters according to the level of risk presented by the rooms.

However, a double transfer does not give a sufficient guarantee to maintain the hierarchy of depression, especially for the intermediate zone, depending on the details of the inlet and extraction facilities in this zone.

In addition, it should be noted that the air coming from a room presenting a particular hazard (toxic emanation, fire, explosion, etc.) must not be transferred to other rooms. For safety reasons, it must be compulsorily extracted by an extraction network designed for this purpose and corresponding to its containment classification and ventilation type.

In some cases, in order to compensate the loss of pressure drops of the filters installed on transfer lines, it has been common practice to include booster fans, with safety devices to avoid the possibility of overpressure in the room in which the air is transferred. Interlocks on the booster fans shall be designed in order to avoid a potential overpressure in rooms or in ducts, in case of failure of the fans downstream in the network. However, this type of design is no longer recommended and shall be avoided in future installations.

8.2.6.2 Layout and location of the ventilation ducts

The layout of the ventilation ducts has to be studied in order to:

a) avoid the abnormal deposition and the accumulation of radioactive matter in ducts;

b) reduce the risk of spread of contamination resulting from air transferring from any high activity area to a low activity area. For this reason, the designer shall always consider the following installation principles:

   — inlet ducts in less contaminated areas;

   — extraction ducts in the most contaminated areas.

Furthermore, the designer shall try to limit, as much as possible, the length of ducts inside class C4 areas.

8.3 Elaboration of the ventilation diagram and calculation of the pressure drops

This step consists of defining the architecture of the installation:

— by identifying all rooms by nature of risks (type of ventilation, fire compartments, fire and containment compartments, etc.);

— by defining the main parameters of the ventilation: depression in the rooms, air-change rates, thermal releases, leak rates, internal temperature, climatic conditions (in winter and summer extremes);

— by characterizing the admission or extraction units;

— by defining the systems of regulation, isolation and filtration.

At the end of this analysis, an outline ventilation diagram has to be elaborated. This diagram shall be refined throughout the subsequent progress of the project, accommodating the increasing precision of knowledge of the environmental conditions required in the rooms or group of rooms, which refines, for each one, the minimum required air-flow rates (admission, extraction, transfer).

At the end of this study, a complete layout diagram defining the distribution of the ventilation ducts and the location of the ventilation networks will have been created. This final diagram will be sufficiently detailed to allow the prediction of the flow dynamics of the ventilation systems.

The calculation of the associated pressure-drop losses shall take into account the predicted clogging margin of the filtration devices, the depression of the rooms, the pressure drops of the heating components, etc.

In order to dimension each junction and section, appropriate aerodynamic calculation codes or nomograms can be used, combined where necessary with fire calculation codes.

Annex B gives some typical examples of ventilation diagrams.

9 Recommendations concerning the management and operation of ventilation systems

9.1 Organization and operating procedures

The management team shall develop operational procedures establishing the rules and principles of operation of the ventilation system, in order to guarantee compliance with the requirements of the design principles and the pertinent safety regulations.

The following features shall therefore be incorporated in these procedures:

— installation considerations;

— technical operating instructions;

— operational management issues;

— test procedures and maintenance;

— procedures applicable in the event of an internal hazard such as a fire;

— decommissioning considerations.

9.2 Technical operating instructions

The technical operating instructions may include the normal and abnormal regimes of functioning of the ventilation and filtration systems as considered in the design. The instructions shall accordingly take into account the availability of the different components and equipment comprising the protection against internal hazards, including the monitoring and control systems, the integrity of the static containment barriers, the correct functioning of the ventilation systems, the efficiency of the filtration and other air-cleaning systems, etc.

All equipment and/or functions that require specific measures such as provision of compensatory or redundant equipment to cope with an incident, accidental failure or deliberate withdrawal for periodic maintenance, must be identified. In addition, the preparations necessary to achieve safe shutdown of the installation, as well as the procedures and time required to recover normal operational conditions, must be estimated.

In addition to the nominal operational values of the characteristic parameters of the ventilation systems, limiting values for certain parameters that should not be exceeded in order to maintain the functionality (e.g. hierarchy of depression, margin against clogging, efficiency of gas-cleaning devices, leaktightness of equipment, enclosures and rooms) and, for some areas, the maximal admissible duration of any partial or total failure of the ventilation shall be defined.

Alarm thresholds and preferred corrective actions following any alarm shall also be specified.

9.3 Operational management issues

The management team must develop all procedures related to at least the range of items listed below:

— surveillance and periodic checking of the parameters of the ventilation and air-cleaning systems;

— periodic review of risks induced by any internal hazard, including verification of the fire loads in the different rooms;

— periodic monitoring of the status of the equipment contributing to the static barriers of the different containments (doors, windows, plugs, penetrations, airlock-chambers, etc.);

— procedures for exceptional intervention or maintenance;

— surveillance and periodic checking of all the structures and control system elements playing a role in the integrity of the fire and containment compartments;

— tests *in situ*, at least annually, and against a clear definition of the filter replacement criteria, of the efficiency of the last filtration stage, the pressure drop across each filtration system, the radiation field around the filtration units (in the case of highly contaminated air flow); etc.;

— feedback of operational experience;

— the influence of any modifications to the plant within the ventilated areas.

9.4 Test procedures and maintenance

The ventilation and filtration systems, and their associated monitoring and control equipment, shall be subject to acceptance tests, functionality tests, commissioning, maintenance and other periodic tests. In addition, a clear set of technical specifications, standing orders, operating instructions and management chains shall be developed.

The different test procedures shall fulfil the requirements: in 9.4.1 to 9.4.4.

9.4.1 Pre-commissioning inspection

Before instigating any commissioning test *in situ*, a systematic inspection of the ventilation networks and the associated air-cleaning devices is required to verify the compliance of the equipment with the detailed design drawings.

This inspection shall also verify that the equipment and plant have not been damaged during transport or installation.

9.4.2 Acceptance tests

The purpose of the acceptance tests is to:

— verify the correct behaviour of each individual component;

— verify the overall compliance of the equipment with the specifications.

These tests must focus on the following equipment:

— ventilation networks, ducts, dampers, valves and associated flow dynamics equipment, including motor-driven fans, continuously adjustable compensation dampers;

— regulation and monitoring networks, traps, filtration systems;

— fire dampers, fire detection systems;

— associated fluid and electricity supplies.

Acceptance tests shall be undertaken in conditions as representative as possible of the operational conditions specified for the design of the ventilation systems. They include tests on individual items (such as gas-cleaning devices) and on the whole assembly. The results of these tests shall be compared with the values established during the design study, whose aim was to define the different operating flow rates of the ventilation system.

Acceptance tests will also include the simulation of some failures of equipment (to simulate abnormal operating rates of the ventilation systems, extractor fans out of order, unintended closing of a valve, etc.) leading to a degraded situation.

9.4.3 Commissioning tests

After the completion of the acceptance tests, and corrections of any faults identified, comprehensive functional tests of the equipment shall be undertaken in order to demonstrate the achievement of the required operational sequences and the nominal functional performance.

These verifications shall be realized in all the functional regimes: manual, automatic, etc., and operated from the different control consoles. During these tests, a number of system adjustments and measurements will be made, including the adjustment of the air supply and exhaust flow rates in the rooms, the pre-setting of control and monitoring loops, measurement of leaks of assemblies or of the whole network, etc.

The aim of these tests is to achieve the desired flow dynamics of the ventilation system. For this purpose, the operators shall make adjustments of the air-flow rates and the depressions using appropriate regulation devices.

The verification of all of the ventilation systems is to be performed only after:

— the construction of the building is totally achieved, and the required leaktightness is ensured;

— the doors are all installed and closed;

— the apparatus and process equipment is in operation;

— the filtering devices are installed;

— and the compensation dampers are in place, with the same setting simulating partial clogging of the filters as during the acceptance tests.

When the filtering devices are installed, the efficiency of the filtering medium and the gas-cleaning equipment, using appropriate standardized test methods suitable for the performance requirements, shall be verified.

According to the objectives defined in the safety analysis, it will be useful to verify other parameters, such as the correct distribution of the air flows, lack of dead areas, air-change rates, etc., using appropriate methods (e.g. fumigants, trace substances).

In addition to the air-flow verification and filter testing described above, the complete ventilation system shall be tested to ensure that it meets the functional requirements both during normal operation and abnormal conditions. This shall include tests of the automatic control devices such as the following:

— controls for the start-up of the standby fan, in the event of failure of the normal operating fans (where such systems are installed);

— stopping of input fans and closure of associated dampers in the event of failure of the system extract fans;

— transfer to alternative power sources in the event of failure of normal supply;

— interlocks related to preserving the pressure differences in any parallel ventilation paths.

9.4.4 Maintenance and other periodic tests

The following features shall be the subject of maintenance programs:

— structures, walls and various construction elements constituting fire compartments;

— structures, walls and various construction elements constituting the other containment barriers;

— equipment and devices contributing to fire detection and fire extinguishing;

— ventilation networks and air-cleaning systems contributing to the containment of radioactive substances, and the associated fluid and electricity supplies, monitoring and control equipment.

The whole system shall be inspected and periodically tested in order to prevent any failures and disturbances.

Provisions shall therefore be made to allow periodic test measurements of pressure drops, air flows and air-cleaning efficiency. For this purpose, the designer shall ensure that sufficient and meaningful test points are provided and located within the ventilation system and the filtering equipment to enable these measurements. The methods, periodicities and accuracy of these tests shall be defined in accordance with the relevant safety regulations in force.

The maintenance schedule shall also address potential degradation of the system over prolonged usage, e.g. increase of by-pass leakage of dampers when closed, reduction in speed of actuation of dampers and clogging of the filters, ensuring that trends are interpreted to allow further maintenance intervention before reaching end-of-life conditions.

9.5 Monitoring of the ventilation system

The aim of the monitoring or surveillance system is to verify the continued proper performance of the ventilation system, and when necessary to identify possible corrective actions. Ventilation system operation is verified using devices located in the permanently accessible areas and by means of calibrated remote sensing equipment. The results of such monitoring will demonstrate that the ventilation system is performing its safety functions as described in the Technical Operating Instructions.

The measurements of the most important parameters (see 10.2) will be formally recorded in the central control system, where information on the configuration of the equipment will also be kept up to date.

Periodic checking of relevant parameters (air velocities on openings, pressure drops, etc.) shall be performed by suitable qualified personnel.

9.6 Control of ventilation systems to prevent fire hazards

9.6.1 General

When combined with an appropriate distribution of fire detectors in fire or containment compartments, the ventilation system can contribute to the early detection and mitigation of a fire.

Accordingly, the design of the ventilation control system of a fire compartment requires a preliminary safety analysis, in order to determine whether the static containment provisions are sufficient to prevent a fire and stop the spread of any radioactive contamination, or if dynamic confinement shall be maintained by the extraction networks.

The choice between these two configurations will depend essentially on:

— the evolution of the fire;

— the quality of the static containment of the envelope of the fire compartment, in particular its leaktightness related to the pressure excursion induced by the fire;

— the quantity and toxicity of the radionuclides present in the fire compartment, as well as the forms in which they appear (solid, powder, liquid, etc);

— the efficiency in dealing with the combustion products of the different filtration barriers between the fire compartment, the adjoining rooms and the external environment in removing the combustion products.

9.6.2 Fire-control philosophy

The option of providing an automatic immediate closure of all the ventilation ducts of the room or cell when a fire occurs within it can have the opposite effect to the desired isolation, as the increasing internal pressure and production of smoke may spread the contamination to adjoining rooms.

Accordingly, the method of operating the ventilation systems in case of fire shall be analyzed in the early stages of the design procedure. This analysis can take into account the results of the determination of the fire behaviour of the materials involved (fire load) or can be evaluated by using modelling codes simulating the development of the fire in different configurations and the responses of the ventilation system.

The point must be emphasised again that the form and implementation of the fire situation control methodology will depend strongly on the particular design philosophy adopted, and it is only possible in this International Standard to indicate general areas of interpretation. It shall also be noted that one of the prime objectives shall be the protection of means of escape for the safe evacuation of the building and for the fire fighters to gain access to the seat of the fire.

Ventilation systems which continue to function will, in general, help to promote personnel safety since clean air is drawn into the contaminated areas from the corridors and work places, thereby keeping them free of smoke due to the higher pressure levels in these areas.

For areas that have only a low dispersible radiotoxic inventory in fire scenarios and that also have unfiltered connections to the exterior, the object is to isolate the fire within the fire compartment. If appropriate, the heat and smoke may be extracted to prevent neighbouring areas being endangered and to allow manual fire fighters safe access. The response of the ventilation system and associated fire dampers may be automatic but also under the supervisory control of building management from a protected area.

For areas that have a high inventory of dispersible radiotoxic material, or for a multi-compartment building where spread of smoke through the ducting may be a problem, dynamic confinement must be a prime consideration. Manual control of the ventilation system and associated fire dampers is recommended, although automatic response with manual override may be necessary for larger buildings, and where manual intervention may be delayed. Automatic or manual tripping of the main inlet and extract fire dampers shall be considered, so that the building can be isolated from the environment in an emergency situation.

Depending on the results of the previous analysis, several options shall be considered:

— closing of the fire damper in the admission duct;

— continuation of the air extraction for as long as possible, without destroying the integrity of the filtering device due to the increase in the temperature of the extracted air and combustion products (this may require cooling of the combustion products, dilution, water-spray devices or high-temperature HEPA filters);

— closing of the admission and extraction dampers, together with a proven reliable solution which limits the excursion of pressure either by relief into the surrounding areas through appropriate devices (e.g. pool condenser) without breaking the containment, or active cooling of the fire compartment walls.

The control of these actions may be automatic or automatic with manual backup. It is generally recommended that the air-admission fire damper be closed as quickly as possible. This equipment is therefore, in general, to be automated and controlled by signals from fire detectors located in the fire compartment.

The closing of the extraction fire dampers can be initiated as a response to the alarm signal:

— of a heat detector installed upstream of the last extraction HEPA filter;

— of a fire detector installed in the room or the extraction duct. The response to this detector shall, in such cases, be confirmed by the simultaneous detection of radioactive contamination upstream of the primary extraction HEPA filter.

It shall be noted that the special extraction duct design often adopted in nuclear installations to assist the removal of radioactive dust from the room, comprising extraction vents in the lowest part of the rooms, is not favourable with regard to the extraction of the hot combustion products from a fire, which of course will rise to the ceiling.

The fire dampers shall be equipped with manual opening and closing facilities which can be reached in a wide range of predictable situations. The re-opening after an incident shall of course only be allowed after the fire has been extinguished and a normal situation has been recovered.

10 Control and instrumentation

10.1 Control

The details of the control system will be determined by the particular ventilation scheme required and it must function during the normal and postulated plant fault conditions. Coordination of the control system operation is essential, and the control panel must be located at points where effective action can be taken, whether routinely carrying out tests of the plant or acting in an incident situation. Critical ventilation systems shall be designed to continue in operation in the event of partial control system failure i.e. by careful design of control logic using pulsed outputs instead of maintained contacts or DC voltages (so as to recognise cable disruption).

In the event of an accident, the access to parts of the building may be restricted and considerations shall be given to the need for a specific ventilation incident control room, or the need to transmit information to an incident control room outside the boundaries of the building involved. This could influence the choice of signal transmitters.

Automatic start-up of the standby fans shall be considered, to cover failure of the main fan (fan supply or supply failure). The automatic start-up procedure shall be initiated by a direct measurement, e.g. detection of loss of flow. If there is a need to start-up an emergency standby plant, the system shall have a backup measurement, e.g. fan rotation detection (not motor current or contactor status). A well-defined sequence shall be developed for starting and stopping the fans, which will form part of the control system. Redundancy and diversity of the Control and Instrumentation components shall be considered and, when necessary, the ventilation systems shall be protected from single-point failure.

Normal control shall be designed to keep the extract ventilation running all the time, with a manual override facility to allow the operator, in the event of an accident, to decide which items of equipment to keep running or to shut down. Means for isolating electrical equipment and monitoring fire control features shall be readily accessible in a safe area.

The significance of fire dampers in the overall control scheme shall be fully considered. The dampers shall be capable of regular testing and resetting from a suitable control point (preferably associated with the main ventilation control unit) and their status should be indicated. As these dampers, when closed, will cause loss of flow signals, their status may need to be incorporated into any changeover system for fans, etc. The absence of meaningful flow signals when dampers have closed may require the system to incorporate manual control of certain components of the ventilation systems, in the event of an incident.

The importance at the construction stage of proper testing and commissioning of the plant to a written test schedule must be stressed. The design shall also allow periodic testing of the standby plant, to demonstrate its state of readiness. Periodic testing of the operational plant simulating abnormal conditions may also be required to demonstrate the necessary reliability. If this is the case, the design must make provision for such testing and the reasons, method, etc. must be recorded in the operating procedure.

10.2 Instrumentation

It is recommended to equip the ventilation system with the following specific devices:

— duct flow measurements;

— continuous monitoring of the status of fire detectors and dampers, control dampers, regulation valves, fans and power supply (running and stand-by);

— indication of the condition of all filters by the pressure drop across each filtering stage;

— means to measure correctly the filter efficiency as specified for the system; this is of considerable importance, since the safety justification for the operation of the facility will be based on the verification of the criteria for the radiological considerations;

— in addition, radioactivity detectors shall be installed in order to monitor the activity in the air, in agreement with the relevant safety regulatory body. Techniques required for the sampling, monitoring and achievement of these measurements are specified in ISO 2889.

In the design of ventilation systems for highly contaminated areas, direct evidence must be available to the operator, by means of pressure gauges or flow indicators, that the required negative pressure differences are being maintained between such areas and the operating areas.

Depending on the classification of the working areas, and on the reliability required, several measurement devices might have to be installed in order to achieve confidence in the signals.

10.3 Alarms

It is recommended to equip the ventilation systems with the following alarm indications:

— stack flow rate;

— flow rates in main ducts;

— differential pressure in the networks as well as in the envelopes;

— filters (HEPA, iodine traps, etc.) pressure drops;

— air temperature (e.g. in the process rooms and in ducts near filters);

— position of dampers, especially fire control dampers;

— fan status (e.g. rotation and bearing temperature, contactor position, fan pressure drop);

— power and compressed air supply status.

These alarm indications shall be relayed to the central control station for the ventilation system and, if possible, they shall be relayed to the emergency control situation with indications of their source.

Annex A
(informative)

Example of classification of working areas according to radiological contamination hazard

A.1 Containment-area classification, according to the level of surface contamination

Table A.1 gives an example of classification of containment areas according to the expected permanent non-fixed surface contamination levels. Surface contamination levels are expressed in $Bq \cdot cm^{-2}$.

Table A.1 — Example of classification of areas according to the expected permanent level of surface contamination

Containment class	Surface contamination ($Bq \cdot cm^{-2}$)	
	Alpha emitters of other toxicity [a]	Beta/gamma emitters and alpha emitters of low toxicity [b]
C1	Determined locally at each site, in agreement with the regulatory body ALARP but not exceeding C2 levels	
C2	Contamination level < 0,4	Contamination level < 4
C3	0,4 < Contamination level < 4,0	4 < Contamination level < 40
C4	Contamination level > 4	Contamination level > 40

[a] The definition of radiotoxicity corresponds to that given in the IAEA Safety Standards Series No. TS-R-1 (ST-1, Revised): *Regulations for the Safe Transport of Radioactive Material*.

[b] Low toxicity alpha emitters are: natural uranium; depleted uranium; natural thorium; uranium-235 or uranium-238; thorium-232; thorium-228 and thorium-230 when contained in ores or physical and chemical concentrates; or alpha emitters with half-lives of less than 10 days.

A.2 Containment-area classification, according to the level of airborne contamination

Table A.2 an example of classification of containment areas according to the expected permanent airborne contamination levels. Airborne contamination levels are expressed in fractions of the DAC[4)].

Table A.2 — Example of classification of areas according to the expected permanent level of airborne contamination

Containment class	Airborne contamination in normal conditions (% of DAC over a working year period)
C1	ALARP [a] principles and in any case < 10 %
C2	10 % < contamination level < 30 %
C3	30 % < contamination level < 100 %
C4	Contamination level > 100 %

[a] As Low as Reasonably Practicable.

4) DAC: Derived Air Concentration. It is the amount of contamination in air, which, if breathed for 2 000 h, would result in the annual limit of intake (ALI). The ALI has to be calculated using reference conversion factors given by IRCP for each radionuclide.

For the containment-area classification, the table leading to the most stringent class shall be used. The limit values stated in Tables A.1 and A.2 may be adapted to acknowledge the chemical toxicity of the radionuclides.

Annex B
(informative)

Example of classification of types of ventilation, according to radiological contamination hazard — Associated recommended ventilation configurations

B.1 Classification of types of ventilation

Table B.1 gives an example of classification of types of ventilation, according to the level of expected and potential airborne contamination compared to the DAC.

Table B.1 — Example of classification of types of ventilation, according to the level of airborne contamination; relation with the containment-area classification

Type of ventilation	Expected normal permanent contamination (Pc)	Potential accidental contamination (Ac)	Containment-areas classification
I	0	$\leqslant 1$	C1
II A	$\leqslant 1$	$\leqslant 80$	C2
II B	$\leqslant 1$	$\leqslant 4\,000$	C3
III A	$\leqslant 80$	$\leqslant 4\,000$	C4*
III B	$\leqslant 4\,000$	$\geqslant 4\,000$	C4**
IV	$> 4\,000$	$>> 4\,000$	C4***

According to the results of the safety analysis, or depending on specific local safety regulations or for practical reasons, the designer can raise the classification of some rooms. Such reclassification of an area for practical reasons alone does not necessitate the application of the recommendations given in Table B.2. Care shall then be taken when any subsequent modifications of the plant in those rooms are proposed.

B.2 Minimal associated recommended ventilation configuration

Table B.2 indicates the arrangement recommended for each of these ventilation types and associated filtration systems.

Table B.2 — Recommended ventilation configurations for the different ventilation types

A transfer from any contaminated area to a lower contaminated area is not allowed.

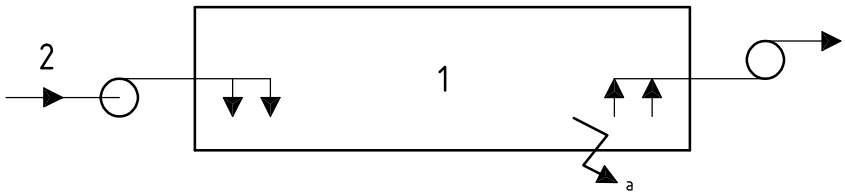
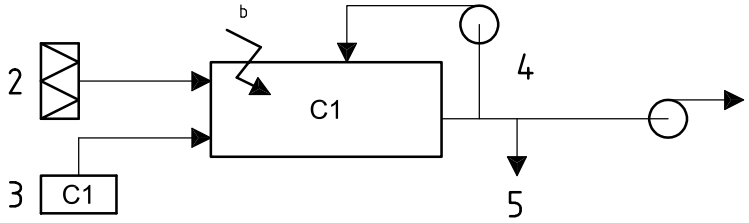
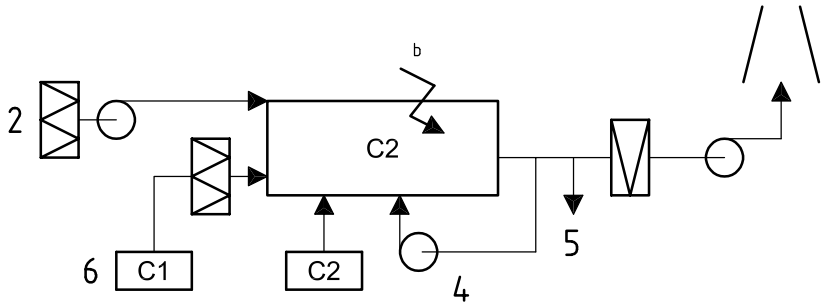
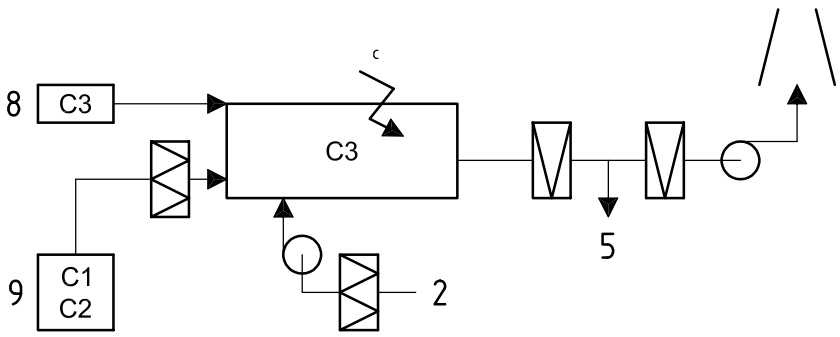
Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems and filtration unit
Non-contaminated areas		
T I	Pc: Not significant Ac: Low	
T II A	Pc: Not significant Ac: Medium	
T II B	Pc: Not significant Ac: High	

Table B.2 (*continued*)

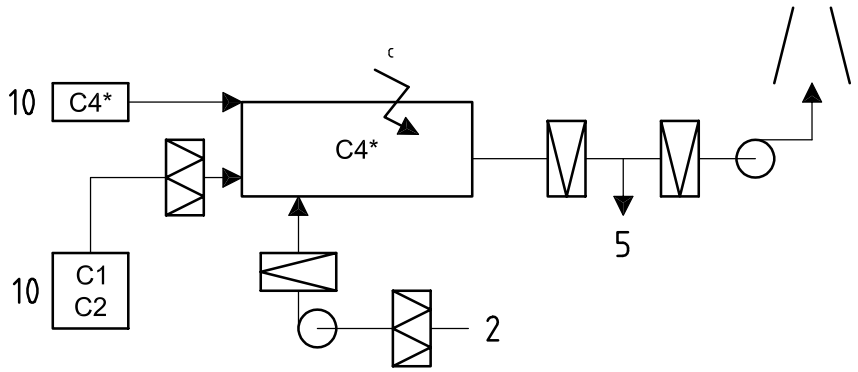
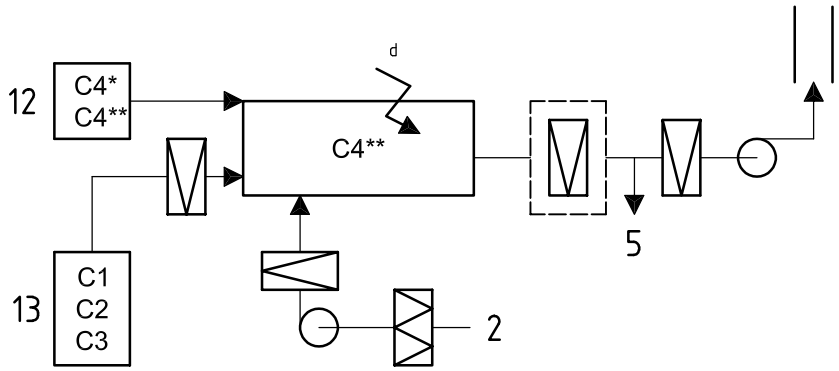
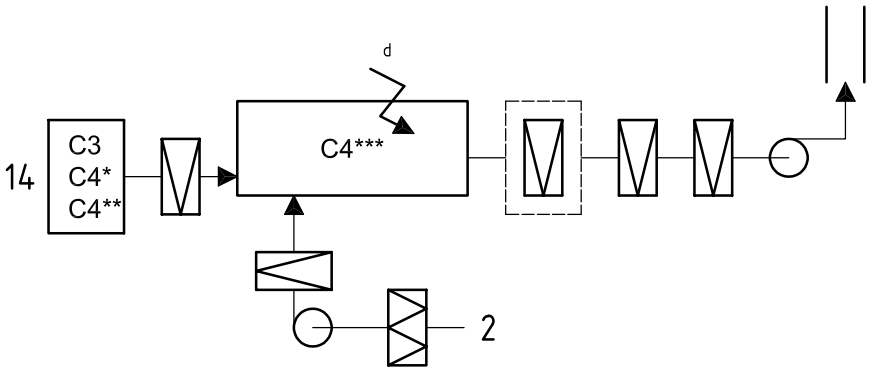
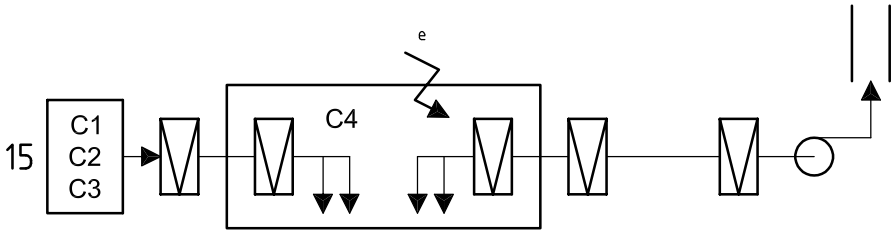
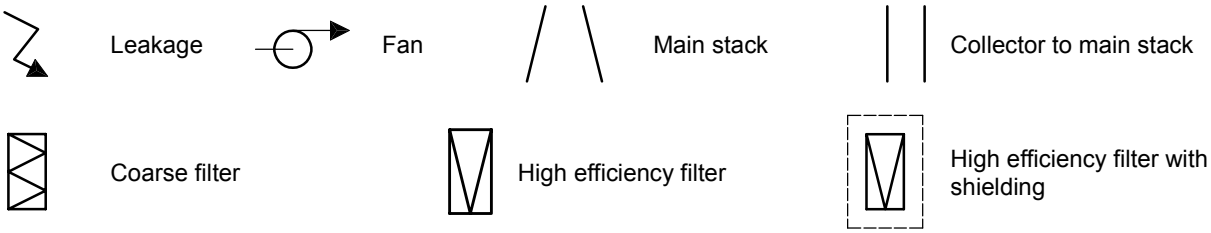
Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems and filtration unit
T III A	Pc: Medium Ac: High	
T III B	Pc: High Ac: Very high	
T IV	Pc: Very high Ac: Very high	

Table B.2 (*continued*)

Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems and filtration unit
C4 containment enclosures or glove boxes (4)		

Key

Pc: Permanent contamination
Ac: Accidental contamination



1 Positive or ambient pressure in operating areas
2 Direct admission from outside the building
3 Direct admission from outside the building, through an industrial grade filter
4 Recycling
5 Transfer to other areas
6 Transfer from a C2 operating area, through an industrial grade filter
7 Transfer from a C1 operating area, without filtration
8 Transfer from a C3 operating area, without filtration
9 Transfer from a C1 or C2 operating area, through an industrial grade filter
10 Transfer from a C4* operating area, without filtration
11 Transfer from a C1 or C2 operating area, through a HEPA filter
12. Transfer from a C4* or C4** operating area, without filtration
13 Transfer from a C1, C2 or C3 operating area, through a HEPA filter
14 Transfer from a C3, C4* or C4** operating area, through a HEPA filter
15 Transfer from a C1, C2 or C3 operating area, through a HEPA filter

[a] Cascade of higher pressures to non-contaminated areas.
[b] Cascade of lower pressures from non-contaminated areas.
[c] Cascade of lower pressures from non-contaminated or low contaminated areas.
[d] Cascade of lower pressures from low or medium contaminated areas.
[e] Cascade of lower pressures to operating areas.

The following comments concern the diagrams in Table B.2.

The designer must ensure that the automatic response of the system precludes the possibility of back-flows from high contamination areas to low contamination areas, or else appropriate filtration shall be incorporated into the paths to mitigate this effect. This also includes possible back-flow to the external environment through failed inlet fans.

The use of coarse filters is optional. They are recommended to increase the lifetime of HEPA filters by reducing the ordinary atmospheric dust burden.

If gases (iodine, tritium, etc) have to be trapped, additional gas absorbers, iodine traps or detritiation devices shall be installed, complementing the HEPA filters.

The ventilation of glove boxes or containment enclosures relevant to this containment class shall also comply with the requirements of ISO 11933-4, especially where a special atmosphere (e.g. inerting) is required in the containment enclosure.

Annex C
(informative)

Requirements for ventilation filters

C.1 Background

Air filters for general air cleaning include particulate filters and vapour filters. Particulate filters include coarse, fine, HEPA (High Efficiency Particulate Air) and ULPA (Ultra Low Penetration Particulate Air) filters. All categories are classified according to their filtration performance. Different national, European and International Standards, as well as relevant trade association standards such as EUROVENT, classify filters according to the test aerosol used.

The standards defining the filter elements and the methods for efficiency testing listed below were not developed especially for the use of filter elements in nuclear facilities. In ventilation systems for nuclear facilities, the following filters are normally installed: coarse filters (G3 or G4), fine filters (F5 – F9) and HEPA filters (H11 – H14) (see Clauses C.4 to C.7).

EXAMPLE

- Sodium fluorescein (particles of 0,15 µm): NF X 44-011
- Monodispersed DOP (dioctylphthalate) of 0,3 µm: US MIL STD 282
- NaCl (sodium chloride) of 0,35 µm: EUROVENT 4/4
- Paraffin oil: DIN 24185
- Particle scanning method: EN 1822, Part 2 and Part 4

The testing methods for efficiency of HEPA and ULPA filters allow the use of either homogeneous monodispersed or polydispersed aerosols for the determination of particulate filtration efficiencies as a function of particle size. The particle size at which maximum penetration occurs is first determined in a flat-sheet media test. Tests on filter elements (constructed using the same filter medium) can be carried out using either a homogeneous monodispersed aerosol of the size at which maximum penetration occurs (the most penetrating particle size, or MPPS, see Figure C.1), or a polydispersed aerosol whose median size is close to the MPPS. Tests with monodispersed aerosols can be conducted using condensation-counting equipment, while tests using polydispersed aerosols require the use of optical sizing particle counters.

When determining the efficiency of filter elements, the downstream aerosol concentration can be determined from air samples obtained using either an overall (single-point sampling after mixing) or scan method. The scan method also allows “local” efficiency to be determined.

C.2 New standards

Requirements for certain European test standards (EN 1822 series) have been compared with the characteristics of existing standard methods, described above.

Filtration-performance testing requirements continue to advance in parallel with the technology of micro-miniature electronic devices. By and large, the filtration efficiency requirements of the nuclear industry are not subject to the same development pressure. However, it was felt that the potential for improved performance using ULPA filters could in some circumstances be beneficial.

It was concluded that the existing standardized methods did not provide an adequate technical basis for meeting the requirements. Deficiencies in existing procedures were identified in the following areas, with the need established:

a) to adopt a generally acceptable continuous classification system for HEPA and ULPA filters;

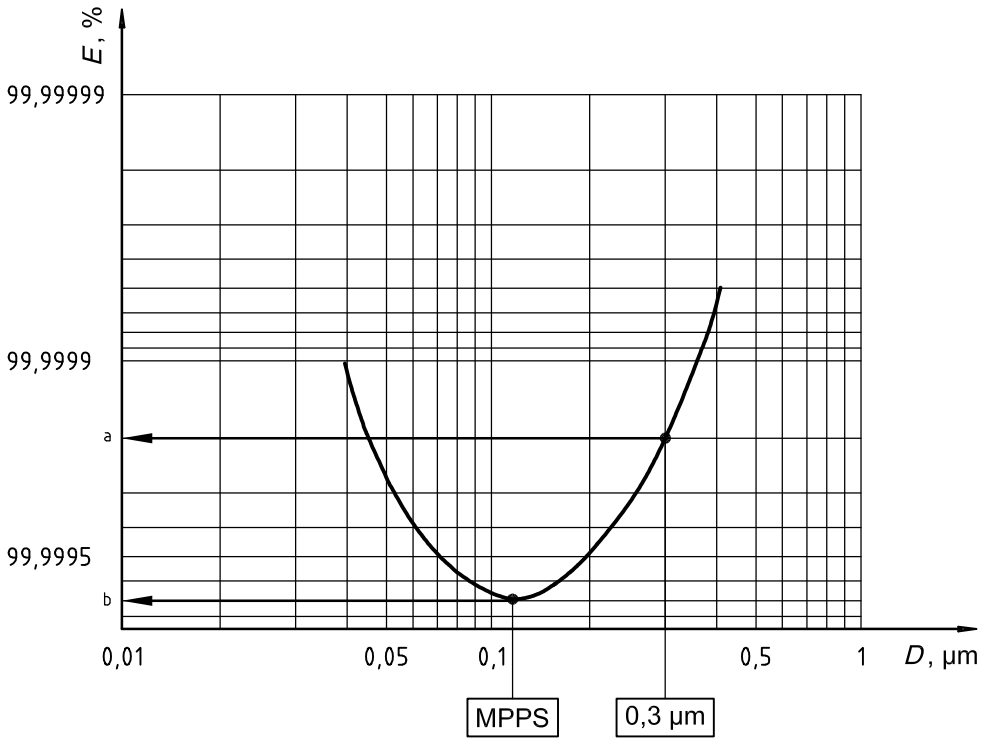
b) for a test method capable of covering the entire efficiency range, from 85 % to 99,999995 %, or DF (Decontamination Factor) over 10^7;

c) to test at the MPPS (see Figure C.1);

d) to include leakage measurements in the testing arrangements and relate them to the overall efficiency and classification of the filters;

e) to include particle size efficiency measurements within the overall procedure;

f) to establish a correlation between results from test-rigs operated by different organizations.



Key

E particle size efficiency
D particle diameter
a Efficiency DOP
b Efficiency MPPS

Figure C.1 — MPPS (Most Penetrating Particle Size) for typical HEPA filters

C.3 Groups and classes of air filters

Particulate air and vapour filters are classified according to their filtration performance (see Table C.1).

Table C.1 — Groups and classes of air filters according to their filtration performances

Filter type	Performance characteristics	
Particulate air filter	G	Coarse filters, classes G1 — G4
	F	Fine filters, classes F5 — F9
	HEPA	High efficiency particulate air, classes, H10 — H14
	ULPA	Ultra low penetration air, classes U15 — U17
Vapour filters	SORPTION	Removal of gaseous or vapour contaminants

C.4 Definitions

C.4.1 Efficiency, E (in percent) of a particulate air filter

The efficiency, E in percent, of a filter is defined as the ratio of the particle concentration arrested by the filter to the particle concentration fed to the filter (expressed in percent). It is calculated as follows:

$$E = \left(\frac{N - n}{N} \right) \times 100$$

where

N is the number of particles upstream of the filter;

n is the number of particles downstream of the filter.

NOTE In nuclear applications, the previous definition is replaced by the ratio of the mass of nuclides arrested by the filter to the mass of the particles fed to the filter.

C.4.2 Average arrestance, A_m (in percent)

The ratio of the weight of synthetic dust arrested by the filter to the weight of the dust fed to the filter (expressed in percent).

C.4.3 Penetration, P (in percent)

The ratio of the particle concentration downstream to upstream of the filter (expressed in percent).

C.4.4 Decontamination factor

A term used by some sectors of industry (especially in the nuclear field) to describe the efficiency of a filter. Normally expressed as a whole number [DF = 100/P].

C.5 EN 779 requirements

For classification according to EN 779 of Class G and F filters, the following criteria are used:

— the air flow shall be 0,944 $m^3 \cdot s^{-1}$ (3 400 $m^3 \cdot h^{-1}$) if the manufacturer does not specify any rated air-flow rate;

— 250 Pa maximum final pressure drop for coarse (G) filters;

— 450 Pa maximum final pressure drop for fine (F) filters.

If the filters are tested at 0,944 $m^3 \cdot s^{-1}$ (3 400 $m^3 \cdot h^{-1}$) and at the maximum final pressure drop, they are classified according to Table C.2 (e.g. G3, F7 etc.).

If the filters are tested at other air flows or lower final pressure drops, they shall be classified according to Table C.2 followed by the test conditions in parenthesis [e.g. G4 (0,7 $m^3 \cdot s^{-1}$, 200 Pa) and F7 (1,25 $m^3 \cdot s^{-1}$, 300 Pa)].

Table C.2 — Classification according to EN 779

EN 779 class	Final pressure drop Pa	Average arrestance, A_m (%) Synthetic dust [a]	Average efficiency, E_m (%) 0,4 µm particles [b]	Equivalence EUROVENT 4/5
G1	250	$A_m < 65$	–	EU 1
G2	250	$65 < A_m < 80$	–	EU 2
G3	250	$80 < A_m < 90$	–	EU 3
G4	250	$90 < A_m$	–	EU 4
F5	450	–	$40 < E_m < 60$	EU 5
F6	450	–	$60 < E_m < 80$	EU 6
F7	450	–	$80 < E_m < 90$	EU 7
F8	450	–	$90 < E_m < 95$	EU 8
F9	450	–	$95 < E_m$	EU 9

[a] The loading dust (synthetic test dust) specified is identical with that in ASHRAE 52.1 and 52.2. The dust is not representative of the real world, but was used for over 20 years to “simulate” filter loading. This dust will continue be used until a more representative dust is developed. ASHRAE and VTT in Finland have research projects for a new loading dust.

[b] A liquid aerosol shall be chosen for the efficiency test for the following reasons:

— experience has already been gained by users of Eurovent 4/5 techniques so that much equipment already exists;

— liquid aerosols are easier to generate than solid aerosols in the concentrations, size range and degree of consistency required;

— the aerosol shall be brought to the Boltzman charge distribution, which represents the charge distribution of an aged ambient atmospheric aerosol.

C.6 EN 1822 and Eurovent requirements for HEPA AND ULPA filters standards

Table C.3 gives the classification of HEPA and ULPA filters proposed by EN 1822, while Table C.4 gives that of Eurovent 4/4 (NaCl method).

Table C.3 — Classification according to EN 1822

Group of filters	Class of filters	Overall MPPS values			Local MPPS values		
		Minimal efficiency E (%)	Maximal penetration P (%)	Minimal decontamination factor (DF)	Minimal efficiency E (%)	Maximal penetration P (%)	Minimal decontamination factor (DF)
HEPA (H)	H10	85	15	6,7	–	–	–
	H11	95	5	20	–	–	–
	H12	99,5	0,5	200	97,5	2,5	40
	H13	99,95	0,05	2 000	99,75	0,25	400
	H14	99,995	0,005	20 000	99,975	0,025	4 000
ULPA (U)	U15	99,9995	0,0005	200 000	99,9975	0,0025	40 000
	U16	99,99995	0,00005	2 000 000	99,99975	0,00025	400 000
	U17	99,999995	0,000005	20 000 000	99,9999	0,0001	1 000 000
	Domain of nuclear industry						

Table C.4 — Classification according to EUROVENT 4/4

EUROVENT 4/4 Filter class	Filter class limits		
	Initial efficiency E_i (%)	Penetration P_i (%)	Minimal decontamination factor (DFi)
E10	$99,0 < E_i < 99,9$	$5 < P_i < 0,1$	$20 < DFi < 1\ 000$
E11	$99,9 < E_i < 99,97$	$0,1 < P_i < 0,03$	$1\ 000 < DFi < 3\ 300$
E12	$99,97 < E_i < 99,99$	$0,03 < P_i < 0,01$	$3\ 300 < DFi < 10\ 000$
E13	$99,99 < E_i < 99,999$	$0,01 < P_i < 0,001$	$10\ 000 < DFi < 100\ 000$
E14	$99,999 < E_i$	$0,001 < P_i$	$100\ 000 < DFi$

C.7 References

C.7.1 References in this annex

ANSI/ASHRAE 52.1:1992, *Gravimetric and dust-spot procedures for testing air-cleaning devices used in general ventilation for removing particulate matter*

ASHRAE 52.2:1999, *Method of testing general ventilation air-cleaning devices for removal efficiency by particle size*

EUROVENT 4/9:1996, *Method of testing air filters used in general ventilation for determination of fractional efficiency*

EUROVENT 4/4:1976, *Method of testing of filters using sodium chloride technique and photometric flame measurement device*

NF X 44-060:1993, *Air cleaning equipment — Oil mist gas purifiers with integral fan for screw-cutting industry*

NORDTEST NT VVS 117:1998, *Test method for electret filters — Determination of the electrostatic enhancement factor of filter media*

EN 779:2002, *Particulate air filters for general ventilation — Determination of the filtration performance*

EN 1822-2:1998, *High efficiency air filters (HEPA and ULPA) — Part 2: Aerosol production, measuring equipment, particle counting statistics*

EN 1822-4:2000, *High efficiency air filters (HEPA and ULPA) — Part 4: Determining leakage of filter element (Scan method)*

DIN 24185:1993, *Measurement of liquid flow in closed conduits weighing method*

C.7.2 List of organizations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
CEN	European Committee for Standardization
EUROVENT	European Committee of Air Hardling and Refrigerating Equipment Manufacturers
NORDTEST	Organization for Common Test Recommendation in Nordic Countries

Bibliography

[1] ISO 8421-1, *Fire protection — Vocabulary — Part 1: General terms and phenomena of fire*

[2] ISO 10648-1, *Containment enclosures — Part 1: Design principles*

[3] ISO 15080, *Nuclear facilities — Ventilation penetrations for shielded enclosures*

[4] IAEA Safety Report Series, *Fire Protection in Nuclear Power Plants*, 1992

[5] IAEA Safety Report Series No. 9, *Safe handling of Plutonium*, 1998

[6] CEA, *Guide for the Ventilation of Nuclear Installations*, 1996

[7] UKAEA, *Code of Practice Ventilation of Radioactive areas*, 1998

[8] OECD publication, State of the Art Report, *Fire Risk Analysis, Fire Simulation, Fire Spreading and Impact of Smoke and Heat on Instrumentation Electronics*

[9] French Basic Safety Rule, *Fire Protection in Nuclear Installations*, 1985 and revision 2001

[10] French Basic Safety Rule, *Ventilation of Nuclear Installations*, 1991

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