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Nuclear facilities — Criteria for the design and the operation of containment and ventilation systems for nuclear reactors

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National foreword

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Nuclear facilities — Criteria for the design and the operation of containment and ventilation systems for nuclear reactors

Installations nucléaires — Critères pour la conception et l'exploitation des systèmes de confinement et de ventilation des réacteurs nucléaires

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Foreword

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ISO 26802 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiological protection*.

Introduction

Containment and ventilation systems of nuclear power plants (NPPs) and research reactors ensure the security of such installations in order to protect the workers, the public and the environment from the dissemination of radioactive contamination originating from the operations of these installations.

This International Standard applies specifically to systems of confinement and ventilation systems for the confinement areas of reactors and their specialized buildings (such as command centres and particular areas for air purging and conditioning). This International Standard is complementary to ISO 17873, which applies mainly to nuclear fuel cycle installations (e.g. reprocessing plants, nuclear fuel fabrication and examination laboratories, plutonium handling facilities) and to radioactive waste storage, research facilities and auxiliary buildings of nuclear reactors.

Nuclear facilities — Criteria for the design and the operation of containment and ventilation systems for nuclear reactors

1 Scope

This International Standard specifies the applicable requirements related to the design and the operation of containment and ventilation systems of nuclear power plants and research reactors, taking into account the following.

For nuclear power plants, this International Standard addresses only reactors that have a secondary confinement system based on International Atomic Energy Agency (IAEA) recommendations (see Reference [10]).

For research reactors, this International Standard applies specifically to reactors for which accidental situations can challenge the integrity or leak-tightness of the containment barrier, i.e. in which a high-pressure or high-temperature transient can occur and for which the isolation of the containment building and the shut-off of the associated ventilation systems of the containment building is required.

For research reactors in which the increase of pressure or temperature during accidental situations will not damage the ventilation systems, the requirements applicable for the design and the use of ventilation systems are given in ISO 17873. However, the requirements of this International Standard can also be applied.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 17873, *Nuclear facilities — Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors*

ICRP 103, *The 2007 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 103, Annals of the ICRP, 37 (2-4), Elsevier

3 Terms and definitions

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

3.1 Accident

3.1.1
design basis accident
DBA
accident conditions against which a facility is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorized limits

3.1.2
beyond-design basis accident
BDBA
accident conditions more severe than a design basis accident

3.1.3
severe accident
accident conditions more severe than a design basis accident and involving significant core degradation

3.2
aerosol
solid particles and liquid droplets of all dimensions in suspension in a gaseous fluid

3.3
air exchange 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

3.4
air conditioning
arrangements that allow sustaining a controlled atmosphere (temperature, humidity, pressure, dust levels, gas content, etc.) in a defined volume

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

EXAMPLE Nuclear fuel cladding, primary circuit, containment building of a nuclear reactor, containment walls of auxiliary buildings, filters for some cases.

3.7
cell
shielded enclosure
shielding structure, of fairly large dimensions, possibly leak-tight

See **containment enclosure** (3.10).

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

3.8
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 that are potentially harmful to workers, to the public, to the external environment, or for the handled products

3.9
containment compartment
CC
compartment of which the walls are able to contain radioactive substances that would be generated by any plausible fire that breaks out in one of the fire compartments included

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

3.10
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

See **cell** (3.7).

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

3.11
containment envelope
volume allowing the enclosure, and thus the isolation from the environment, of those structures, systems and components whose failure can lead to an unacceptable release of radionuclides

3.12
containment/confinement system
system constituted of a coherent set of physical barriers and/or 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 and to avoid releases of radioactive materials in the environment

NOTE According to IAEA definitions, a containment system concerns the containment structure and the associated systems with the functions of isolation, energy management, and control of radionuclides and combustible gases. This containment system also protects the reactor against external events and provides radiation shielding during operational states and accident conditions. These two last functions are not described in this International Standard, due to the absence of link with the ventilation systems.

3.13
contamination
presence of radioactive substances on or in a material or a human body or any place where they are undesirable or can be harmful

3.14
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

3.15
discharge stack
duct (usually vertical) at the termination of a system, from which the air is discharged to the atmosphere after control

3.16
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

3.17
event
unintended occurrence of a hazard leading to potential safety consequences for the plant and in particular for containment systems

NOTE An event can be internal or external to the plant.

EXAMPLE 1 Internal events:

- human errors;
- loss of coolant accidents (LOCA);
- failures in steam piping systems;
- steam generator tube rupture;
- leakage or failure of a system carrying radioactive fluid;
- fuel handling accident;
- loss of electric power;
- internal missile or explosion;
- fire;
- internal flooding.

EXAMPLE 2 External events:

- aircraft crash;
- external explosion;
- earthquake;
- flood or drought;
- winds and tornados;
- extreme temperature (high and low).

3.18
filter
device intended to trap particles suspended in gases or to trap gases themselves

NOTE A particle filter consists of a filtering medium, generally made of a porous or fibrous material (glass fibre or paper) fixed within a frame or casing. During the manufacturing process, the filter is mounted in a leak-tight manner in this frame, using a lute. Gas or vapour filters are generally found in physical or chemical process units where the primary aim is to trap certain gases. They cover in particular iodine traps (activated charcoal).

3.19
fire area
volume comprising one or more rooms or spaces, surrounded by boundaries (geographical separation) constructed to prevent the spreading of fire to or from the remainder building for a period of time allowing the extinction of the fire

3.20
fire compartment
FC
reference volume delimited by construction elements for which fire resistance has been chosen according to the plausibility that a fire could break out within this volume or penetrate into it

3.21
fire damper
fire blocking valve
device that 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

3.22
fire load
heat energy that can be released in the event of a fire involving the whole combustible contents of a volume, including the surfaces of the walls, partitions, floors and ceilings

3.23
gas cleaning
scrubbing
action that consists of decreasing the content of undesirable constituents in a fluid

EXAMPLE Aerosol filtration, iodine trapping or decay storage of gases.

3.24
iodine trap
scrubbing device, usually based on activated charcoal, intended to remove volatile radioactive components of radioactive iodine from the air or the ventilation gases

3.25
load
physical static or dynamic phenomena that impact the containment systems during plant life or which can be associated with postulated internal or external events, or postulated accidents

3.26
negative pressure
depression
difference in pressure between the pressure of a given volume, which is maintained lower than the pressure in a reference volume or the external ambient pressure

3.27
negative pressure system
regulated ventilation system, which ensures a negative pressure between the ventilated area and an adjoining zone or the external ambient pressure

3.28
off-gas treatment system
system often associated with the primary circuit, that permits a decrease in the gaseous effluent inventory prior to its discharge in the atmosphere

NOTE This system might or might not be associated with the room's ventilation systems.

3.29
prefilter
filter fitted upstream from the main air filters to minimize, by removal of large particles, the dust burden on the latter

3.30
pressure drop
pressure loss in an air stream due to its passing through a section of ductwork or a filter or fittings

3.31
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)

NOTE 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) are not considered part of the process ventilation system.

3.32
safety classification
classification of structures, systems and components, including software instrumentation and control, according to their function and significance with regard to safety

3.33
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 clean products within the working volume

3.34
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; the term is also used 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).

3.35
ventilation duct
envelope generally of rectangular or circular section, allowing air or gas flow to pass through

3.36
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 this International Standard

4 Functions ensured by the ventilation system

4.1 General

The ventilation of nuclear reactors enables the improvement of the safety of the workers, general public and environment and the protection of the safety classified equipment. It plays a role of

— **safety**, by contributing to keeping the work areas and the environment free of contamination in normal situations, to mitigating releases during incidental or accidental situations, and to providing adequate ambient conditions to safety-related components;

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

4.2 Main functions

The ventilation ensures the main following functions, without ranking.

a) **Confinement**, by acting in a dynamic manner in order to counteract any defects in the leak tightness of the static containment consisting of the physical limits of the relevant enclosures. In this case, the “dynamic” confinement ensured by the ventilation systems has the following two aspects:

— Between 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. This dynamic confinement is also able to isolate or circumscribe, to process and to control the contamination as closely as possible to its source, at least in the reactor building and, therefore, it complements the other systems provided to protect the workers or the public against the hazards of ionizing radiations [see isolation function b) below].

— At the interface with the environment (i.e. external dynamic confinement), the ventilation system maintains a significant negative pressure 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 needed, their gas cleaning (purification) and monitoring.

b) **Isolation**, by closing in a safe and tight way the equipment needed to avoid or limit the spread of the contamination to the other surrounding volumes and the environment. In particular, this function is required to maintain the required leak tightness of the reactor building with regard to the activity released in the reactor building during accidents leading to an increase in mass and energy (increase of pressure, temperature, discharge of vapours and gases) above the design level of the ventilation system's components.

c) **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, storage for decay, etc.).

d) **Monitoring** of the installation, by organizing air flows in such a manner as to allow meaningful measurements in order to demonstrate the suppression of the spread of radioactive components or fire. Ventilation systems, with or without surveillance monitoring, can also contribute to the improvement of some radiological protection measures inside rooms by helping to control the background level of natural radioactivity (radon).

e) **Cleaning** of the atmosphere of the enclosures or rooms, by renewing the volumes of air within it, in order to minimize the hazard levels of the corresponding atmosphere (for example, the elimination of any gas necessary to create the risk of an explosion hazard).

f) **Conditioning** of the atmosphere of the enclosures or the rooms, to obtain the optimum ambient conditions for the equipment or to improve the safety of some otherwise hazardous operations.

g) **Comfort** (conditioning of the work place), by ensuring the processing of the air, the regulation of the temperature and the relative humidity of the atmosphere of the rooms, in order to maintain their ambient and hygiene conditions to suit the work that the personnel shall undertake.

According to the results of safety analyses, these functions can be considered important to safety functions. For example, the achievement of comfort is indirectly a safety function, because “human risks”, which can be caused by inadequately regulated ambient conditions, are then substantially reduced.

In any event, the confinement of radioactive materials within a nuclear plant, including the control of discharges and the minimization of releases, is a main safety function that is ensured in normal operational modes, anticipated operational occurrences, design basis accidents and selected beyond-design basis accidents. In this context, according to IAEA principles for nuclear power plants (see Reference [12]), severe accidents should be considered during the design of the confinement function.

According to the concept of in-depth defence, the confinement function is achieved by several barriers and in some cases by accident mitigation systems that can be ensured by the ventilation system.

5 Architecture and description of the different ventilation systems

5.1 Ventilation of the volumes within the primary containment envelope

5.1.1 General

These systems are located mainly inside the reactor building.

The ventilations systems concerned are

- either designed only for normal situations (see 5.1.2), or
- designed for ensuring both safety and protection function in the event of a design basis accident and may be located either inside or outside the reactor building, according to the type of reactor design (see 5.1.3).

5.1.2 Ventilation systems designed for normal operations

5.1.2.1 Ventilation systems located inside the reactor building

In these designs, the ventilation systems usually operate for normal operations and they are not generally able to operate under the conditions of an accident in the reactor building, due to the potentially high pressures and temperatures that can be reached in the reactor building during such accidents.

These systems ensure three main functions:

- conditioning the atmosphere;
- cleaning the atmosphere of the reactor building when people enter in the reactor building;
- purification of the reactor building atmosphere.

As these systems are used only for normal operations, the associated functions described above are similar to those developed in ISO 17873 and the corresponding ISO 17873 requirements shall be met.

5.1.2.2 Ventilation systems located outside the reactor building but ventilating its inner atmosphere

These systems usually operate for normal operations and most of the systems are not designed to operate under the conditions of an accident leading to an increase in mass and energy in the reactor building that initiates the isolation of the fluid systems. They ensure the following functions:

- internal and external dynamic confinement during normal operations or for minor incidents that do not lead to an increase in mass and energy in the reactor building;
- purification or gas cleaning of the reactor building atmosphere for minor incidents that do not lead to an increase in mass and energy in the reactor building;
- monitoring of gases and aerosols in the atmosphere of the reactor building during normal operations or for minor incidents that do not lead to an increase in mass and energy in the reactor building;
- isolation during accidental situations to maintain the integrity of the primary containment envelope and leak tightness.

For the first three functions, the systems shall fulfil the corresponding requirements of ISO 17873.

For isolation function during accidental situations, additional leak-tightness requirements for the isolation valves and ducts shall be fulfilled (see 7.1.4).

5.1.2.3 Ventilation systems used as off-gas treatment systems

These systems are associated with the operation of the components of the primary circuits of the reactor, or are connected to it, where they remove large quantities of gaseous effluents. The systems ensure the following functions:

- purification of the process off-gases prior to their discharge into the environment;
- isolation during accident situations in order to rapidly halt radioactive releases to the environment;
- cleaning and protection by avoiding the mixing of gases in the off-gases systems with those of the room's atmosphere.

The off-gas treatment systems can also be useful during radioactive measurements made at the stack level, in particular associated with routine release measurements.

5.1.3 Ventilation systems designed for accident conditions

5.1.3.1 General

These systems are designed to cope with accidental conditions and can also deal with normal operations.

Two kinds of systems are described in 5.1.3.2 and 5.1.3.3.

5.1.3.2 Ventilation systems ensuring both safety and protection function in the event of a DBA

These systems may be located either inside or outside the containment. It is necessary that they function in the event of a DBA in the containment envelope or support buildings.

These systems, depending on their use, may have the following functions:

- cleaning the atmosphere, consisting mainly to reduce the hydrogen by detection and mitigation (e.g. recombiners, systems for the homogenization or dilution of combustible gases);
- monitoring the atmosphere (pressure, temperature, humidity, hydrogen content, contamination content);
- purification of the atmosphere;
- isolation of radioactive materials contained in the reactor building atmosphere;
- confinement of radioactive products.

In addition to the requirements during normal operations, it is necessary that these ventilation systems fulfil specific requirements, in particular associated with behaviour and leak-tightness requirements (see 7.1.3).

5.1.3.3 Ventilation systems ensuring a mitigation function in the event of a severe accident (mainly for NPPs)

These ventilation systems may be located either inside or outside the containment. They can also be used to clean up the atmosphere following other types of accidents.

They ensure the following functions:

- confinement of radioactive materials;
- isolation of radioactive materials located inside the reactor building;

— purification of the releases;

— cleaning the atmosphere with regard to the management of combustible gases;

— monitoring the atmosphere content in order to be able to manage the severe accident.

These systems function to limit the consequences of a severe accident. It is necessary that these ventilation systems fulfil very specific requirements, in particular associated with integrity, leak-tightness and filtration requirements (see 7.3).

5.2 Ventilation of the volumes located within the secondary confinement

The ventilation systems for the volumes within the secondary confinement usually operate during normal and accidental situations, even during an accident in the reactor building.

The secondary confinement is comprised of all the buildings and rooms that help to collect radioactive materials in order to filter them. Depending on the design types of the reactors, these buildings are either specific to the collection of leaks (for example, the annulus space around the reactor building) or designed to collect leaks in addition to other functions (for example, auxiliary buildings that are designed to collect the leaks). The system shall contribute to limiting non-filtered leaks from the primary containment envelope towards the environment. The system can also lead to a positive or negative pressure inside the dedicated volumes to reach this objective.

With regard to the leaks issued from the primary containment envelope, these ventilation systems shall fulfil the following functions:

— confinement during accidental situations resulting in the leakages released from the primary containment envelope that initiate containment radioactive materials, in particular those emerging in non-filtered areas;

— purification of radioactive leakages in order to minimize the releases into the environment.

Depending on the design, the secondary confinement either provides only additional confinement around the primary containment envelope penetrations and extensions, or completely surrounds the primary containment envelope. In the latter case, it is necessary that specific requirements be fulfilled by the secondary confinement: leak tightness, integrity and protection (e.g. against aircraft crashes, missiles) and dynamic confinement (e.g. ensuring negative pressure in order to cope with severe winds).

Regarding the components or equipment located in these volumes, the ventilation systems shall fulfil the following additional functions:

— monitoring function;

— cleaning function;

— conditioning function.

For these additional functions, the systems shall fulfil the corresponding ISO 17873 requirements.

5.3 Ventilation of the volumes located outside the secondary confinement

This subclause concerns the ventilation systems that ensure a confinement function for rooms or buildings that are not specifically designed to collect and filter leaks from the primary containment envelope, associated with the annex, fuel, waste and effluents treatment buildings. These systems usually operate during normal and accidental situations, even during an accident in the reactor building. As these systems are not designed specifically for the reactor itself, the requirements they shall fulfil are specified in ISO 17873.

5.4 Miscellaneous ventilation systems not connected with containment envelopes

5.4.1 Ventilation systems for control rooms

These systems are designed to operate during normal situations and accidental conditions within the reactor building and auxiliary buildings. According to the design, they are located either within or outside the secondary confinement.

These systems have the following functions:

— conditioning the atmosphere of the control rooms in order to protect both safety systems (e.g. electronic and electrical systems) and workers, by giving them adequate comfort;

— protection function by ensuring a positive pressure inside the control room and purification of the inlet air of the control rooms in order to mitigate and control potential radioactive releases that can enter the control rooms during an accident.

These two functions participate in the "long-term habitability of the control rooms" function.

As they prevent the ingress of contamination (chemicals, radioactive materials, smoke, gases, etc.), rather than providing confinement, these systems shall meet special requirements regarding the protection and the purification function (see 7.2).

Concerning the conditioning function, the requirements given in ISO 17873 shall be fulfilled.

5.4.2 Smoke removal ventilation systems

The smoke removal ventilation systems in contaminated areas shall fulfil the requirements of ISO 17873.

NOTE For smoke removal systems in non-contaminated areas, reference can be made to national or regional standards regarding systems for the evaluation of smoke (for example, the EN 12101 series[9]).

5.4.3 Ventilation systems ensuring the protection of safety systems

These systems are associated with the operation of the safety systems of the reactor, such as electrical power supply (back-up power and normal), water injection systems, electronic control systems. These systems are designed to operate whatever the situation in the reactor building. They are also classified as safety systems.

The functions ensured by these systems are

— cleaning function;

— conditioning function.

They shall fulfil the corresponding requirements of ISO 17873. Nevertheless, the conditioning function can be highlighted for reactors relative to other types of nuclear facilities due to the fact that they can support the safety systems.

6 Safety aspects for ventilation systems

6.1 General principles

Ventilation systems shall be able to ensure the safety and protection functions defined in the previous clause, in all normal operations and maintenance conditions. Ventilation systems shall also be able to ensure these functions or some of these functions during abnormal operating conditions, exceptional intervention or accidental situations. According to IAEA principles[10], severe accidents in nuclear power plants should be considered during the design of containment systems. In this context, the associated requirements are given in 7.3.2.

For new research reactors, it is not possible to take severe accidents into consideration during the design of the containment systems if the probability of the occurrence of such events is extremely low (e.g. $P < 10^{-7}$/y), or if a sufficient number of in-depth defence lines are implemented.

Before beginning any detailed ventilation design, a hazard assessment shall be made so that design safety principles and actual targets can be adequately defined. Subclause 6.2 provides an outline of the hazard assessment process as it relates to ventilation design.

This approach shall be based mainly on the experience derived from the design and operation of existing reactors and it should apply to the most common types of reactor designs. It addresses the functional aspects of the containment systems, such as energy management systems or mitigation systems. It also includes some general recommendations for the features that can be used in new nuclear reactor plants to cope with severe accidents. Particular care is given to the design of the containment systems, in particular those aspects affected by loads identification and loads combination.

General recommendations shall be followed during tests and inspections to ensure that the functional requirements for the ventilation systems can be met throughout the operating life. Design limits and acceptance criteria, together with the system parameters that should be used to verify them, shall be adopted in accordance with the safety authorities.

6.2 Risk assessment procedure — General

6.2.1 Preliminary analysis

The design of an appropriate ventilation system requires a preliminary analysis that takes into account the following.

a) Radiological hazards arising from the materials and operations that lead to the need for the confinement and purification function of the ventilation systems, with regard to the permitted levels of air and surface contamination within the building and the air monitoring requirements. This can lead to a classification of the area with respect to the contamination hazard, as defined in 7.1.5.1. In the event of radiation exposure hazard (internal and external exposure) for normal operations, a complementary classification of the installation into radiological areas shall be made according to the recommendations proposed by ICRP 103.

b) Discharge limits from the ventilation system as a whole, and the scrubbing requirements (if any) prior to discharge.

c) The need to use the ventilation systems to mitigate design basis accidents. If severe accidents are considered, then ventilation systems should be used to mitigate severe accident consequences.

d) The isolation of some containment penetrations during accidents that involves pressure and temperature conditions in the atmosphere that exceed the design values of these ventilation systems.

e) The necessity for minimizing the direct leaks from the containment to the atmosphere that are not collected by the dynamic confinement provisions.

f) Non-radiological internal events (e.g. catastrophic rupture of containment enclosure caused by some mechanical failure, abrupt variation of pressure, explosion, fire, corrosion, condensation, human errors) related to the processes and equipment implemented in the enclosures that shall be ventilated and that can necessitate or jeopardize the confinement functions.

g) External events (aircraft crash, explosion, fire, flood, earthquake, tornados, wind and extreme temperatures) to which the safety components and the ventilation system itself can be exposed and that can challenge the functions of the ventilation or containment systems (see 4.1).

h) Possible temporary unavailability of fluids or energy supply (e.g. compressed air or electrical supply) needed for the correct functioning of the ventilation system.

i) Loads and events combinations that challenge the operation and the design of the ventilation systems. These combinations shall take into account whether loads are consequential or simultaneous (e.g. loss-of-coolant accidents, pressure and temperature loads), the time history of each load (to avoid unrealistic superposition of load peaks if they cannot be simultaneous), the probability of occurrence of each load combination (combinations of unlikely loads should have a reduced probability relative to the probability of each single load).

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

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

— For protection of the environment, it is necessary to design nuclear process plant systems so as to minimize radioactive waste produced and radioactive releases (liquid and gaseous) as far as practicable. Thus, attention shall 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 “best practice” to ensure that the minimum possible quantities of waste are produced in the higher categories of radioactive waste and the maximum possible fraction in the lowest activity level. In particular, contaminated filters[1)], being of low density, are very expensive to store or dispose of as radioactive waste and consideration should 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, shall take into account the variations of pressure, temperature and humidity that can be tolerated by each component, in an appropriate range of operational and fault conditions.

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

6.2.2 Risk evaluation

For each element considered, the ventilation systems shall be designed, using a safety risk assessment consistent with that given by IAEA (see References [12] and [13]).

For NPPs, this safety risk assessment includes the combination of the following approaches:

— a deterministic approach, applying safety criteria, such as the single-failure criterion used for the risks linked to the process (circuits connected to the primary circuits, fluid circuits under pressure);

— a probabilistic approach, using a probabilistic safety assessment, in order to identify potential accidental sequences that might not have been identified using the deterministic approach.

For research reactors, this safety risk assessment shall be based on deterministic methods, complemented where appropriate by probabilistic methods and engineering judgement.

It is important not to primarily exclude some combinations of loads when their probability is not residual, in case of effects between loads (e.g. earthquake leading to a fire) or in case of load combinations with a low magnitude load, but with higher probability.

1) The definition of HEPA filters is given in Annex F.

Loads combination rules shall be indicated in the safety documents of the plant. Subclause 4.58 of the IAEA *Safety Standards Series NS-G-1.10-2004* (see Reference [10]) gives minimum load combinations for all the containment systems, including ventilation systems of nuclear power plants.

For DBA, it shall be verified that the design and operation of ventilation systems do not lead to cliff-edge effects[2)] or to unacceptable consequences to workers, the public or the environment. If one of the functions of the ventilation systems defined in 4.1 is used to limit the consequences of a DBA, then this function shall be designed to cope with this DBA.

For BDBA, an analysis should be carried out in order to establish the margins between ventilation or containment systems design parameters and those needed for coping with these BDBAs (e.g. fire with several in-depth defence lines).

6.2.3 Safety classification

All structures, systems and components of the ventilation or confining systems, including software instrumentation and control, that are items important to safety shall be first identified and then classified on the basis of their function and significance with regard to safety. They shall be designed, constructed and maintained such that their quality and reliability is adapted to this classification. The method for classifying the safety significance of a structure, a system or a component shall primarily be based on deterministic methods, complemented where appropriate by probabilistic methods and engineering judgement taking account of the following:

- the safety function(s) that it is necessary for the item to perform,
- the consequences of failure to perform its function,
- the probability that the item will be called upon to perform the safety function,
- the time following an initiating event at which, or period throughout which, it will be called upon to operate.

Appropriately designed interfaces shall be provided between structures, systems and components of different classes to ensure that any failure in a system classified in a lower class does not propagate to a system classified in a higher class.

All structures, systems and components (SSCs) important to safety shall be clearly identified. This identification is necessary to focus the attention of designers, manufacturers and operators on features that assure the safety of the plant and are associated with the application of specific design requirements (e.g. single failure criterion) or of more conservative codes and standards.

SSCs important to safety may be further sub-classified according to a number of criteria. Different safety classification systems are used worldwide for the purpose of assigning structures, SSCs important to safety to the different classes and controlling the application of codes and standards, as well as of quality assurance procedures.

Examples of safety classification systems are given in Annex C.

6.3 Risk assessment procedure for severe accidents

Concerning more specifically the severe accidents, IAEA indicates (see Reference [10]), for nuclear power plants, that “consideration shall be given to severe accident sequences, using a combination of engineering judgement and probabilistic methods, to determine those sequences for which reasonably practicable preventive or mitigation measures can be identified”.

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2) As defined by IAEA in Reference [10].

A severe accident corresponds to a significant core degradation resulting from the multiple failures in redundant safety systems that can lead to their complete loss and even threaten the containment integrity or the ventilation systems used to cope with this type of accident. Though sequences exhibiting such characteristics have a very low probability, IAEA (see Reference [10]) indicates that they should be evaluated to assess whether it is necessary that they be addressed in the containment systems design. The occurrence of accidents with severe environmental consequences should be made extremely unlikely by means of preventive and mitigation measures.

Severe accidents should be evaluated by means of the best estimate approach, i.e. without excessively conservative margins.

As severe accidents are difficult to take into account for existing plants, IAEA (see Reference [10]) distinguishes two types of recommendations.

a) For *existing* plants, the phenomena relating to potentially severe accidents and their consequences should be carefully analysed in order to identify design margins and accident management measures that can be carried out to prevent or mitigate their effects. These accident management measures should make full use of all available equipment, including the use of alternate or diverse equipment, as well as of external equipment for the temporary replacement of design basis components. Furthermore, the introduction of complementary equipment should be considered in order to improve the preventive and mitigation capabilities of the containment systems. Then, an analysis should be carried out in order to establish the margins between ventilation or containment systems design parameters and the severe accident conditions, in particular with regard to temperature, pressure, irradiation and contamination conditions. If not qualified for severe accident conditions, modifications should be considered on these systems.

b) For *new* plants, severe accidents should be taken into consideration at the design stage of the containment systems. Consideration of severe accidents should be aimed at practically eliminating the following:

   — severe accident conditions that can damage the containment in an early or late phase;

   — severe accident conditions with an open containment, namely during shutdown states;

   — severe accident conditions with containment bypass.

In this context, severe conditions are considered practically eliminated if they are physically impossible or when it can be considered with a high degree of confidence that they are extremely unlikely to arise. For severe accidents that cannot be practically eliminated, the containment systems should contribute to reducing their releases to such a level that the extent in area and time of off-site emergency measures is small. Therefore, ventilation systems should be designed to cope with the severe accident conditions, in particular with regard to temperature, pressure, irradiation and contamination conditions.

Concerning research reactors, considerations of severe accidents shall be used carefully. These severe accidents can be considered in the same way as for NPPs, except when it is demonstrated that by adequate and strong prevention provisions their occurrence is extremely low.

7 Requirements for the design of ventilation systems

According to Clauses 4 and 5, the ventilation systems ensure several functions that shall fulfil several general requirements[3), 4)]. In 7.2 and 7.3, the requirements for application to the ventilation systems for each function are considered, and in 7.4 the specific requirements associated with specific functions that exist in various nuclear reactors are considered.

3) Most of the ISO 17873 requirements for the ventilation systems are completely applicable to nuclear power reactors. However, some possible exceptions are related to the definitions of the barriers, the confinement requirements for the containment, and the different safety approach for nuclear power plants.

4) For research reactors, the safety approach is very similar to the ISO 17873 approach.

7.1 Confinement of radioactive material

7.1.1 General

In nuclear reactors, the confinement of radioactive material is one fundamental safety function, together with

— the safe shutdown of the reactor and maintenance in the safe shutdown condition, and

— the removal of heat from the core and maintenance of the water inventory.

To ensure the safety of a nuclear reactor, these safety functions shall be achieved during operational states, during and following a design basis accident, and to the extent practical during and following the considered plant conditions beyond the design basis accident conditions.

The function of the confinement of radioactive materials also includes the control of normal operational discharges, as well as the limitation of accidental releases.

7.1.2 Source term

Ventilation systems are used to strongly reduce radionuclide releases under normal circumstances, incident situations and to mitigate the consequences of accidents[5)]. In order to quantify the performances of such systems, an evaluation of the nuclides inventory and source term that shall be dealt with by ventilation systems is necessary.

For light, heavy-water or gas-cooled (VVER, PHWR, PWR, BWR, PBMR)[6)] and research reactors, radioactive inventory in the circuits usually contains

— noble gases such as fission products (^{133}Xe, ^{85}Kr, etc.);

— gaseous activated products with structure or coolant, such as tritium and carbon 14;

— iodine products (^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I, traces of ^{129}I, etc.);

— aerosols such as fission products (^{137}Cs, ^{134}Cs, ^{106}Ru, etc.) or activation products (^{60}Co, ^{58}Co, etc.);

— alpha emitters from the fuel.

For sodium-cooled reactors, radioactive inventory contains sodium nuclides (^{22}Na, ^{24}Na, etc.) in addition to the nuclides for water-cooled reactors.

Annex A summarizes typical products associated with different types of reactors in the reactor core, and in the gaseous releases in normal and accident conditions. The possible releases into the environment depend on the fuel inventory and quality of confinement and ventilation systems in addition to containment requirements.

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5) For new nuclear power plants, design stages shall also include the identification and the evaluation of the source term for accident situations, including severe accidents.

6) VVER: water-water energetic reactor
PHWR: pressurized heavy water reactor
PWR: pressurized water reactor
BWR: boiling water reactor
PBMR: pebble bed modular reactor

7.1.3 Containment barriers and systems

7.1.3.1 General requirements concerning the confinement function

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

a) 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 reasonably achievable inside the facility;

b) in incidental or accidental situations, to limit to acceptable levels the radiological consequences for the environment, for the operators and for the general public.

The application of this principle leads to the provision of different containment barriers between the environment and the radioactive substances. Each containment/confinement system and the associated devices are designed to suit the risks that they are intended to control. The potential use of dynamic systems during an accident requires the functionality of at least one stage of effective filtration between the contaminated areas and the environment.

In nuclear reactors, several containment/confinement systems and barriers are distinguished. Each system can be made of

— 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.

The design should be based on the possible compromise between a static containment and the different types of dynamic confinement systems presented in Clause 5. Generally, this best compromise for the radiological consequences is based on the operation of a ventilation system ensuring a negative pressure with the lowest possible flow rate.

Figure 1 shows the principle of the confinement for nuclear reactors. Annex B gives several schematic diagrams of typical NNP designs.

7.1.3.2 First barrier

The first barrier is the fuel cladding. Its purpose is to be as tight as possible during normal operations or accidental situations in order to prevent the release of radioactive substances into the primary circuit.

However, operational feedback has shown that it cannot be assumed that this barrier is absolutely tight for normal operations or accidental transients. Therefore, the design of the other barriers shall take into account failure of the first barrier.

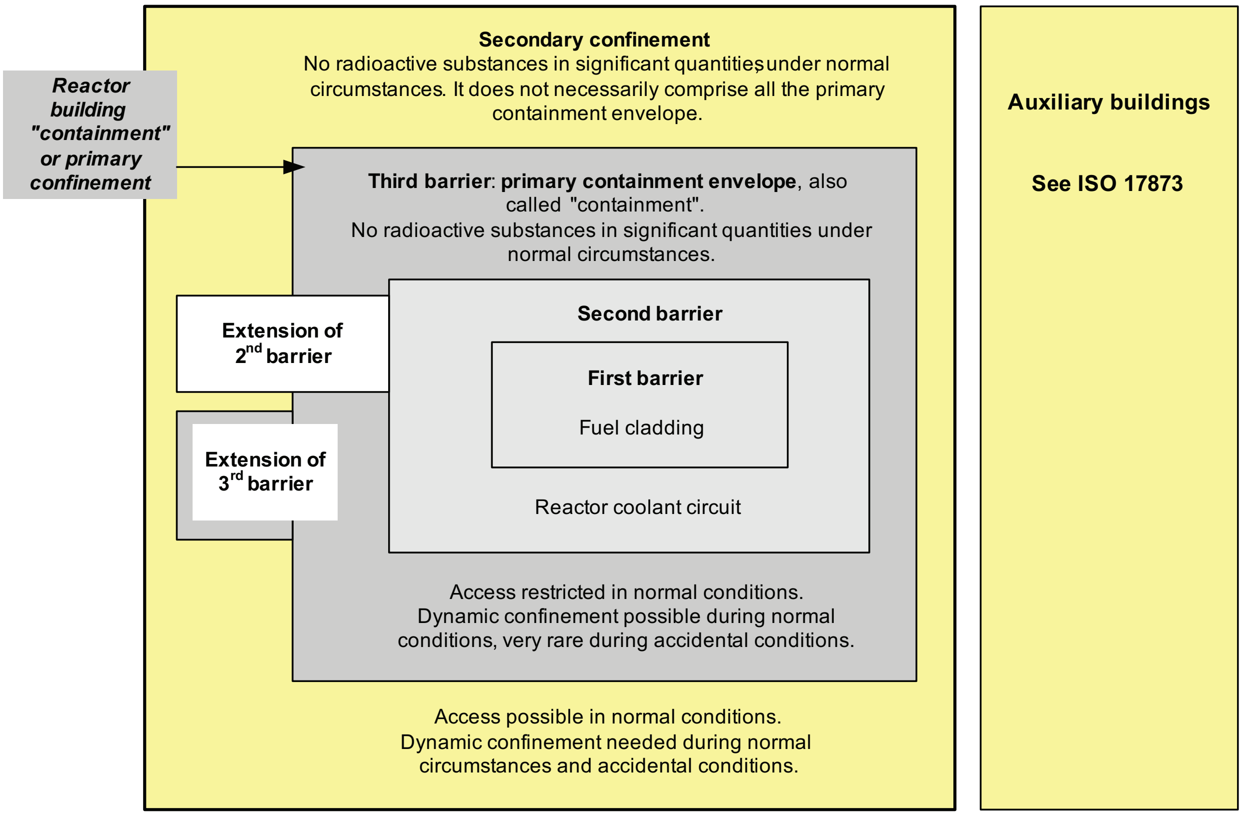


Figure 1 — Schematic diagram of reactor confinement systems

7.1.3.3 Second barrier

The second barrier consists of the primary circuit(s). The goal of the second barrier is to limit the releases of radioactive contamination from the primary circuit into the containment building in normal situations, as well as in accidental situations.

For nuclear power plants, the second barrier also comprises the internal tubes of the steam generator with the goal of minimizing leaks. It could also include the circuits, connected to the primary circuit, which are used in normal conditions to help to operate the reactor (e.g. water purification system, chemical treatment system, etc.) and considered as extensions of the second barrier.

Nevertheless, despite the very high quality of the primary circuit, many postulated accidents take into account the failure of this barrier as an initiating event, which leads to an increase of mass, energy and radioactive products in the containment building. It is necessary to consider the ambient and radiological conditions issuing from these postulated accidents during the design of the containment systems and, in particular, the ventilation systems.

7.1.3.4 Third barrier: primary containment envelope

7.1.3.4.1 Structural parts of the primary containment envelope

The first two barriers cannot be considered as totally efficient barriers against the spread of radioactive material during accidents, due to the fact that fuel cladding cannot ensure its leak tightness during accidents, and that primary-circuit-pipe failures are considered as initiating events for design basis accidents.

Therefore, the goal of the third barrier is to prevent the release of radioactive contamination outside the whole building in case of failure of the first two barriers and to provide for the protection of the general public, the environment and the workers located in annex buildings. The third barrier is, therefore, the primary containment envelope, also called “containment” and is generally composed of the inner walls of the reactor building and also the circuit penetrations passing through these walls and the associated isolation valves. The ventilation and air conditioning system boundaries associated with the primary containment envelope are, in some designs, parts of the primary containment envelope, e.g. if they are located outside this envelope.

All the ventilation systems that constitute parts of the primary confinement shall withstand the same accident conditions as the structural parts themselves. If they cannot cope with accident conditions, these systems are considered as lost during accidents and, therefore, are isolated if they are located outside the primary containment.

It shall be noted that depending on the design of the reactor, the primary containment can be an area non-accessible to workers during normal operations. Nevertheless, in some designs, in particular research reactors or boiling water reactors, there is a possibility for these workers to access it. The design of ventilation systems shall take into account the possible access or not of workers inside the primary containment.

Primary containment should satisfy the requirements of the static containment leak-tightness in order to be able to mitigate accident consequences.

7.1.3.4.2 Extensions of the third barrier

Some circuits located outside the primary containment envelope constitute extensions of the third barrier when

— these circuits are open voluntarily or incidentally to the primary containment atmosphere during accidents;

— they are closed to the containment atmosphere, but can carry, voluntarily or incidentally, primary circuit radioactive products during accidents.

The ventilation systems can constitute an extension of the primary containment envelope.

Leaks from components belonging to the extension of the third barrier can lead to a containment bypass. The releases arising from a containment bypass, i.e. arising with a sequence of faults that allows primary coolant and any accompanying fission products to escape to the outside atmosphere without having been discharged into and mixed with the air in the containment, shall be minimized as much as possible.

One example of containment bypass involves the use of the safety injection system located outside the primary containment envelope during accidents.

The components of this extension shall satisfy the requirements for a high degree of leak tightness and integrity. Strong safety provisions (e.g. passive or an active single-failure criterion) should be given to these components. The rooms in which these components are located should be considered as part of the secondary confinement (see 7.1.3.5).

7.1.3.5 Secondary confinement

The goal of the secondary confinement is to ensure the recovery of leaks from the containment in order to protect the general public and the environment and, thus, to limit non-filtered or non-controlled releases, in particular in the case of the severe accidents considered in the design, if any.

The secondary confinement may include

— the outer wall of the double wall containment and the ventilation systems of the internal space between the two walls;

— the structure of the rooms enclosing the primary containment volumes and their associated ventilation systems: rooms, ducts of the associated ventilation networks, filters installed on these ducts, etc.;

— the volumes in which leaks from the penetrations through the primary containment envelope are collected and the associated ventilation systems.

It is not necessarily comprised of the entire primary containment envelope.

The design of the secondary confinement shall take into account the maximum quantity of radioactive substances that is 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.

Ventilation systems can be used to collect leaks from pipes used as an extension of the primary containment envelope.

The requirements applicable to the static containment of auxiliary buildings are given in ISO 17873.

It should be noted that the secondary confinement constitutes the last barrier in the event of a severe accident, in particular when leaks are collected through these buildings and when the ventilation systems are not designed to cope with the events that are at the origin of the severe accident (e.g. the total loss of electrical supply). In most designs, auxiliary buildings are included in the secondary confinement.

Table 1 summarizes the constitution of the different containment/confinement systems.

Table 1 — Typical examples of containment/confinement systems

	Barrier	NPP	Research reactors
	First barrier	Fuel cladding	Fuel cladding (or primary circuits for research reactors aiming to study limited core melting)
	Second barrier and extensions	Primary circuit (vessel, pipes, etc.) and connected circuits	Process circuits, pool boundaries[a]
Primary containment/ confinement	Third barrier, also called “containment”	Reactor building, building ventilation network, mechanical and electrical penetrations, containment hatch, etc.	Reactor building, building ventilation network, mechanical and electrical penetrations, containment hatch.
	Extension of third barrier	Parts of connected circuits located outside the third barrier and opened during normal or accidental situations (safety injection system, heat exchangers of heat removal system, etc.) Parts of circuits located outside the third barrier and open to the containment atmosphere and used during normal or accidental situations (ventilation systems, hydrogen removal system, etc.)	
Secondary containment/confinement		Outer wall of a double wall containment system, NPP auxiliary buildings, volumes in which leaks from the penetrations through the primary containment envelope are collected and the associated ventilation systems	

[a] Pool boundaries, often used in research reactors, cannot be considered as efficient barriers (no warranty of presence during all types of accidents and bad retention factors for gases), although they have retention capabilities.

7.1.4 Isolation function (static containment)

This isolation function is useful for volumes (mainly containment building) during a DBA and for which confinement strategy is based on a tight isolation of this volume, on leak tightness of the structure and on the collection of leaks by a secondary confinement.

For isolation function during accidental situations, it is necessary that additional requirements be fulfilled for the systems located outside of, and requiring some penetrations through, the containment building. These systems

a) might not be needed for accident conditions or not qualified for accident conditions (they are considered as lost); these systems shall fulfil an isolation function when located outside the containment;

b) might not be needed for short-term accidental conditions (i.e. the systems are not designed to cope with the peak pressure and the temperature resulting from accidental conditions, but designed to lower pressure and temperature conditions); they are located outside the containment and require an isolation function;

c) can be required for accident situations and designed for the accident ambient condition; whether or not they require an isolation function depends on whether they are located inside or outside the accident zone.

This function can also be required when an accident occurs in buildings other than the reactor containment building. In addition, this function makes some specific demands related to

— the leak tightness of structures, penetrations, valves, etc.;

— the safe and quick actuation of valves or circuits.

To ensure the reliability of the isolation, the isolation valves should be redundant, hermitically sealed in the event of a loss of fluid (electrical supply, compressed air), be seismically resistant and be backed up by diesel generators and a permanent electrical supply, when necessary. They shall satisfy the same requirements as the containment structure itself.

For safety reasons or protection purposes, exceptions can, nevertheless, be accepted for the isolation valves of circuits that are required during an accident (e.g. systems belonging to the extension of the third barrier and for which redundancy on isolation valves can reduce the reliability of the function ensured by the valves). Then the leak tightness criteria shall be associated with the pipes and ducts of the circuits.

The leak tightness of buildings and structures varies according to the type of reactor design. Typical examples of leak tightness rates for NPP primary-containment envelopes for the peak pressure and temperature ambient conditions are

— double containment without liner: $\leqslant$ 1 %/day;

— double containment with an internal liner: $\leqslant$ 0,3 %/day;

— single containment with an internal liner: $\leqslant$ 0,3 %/day.

The ventilation design should minimize the discharge of unfiltered gas leaking from the primary containment envelope to work areas or to the environment, consistent with the safety analysis.

The average values of leak tightness of other specific isolation components, established for the peak accident conditions, should not affect the global leak rate of the primary containment envelope. Typical examples of leak rate are given in Annex H.

The secondary confinement envelope is affected by the leaks as a result of the pressure and temperature effects induced by the accident in the primary containment envelope and by the wind effects on the structure. To minimize these winds effects, one solution can be to adopt a very low leak rate for the secondary confinement envelope (e.g. $<$ 1 %/day for the pressure induced by the most severe winds).

For the auxiliary buildings included in the secondary containment envelope, appropriate leak-tightness requirements (e.g. $<$ 0,1 vol/h during DBAs, 1 vol/h during seismic conditions) shall be satisfied.

Time closure of valves shall be consistent with the accident kinetics. Examples of time closure are between 3 s and 5 s, depending on the diameter of the valves.

Finally, NPP ventilation systems with confinement function located outside the containment shall satisfy additional requirements related to their leak tightness and safe closure in order to limit external leaks. These circuits shall be located in confined rooms.

The leak tightness of ventilation ducts and filtration housing should be adjusted according to the safety importance of these systems, keeping in mind that the leaks through ducts and filtration housing should be minimized in such a way that the filtration performance is not affected. Annex H gives typical leak rate values for ventilation components.

7.1.5 Dynamic confinement

Dynamic confinement is used, in complement of static containment, to ensure in the two following situations additional ventilation of

a) the primary containment envelope in normal conditions and accident situations having a limited increase in ambient conditions (pressure, temperature, humidity level, etc.);

b) the secondary confinement in all situations, in particular the situations for which a high risk of escape of radioactive material from primary containment envelope is expected (e.g. when the primary containment envelope is isolated).

Compliance with this International Standard requires a full implementation of all the principles defined in ISO 17873 for the dynamic confinement, with the following additional considerations:

— special attention should be paid to fission products and especially iodine-131,

— rooms in which fission products can be released during normal operations and accident situations (e.g. liquid or gaseous effluent-treatment systems, circuits containing iodine) shall be maintained at a lower pressure than adjacent rooms.

In some specific cases, rarely used in nuclear industry, rooms under positive pressure are used in order to help the dynamic confinement by ducting the leaks to controlled places (e.g. an annulus space under positive pressure for some designs). This solution shall be used carefully, as it is necessary to maintain this positive pressure during accident situations in which it is required to maintain the dynamic confinement.

7.1.5.1 Classification of the installation into working areas

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

The classification of containment envelopes into categories depends on the reactor design type. It depends on

— the level of atmospheric contamination within these envelopes during normal operation;

— the level of atmospheric contamination during accidents, which itself depends on the type of accidents considered in the design;

— the possibility of not entering inside the primary containment envelope of the reactor during normal operation, either for radiological reasons or other provisions (heat, safety, accessibility);

— the design choice between continuing the operation of ventilation systems during accidents (generally research reactors) based firmly on the worst-case accident conditions and the static containment necessary to isolate the systems (generally pressurized reactors).

7.1.5.1.1 Confinement 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 confinement areas based on the risk of the spread of contamination during normal operation or during a foreseeable accidental, should be defined in accordance with the respective national safety authorities.

Different systems of classification are used around the world for installations other than the reactor primary containment envelope. Most of them use a four-grade subdivision, designated as the C1, C2, C3 and C4 areas in the text below. The definitions of these four areas are given in Table 2 here after, taken from ISO 17873.

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

Table 2 — Usual classification of confinement areas for rooms other than containment envelopes

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

To complete this classification, it is necessary to introduce a classification of containment envelopes based on the management of the confinement system during normal operation or during accident situations. A specific classification is given in Table 3.

Some reactors feature one type of classification for some circumstances and a different classification for others. The ventilation systems shall be designed to cope with the most demanding situation in which they are used.

Table 3 — Classification for containment envelopes

Class	Expected contamination levels for normal and accident situations
C5D	Primary or secondary confinement in which the permanent contamination is low[a], so that restricted access for personnel during normal operation[b] is allowed with adequate protection, but for which the consequences of accident contamination and worst-case accident conditions can be mitigated by a dynamic confinement using ventilation systems.
C5S	Primary containment envelope in which the permanent contamination is low, so that restricted access for personnel is allowed with adequate protection, but for which the contamination and conditions during some accident scenarios are so high that no dynamic confinement is possible during the short term and only static containment can mitigate the accident consequences.

[a] Either the permanent contamination is low or the contamination prior to the access is reduced by special ventilation sequence.

[b] Normal operation corresponds to the period of functioning of the reactor, maintenance, shutdown or refuelling phases.

Examples of recommended classifications are as follows.

— Mechanical process rooms presenting a high level of radioactive contamination (gaseous effluent treatment systems, evaporator): C4 or C3.

— Mechanical process cells presenting a low level of radioactive contamination: C3 or C2.

— Chemical process rooms with strict processing: C2 or C3.

— Rooms in auxiliary buildings with iodine risk: C3 or C4.

— Fuel storage rooms: C3 or C4.

— The inter-space volume of double-wall containment (secondary confinement): C5D.

— Rooms with components that are part of the extension of the third barrier: C3 or C4.

— Reactor primary containment envelope for most light- or heavy-water-cooled reactors during power operation: C5S.

— Reactor primary containment envelope for BWR, pool research reactors and some light- or heavy-water-cooled reactors during normal operation and most light- or heavy-water-cooled reactors during refuelling: C5D.

For some reactor designs, the same containment building can be classified C5S or C5D according to the operational states (power operation, shutdown states) and accident situations (see Annex D). It should be noted that different ventilation systems can be used according to the operational states (e.g. use of a specific ventilation system in some shutdown states when the risks inside the containment are low).

Mainly for research reactors, some rooms classified C1, C2, C3 or C4 can exist inside the reactor building (C5S or C5D), for some specific reasons related to presence of personnel inside the reactor or for specific experiments (e.g. hot cells) during normal operation of the reactor. This leads mainly to specific isolation, leak tightness, and negative pressure requirements.

For each of these classes, appropriate ventilation architecture and a specific air-cleaning system shall be provided. Basic considerations for the constitution of these systems are given in 7.2.

7.1.5.1.2 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 areas. Areas in which internal or external exposure levels are very high shall be forbidden for human access during normal operations, however access can be possible under certain circumstances.

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 shall comply with the pertinent national regulations.

7.1.5.2 Factors influencing the design of ventilation systems

In order to ensure the adequacy of the dynamic confinement function in all operational regimes of the installation, criteria should be defined during the design stage, taking into account the influence of several factors described in ISO 17873, and especially including the effect of the speed of the wind impinging on the building facades (with adventitious or temporary openings) and on the ventilation air intakes. According to the safety analysis, possible failures of ventilation systems components can lead to the need for redundancy of corresponding components.

7.1.5.3 Negative pressure

Here also, the requirements of ISO 17873 shall be fulfilled with special considerations to suit the particular installation (see below for a list of examples).

Negative pressure shall be adopted in all the rooms or buildings in which dynamic confinement is required:

- rooms surrounding the first reactor containment barrier;
- those in which there is the risk of having some contamination, and notably gaseous iodine leakages;
- those in which a specifically hazardous radioactive process is under operation (evaporators, gaseous treatment systems, glove boxes, hot cells, etc.);
- those in which some maintenance or decontamination operations are performed (e.g. filters maintenance, change of pumps of nuclear auxiliary circuits, etc.);
- those in which the ducts are at positive pressure (i.e. downstream from a fan) without tightness provisions and which shall be maintained at a negative pressure in order to cope with leaks of the ducts, even if the ducts are located upstream from the filtration systems, such that the filtration systems are not able to filter all gases.

The following secondary confinement features should be distinguished in order to drastically reduce the direct leaks into the environment.

a) The secondary confinement is constituted by the outer wall of a double-wall containment design. In this case, the negative pressure in the inter-space volume of the double-wall containment should take into account the effects of the most severe wind on the structure. This can imply very high levels of negative pressure in this volume and, consequently, high leak-tightness requirements for the secondary confinement envelope itself.

b) The secondary confinement is composed of the outer wall of a double-wall containment design complemented by auxiliary buildings in which leakage is possible, as in the previous requirement for a double-wall containment design. In this case, the negative pressure inside the auxiliary buildings can be reduced, accounting for less severe wind effects.

c) The secondary confinement is composed only of auxiliary buildings. In this case, the auxiliary buildings should take into account the effects of the most severe wind conditions on the structure. These effects should be taken into account by increasing negative pressure levels, implementing adequate static confinement provisions (e.g. tight enclosures, multiple enclosures), or by specific air-intake designs. It should be noted that high negative pressure levels can create additional risks during operation (difficulties in opening doors).

The negative pressures that shall be maintained correspond to those described in ISO 17873. Table 4 gives some examples of the usual values of negative pressures.

When adjacent areas have different classification levels, the differential pressure should be chosen to suit particular conditions, but it should be at least 40 Pa. For the interfaces between C1 and C2 areas, the differential pressure may be reduced.

It should be noted however that very high negative pressures can be required for glove boxes or containment enclosures (e.g. hot cells in research reactors).

Table 4 — Guide to negative pressure values (see also ISO 17873)

Nature of room or area	Negative pressure value[a]	Containment class
Control rooms	Positive pressure	Unclassified
Non-controlled rooms or areas free from contamination	Atmospheric pressure or small overpressure	Unclassified
Supervised areas with low levels of surface or airborne contamination in abnormal situations These areas shall be uncontaminated in normal operations	0 Pa to 60 Pa	C1
Controlled areas with moderate levels of surface or airborne contamination	80 Pa to 100 Pa	C2
Controlled areas with high levels of surface or airborne contamination	120 Pa to 140 Pa	C3
Controlled areas with very high levels of surface or airborne contamination even during normal operations Areas that are not accessible except under specific circumstances	220 Pa to 300 Pa	C4
Reactor primary containment with containment isolation	b	C5S
Reactor primary containment with operation of dynamic confinement Secondary confinement during accident	200 Pa to 3 000 Pa	C5D

[a] Compared to the reference pressure or, for rooms inside C5 containment envelopes, the pressure inside this envelope.

[b] For normal operation, a typical range is from a negative pressure of 1 500 Pa to a positive pressure of 4 000 Pa.

7.1.5.4 Air velocities between areas

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

— by openings required for operation (doors, ground siphons, front faces of fume cupboards, etc.), or

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

For limiting the volume of air used, it is recommended to employ, if necessary, the possibility of transferring air from one area to another, while respecting the confinement principles given in 6.1, for instance by installing on the transfer lines medium high efficiency or HEPA filters according to the level of risks presented by the rooms.

A multiple transfer does not give a sufficient guarantee to maintain the hierarchy of negative pressure levels, especially for the intermediate zone, if sufficient leak tightness of rooms or enclosures is not ensured between the different zones. Consequently, this design should be avoided when it is necessary to isolate the contamination at its source.

Minimal air velocities have been recommended (see ISO 11933-4 and ISO 17873). For the particular case of gaseous iodine products, a minimal air velocity of 1 m/s is recommended. Nevertheless, each situation shall be studied on a case-by-case basis, 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 situations, the use of a ventilated airlock-chamber should represent a satisfactory alternative solution for ensuring a complementary dynamic confinement.

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

7.1.5.5 Basic air pattern and clean-up systems

7.1.5.5.1 The functions attributed to the system of ventilation and the classification of rooms according to the risk of contamination lead to the construction 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),
- operation and installation constraints (decontamination, dismantling).

In order to guarantee a secure state of the installation in all cases, the study of the nominal regimes of functioning of the different types of ventilation networks shall be completed with a thorough examination of the totality of the transitory regimes of the installation following an incident or accident.

In addition, the analysis shall take into account the criteria in 7.1.5.5.2 to 7.1.5.5.9.

7.1.5.5.2 C1 areas should normally not be filtered. Only appropriate air treatment should be foreseen when the corresponding rooms are occupied by workers. The extract air can be ejected locally without filtration.

7.1.5.5.3 Air should enter the building through an industrial-grade filter to reduce the quantity of dust and impurities in the inlet air. Recycling the air that is released from the stack should be avoided by choosing adequate locations for air inlet. Inlet to C2 areas shall be equipped with particulate air filters, class F or HEPA, to protect against back diffusion in the event of loss of the extract system air flow and, where necessary, in locations having a higher potential level of contamination. The air may be treated to maintain the designed environmental conditions.

7.1.5.5.4 Within the building, air flows should 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 should be sufficient to prevent unacceptable back-flow of contaminated aerosols into the less-contaminated atmosphere of the adjoining area. Where shown to be necessary as a result of hazard assessment, air flow paths should be through filters, in accordance with the contamination risk, between areas with different classifications. Consideration should 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 potentially radioactive contamination can be released.

7.1.5.5.5 In general, air is extracted from the C2 areas via ductwork to the discharge duct or stack. The number and type of filters in series in the duct system from the various areas, prior to the discharge point, is determined as a result of hazard assessment. This extraction system is comprised of at least one filtration stage (HEPA filters, iodine traps, detritiation devices) adapted to the type of contamination.

7.1.5.5.6 The air in C3 areas, relative to that in C2 areas, is likely to be sufficiently contaminated to require more than one filtration stage (HEPA filters, iodine traps, detritiation devices) adapted to the type of contamination. The number and the type of filtering devices are determined according to a risk assessment taking into account the potential releases that can occur during accident situations. It should be noted, in this context, that the level of activity in areas with operator access is not directly relevant to the need for discharge filtration; this latter requirement arises more from the need to keep discharges as low as reasonably achievable (ALARA). Due to the safety requirements for the plant, inlets to C3 areas shall be equipped with particulate air filters, class F or HEPA, to protect against possible back-diffusion of contamination due to loss of extract flow from the C3 areas. Releases shall be made through a stack allowing sufficient dilution (with an adequate height).

7.1.5.5.7 Containments for C4 areas (i.e. in research reactors), such as glove boxes, shielded cells, etc., that contain free radioactive materials, a very small proportion of which is airborne at any time, require special consideration. The activity extracted from these facilities is directly proportional to both the airborne contamination concentration and the extract air flow rate. As a general rule, several high-efficiency filtration stages (HEPA filters, completed if necessary by iodine traps or detritiation devices) appropriate for the contamination risk are recommended to provide the necessary clean-up for these extracts. Releases shall be made through a stack allowing sufficient dilution (with an adequate height).

7.1.5.5.8 The requirement to equip C5S and C5D with filtering systems depends on the functions being ensured (ventilation during normal operation, or during accident situations, etc.), taking into account the following considerations:

— for C5S designs, leak-tightness requirements on the containment envelope are so high that no filtration stage is needed;

— for C5D exhaust lines used during normal operations (power and shutdown phases), at least one HEPA filtration stage is recommended;

— for C5D exhaust lines used to mitigate consequences of accidents, at least one HEPA filtration stage complemented by an adequate device (i.e. iodine trap) is generally recommended. Particularities related to the filtration of radioactive materials in case of severe accidents are treated in 7.3.2.

Releases shall be made through a stack allowing sufficient dilution (with an adequate height).

7.1.5.5.9 If the deposition of radioactive materials on the main filtration devices during accidents leads to excessive exposure of operators or materials, then adequate protection measures against gamma radiation shall be taken, such as installation of shielding or implementation of primary filtration stage upstream from these filters. This main filtration device, which is generally located in the filtration unit, constitutes the last cleaning stage before release into the environment via the general stack.

7.1.5.6 Classification into ventilation types

In addition to the classification into confinement area classes, and in accordance with the previous requirements, a classification into ventilation families can be established, permitting the definition of the principal rules for the general design and equipment specific to the different ventilation networks.

Annex E gives an example of such a classification, which is based on the maximum expected contamination level during normal operations as well as the potential accident contamination levels.

7.1.5.7 Optimization of air exchanges

The number of air exchanges is determined by the conventional ventilation requirements necessary to supply fresh air, and remove odours, potential asphyxiants, vapours and heat, etc. In addition, the air exchange rates can be determined by the radiological requirement to maintain the proper negative pressure 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 requires four iterative steps described in detail in 7.1.5.7.1 to 7.1.7.5.7.5:

a) estimation of the typical air flow rate according to the classification of the working areas (radiological areas, containment areas);

b) consideration of reducing radioactive releases and internal doses for the workers;

c) consideration of the specific risks;

d) study of the containment function;

e) maintenance of the ambient and hygienic conditions.

The first three steps are directly dependent 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.

7.1.5.7.1 First step

This step provides for the definition of a minimal air exchange rate, taking into account the level of air contamination under 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 exchange rates are given in Table 5.

7.1.5.7.2 Second step

Two situations shall be considered: normal operation and accident situations.

— Normal operation: air exchange rate does not have a significant impact on the radioactive releases of short- and long-lived nuclides.

— Accident situations: whatever the lifetime of the nuclides, radiological consequences shall be maintained as low as possible for the members of the public and the workers. The reduction of air exchange rates contributes directly to the reduction of the consequences on the public, significantly for short-lived nuclides, but increases the consequences for the workers. An optimization shall therefore be undertaken in order to define the appropriate air exchange rate. Table 6 below gives the corresponding indications.

NOTE All these air exchange rate values can be reduced according to the approach defined in the third step (see 7.1.5.7.3), taking into account whether or not personnel are present in the rooms and an evaluation of the radiological consequences subsequent to an accident.

Table 5 — Guide to air exchange rates

Units are in air exchanges per hour

Compartment	Typical air exchanges per hour	Area
Change 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 for primary containment of risk process plants	1 to 5	C3
Controlled area of high potential hazard, including iodine-risk rooms	4 to 10	C3
Maintenance areas for primary containment of high-risk process plants	10	C3
Inter-space volume of double-wall containment	<< 1	C3 or C4
Research reactors: primary containment without personnel entrance (glove box, containment enclosure or shielded cell)	1 to 30 (depending entirely on process, volume of the containment enclosure and hazard)	C4
Primary containment without personnel entrance	1 to 4 (depending entirely on process, volume of the containment enclosure and hazard)	C5D

Table 6 — Guide to air exchange rates, according to whether or not personnel are present

Units are in air exchanges per hour

Compartment	Situations	Presence of personnel	Absence of personnel
Spent fuel storage areas	Normal	1 to 5	Not specified
	Accident with short-lived nuclides	Not specified	0,1 to 1
	Accident with long-lived nuclides	Not specified	1 to 5
Reactor building	Normal	1 to 4	Not specified
	Accident with short-lived nuclides	Not specified	C5S: approximately 0 C5D: optimization needed (generally << 1)
	Accident with long-lived nuclides	Not specified	C5S: approximately 0 C5D: optimization needed (generally 0,1 to 1)

7.1.5.7.3 Third step

Consideration of hazards and the specific constraints such as

— explosive and inflammable gases, for example H_2,

— presence of radioactive gases (e.g. tritium),

— iodine releases in the rooms,

— presence of inert or toxic gases, and

— thermal constraints due to processes or equipment located in the room, etc., shall be taken into account during the determination of the required air exchange rate of the room. This evaluation necessitates an individual study, which can lead to increasing the air exchange rates above the values indicated in Tables 5 and 6.

7.1.5.7.4 Fourth step

In order to ensure the dynamic confinement of the room, i.e. to maintain the necessary negative pressure, 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 foreseen 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 when the exhaust air flows required to compensate for the predicted leak flow rates appear to be excessive, a cost optimization study should be undertaken, balancing the cost of the ventilation against the cost of improvement of the leak tightness of the room, while achieving the required degree of safety of the installation.

7.1.5.7.5 Fifth 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 air flow rate required to maintain the ambient conditions of the room, considering the equipment, processes and personnel.

A study shall be undertaken for both the normal and likely off-normal functioning of the installation, which takes 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 Annex E,

— the uncertainties linked to the functioning of the ventilation system, and

— the fresh air that it is required to provide to ensure acceptable industrial-hygiene conditions in the areas that are normally occupied.

7.1.5.7.6 Determination of the final air flow rates

The optimization process defined above can require several iterations. In practice, the methodology consists of

— analysis of the results obtained in the five steps, and

— retention of the optimized air flow rate derived from these steps, taking into account the necessity to minimize radioactive releases into the environment and internal doses for workers, while ensuring the safe functioning of the installation.

The air flow rates thus obtained (the optimized air flow rate resulting from all the steps) are the air flow rates taken into account for dimensioning the ventilation system.

It shall be noted that for a given room, several air exchange rates can be allocated depending on the operational situations defined for this room. In this case, the ventilation systems shall be able to cover the overall air exchange rates.

In establishing the air exchange rates, the following provisions shall be taken into account:

a) C1 areas, by definition, are free from contamination and generally do not require special consideration other than to maintain the proper air circulation towards the surrounding C2 areas. This does not preclude the use of ventilation in these areas, as determined by the climatic and ambient conditions associated with these rooms.

b) In those areas that have a potential for airborne activity, increasing the air exchange rate might not result in a significant reduction of airborne activity to the level of the operator. Excessive flow rates should be avoided, since they can cause a suspension of the 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.

c) The air flow rates into C2 areas may include a proportion taken from the C1 volumes or from the exterior. In certain circumstances, subject to hazard assessment and by agreement with the responsible safety authority, a significant fraction of the air exchange 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 shall be filtered through adapted filtration devices (HEPA filter, iodine trap, etc.) before recirculating or transferring to a lower contamination risk room.

7.1.5.8 Layout and location of the ventilation ducts

The layout of the ventilation ducts shall be studied in order to

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

b) reduce wind effects (for air inlets);

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

   — install the inlet ducts in less-contaminated areas;

   — install extraction ducts in the most-contaminated areas;

   — in class C4 areas, limit the length of ducts and implement adequate tightness (e.g. welded ducts).

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

This activity consists of defining the architecture of the installation:

— by defining all rooms according to the nature of the risks (type of ventilation, fire compartments, containment compartments, iodine risk rooms);

— by defining the main parameters of the ventilation: negative pressure in the rooms, air exchange 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 shall be drawn. This diagram shall be refined throughout the subsequent progress of the project, accommodating the increasing precision of the 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 should 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 negative pressure 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 E gives some typical examples of ventilation diagrams.

7.2 Filtration

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

During the design stage, consideration is also given to the necessity of installing 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.

Filtration systems are also recommended for the air inlets to reduce the quantity of dust and impurities burdening the extract filters and, hence, prolong their lifetime.

Filtering and air-cleaning devices shall be designed in order to limit the volume of waste that they produce. If filtering and air-cleaning devices in the design of ventilation systems are considered replaceable, it shall be possible to replace them without risk of spreading radioactive contamination and without risk of excessive exposure of the workers during the operation. If necessary, remote handling means shall be provided.

Potential loss of the efficiency of filtration systems shall lead to the inclusion of redundant equipment for the ventilation areas (e.g. C4 and C5) that have a high-risk contamination classification.

7.2.1 HEPA filters

The design of HEPA filters for nuclear reactors is exactly the same as for those of other nuclear installations. The design, control methods and tests are indicated in ISO 17873. The requirement for HEPA filters on ventilation systems shall be assessed according to the expected maximum contamination level during normal operations and during accident situations in rooms.

In particular, for HEPA filters located at the last filtration stage or those used for the safety analysis, the minimum decontamination factor shall not be lower than 1 000 at the most penetrating particle size (MPPS) (see Annex F). HEPA filters for nuclear applications are defined according to this criterion.

Adequate validated normative methods shall be used in order to test periodically the efficiency of HEPA filters. These methods shall give conservative values and shall use the ratio of the mass upstream from the filter to that downstream from the filter of the MPPS in order to be representative of the radiological consequences of normal and off-normal releases.

The location of the nozzles used for injection upstream from the filter being tested and the take-off of the MPPS particles upstream from and downstream from the filter being tested shall be qualified in order to ensure a homogeneous spread of these particles at these take-off points.

HEPA filters shall also be qualified for nuclear conditions (resistance to ionizing radiations, ageing of lute and seals).

Fire resistance is considered in 8.5.

7.2.2 Iodine traps

Iodine nuclides contribute a major part of the radioactive inventory in the case of an accident, so the associated filtration requirements shall be implemented very carefully. The requirement for iodine traps shall be assessed according to the same methodology as for HEPA filters, i.e. permanent and accident situations contamination levels in rooms.

The following aspects are taken into account with regard to this objective:

a) the decontamination factor required during accidents, associated with the different iodine chemical forms;

b) the qualification of iodine filter during the whole accident period;

c) the achievement of periodic tests proving the decontamination factor.

The decontamination factor of iodine traps is very sensitive to

— humidity levels of the atmosphere passing through the filtering media;

— air speed through the filtering media;

— iodine mass filtering capacity of the filtering media;

— static ageing of the trap;

— chemical form of the iodine released during an accident (i.e. organic iodine, molecular iodine, particulate iodine).

Therefore, the following provisions shall be taken into account.

a) In order to limit, upstream from the iodine filter, the maximum relative humidity, which can degrade charcoal efficiency (tests have shown that efficiency of iodine traps decreases significantly for a relative humidity higher than 40 %), dehumidifier systems (heaters, condensers) shall be installed upstream from the traps. Relevant information (humidity sensor or temperature measurement) shall be continuously available in order to control this parameter.

b) In order to ensure high efficiency and the optimum retention time of iodine inside the trap, the air-speed limit shall be lower than the value achieving this goal (i.e. 25 cm/s for 10 cm thickness of charcoal bed). It shall be demonstrated that the provisions with respect to this value are adequate.

c) Stand-by iodine traps shall be tested as frequently as those in normal operation (operation feedback has shown that six months to one year periodicity is sufficient for an iodine filter not subjected to high humidity levels during normal operation).

d) The chemical form of the iodine during accidents shall be known in order to be able to establish the decontamination factor used in the safety assessment.

e) It shall be demonstrated that iodine traps, when used in stand-by mode, can guarantee their efficiency at an early stage of iodine release into the environment. In addition, the ventilation systems used during normal operation should be isolated sufficiently quickly to avoid any spread of contamination into the environment. To ensure this function, periodic tests shall be performed to verify the length of time required for the isolation devices to close.

f) Iodine traps shall not be damaged by foreseeable fire risks (internal to the ventilation systems as well as in the rooms where the iodine trap is located): the protection against this risk is achieved by the installation of appropriate sensors (temperature sensors, smoke sensors) and devices that prevent fire from destroying the trap and limit the releases into the environment due to the destruction of this iodine trap (e.g. appropriate fire dampers installed on the ventilation systems for the iodine trap and on the overall ventilation system of the surrounding room).

g) When fire risks exist, provisions shall be adopted that prevent trap destruction from external fire (e.g. insulation) and internal fire (e.g. appropriate fire dampers on the ventilation systems of the iodine trap and on the overall ventilation system of the surrounding room).

h) Activated charcoal used for iodine filters shall be impregnated in order to increase the chemical sorption (e.g. TEDA) and/or isotopic exchange (e.g. potassium iodide, KI) and to limit desorption phenomena.

Decontamination factors often used in nuclear reactors are

— 1 000 for molecular iodine (I_2);

— 100 for organic iodine (CH_3I);

— 1 000 for particulate iodine (NaI, CsI,); corresponding filtration is ensured by HEPA filters.

It shall be noted that these values are not equivalent in terms of retention. Periodic *in situ* tests shall be performed according to the most penetrating form of iodine released in the facility. When the iodine molecular form that can be released during accident situations is not known, organic iodine is recommended for the testing of the iodine traps.

According to IAEA recommendations (see Reference [10]), new power reactors should be designed to cope with severe accidents. Therefore, the filtration systems, in particular iodine sorption ability, used to mitigate the consequences of severe accidents should be designed with regard to severe accident conditions and source term inventory.

Depending on the results of the safety assessment, in particular when this function is used to cope with DBA, the iodine filtering function (traps with associated control and protection devices) shall be based on redundant components, seismically classified and supported by an auxiliary diesel generator.

7.2.3 Other gas-trapping devices

Other gas-trapping devices, such as zeolites, washing columns and detritiation devices, should meet requirements allowing the demonstration of their efficiency during normal operation and accident conditions.

Activated carbon traps are used, via dynamic adsorption, as retention beds that permit some decay of the radioactivity of the releases. These systems are the most efficient for short-half-life nuclides.

Detritiation devices, mainly based on the oxidation of tritium gas and on the retention of oxidized tritium on a trapping device (e.g. molecular sieve), shall be designed to cope with hydrogen combustion and fire risks.

The purification devices shall be designed according to the quantity of gas being treated.

7.3 Reactor specificities

7.3.1 Containment leak detection

For C5S designs, the leak tightness should be estimated during normal operations in order to detect leaks.

The current method consists in measuring the mass of the atmosphere in the primary containment envelop, by measuring pressure, temperature and humidity at several points. A calculator determines the mass variations versus time. These variations correspond to the leak of the primary containment envelope during normal operations.

Internal leaks due to compressed gases should be taken into account in the calculations. The number and location of the points shall be selected in such a way as to be the most representative.

For C5D designs, the methods described in ISO 10648-2 are applicable.

7.3.2 Confinement in the event of severe accidents and ventilation system specificities

The management of the radionuclides present in the containment after a severe accident is similar to radionuclide management in the event of a DBA. The aim is still to limit containment leakage and to avoid as far as possible the creation of unfiltered leakage paths to the environment.

An assessment of the radioactive releases from the containment should be made for selected severe accident sequences in order to identify potential weaknesses in relation to the leak tightness of the containment and to determine ways to eliminate them. This assessment should use a best-estimate approach to identify the potential leaks from the containment, and the consequences of the unavailability of systems (such as the potential loss of containment isolation in the event of a total loss of electricity power) for each sequence.

For existing plants, any path for significant releases, in addition to those of the existing exhaust ventilation systems provided for accidents in the design process, should be filtered. Moreover, a strategy shall be adopted to optimize the effectiveness of passive features (such as the retention capacity of rooms and buildings) and of active systems (such as dynamic confinement by the ventilation systems, if available). Requirements for the filtration components should be adapted to the nature and the inventory of the nuclides.

In existing plants, for situations that can damage the integrity of the primary containment envelope, specific filtering systems should be implemented in order to collect the contaminated atmosphere and to limit its spread into the environment. Examples of such systems are sand filters, metallic filtering medium, venture scrubbers, etc.

For new plants, a secondary confinement should be incorporated into the design.

7.3.3 Secondary confinement systems

For reactors including double-wall containment, the space between the two walls (annulus space) shall be ventilated. Two types of design are available:

- by maintaining a negative pressure in the annulus space in order to collect and filter the leaks from the primary containment envelope;
- by maintaining a positive pressure in the annulus space in order to avoid leaks from primary containment to secondary confinement systems and, thus, towards the environment. The nuclides released during an accident are collected and filtered through primary containment ventilation systems.

The first option is preferable.

Design of secondary confinement systems shall take into account internal and external hazards. As mentioned in 7.1.5.3, the pressure in the annulus space shall account for strong winds. If such events are liable to lead to a design basis accident, then complementary requirements shall be satisfied for the systems used to operate during this situation.

When these systems operate during design basis accident situations, the requirements for these ventilation systems shall be very high:

- iodine and aerosol filtration efficiencies (see 7.2);
- high reliability of the dynamic confinement function (e.g. redundancy of fans and filters);
- permanency of the electrical supply (e.g. diesel generators);
- seismic classification and operability during and after an earthquake.

For NPPs, these systems shall have a seismic classification and shall continue to function during and after an earthquake.

For research reactors, if an earthquake is liable to lead to a DBA, then complementary seismic requirements shall be satisfied for the systems operating during this design basis accident situation.

The final requirements associated with secondary confinement systems are dependent on the level of contamination expected during design basis accidents.

For beyond-design basis accidents, the above requirements should be selected on a case-by-case basis depending on the safety assessment results.

7.3.4 Off-gas treatment systems

Radioactive fission gases, among them xenon and krypton gases, are generated in the reactor core. A portion of these gases is released into the reactor coolant when the fuel cladding is defective. For oxygen control, hydrogen is added to the primary system using a volume-control system. Since the gases are dissolved in the reactor coolant, they are transported to various systems in the plant. Because of the explosive nature of hydrogen in a mixture with oxygen, its presence in components of the process systems shall be controlled.

The different process systems connected to the off-gas systems are mostly tanks and vessels, which contain variable volumes of free gas and noble gases.

In addition to the ventilation systems dedicated to the rooms or containment envelopes, specific ventilation systems shall be implemented in order to collect material generated from the components and process equipment, such as pressurizers and tanks, and then to filter them. The design of the systems shall take into account normal operations, including shutdown states, as well as accident situations.

In order to cope with accident situations, provisions should be taken to assess whether static containment (e.g. isolation and leak tightness) or a dynamic confinement of the process systems is required.

For tanks without explosive gases, the effluent gases shall be collected by an exhaust ventilation system equipped with filtration systems. These ventilation systems can also be used for the ventilation of the contaminated rooms.

For tanks with explosive gases (e.g. hydrogen), a dedicated system is required in order to avoid any mixing of the collected gases with the buildings' atmosphere and, therefore, to avoid the possibility of an explosion.

Two types of design are available to reduce contamination level:

- a storage for decay prior to release and filtration,
- a continuous treatment (adsorption-desorption) using retention beds (activated carbon).

In any case, provisions shall be taken into account to eliminate explosion risks. The functions dedicated to these kinds of design should

- compensate the level deviations of the free-gas atmosphere in the connected tanks by discharge or intake the corresponding gas volume;
- flush components in which coolant degasification occurs with nitrogen in order to process the extracted gases;
- retard the process and allow the radionuclides to decay (noble gases, iodine, etc.) to obtain an acceptable level of releases to the atmosphere.

Elimination of the explosion risk is ensured as follows.

a) For continuous filtration systems, by preventing the escape of radioactive gases from the connected components into the building air by maintaining a negative pressure, and by limiting the hydrogen content in the system and in the flushed components to under 4 % by volume and the oxygen content to a low level in order to prevent the formation of a combustible mixture. For this function, a recombiner is recommended.

b) For retarding systems to allow radioactive decay, by pressuring the pipes and tanks. In this technology, additional provisions shall be taken, such as

— severely limiting the entrance of oxygen (e.g. less than 0,1 % volume fraction O_2 in the system) into the process systems arising from the rooms' ambient air and measuring the oxygen content in these systems;

— ensuring a high level of leak tightness of the pipes in order to avoid hydrogen leaks into the rooms;

— ensuring a sufficient dilution of the explosive gases (e.g. significantly below the lower flammability limit) at any points of the exhaust line, including the connection points with the other ventilation systems.

Requirements concerning the redundancy, the seismic classification and the emergency electrical supply shall be defined according to the safety analysis. A single failure of the systems shall not lead to an explosion or unacceptable radioactive risk.

7.3.5 Consideration for leak tightness of ventilation components

Specific guidance for leak-tightness criteria on ventilation components and primary containment penetrations are given in Annex H.

7.3.6 Ventilation of inner volumes inside the reactor building

For the rooms and enclosures inside the reactor building that need ventilation systems during normal operations (e.g. the presence of personnel, specific experimentation such as hot cells) and that can be classified C1, C2, C3 or C4, the sudden closure (inadvertent or due to reactor accident situations) of the containment building leads to the closure of the ventilation systems of these volumes.

The closure of the valves located on these systems shall be taken into account in the design of the confinement provisions (static or dynamic).

8 Management of specific risks

NOTE The generic risks described in this clause can concern either all reactors or only certain types of reactors.

8.1 Control of combustible gases in the reactor building

In a severe accident, large amounts of hydrogen can be released to the atmosphere of the containment, potentially exceeding the flammability limit and jeopardizing the integrity of the containment. Later in the accident sequence, in the event of corium/concrete interactions, carbon monoxide can also be released, contributing to the hazard. In order to assess the need to install specific features to control combustible gases, an assessment of the threats to the containment posed by those gases should be made for selected severe accident sequences, using a best-estimate approach. The assessment should cover the generation, transport and mixing of combustible gases in the containment, combustion phenomena (diffusion flames, deflagrations and detonations) and consequent thermal and mechanical loads, and the efficiency of mitigation systems.

According to IAEA recommendations (see Reference [10]), the efficiency of the means of mitigation for new power plants should be such that, with an amount of hydrogen generated equivalent to a total fuel cladding oxidation, coupled with appropriate kinetics of release, the concentration of hydrogen in the containment compartments would at all times be sufficiently low to preclude a detonation. Design provisions for achieving this goal are, for example, an enhanced natural mixing capability of the containment atmosphere coupled with a sufficiently large free volume, passive autocatalytic recombiners and/or igniters suitably distributed in the containment, or inertization.

The means of hydrogen mitigation provided can be the same for DBA conditions and for severe accident conditions.

The leak tightness of the containment for the most probable accident sequences should be ensured with sufficient margins to take into account severe dynamic phenomena, such as a fast local deflagration, if these cannot be avoided.

Even in a containment that has been rendered inert, hydrogen and oxygen generated over a long period of time by water radiolysis can eventually cause the flammability limit to be exceeded. If this is a potential threat, passive autocatalytic recombiners should be installed to deal with it.

Provision should be made for hydrogen monitoring or sampling.

Severe accident conditions can pose a threat to the survivability of equipment inside the containment due to high pressures, temperature, radiation doses and dose rates (including those due to aerosol deposition), and concentrations of combustible gases.

8.2 Management of ambient conditions

8.2.1 Temperature control of boron compartments

For some types of water-cooled reactors, boron is used in order to control the reactivity of the core.

In order to avoid crystallization of boron in pipes, the temperature in the rooms containing these pipes should be high enough based on the specific boron concentrations to exclude this phenomenon.

For example, the minimum temperature ensured in rooms conditioned by the ventilation systems shall be higher than 7 °C for 0,2 % boron concentration and 18 °C for 0,7 % boron concentration.

NOTE This can be achieved by directly heating the pipes.

Requirements for the heating function of these rooms shall be consistent with the importance for safety of the systems containing the boron.

8.2.2 Sodium

For sodium-cooled reactors, the sodium shall be maintained within a given temperature range in order to avoid its crystallization or its ignition in the air. These conditions can also be achieved by directly heating or cooling the pipes.

The temperatures for the changes of state of sodium are

- melting point: 97,9 °C;
- vaporization temperature at atmospheric pressure: 882 °C;
- ignition temperature depends on the sodium physical conditions, but from 120 °C for sodium drops to more than 200 °C for pre-heated sodium layers.

Requirements for the air-conditioning function of these rooms shall be consistent with the importance for safety of the systems containing the sodium.

8.2.3 Conditioning of safety-classified components

Rooms containing safety-classified components as defined in Annex C shall be ventilated in order to maintain the range of temperatures required for the safe operation of these components[7)].

Requirements for the air-conditioning function of these rooms shall be consistent with the importance of the safety-classified components in the safety analysis.

The sizing of the heating and cooling capacities shall take into account the extreme external temperature range.

Typical temperature values of safety components are given in Table 7.

Table 7 — Guide to temperature resistance of safety components

Component	Minimal temperature requirements		Maximal temperature requirements	
	Accidental conditions	Normal conditions	Normal conditions	Accidental conditions
Electronic and electrical equipments(including control rooms)	5 °C	15 °C	25 °C	35 °C
Pumps	5 °C	15 °C	25 °C	45 °C
Diesel equipments	10 °C	15 °C	35 °C	40 °C

8.2.4 Ventilation systems of the control rooms

These systems shall meet special requirements as they prevent the ingress of contamination (chemicals, radioactive materials, smoke, gases, etc.) rather than providing a confinement function.

8.2.4.1 General requirements

Back-up control rooms are necessary either if personnel shall remain in the control room for long periods after an accident in order to survey the facility, or if the main control room (MCR) is not designed to protect workers to ensure long-term habitability of the control room. It is important to mention that, in order to manage accident situations, the long-term habitability shall be ensured for only one, not both, of these control rooms.

When the long-term habitability of one of the control rooms is threatened by an accident, ventilation systems shall ensure

a) with regard to the single-failure criterion and common mode failures:

— a complete separation (geographical and physical) between the ventilation systems of the two control rooms,

— global redundancy of the air-conditioning (heating and cooling) of both control rooms,

— a specific redundancy of the air-cleaning function of the ventilation system, at least for the MCR;

7) These components are generally qualified to the conditions in which they are expected to be used during normal operations and accident conditions, in particular when the temperature exceeds the range of typical temperatures mentioned in Table 7.

b) with regard to seismic conditions:

   — the complete qualification of the ventilation systems of the control rooms against earthquakes, at least for that of the MCR;

c) with regard to the permanency of the electrical supply:

   — its operability in case of loss of normal power supply by back-up diesel generators, at least for the MCR ventilation systems.

8.2.4.2 Specific requirements for the design

The following specific requirements shall be introduced for these systems:

- implementation of specific filtration systems (equipped with aerosol and iodine filters) on the air-inlet ventilation system, at least for the MCR ventilation system;
- implementation of air dehumidifier (e.g. heaters) upstream from the iodine filters defined in 7.2.2 to protect the iodine filters in all weather conditions;
- implementation of a positive pressure in the MCR ventilation systems to avoid air infiltration without filtration in the MCR;
- performance of an air-conditioning function (heating and cooling) in accordance with the temperature requirements of the safety equipment on one hand and with the external cold and hot temperatures on the other.

Periodic tests of filtration systems shall be performed.

8.3 Prevention of risks linked to releases of heat, gases 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 renewal of the atmosphere, ensuring that the creation of any “dead areas” inside the defined volumes is avoided. These functions can be ensured by open or closed ventilation networks. It is necessary to analyse these risks and to specify the reliability of the systems concerned and their control devices to suit the consequences of possible accidents.

Special attention should be paid to controlling the release of radioactive gas and vapours into the rooms and/or the environment. This can require the introduction of appropriate equipment such as scrubbers, chemical traps (e.g. iodine traps) and noble-gas delay systems. Examples of such 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 can pose particular hazards. Some ventilation systems shall accommodate the air flow associated with cooling the process plant. These objectives can be achieved by appropriate selection of air exchange rate, depending on the specific safety analysis.

8.4 Prevention of risks linked to the 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 should be adopted:

- installation of appropriate air-cleaning or filtering devices as near as possible to the source points, except with special justification;
- adoption of an air velocity inside the ducts sufficient to entrain the predicted particles;

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

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

8.5 Prevention of fire hazard

8.5.1 Compartmentalization

To inhibit the spreading of a fire, the best strategy for prevention 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 predefined volumes for a sufficient period to facilitate intervention for extinguishing the fire, and to protect these compartments against possible external fires. Nevertheless, fire areas can be used in certain specific cases presented in 8.5.3.

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 workers, the general public or the environment, additional containment compartments (CC) shall be defined in order to limit these consequences.

When no distinction between fire compartment walls and containment compartment walls is taken into account in the design, then it shall be demonstrated in a specific study that the walls can ensure both functions of fire resistance and limitation of the spread of radioactive materials.

8.5.2 Fire compartments

Fire compartments shall fulfil the following requirements.

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

b) 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.).

c) When fire compartments are likely to contain radioactive substances such that a possible fire leads to significant consequences for the environment and the general public, it is strongly recommended that designers avoid making the fire-compartment walls coincide with those of the external building structures. It is preferable to insert a room or group of rooms with specific ventilation networks equipped with adapted filtration devices (HEPA filters, iodine traps) between these walls. 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, in particular by external means (doors equipped with fire-proof 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.

d) Relevant information identified in the plant safety report and design provisions (e.g. for temperature, pressure, presence of smoke) shall be continuously available to allow the operation of the ventilation system in an appropriate way, with regard to smoke, hot gases and dust.

e) The ventilation shall be capable of being isolated, unless it can be demonstrated that the ventilation equipment is not challenged by the fire and that smoke, combustion gases, heat and the spread of radioactive materials cannot challenge the equipment in the other rooms and inlet and extraction network. In addition, air supply to the fire source shall be restricted.

f) A compromise between the closure of the fire compartment and the question of whether or not to maintain the functioning of the extraction network and the air-cleaning system shall be obtained, in order to

1) ensure the control of the dynamic confinement as long as possible during and after the possible fires considered in the safety analysis,

2) minimize creating the risk of an explosive atmosphere within the containment areas or rooms,

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

4) 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).

The operation of the ventilation system in case of a fire shall be carried out according to the findings of a suitable safety study and respect the recommendations given in 9.6. To fulfil these principles for the use of ventilation systems in accordance with the safety demonstration mentioned in 9.6, the following measures shall be taken.

— The fire resistance of the walls of the fire compartments required by the safety analysis shall be maintained by the installation of suitably positioned fire dampers within the associated ventilation ducts, with the exceptions mentioned above. The control devices of these fire dampers shall be protected against the effects of the considered fire.

— The extraction circuit designed for use 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 in the extraction air flow rates to such an extent that a significant positive pressure excursion can arise, or the dynamic confinement becomes ineffective. In order to avoid this phenomena, a bypass can be used.

  — 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).

— The ventilation ducts and their connection flanges outside a fire compartment, etc., shall be leak-tight and shall be designed to maintain their initial behaviour with regard to fire loads (dilatation, smoke, pressure) in the rooms that they serve or cross. If it cannot be avoided that ducts cross other fire compartments, these ducts shall be fire-resistant to at least the same safety level required for walls of the fire compartments that they cross.

— The admission ducts to a fire compartment can be equipped, if necessary, with one filtering stage, located as close as possible to the compartment and upstream from a suitable fire-resistant isolation valve in the admission line.

— Transfer of air from fire compartments or from fire-and-containment compartments to other rooms shall be made impossible in new installations. For existing installations, if such a transfer exists, it should be equipped by adequate provisions. Air-recycling systems should, accordingly, meet the same requirements.

— The releases in the event of a fire shall be calculated taking into account the maximum leak rate of the fire compartment.

It arises from the above that certain general safety principles shall be followed when designing fire compartments, namely the following.

— The systems shall be designed to keep to a minimum the size and number of penetrations in the associated barriers.

— Where a ventilation duct penetrates a fire barrier, a fire damper shall be fitted with the same standard of fire resistance as is required by the safety analysis for the wall through which it passes.

— Fire dampers and barriers shall be tested and approved with regard to expected performances by a competent authority in accordance with a nationally recognized standard. The designer shall ensure that the fire damper is installed in the same manner in which it was tested.

— During operation, periodic tests of fire dampers shall be carried out, in accordance with 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 provided, for example by the use of limit switches. Multiple-use dampers (e.g. those that can be reopened during a fire) should be resettable without having to gain access to the interior of the duct.

— The materials of construction for fire dampers shall be suitable for the likely environment within the duct. It is necessary to take care in the presence of acid and other reactive vapours, which can cause long-term corrosion. It is necessary to take care regarding the temperature; in particular, fire dampers with intumescent materials for which the reaction temperature, around 100 °C, is well below the maximum permitted operation temperature of the associated filtration systems and as a consequence, cannot be used when it is necessary to maintain extractions from fire compartments during a fire.

— Depending on individual circumstances, it can be required that some of the fire dampers be resettable from a safe location, e.g. a control room. The requirement for this capability is dependent on factors such as the 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).

— Automatically initiated closure of fire dampers within certain ductwork systems shall be used with caution because the associated pressure excursions can breach the room's containment.

8.5.3 Fire areas

In addition to the previous concept, fire areas can be established in order to protect combustible materials from ignition sources and to reduce the risk of the spread of a fire by means of a separation by a sufficient distance from radioactive sources, safety systems, worker escape routes, etc.

In such cases, a specific fire assessment shall be performed in order to prove that this separation is sufficient with regard to the phenomena induced by a fire (temperature, pressure, smoke). In case of doubt, fire compartments or other mitigation systems with safety requirements shall be adopted.

8.5.4 Containment compartments

When a fire in a fire compartment containing radioactive substances can lead to unacceptable consequences for the workers, the general public and the environment, the spread of contamination is restricted 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, except if it is demonstrated that the functionality of the walls allows the control of liquid and gaseous releases from this compartment.

— The ventilation of the containment compartment shall have a ventilation network equipped with adequate purification devices (HEPA filters, iodine trap) and shall maintain, as long as possible, its performance against the effects of the fire in the fire compartment. Thus, it is preferable to build a specific ventilation network for the containment compartment.

— The walls 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 wall of the containment compartment 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 filtration systems, the containment enclosure shall be entirely free from penetrations.

— In order to limit the risk of the spread of radioactive contamination within the facility, and to facilitate interventions and subsequent decontamination, the walls 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 either via an appropriate ventilated airlock chamber or directly via the surrounding rooms, with provisions aimed at restoring static confinement during the fire and that consider the potential for the additional spread of radioactive materials during the design of the ventilation of these surrounding rooms. In case of openings to the outside of the buildings, only the first solution is required.

The ventilation philosophy of containment compartments shall permit the control of the smoke and radioactive particles that can 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 should be dimensioned with a consideration of the leak rates induced by these fire compartments as well as of the maximum temperatures and pressures predicted for these volumes.

During the entire duration of a fire, the containment compartment shall, to the extent possible, be maintained at a negative pressure relative to the adjoining rooms or to atmospheric pressure.

8.6 Consideration of external hazards

The design of the plant should take into consideration a variety of risks from 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 Clauses 4 and 5.

External events to consider in the design of containment systems are those resulting from human activities in the vicinity of the plant, as well as natural hazards that can challenge the integrity of the barriers and the functions of the containment systems.

All relevant external events shall be evaluated to determine the possible effects, to establish the safety systems required for prevention or mitigation, and to 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, tornados, flood, fire, lightning, external missile impact, extreme temperatures (high and low).

The objective is to adapt the design of ventilation systems taking into account the probability and the effects of these events and maintaining at least one effective confinement system between the radioactive substances and the environment for any plausible risk during the projected lifetime of the plant. For that purpose, confinement systems shall be designed in such a way that external events do not lead to

— total loss of the safety-classified function required to cope with these events,

— total loss of the monitoring function for radioactive releases for events leading to radioactive releases,

— 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 (i.e. passive features) 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.

Examples of ventilation and confinement systems and systems for considered external hazards include the following:

a) with regard to external fire, explosion or releases of toxic gases, damage inside the buildings shall be avoided [e.g. using passive features or closure of inlet air dampers activated by adequate detectors (smoke, pressure, toxic gases)]. In the latter case, a specific analysis shall be performed to assess the interaction of this closure with the other functions ensured by the ventilation and containment systems;

b) with regard to earthquakes, safety-classified ventilation systems and containment systems should have a seismic classification (e.g. integrity, operability);

c) with regard to strong winds and tornados, specific analysis shall be performed to assess the potential wind effects on air intakes from by the wind, on the stacks and on negative pressure being maintained in the rooms; this assessment can lead to the implementation of passive or active dampers on air intakes or exhausts and to a specific operation of ventilation systems;

d) with regard to extreme temperatures, specific analysis shall be performed to assess the potential effects on the safety functions ensured by the ventilation systems in order to check the necessity to increase cooling or heating capacities.

9 Dispositions concerning the management and the operation of the 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 systems, 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 (see 9.2);

— operational management issues (see 9.3);

— test procedures and maintenance (see 9.4);

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

— decommissioning considerations.

9.2 Technical operating instructions

The technical operating instructions shall 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 shall 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 shall 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 negative pressures, margin against clogging, efficiency of gas cleaning devices, leak tightness of equipment, enclosures and rooms) and, for some areas, the maximum 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. Thus, the technical operating instructions shall contain at least

- the required leak tightness for static containment features (primary and secondary containment barriers, isolation valves, hot cells, glove boxes, etc.);
- the ventilation regimes in normal, incident or accident situations, as well as the instrumentation and control associated with these different regimes;
- the negative pressure range during normal operations, incident and accident situations, for all the different types of rooms containing radioactive materials;
- the filtration efficiency required for the different types of filters, as well as clogging parameters;
- the nominal and minimal flow rates in the stack and in the main conducting ducts;
- the minimum air exchange rate in rooms in which the cleaning function is required according to the safety analysis.

9.3 Operational management issues

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

- surveillance and periodic checking of the parameters of the ventilation 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* (e.g. 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;
- 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 given in 9.4.1 to 9.4.4.

9.4.1 Pre-commissioning inspection

Before initiating 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.

The inspection shall also permit the verification that the equipment of the plant was not damaged during transport or installation.

According to the role of the ventilation network, the quality of ducts as built shall be checked before commissioning. In particular, the leak tightness of the extraction ducts under positive pressure (downstream fans) or the ducts upstream the first filtration stage shall be checked by using simple inspection methods (soap bubbles, tracer gases, etc.).

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 shall focus on the following equipment:

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

b) regulation and monitoring networks, traps and filtration systems;

c) fire dampers and fire detection systems;

d) 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 shall 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. Tests shall demonstrate that transitory phases (sequences with operations of redundant or stand-by systems) do not create air back-flow in the rooms or enclosures.

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 shall 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 negative pressures using appropriate regulation devices.

The verification of all of the ventilation systems is not undertaken until

a) the construction of the building is totally achieved and the required leak tightness is ensured;

b) all the doors are installed and closed;

c) the apparatus and process equipment are in operation;

d) the filtering devices are installed; and

e) 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 shall be verified, using appropriate standardized test methods suitable to the performance requirements.

According to the objectives defined in the safety analysis, it is useful to verify other parameters, such as the correct distribution of the air flows, lack of dead areas, air exchange 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 should 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:

— those associated with the start-up of the standby fan in the event of failure of the normal operating fan (where such a system is installed),

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

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

— interlocks related to preserving the pressure differences.

After appropriate tests, valves explicitly used during commissioning to ensure the correct design parameters for the ventilation systems should be locked in nominal position by appropriate devices.

9.4.4 Maintenance and other periodic tests

The following features shall be the subject of maintenance programmes:

a) structures, walls and various construction elements constituting of

   1) the primary and secondary containment walls (if any),

   2) the other containment barriers, including those of peripheral buildings,

   3) the fire and containment compartments;

b) equipment and devices contributing to fire detection and fire extinguishing;

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

The whole system shall be periodically inspected and tested in order to identify potential 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, taking into account the relevant safety regulations in force.

The maintenance schedule shall also address potential degradation of the system over prolonged usage, e.g. increase of bypass 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. In particular, weak points of the barriers (doors, airlocks, ground siphon, seals) shall be noted and submitted to special periodic maintenance in order to control an increase of the leaks of the static containment features that can be collected by ventilation systems. The type and periodicity of control shall be adapted to the importance for the confinement of potential leaks (an annual visual check as a minimum).

A recommended method for determining leakage rates of the primary containment envelope during normal operation is the absolute pressure method, in which the leakage flow is determined by measuring the pressure decrease as a function of time. For this method, the temperature and pressure of the containment atmosphere, the external atmospheric temperature and pressure, and the humidity of the containment atmosphere should be continuously measured and factored into the evaluation. Means shall be provided to ensure uniform humidity and temperature of the containment atmosphere during the test.

Leakage of fluids inside the containment from circuits such as compressed air, nitrogen or water circuits can cause pressure or temperature increases in the containment. To detect such leaks and also potential leaks from the containment, continuous monitoring of the leak tightness of the containment is necessary. Measurement of this leak tightness is ensured by the record of the loss of mass inside the containment, accounting for variations in other parameters, such as temperature, pressure and humidity. These measurements should be recorded to show trends.

The design of the reactor containment envelope shall provide the capability for periodic in-service testing of the leak rate to prove that the leak rate assumed in the safety analysis is maintained throughout the operating lifetime of the plant. The in-service leak rate tests shall be performed periodically at least every ten years, and may be made at either

— a pressure that permits a sufficiently accurate extrapolation of the measured leak rate to the leak rates at the accident pressures considered in the safety analysis; or

— a pressure that corresponds to the design pressure, including design margins due to thermal effects.

Testing with a reduced pressure with regard to full design pressure can be acceptable only if an extrapolation method of the leaks to the full design pressure is validated, in particular with regard to the seals, potential cracks or other weak points of the containment.

For new plants, the integrity and leak tightness of the containment should be ensured for all the accidental situations considered during the design stage.

Secondary containment walls, when present, shall be tested at least with the same periodicity as primary containment walls. Methods should consist in testing the leak tightness of the secondary containment walls at different pressure levels, including negative and positive values.

All the other parameters mentioned in the technical operating instructions shall be submitted to periodic tests. The periodicity of tests shall be in accordance with the importance for the safety of the equipment or the function ensured.

Nevertheless, an annual test, or when not possible, during outages, shall be performed for the parameters that can degrade during the normal operation (filter efficiency, etc.). Negative pressure in rooms shall be controlled more frequently due to the sensibility to external conditions.

Qualification tests after component maintenance, including filters, shall be carried out as soon as possible, with the components being considered as unavailable until the acceptance of the tests results.

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. The operatrion of ventilation systems is verified using devices located in the permanently accessible areas and by means of calibrated remote-sensing equipment. The results of such monitoring can 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) shall be formally recorded in the central control system, where information on the configuration of the equipment shall 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 the ventilation system 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 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 the propagation of the fire and limit the spread of any radioactive contamination, or if dynamic confinement should 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 boundary of the fire compartment or area, in particular its leak tightness related to the pressure excursion induced by the fire,

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

— 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

9.6.2.1 Fire control analysis

The option of favouring an immediate automatic closure of all the ventilation ducts of the room or cell when a fire occurs within it can have an effect opposite to the desired isolation, as increasing the internal pressure is liable to spread the contamination, as well as accumulation of smoke, to surrounding rooms.

Accordingly, the method of operating the ventilation systems in case of fire shall be analysed in the early stages of the design procedure. This analysis can, in particular, take into account the type, the mass, the physical and chemical properties of the combustible, the fire loads, the quantity of oxygen available for the determination of the fire behaviour of the materials involved 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 shall be emphasised that the fire situation control strategy depends strongly on the particular design philosophy adopted, and in this International Standard it is possible only to indicate general areas of interpretation. It should also be noted that one of the prime objectives should be the protection of the 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 that continue to operate, in general, help to promote personnel safety since clean air is drawn into the contaminated areas from the corridors and specific work places, by setting up a pressure hierarchy, and thereby keeping them free of smoke due to the higher pressure levels in these areas.

For areas that have only a small 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 or area. If appropriate, the heat and smoke should be extracted to prevent neighbouring areas from being endangered and to allow manual fire fighters safe access. The response of the ventilation system and associated fire dampers should be under the supervisory control of building management from a protected area.

For areas that have a large inventory of dispersible radiotoxic material, or for a multi-compartment building where the spread of radioactive or the propagation of smoke, notably through the ducting, can be a problem, then confinement shall be the prime consideration. Then, it shall be assessed whether automatic or manual tripping of the inlet and extract fire dampers shall be considered with regard to radiological consequences.

The global fire strategy shall take into account the safety rules applied according to IAEA principles. According to the principles, some safety rules should be carefully assessed for research reactors, in particular the applicability of single failure criterion.

9.6.2.2 Application of the analysis

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

a) closing the fire damper in the admission duct on a fire signal (e.g. smoke detectors) or temperature signals (e.g. sensor or fusible), or contamination thresholds in the stack;

b) 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 can require cooling the combustion products, dilution, water-spray devices or high-temperature HEPA filters but preference should be given to passive protection component such as high-temperature HEPA filters;

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

Automatic control with manual backup of these actions is recommended. It is generally recommended that the air-admission fire damper be closed as quickly as possible. This equipment is, therefore, in general, 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 from the last extraction HEPA filter,

— of a smoke detector downstream from 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 or downstream of the last extraction HEPA filter.

In addition, a complete halt of the extraction network can be considered in the event of the three previous alarm signals, as well as the maximum pressure clogging limit of the last extraction HEPA filter.

It shall be noted that the special extraction duct design, often adopted in nuclear facilities to assist the removal of radioactive dust from the room and comprised of extraction vents in the lowest part of the rooms, shall be evaluated carefully, taking into account contradictory aspects such as

— stratification and potential degradation of ceiling by the heat, which can necessitate extraction at ceiling level, and

— potential degradation of the ducts and filters due to the heat and smoke produced during the fire, which can necessitate extraction at ground level.

The fire dampers should be equipped with manual opening and closing facilities which can be reached in a wide range of predictable situations, notably during the fire fighting. The re-opening after an incident should 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 are determined by the architecture of the ventilation systems and it shall function during the normal conditions and foreseeable plant fault conditions. Co-ordination of the control system operation is essential: several control panels shall be implemented and located at points where effective action can be taken, whether routinely carrying out tests of the plant or acting in an incident situation. The location of these control panels shall take into account common cause failures of control systems (notably in the case of fire, earthquake, flooding, site contamination).

Critical ventilation systems should be designed to continue in operation in the event of partial control system failure, i.e. by careful design of control logic in order to recognize cable disruption; therefore, maintained contacts or DC voltages should be preferred to pulsed outputs, which require a specific system to control the lines and the signals.

In the event of an accident, access to parts of the building can be restricted and considerations should be given to the requirement 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 can influence the choice of signal transmitters.

Automatic start-up of the standby fans shall be considered, to cover a 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 a loss of flow. If there is a requirement to rapidly start an emergency standby component, the system shall have a representative measurement, e.g. fan rotation detection (not motor current or contactor status). A well-defined sequence, which forms part of the control system, shall be developed for starting and stopping the fans. Redundancy and diversity of the control and instrumentation components shall be considered and, when necessary, the ventilation systems shall be protected from a 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 and which 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 being regularly tested and reset from a suitable control point (preferably associated with the main ventilation control unit) and their status should be indicated. As these dampers, when closed, cause loss of flow signals, it can be necessary to incorporate their status into any changeover system for fans, etc. The absence of meaningful flow signals when dampers are closed can 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 shall be stressed. The design shall also allow periodic testing of standby components, to demonstrate their state of readiness. Periodic testing of the operational components simulating abnormal conditions can also be required to demonstrate the necessary reliability. If this is the case, the design shall make provision for such testing and the reasons, method, etc., shall be recorded in the operating procedure.

10.2 Instrumentation

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

— duct flow measurements;

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

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

- nozzles at adequate locations for allowing the correct measurement of the filter efficiency as specified for the system; this is of considerable importance, since the safety justification for the operation of the facility is 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 requirements of the safety regulatory body. Techniques required for the sampling, monitoring and achievement of these measurements are described in ISO 2889.

In the design of ventilation systems for highly contaminated areas, direct evidence shall 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.

Redundancy of instrumentation devices depends on the safety classification adopted for the ventilation systems. Nevertheless, primary and secondary containment systems, safety classified thermal conditioning ventilation systems, as well as release monitoring systems, shall be redundant, backed up by a permanent electrical supply and, on a case-by-case analysis, have a seismic classification.

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;
- filter (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;
- air activity concentration in stacks;
- air activity concentration in specific ducts (e.g. servicing highly contaminated rooms, requiring actions on the ventilation systems).

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

Annex A
(informative)

Typical radioactive products in nuclear reactors

The present annex gives typical radioactive products in research and power reactors. Associated quantities are given in IAEA technical reports series No. 274 and No. 358 (see References [17] and [18]).

A.1 Identification of radioactive product sources

The radioactive product sources are usually the following:

a) fission products of the reactor core in normal and degraded situations;

b) corrosion and activation products in the coolant system;

c) spent fuel and core components;

d) fission products and activation and corrosion products in the pools;

e) activated sources contained in different equipment, systems and pipes;

f) solid and liquid waste and waste treatment materials;

g) gaseous radioactive materials in off-gas treatment systems;

h) tools and facilities for storage and handling of radioactive material.

In addition, for research reactors, other sources can include

— experimental facilities with the potential to generate activated or other radioactive products;

— associated hot cells.

Table A.1 gives examples of emissions of fission products with their main associated safety considerations.

Table A.1 — Main fissions products emissions and associated safety considerations

Nuclide type	Typical nuclides	Half life	Safety considerations
Noble gases	^{85}Kr	10,8 y	Cannot be filtered or delayed
	^{133}Xe/^{133m}Xe	5,3 d/2,3 d	Can be delayed in retention beds or tanks Indicators of fuel degradation
	^{85m}Kr, ^{87}Kr, ^{88}Kr	< 5 h	
	^{135}Xe, ^{138}Xe	< 10 h	
Iodine forms	^{131}I	8,1 d	Important contributors (except ^{129}I) to exposure of the public in accident situations Indicators of fuel degradation Very low inventory of ^{129}I but very long half life
	^{132}I, ^{133}I, ^{134}I, ^{135}I	< 21 h	
	^{129}I	>> 10^6 y	
Aerosols	^{134}Cs	2,1 y	
	^{137}Cs	29,4 y	
	^{138}Cs	32 min	Indicator of fuel degradation
	$^{106}Ru/Rh$	1 y	Important for severe accidents because it can be converted into gaseous form under specific conditions
	^{90}Sr	50,5 d	Important for specific severe accident conditions

A.2 Nuclides in nuclear reactors

Table A.2 gives examples of activation and corrosion products with their main associated safety considerations.

Table A.2 — Corrosion and activation product emissions and associated safety considerations

Nuclide type	Typical nuclides	Half life	Safety considerations
Main aerosol formed from activation of structures and fuel	^{58}Co	71,3 d	Important contributors to exposure of the workers
	^{60}Co	5,27 y	
	^{51}Cr, ^{54}Mn, ^{59}Fe, ^{110m}Ag	1 min << 1 y	
Main gases formed from activation of air, coolant system, structures and fuel	^{41}Ar	1,8 h	Can be delayed
	^{3}H	12,3 y	Released with or without purification during normal operations; can be produced in large quantities in heavy-water reactors
	^{13}N, ^{16}N	< 10 min	Can be an indicator of steam-generator tube rupture
	^{14}C	5 730 y	Contributor to exposure of the public during normal situations

In addition, alpha-emitter aerosols such as uranium, plutonium, curium and other actinides can be released during core degradations. They can be important contributors to exposure of workers.

The nuclides included in Tables A.1 and A.2 are formed and released under different chemical forms that shall be taken into account when designing purification systems as well as evaluating the exposure effects to workers and the public.

EXAMPLES

— iodine in different forms, such as molecular iodine (I_2), organic iodine (CH_3I, CH_5I_2), aerosols (CsI, AgI),

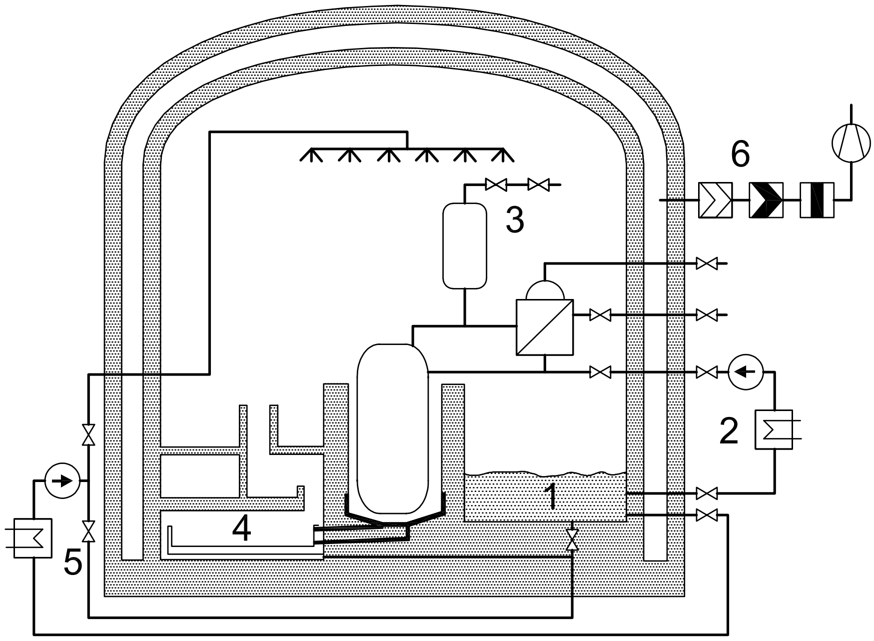
— carbon in gaseous forms (CO_2, CH_4) or aerosols.

In order to design containment and ventilation systems, the identification and the evaluation of potential releases in rooms and in the environment shall be performed for normal and accident situations, including for new plants severe accidents, incorporated in the design of the plant. Corresponding IAEA technical reports series give indications on the methodology for evaluating these source terms.

Annex B
(informative)

Examples of general confinement concepts for nuclear power reactors

The object of all the following diagrams is to present in more detail the general confinement concepts of reactors, and they include the systems needed for confining radioactive materials (e.g. ventilation systems) and those used to protect the containment barriers against the risk of overpressure (e.g. spray systems).



Key

1 ECCS water storage

2 ECCS

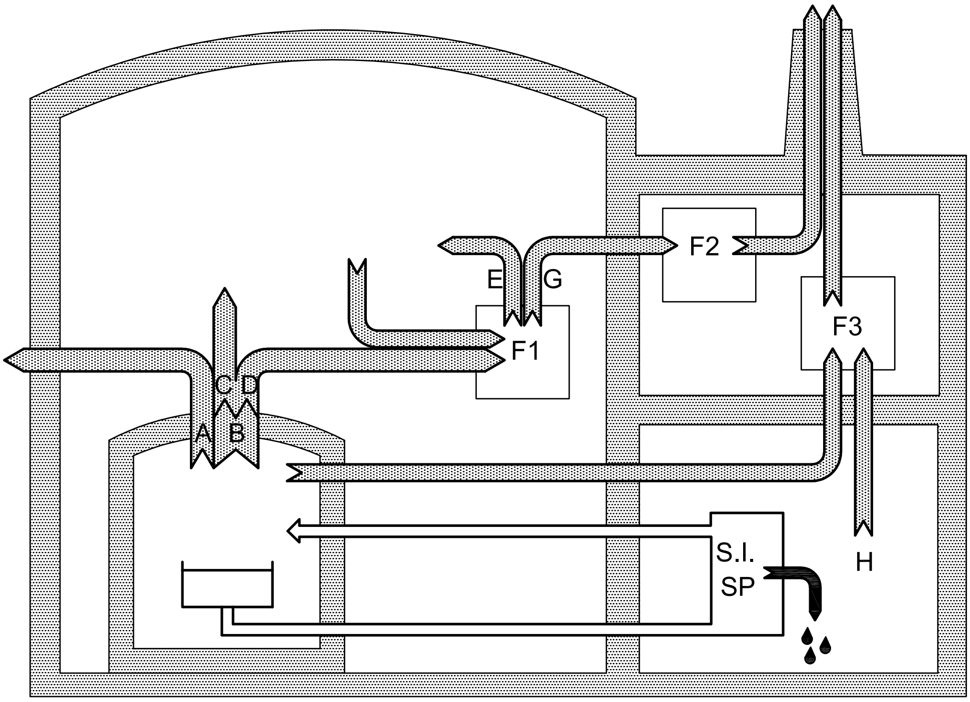
3 primary depressurization device

4 core catcher

5 containment heat removal system

6 annulus filtered air extraction system

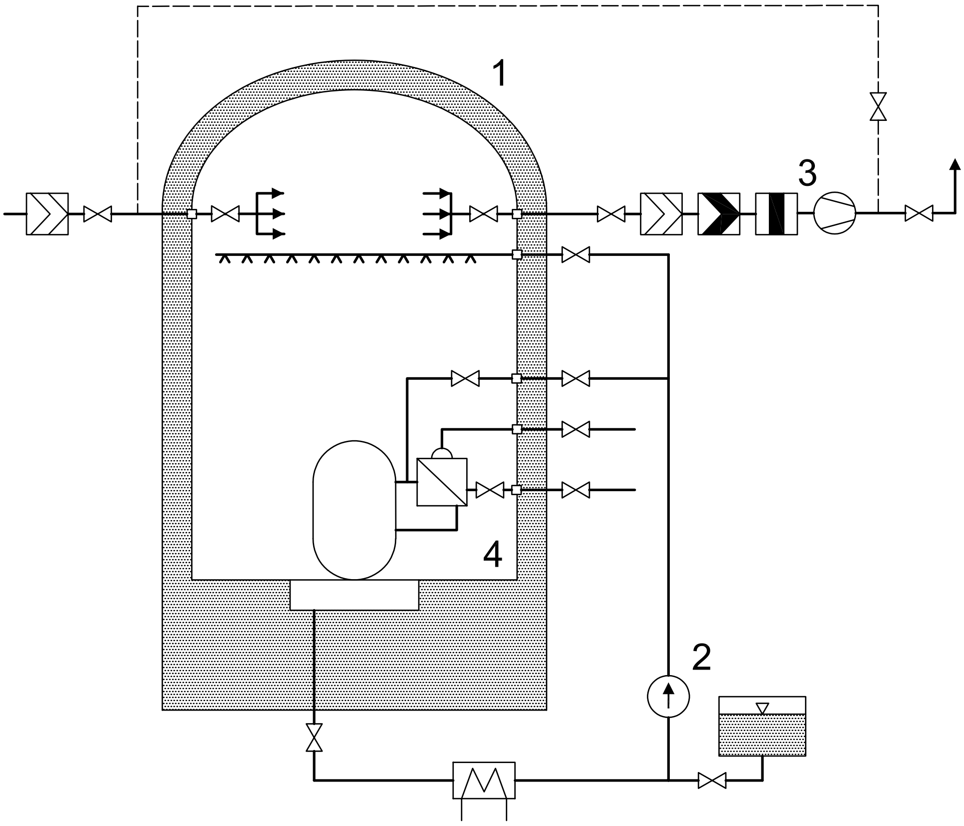
Figure B.1 — Dual containment NPP with a severe accident design



Key

A direct gaseous leak to the environment
B total gaseous leak to the annular space
C gaseous leak to the annular space filtration system
F1 annular space filtration system
E recirculation flow
G flow to the stack filtration system
F2 stack filtration system
H liquid leak to the auxiliary building
F3 filtration system of the auxiliary building
SI safety injection system
SP spray system

Figure B.2 — Dual NPP containment without severe accident designs



Key

1 containment
2 containment spray system
3 filtered air discharge system
4 liner

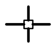
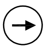
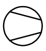
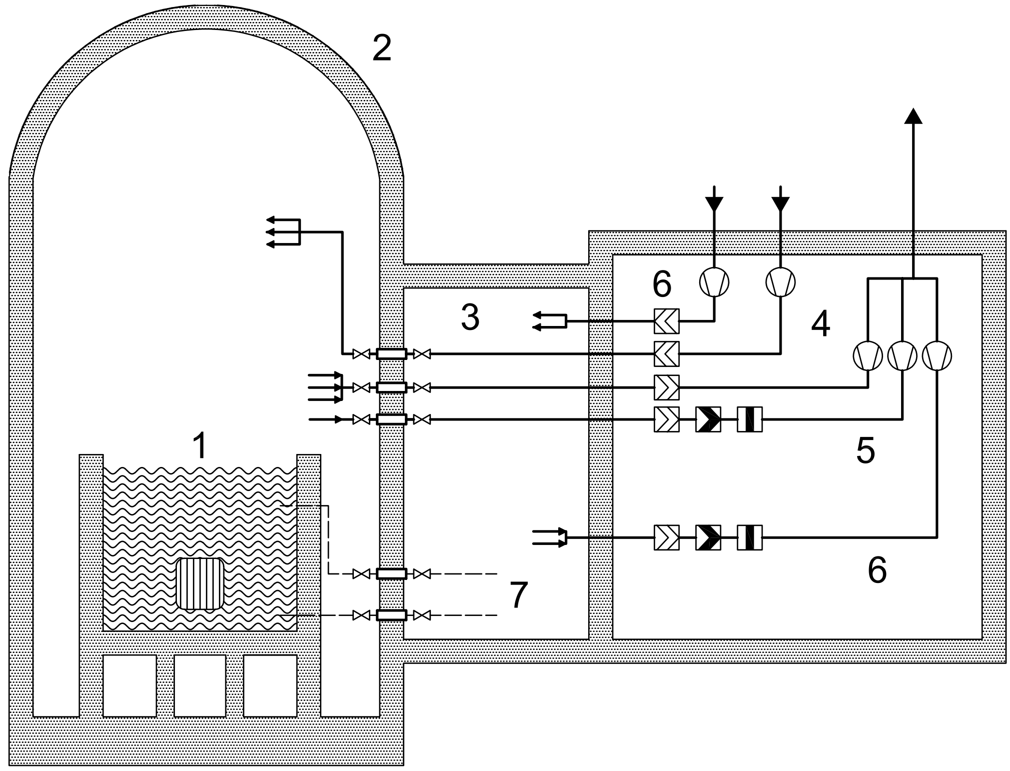
	valve		containment penetration
	dust filter		heat exchanger
	HEPA filter		steam generator
	pump		line with spray nozzles
	blower, fan		liquid level
	iodine trap		

Figure B.3 — Single containment NPP



Key

1 pool of the reactor
2 primary containment envelope
3 partial secondary containment envelope
4 ventilation of the primary containment envelope
5 accidental overpressure discharge system
6 ventilation of the secondary containment envelope
7 core cooling system

valve

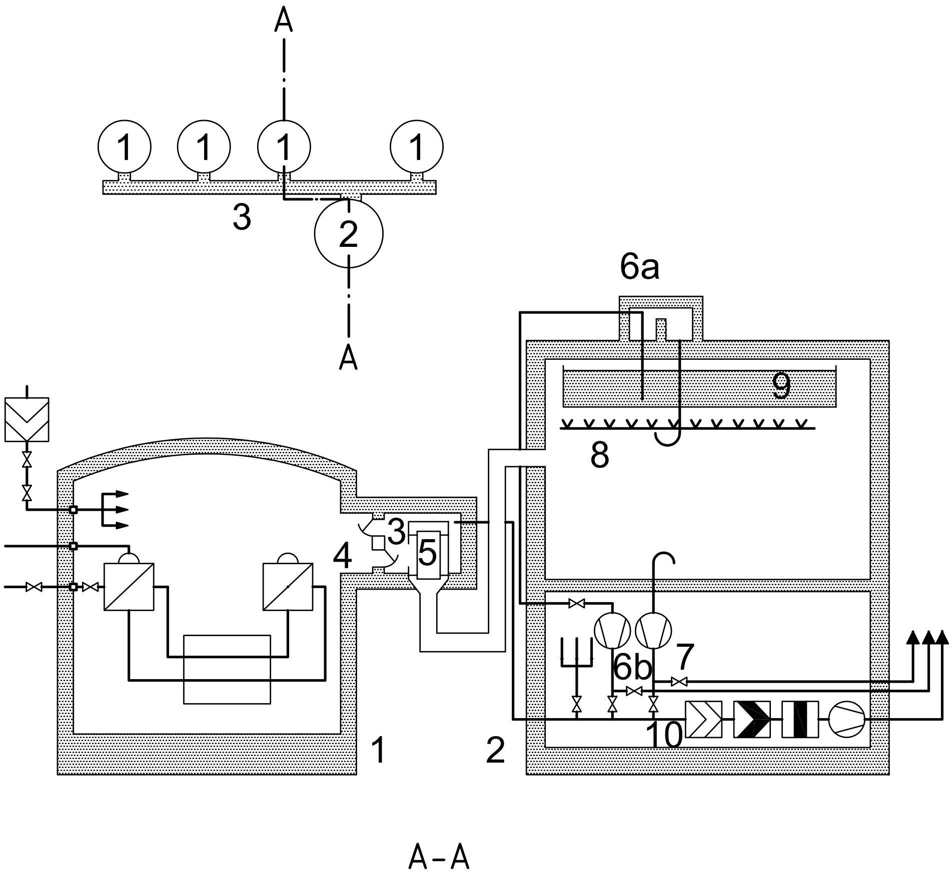
dust filter

HEPA filter

iodine trap

blower, fan

Figure B.4 — Dual containment pool research reactor



Key

1 reactor buildings
2 vacuum building
3 pressure relief duct
4 blow-out and blow-in panels
5 pressure relief valve
6a upper chamber
6b evacuation system
7 vacuum building evacuation system
8 vacuum building spray system
9 dousing tank
10 filtered air discharge system

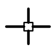
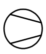
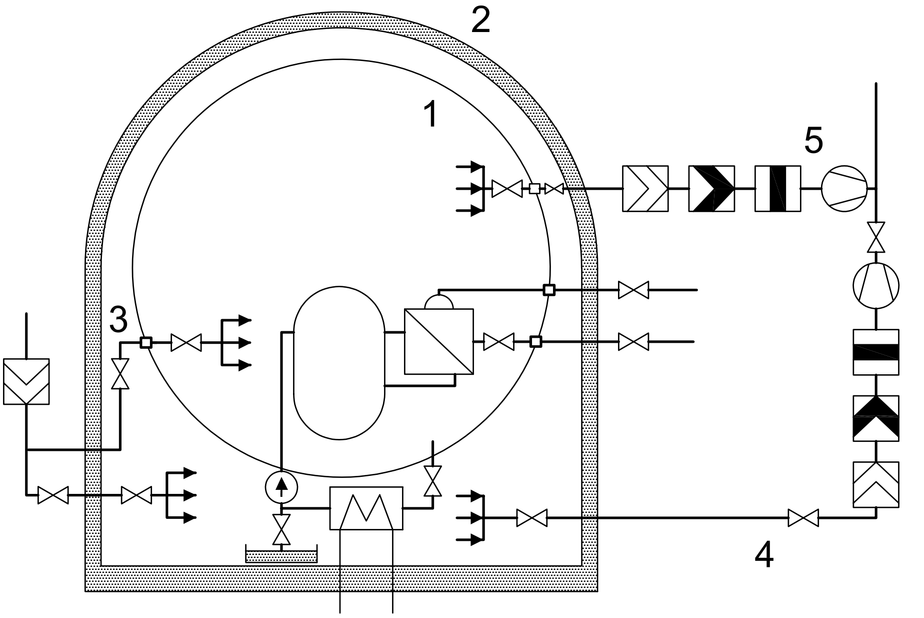
	valve		containment penetration
	dust filter		iodine trap
	HEPA filter		steam generator
	blower, fan		line with spray nozzles

Figure B.5 — Pressurized heavy-water NPP with additional confinement



Key

1 full-pressure containment

2 secondary confinement

3 annulus

4 annulus evacuation system

5 filtered air discharge system

	valve		containment penetration
	dust filter		heat exchanger
	HEPA filter		steam generator
	pump		iodine trap
	blower, fan		

Figure B.6 — Double containment NPP design with safeguard components within secondary confinement

Annex C
(informative)

Examples of safety classification for nuclear power reactors

Many safety classification systems for pressure-retaining mechanical equipment use three safety classes and one non-nuclear safety class. The highest safety class (safety class 1) is generally restricted to the reactor coolant pressure circuits. The part of the containment, including penetrations and isolation valves, as well as pressure-retaining portions of front line systems used for management of energy levels and radionuclide concentrations in the primary containment during a DBA, is generally assigned to safety class 2.

Pressure retaining portions of systems for the management of energy levels and radionuclide concentrations in the secondary containment during a DBA, of systems for control of combustible gases during a DBA, and of the cooling chain are often assigned to safety class 3.

Many safety classification systems are also devoted to the structural parts of the components according to their seismic resistance. Insofar as they are relied upon in DBAs, the containment systems are safety systems and should be classified seismic class 1, the highest level of seismic classification.

Electrical equipment of containment systems, including those for emergency power supply, shall be assigned to electrical class 1E, the highest level for electrical safety classification.

The importance to safety of all SSCs shall be established and a safety classification system as defined in the safety requirements for the design should be set up in order to identify for each safety class

— the appropriate codes and standards, and hence the appropriate provisions to apply in design, manufacturing, construction and inspection of a component;

— system-related characteristics such as degree of redundancy, the requirement for an emergency power supply and for qualification to environmental conditions;

— the availability or unavailability status of systems for postulated initiating events (PIEs) for consideration in deterministic safety analysis;

— quality assurance provisions.

In general, the following classifications shall be established and shall be verified for adequacy and consistency:

— classification of systems on the basis of the importance of the affected safety function;

— classification for pressure components, on the basis of the severity of the consequences of their failure, the mechanical complexity and the pressure rating;

— classification for resistance to earthquakes, on the basis of the requirement for the structure or component considered to retain its integrity and to perform its function during and after an earthquake, taking into account aftershocks and consequent incremental damage;

— classification of electrical, instrumentation and control systems on the basis of their safety or safety support functions, which may be different from the classification of other plant systems due to the existence of field-specific, widely used classification schemes;

— classification for quality assurance provisions.

The assignment of SSCs to safety classes shall be based on national approaches and appropriately credit deterministic and probabilistic considerations as well as engineering judgement.

For the purposes of the deterministic safety analysis, those safety functions that are used to determine compliance with acceptance criteria shall be performed using classified SSCs only.

Probabilistic safety analysis (PSA) shall be used to determine in the design phase the appropriate classification of structures, systems and components.

The failure of a system/component in one safety class shall not cause the failure of other systems/components of a higher safety class. The adequacy of the isolation and separation of different and potentially interacting systems assigned to different safety classes shall be assessed.

Annex D
(informative)

Examples of classification of working areas according to radiological contamination hazard

D.1 Containment area classification according to the level of surface contamination

Table D.1 gives an example of the classification of containment areas according to the expected permanent non-fixed surface contamination levels.

Surface contamination levels are expressed in becquerels per square centimetre.

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

Values in becquerels per square centimetre

Containment class	Surface contamination	
C1	Determined locally at each site, in agreement with the regulatory body According to ALARA[8)] principle, but not exceeding C2 levels	
	Alpha emitters of other toxicity[a]	**Beta/gamma emitters and alpha emitters of low toxicity[b]**
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
C5S or C5D[c]	Contamination level < 0,4	Contamination level < 4

[a] The definition of radiotoxicity corresponds to that given in the IAEA Safety Standard Series TS-R-1 (ST-1, revised) (see Reference [14]).

[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.

[c] For accessible areas.

8) ALARA, As Low As Reasonably Achievable.

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

Table D.2 gives an example of the classification of containment areas according to the expected permanent airborne contamination levels.

Airborne contamination levels are expressed in fractions of the DAC[9].

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

Values in per cent of DAC over a working year period

Containment class	Airborne contamination in normal conditions
C1	According to ALARA principle and in any case < 10 %
C2	10 % < contamination level < 30 %
C3	30 % < contamination level < 100 %
C4	Contamination level > 100 %
C5S or C5D[a]	10 % < contamination level < 30 %

[a] For accessible areas.

For the containment area classification, the table leading to the most stringent class shall be used. The limit values stated in these tables may be adapted to acknowledge the chemical toxicity of the radionuclides.

9) DAC: derived air concentration. It is the amount of contamination in air, which, if breathed for 2 000 hours, would result in the annual limit of intake (ALI). The ALI shall be calculated using reference conversion factors given by ICRP for each radionuclide.

Annex E
(informative)

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

E.1 Classification of types of ventilation

Table E.1 gives an example of the classification of types of ventilation, according to the level of expected and potential airborne contamination as compared with the DAC defined in Annex D.

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

Values in DAC

Type of ventilation	Expected normal permanent contamination Pc	Potential accidental contamination Ac	Containment area classification
I	0	⩽ 1	C1
II A	⩽ 1	⩽ 80	C2
II B	⩽ 1	⩽ 4 000	C3
III A	⩽ 80	⩽ 4 000	C4*
III B	⩽ 4 000	⩾ 4 000	C4**
IV	> 4 000	>> 4 000	C4***
—	⩽ 1	>> 4 000	C5D
—	⩽ 1	>> 4 000	C5S
C5S: Containment area classification with static containment C5D: Containment area classification with dynamic containment			
NOTE 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 D.2.			

Care should then be taken when any subsequent modifications of the plant in those rooms are proposed.

E.2 Minimum recommendations for ventilation configurations

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

The following scenarios are based on aerosol dissemination analysis and consequently show HEPA filters, according to the permanent and accident situations contamination levels. The requirement for additional iodine filters shall be assessed according to the same methodology with regard to iodine risks as for HEPA filters. For control rooms, iodine filters shall be added at the air inlet in order to protect the workers in the event of large accident releases, in particular for NPPs. A transfer from a contaminated area to any area with lower contaminated is not allowed.

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

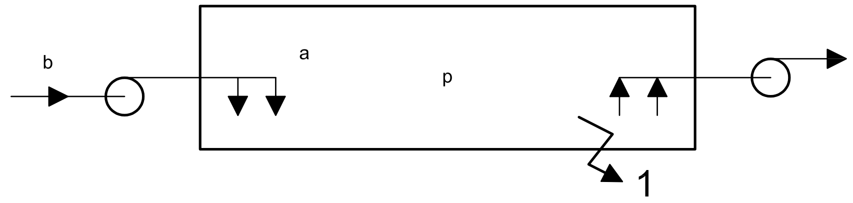
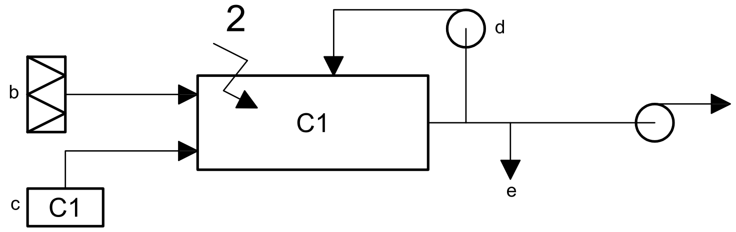
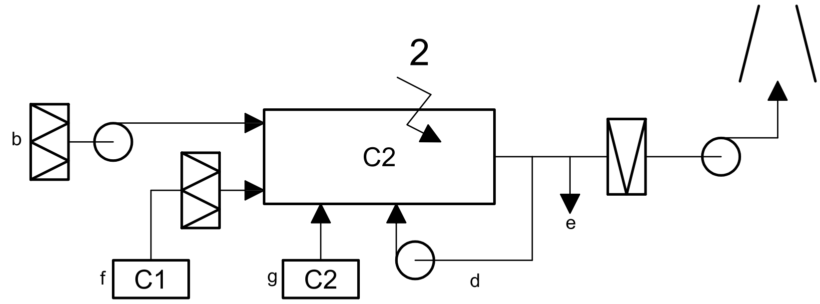
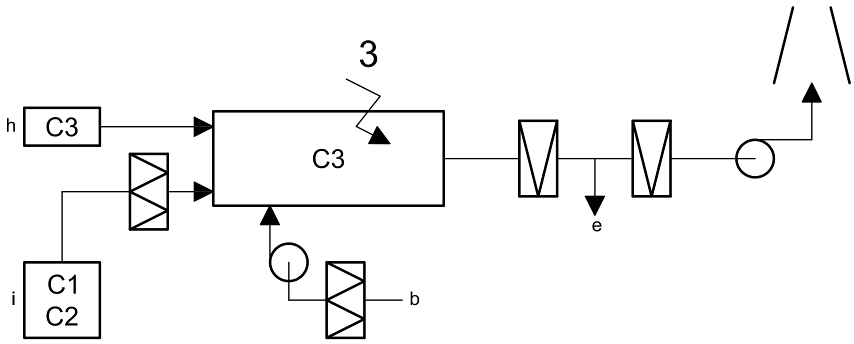
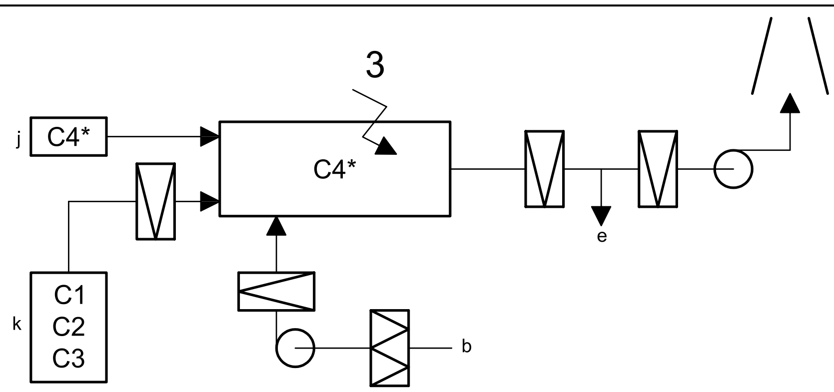
Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Non-contaminated areas			
I	Pc: Not significant Ac: Low		
II A	Pc: Not significant Ac: Medium		
II B	Pc: Not significant Ac: High		
III A	Pc: Medium Ac: High		

Table E.2 (*continued*)

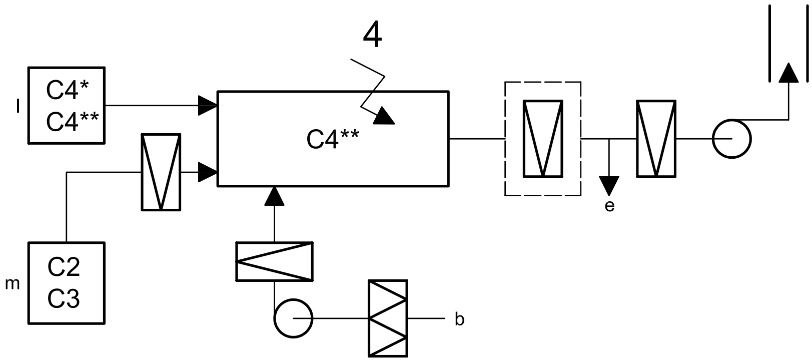
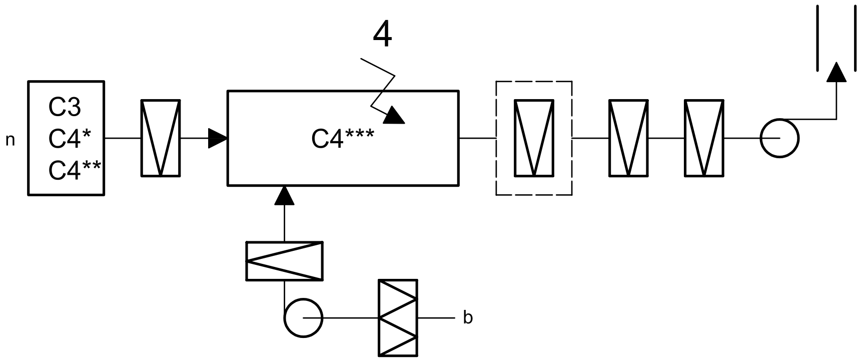
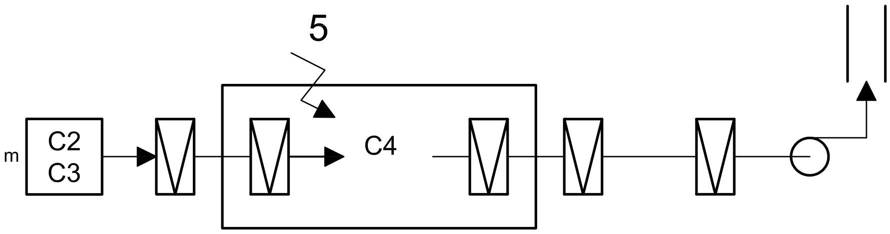
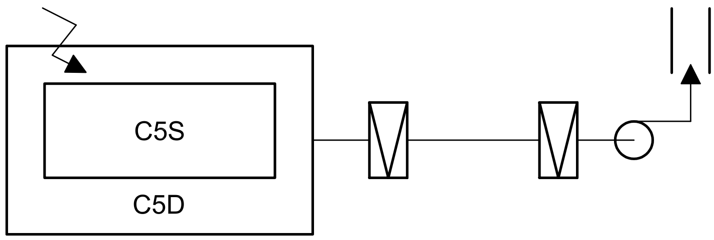
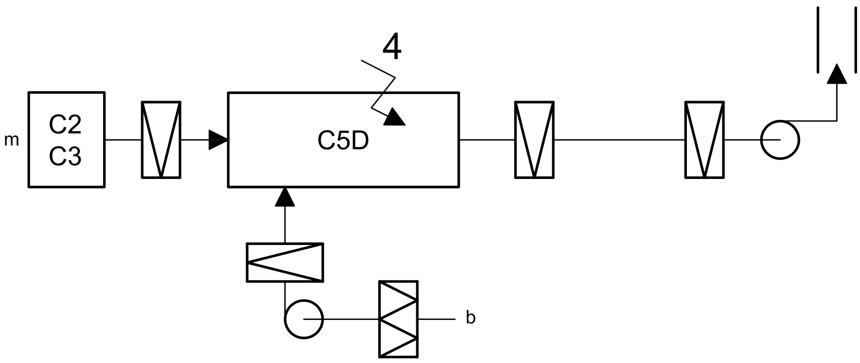
Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
III B	Pc: High Ac: Very high		
IV	Pc: Very high Ac: Very high		
C4 containment enclosures or glove boxes (See NOTE 4)			
Static containment of the primary containment envelope, surrounded by a secondary containment envelope with dynamic confinement at power operation Pc: Low Ac: Very high			
Dynamic confinement of the primary containment envelope at power operation Pc: Low Ac: Very high			

Table E.2 (*continued*)

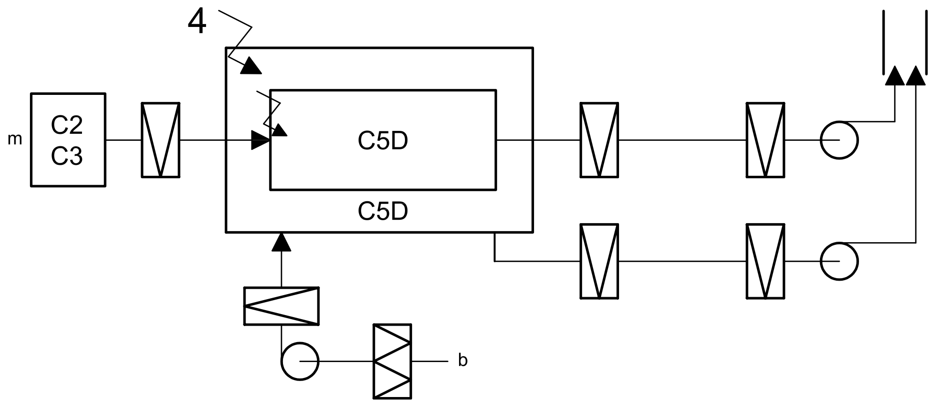
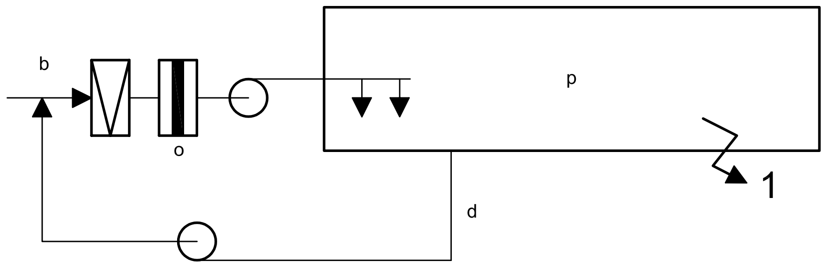
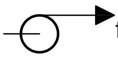
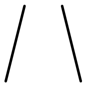
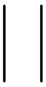
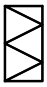
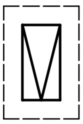
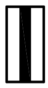
Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Static containment of the primary containment envelope, surrounded by a secondary containment envelope with dynamic confinement at power operation Pc: Low Ac: Very high			
Control rooms			
NOTE 1 The designer shall ensure that the automatic response of the system precludes the possibility of back-flows from areas with high contamination to areas with low contamination, or else appropriate filtration should be incorporated into the paths to mitigate this effect. This also includes possible back-flow to the external environment through failed inlet fans. NOTE 2 The use of coarse filters is optional. They are recommended to increase the lifetime of HEPA filters by reducing the ordinary atmospheric dust burden. NOTE 3 If it is necessary to trap gases (iodine, tritium, etc.), additional gas absorbers, iodine traps or detritiation devices shall be installed, complementing the HEPA filters. NOTE 4 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. This present table corresponds to an example of a glove box whose associated requirements are between a C4** and a C4*** area. NOTE 5 For some reactor designs, the same containment building could be classified C5S or C5D, according to the operational states (power operation, shutdown states) and accident situations. NOTE 6 Ventilation networks which need to be isolated during some operational situations are not represented in these schemes.			

Table E.2 (*continued*)

Type of ventilation	Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit

Key

1 cascade of higher pressures to non-contaminated areas
2 cascade of lower pressures from non-contaminated areas
3 cascade of lower pressures from non-contaminated or low-contaminated areas
4 cascade of lower pressures from low- or medium-contaminated areas
5 cascade of lower pressures to operating areas
Pc permanent contamination
Ac accidental contamination

 leakage
 fan
 main stack
 collector to main stack
 coarse or fin filter
 high-efficiency filter
 high-efficiency filter with shielding
 charcoal impregnated filter for trapping iodine and other gases

[a] Positive pressure in operating areas.
[b] Direct admission from outside of the building.
[c] Transfer from a C1 operating area, without filtration.
[d] Recycling.
[e] Potential transfer to an area with the same or higher classification through an independent ventilation system.
[f] Transfer from a C1 operating area, through an industrial grade filter.
[g] Transfer from a C2 operating area, without filtration.
[h] Transfer from a C3 operating area, without filtration.
[i] Transfer from a C1 or C2 operating area, through an industrial grade filter.
[j] Transfer from a C4* operating area, without filtration.
[k] Transfer from a C1, C2 or C3 operating area, through a HEPA filter.
[l] Transfer from a C4* or C4** operating area, without filtration.
[m] Transfer from a C2 or C3 operating area, through a HEPA filter.
[n] Transfer from a C3, C4* or C4** operating area, through a HEPA filter.
[o] The iodine filters can be by passed during normal operations.
[p] Overpressure.

Annex F
(informative)

Existing requirements for aerosol filters

F.1 General

Air filters for general air cleaning include particulate filters and vapour filters. Particulate filters include coarse, fine, HEPA (High-Efficiency Particulate Air filters) and ULPA (Ultra-Low Penetration Particulate Air filters) 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 are 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 to F9) and HEPA filters (H11 to H14) (see F.3 to F.6).

EXAMPLES

— Sodium fluorescein (particles of 0,15 µm):	NF X 44-011
— Monodispersed DOP (dioctylphtalate) of 0,3 µm:	US MIL STD 282
— NaCl (sodium chloride) of 0,35 µm:	EUROVENT 4/4
— Paraffin oil:	DIN 24184
— Particle scanning method:	EN 1822- 2 and EN 1822-4

The testing methods for the 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 F.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 a determination of the “local” efficiency.

F.2 New standards

The requirements of a new European test standard (EN 1822) 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 is felt that the potential for improved performance using ULPA filters can 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 a requirement established

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

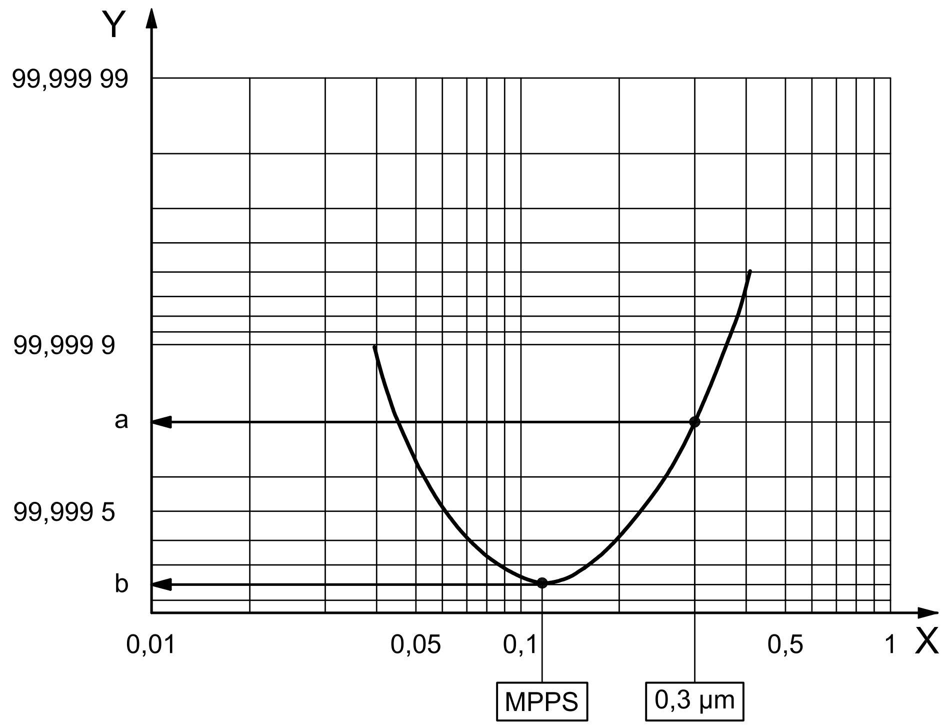
b) for a test method capable of covering the entire efficiency range, from 85 % to 99,999 995 %, or a decontamination factor (DF) from 1 to 10^7;

c) to test at the MPPS;

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

X particle diameter, expressed in micrometres

Y efficiency, expressed in per cent

1 efficiency DOP

2 efficiency MPPS

Figure F.1 — MPPS for typical HEPA filters

F.3 Groups and classes of air filters

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

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

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

F.4 Definitions

F.4.1 Efficiency, E, of a particulate air filter

The efficiency, E , expressed in per cent, of a filter is defined as the ratio of the particle concentration arrested by the filter to the particle concentration fed to the filter. It is calculated as given in Equation (F.1):

$$E = \left(\frac{N - n}{N} \right) \times 100 \tag{F.1}$$

where

N is the number of particles upstream from 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.

F.4.2 Average arrestance, A_m

Average arrestance, A_m, expressed in per cent, is the ratio of the mass of synthetic dust arrested by the filter to the mass of the dust fed to the filter.

F.4.3 Penetration, P

The penetration, P, expressed in per cent, is the ratio of the particle concentration downstream to that upstream from the filter.

F.4.4 Decontamination factor, DF

Decontamination factor is a term used by some sectors of industry (especially in the nuclear field) to describe the efficiency of a filter. Normally, it is expressed as a whole number (DF = 100/P).

F.5 Requirements of EN 779

The following criteria are used to classify classes G and F filters according to EN 779 (see Reference [6]).

— The air flow is 0,944 $m^3.s^{-1}$ (3 400 $m^3.h^{-1}$) if the manufacturer does not specify any rated air flow rate.

— The maximum final pressure drop for coarse (G) filters is 250 Pa.

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

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

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

Table F.2 — Classification according to EN 779:2002

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**[33]
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 (see References [24], [25] and [26]) . The dust is not representative of the real world, but has been used for over 20 years to “simulate” filter loading. The use of this dust shall be continued 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:

— significant experience has already been gained by users of EUROVENT 4/5 techniques (see Reference [33]) so that a lot of 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 have a Boltzman distribution that is representative of the contaminated atmosphere of the work spaces.

F.6 EN 1822 and EUROVENT requirements for efficient, HEPA and ULPA filter standards

Table F.3 gives the classification of efficient, HEPA and ULPA filters proposed by EN 1822:2009 (see References [7] and [8]), while Table F.4 gives that of EUROVENT 4/4 (NaCl method) (see Reference [32]).

Table F.3 — Classification according to EN 1822:2009

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
Efficient (E)	E10	85	15	6,7	—	—	—
	E11	95	5	20	—	—	—
	E12	99,5	0,5	200	—	—	—
HEPA (H)	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	99,999 5	0,000 5	200 000	99,997 5	0,002 5	40 000
	U16	99,999 95	0,000 05	2 000 000	99,999 75	0,000 25	400 000
	U17	99,999 995	0,000 005	20 000 000	99,999 9	0,000 1	1 000 000

(shaded) Domain of nuclear industry

Table F.4 — Classification according to EUROVENT 4/4:1976

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

Annex G
(informative)

Examples of loads to consider during the design of NPP ventilation systems

Table G.1 gives examples of loads that can be considered during the design of NPP ventilation systems.

Table G.1 — Typical loads for NPP ventilation systems

	Load	Comments
Normal or service loads	Test pressure or temperature	—
	Safety relief valve actuation or lift	Only BWR
	Operating pressure and temperature	Normal operations include transient and shutdown stages
	Pipe reactions	Pipe reaction during normal operations, including transient conditions and shutdown
	Frequent and strong winds	Maximum wind assumed to occur during plant life
	External pressure	Resulting from pressure variations both inside and outside the enclosures
Extreme environmental loads	Extreme wind	Loads generated by extreme wind, i.e. maximum wind that can occur at the site
	Design basis earthquake	—
	Extreme wind associated loads and tornados	Associated effects are considered
Abnormal loads	DBA pressure and temperature	Calculated accident peak pressure and temperature
	DBA pipe reactions	—
	Internal fire	—
	Local effects consequential to DBA	—
	Depressurization system actuation	Depressurization of the primary circuit, if present
	Internal flooding	—
	Severe accident pressure	—
	Severe accident temperature	—
	Severe accident pipe reactions	—
	Local effects consequential to severe accidents	—
	Aircraft crash	—
	External explosions	—

Annex H
(informative)

Typical values of leaktightness for containment and ventilation systems and periodicities of associated controls

H.1 Typical values of specific leak rate associated with service penetrations in the primary containment

a) Electrical penetrations

— less than 1 % of the global primary containment leak, periodicity every 10 years.

b) Air locks

— for each door: less than 1 % of the global primary containment leak, periodicity every 10 years;

— for seals: < 0,04 Ncm^3/s/linear metre;

— isolation valves: < 600 cm^3/h/mm diameter.

c) Mechanical penetrations

— global amount of penetration < 50 % of global primary containment leak, periodicity every 10 years;

— isolation valves < 600 cm^3/h/mm diameter or < 0,1 m^3/h/m^2 under 2 000 Pa;

— external leaks: 0,01 Nm^3/h/m^2 under 2 000 Pa.

d) Containment hatch

— less than 1 % of the global primary containment leak, periodicity every 10 years.

e) Fuel transfer tube

— less than 1 % of the global primary containment leak, periodicity every 10 years.

H.2 Typical values of specific leak rate associated with ventilation components

H.2.1 Valves and dampers

Table H.1 provides typical values of leak rates associated with main ventilation components.

Table H.1 — Typical values of leak rates associated with containment and ventilation components

Equipment	**Internal leaks** (upstream/downstream)	**External leaks** (towards the exterior of the equipment)
Isolation dampers or backdraft dampers with reinforced leak tightness	0,1 $Nm^3/h/m^2$ flow section under a pressure drop of 2 000 Pa	0,01 $Nm^3/h/m^2$ external reference surface under a pressure drop of 2 000 Pa
Isolation dampers with normal tightness	10 $Nm^3/h/m^2$ flow section under a pressure drop of 2 000 Pa	1,5 $Nm^3/h/m^2$ external reference surface under a pressure drop of 2 000 Pa
Isolation dampers without required leak tightness	160 $Nm^3/h/m^2$ flow section under a pressure drop of 2 000 Pa	15 $Nm^3/h/m^2$ external reference surface under a pressure drop of 2 000 Pa
Backdraft dampers with normal leak tightness	200 $Nm^3/h/m^2$ flow section under a pressure drop of 2 000 Pa	1,5 $Nm^3/h/m^2$ external reference surface under a pressure drop of 2 000 Pa
Backdraft dampers without required leak tightness	200 $Nm^3/h/m^2$ flow section under a pressure drop of 2 000 Pa	15 $Nm^3/h/m^2$ external reference surface under a pressure drop of 2 000 Pa

H.2.2 Fire dampers

Upstream/downstream internal leak tightness criteria are

— at ambient temperatures: $<$ 1 100 $Nm^3/h/m^2$ flow section under a pressure drop of 1 500 Pa;

— at fire representative temperatures: $<$ 1 600 $Nm^3/h/m^2$ flow section under a pressure drop of 1 500 Pa;

— internal/external leak tightness criterion: $<$ 1 m^3/h under a pressure drop of 1 500 Pa.

H.2.3 Air filtering devices

a) Criterion for external leak tightness for filter housing:

Class 4 according to ISO 10648-2 (0,1 volume/hour under operating pressure).

b) Criterion for internal leak tightness for filter housing (i.e. the flow rate bypassing the filtering elements):

Maximum flow rate is 3×10^{-5} of the nominal flow rate (for a pressure drop of 2 000 Pa).

H.2.4 Other components

Criteria for external leak tightness for ducts and heat exchangers:

— equipment with reinforced leak tightness: 0,01 $Nm^3/h/m^2$ external reference surface for a pressure drop of 2 000 Pa;

— equipment with normal leak tightness: 1,5 $Nm^3/h/m^2$ external reference surface for a pressure drop of 2 000 Pa.

Annex I
(informative)

Primary containment envelope status

Table I.1 provides information on the different statuses of the primary containment envelope according to the different operation or situations.

Table I.1 — Typical status of primary containment envelope of different reactor types according to the operation situations

Operation states or situations		Power reactors				Research reactors	
		PWR with normal access during operation	PHWR type	PWR with typical double containment wall	BWR type	Pool reactors	Pressure effects types
Normal operation	Power operation	C5D	C5D	C5S	C5D	C5D	C5D
	Shutdown states[a]	C2 to C5D	C2 to C5D	C2 to C5D	C2 to C5D	C2 to C5D	C2 to C5D
Most accident situations		C5S	C5S	C5S	C5S	C5D	C5D
Severe accident situations[b]		C5D/C5S	C5S	C5S/C5D[c]	C5D/C5S	C5D	C5D/C5S

[a] During shutdown states, a separate ventilation system may be used for the primary containment envelope. The design of this ventilation system depends on the way of using ventilation systems during the various stages of these shutdown states: from C2 to C5D.

[b] For most power reactor designs, dynamic confinement of the primary containment envelope is used only in exceptional situations.

[c] C5D can also be used depending on national regulations in very exceptional situations.

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15) ASME, *American Society for Mechanical Engineers*

16) CEA, Commissariat à l'énergie atomique, France; CETREVE, Centre technique de référence en ventilation et épuration

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