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Fusion installations — Criteria for the design and operation of confinement and ventilation systems of tritium fusion facilities and fusion fuel handling facilities

Installations de fusion — Critères pour la conception et l'exploitation des systèmes de confinement et de ventilation des installations de fusion avec tritium et des installations de traitement des combustibles de fusion

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

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Introduction

Confinement and ventilation systems implemented in fusion facilities using radioactive materials and fusion fuel handling facilities ensure a safety function aiming at protecting the workers, the public and the environment from the dissemination of radioactive contamination, including but not limited to tritium, likely to be released from the operation of these installations.

This document applies specifically to confinement and ventilation systems for tritium fusion facilities and fusion fuel handling facilities and their specific buildings (such as fuel handling facilities, hot cells, examination laboratories, emergency management centres, radioactive waste treatment and storage station).

In such fusion installations, tritium is particularly focused, as their tritium inventory may be high and as it is likely to have a broader impact on workers, the environment or the members of the public than the other radionuclides.

In most countries, a tritium quantity is declared as high for tritium inventories in a facility site higher than a range of 10 g to 100 g. In the tritium fusion facilities in the scope of this document, the tritium inventory is deemed to be much higher than this range for the whole facility site.

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Fusion installations — Criteria for the design and operation of confinement and ventilation systems of tritium fusion facilities and fusion fuel handling facilities

1 Scope

This document specifies the applicable requirements related to the design and the operation of confinement and ventilation systems for fusion facilities for tritium fuels and tritium fuel handling facilities specific for fusion applications for peaceful purposes using high tritium inventories, as well as for their specialized buildings such as hot cells, examination laboratories, emergency management centres, radioactive waste treatment and storage facilities.

In most countries, a tritium quantity is declared as high for tritium inventories higher than a range of 10 g to 100 g. In the tritium fusion facilities in the scope of this document, the tritium inventory is deemed to be higher than this range for the whole site.

This document applies especially to confinement and ventilation systems that ensure the safety function of nuclear facilities involved in nuclear fusion with the goal to protect the workers, the public and the environment from the dissemination of radioactive contamination originating from the operation of these installations, and in particular from airborne tritium contamination with adequate confinement systems.

The types of confinement systems for other facilities are covered by ISO 26802 for fission nuclear reactors, by ISO 17873 for facilities other than fission nuclear reactors and by ISO 16647 for nuclear worksite and for nuclear installations under decommissioning. The facilities covered by these three standards, notably ISO 17873, include tritium as a radioactive material among the ones to be confined, but tritium is not their driver of the risks for workers and for members of the public. Nevertheless, the tritium quantities and risks from fusion facilities create specificities for a specific standard (e.g. in fusion facilities, tritium is the driver of routine and accident consequences). Therefore, the scope of this document does not cover the other facilities involved in tritium releases (ISO 17873, ISO 16647 and ISO 26802), even though these other facilities create tritium releases (e.g. non-reactor fission facilities, tritium laboratories, tritium removal facilities from fission plants, tritium defence facilities).

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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3.1
accidents

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

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

3.1.2
design extension conditions
DEC
postulated accident conditions not considered for design basis accidents, but considered in the design process for the facility in accordance with best estimate methodology, and for which release of radioactive material is kept within acceptable limits

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

Note 1 to entry: This new IAEA expression has been introduced for upgrading existing facilities or designing new facilities, following the occurrence of core melt accident situations in fission facilities. DEC cover the former situations, that were in the past included in the Beyond Design Basis Accidents category, related to multiple failures in the facility as well the ones that were supposed to create core melt and that are now supposed not to impact the containment of the facility (and thus that would become a design condition for the confinement of the nuclear facility).

Note 2 to entry: For new fusion facilities using radioactive materials, this expression cover accidents scenarios that were also considered as beyond design basis accidents for former designs, but that shall be considered in the design process of the facility in order to limit radioactive releases within acceptable limits. For fusion facilities, examples of DEC covered by this expression are the multiple failures scenarios (e.g. combination of loss of coolant events and loss of vacuum accidents), explosion scenarios, generalised fire scenarios.

3.1.3
beyond-design basis accident
BDBA
postulated accident with accident conditions more severe than those of a *design basis accident* (3.1.1)

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

Note 1 to entry: This expression was first used for fission reactors after the first core melt accident situations that occurred in the 20th century, in order to identify the situations that were not considered in the design of the facility but for which specific requirements should be considered to reduce the likelihood of fission reactors core melt situations as well as the consequences of such situations, that are now covered by the IAEA expression “design extension conditions (DEC)” (3.1.2). In the most recent years, for new facilities, BDBA cover only the accidents that are even beyond the DEC, and that shall be practically eliminated.

Note 2 to entry: IAEA defines also severe accidents as “accident conditions more severe than a design basis accident and involving significant core degradation”. In a fusion facility, there is no possibility of core degradation and therefore this definition is not used.

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

Note 1 to entry: The SI unit is s^{-1} but the general usage is in d^{-1} for leaktight volumes or in h^{-1} for general ventilation.

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3.4
air conditioning
arrangements that allow sustaining a controlled atmosphere (temperature, humidity, pressure, dust levels, gas content, etc.) in a defined volume, in order to ensure comfort of the personnel and/or the conditions for adequate operation of safety systems used in fusion facility

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
physical obstruction that prevents or inhibits the movement of people, radionuclides or some other phenomenon (e.g. fire), or provides shielding against radiation

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

Note 1 to entry: In the context of this document regarding the confinement function, it concerns a 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.

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

Note 1 to entry: See *containment enclosure* (3.10).

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

Note 1 to entry: the word containment is used for the leak-tight performances of a static physical *barrier* (3.6) confining radioactive materials, whereas confinement is used for the global function of confining hazardous materials including also the use of active systems ensuing a *dynamic confinement* (3.17). Therefore, confinement is used for the function of preventing or controlling the releases of radioactive material to the environment in operation or in accidents. Containment is used for the physical structures designed to prevent or control the release and the dispersion of radioactive substances. In the context of facilities handling radioactive materials it covers structural elements (cans, gloveboxes, storage cabinets, rooms, vaults, etc.), which are used to establish the physical integrity of an area.

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 1 to entry: 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

Note 1 to entry: See *cell* (3.7).

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Note 2 to entry: 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 system
confinement system
system constituted of a coherent set of physical *barriers* (3.6) 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 1 to entry: 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 facility against external events and provides radiation shielding during operational states and accident conditions. These two last functions are not described in this document, due to the absence of link with the ventilation systems. In a fusion facility, the *dynamic confinement* (3.17) is more important than in other facilities because of the tritium dispersion and permeation properties. Therefore, in fusion facilities, the term confinement system is more generally used.

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
cubicle
generic term used to describe enclosures containing electrical equipment (power or instrumentation and control) or cables

EXAMPLE Cabinets, junction boxes, switchboards.

3.15
decontamination factor
ratio of the contaminant concentration or particle number upstream of a filtration system to the contaminant concentration or particle number downstream of the filtration system

Note 1 to entry: definition derived from ISO 29464:2017.

3.16
discharge stack
duct (usually vertical) at the termination of a system, from which the air is discharged to the atmosphere after control and monitoring of contaminants

3.17
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

3.18
event
any occurrence unintended by the operator, including operator error, equipment failure or other mishap, and deliberate action on the part of others, the consequences or potential consequences of which are not negligible from the point of view of protection and safety

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

Note 1 to entry: In the context of this standard regarding the confinement function, the events are those challenging the confinement function, whether the event is internal or external to the plant.

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Note 2 to entry: EXAMPLES of internal events for fusion type facilities are plasma events, human errors, loss of coolant (LOCA), loss of vacuum (LOVA), loss of cryogenic inventories, electromagnetic loads, failures in steam piping systems, leakage or failure of a system carrying radioactive fluid; fuel handling accident, loss of electrical power, drop loads, internal missile, explosion, fire, and internal flooding.

Note 3 to entry: Examples of external events are aircraft crash, external explosion, earthquake, flood or drought, winds and tornados, extreme temperature (high and low), human induced accidents, neighbouring facilities accidents, external fires.

3.19
filter
device intended to trap particles suspended in gases or to trap gases themselves

Note 1 to entry: 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).

3.20
fire area
fire zone
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

Note 1 to entry: It is often more practicable to limit the spread of a fire, and to prevent the spread of contamination in the adjacent volumes by using fire-resistant walls (fire barriers) via *fire compartment* (3.21)

Note 2 to entry: in many countries, the use of fire compartment is preferred to fire area since fire barriers are more easily credited in safety demonstration.

3.21
fire compartment
fire sector
FC
reference volume delimited by construction elements (fire barrier) for which fire resistance has been chosen according to the plausibility that a fire could break out within this volume or penetrate into it

3.22
fire damper
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

3.23
fire load
sum of the calorific energies calculated to be released by the complete combustion of all the combustible materials in a space, including the facing of the walls, partitions, floors and ceiling

[SOURCE: IAEA Nuclear Safety and Security Glossary (2022 interim edition)]

3.24
fuel cycle system
system or group of systems that undertake the collection of un-used fusion fuels, their processing, and the re-use of fusion fuels, in order to allow the recycling of these fusion fuels such as hydrogen isotopes and in particular tritium

Note 1 to entry: Hydrogen isotopes and in particular tritium are the most used fusion fuels of interest in this document.

3.25
gas scrubbing
action that consists of decreasing the content of undesirable constituents in a fluid

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

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3.26
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

3.27
liquid tritium treatment system
system associated to the purification of a product that decreases the liquid effluent inventory downstream this system

Note 1 to entry: for specific tritium liquid treatment systems used for fuel cycle systems, this would lead to split the downstream parts in two streams, one more concentrated for a further re-use, and another one with a reduction of the concentration (generally for a further discharge).

3.28
load
physical static or dynamic phenomena that impact the *confinement systems* (3.12) during plant life or which can be associated with postulated internal or external events, or postulated accidents

3.29
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

3.30
negative pressure cascade
successive differences in pressure between the pressure of given volumes, such as to maintain an airflow from low contaminated volumes to high contaminated volumes

3.31
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 1 to entry: This system might or might not be associated with the room's ventilation systems.

3.32
pressure drop
pressure loss in an air stream due to its passing through a section of ductwork or a filter or fittings

3.33
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 1 to entry: 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.

3.34
recombiner
catalytic reactor
component containing catalyst to oxidize hydrogen isotopes in gas from to water form ($HQ + ½\ O_2$ -> HQO)

Note 1 to entry: Q stand for hydrogen isotopes (either H, D or T).

Note 2 to entry: The term “recombiner” is often used to name a catalytic reactor, which is a more accurate name.

3.35
safety classification
classification of structures, systems and components, including software instrumentation and control, according to their function and significance with regard to safety

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3.36
safety flowrate
flow rate that guarantees air flow through any occasional or accidental opening, sufficient to either limit the back-flow of *contamination* (3.13) (radioactive or other) from the working volume, or to avoid the pollution of clean products within the working volume

3.37
tritium trap
system intended to collect tritium under specific chemical or physical forms from the air or the ventilation gases

EXAMPLE adsorption on zeolite, condensation on cryogenic panel, isotopic exchange on trickle or bubbler columns.

3.38
vacuum vessel
vessel under vacuum where the plasma is magnetically confined

Note 1 to entry: the vacuum vessel is not a pressurised equipment for its main function and is connected and open to other volumes, all also under vacuum. All forms the first containment barrier. The vacuum vessel is generally equipped with a pressure limiting system consisting of a line and a discharge tank in case pressurised water is accidentally sent inside the vacuum vessel.

3.39
ventilation
organization of air flow patterns within an installation

Note 1 to entry: 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 supply and extraction circuits of each particular volume is directly connected to the general network (in contrast to ventilation in series).

Note 2 to entry: the word “ventilation” is used for both primary and secondary confinement systems, e.g. process ventilation systems in primary confinement systems, or detritiation systems that can exist in both primary and secondary systems, as well as for room ventilation buildings (generally called HVAC stating for Heating ventilation Air-conditioning systems).

3.40
ventilation duct
envelope generally of rectangular or circular section, allowing air or gas flow to pass through

3.41
ventilation system
totality of network components such as ducts, fans, filter units and other equipment, that ensures proper ventilation and gas cleaning functions

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4 General confinement specificities of tritium fusion facilities or fusion fuel handling facilities

4.1 General

In fusion facilities using radioactive materials, the confinement of radioactive material, and in particular tritium, is one fundamental safety function, together with radiation protection function.

In many facilities handling radioactive materials, the confinement function generally relies on the fact that the safe shutdown of the facility is performed, using static containment systems. Nevertheless, for fusion facilities, dynamic systems are sometimes used due to the volatile property of tritium under its gaseous form, otherwise tritium would permeate into confinement barriers and would be partially released.

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Confinement systems for fusion facilities comprise then both static containment requirements, and where needed dynamic confinement requirements.

To ensure the safety of a fusion facility, these safety functions shall be achieved during operational states, during and following both design basis accidents and design extension conditions.

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

The specificities of the fusion facilities compared to fission reactors are multiple:

— In fission-type nuclear facilities, there may be a very wide range of radioactive materials: fission products such as noble gases such as ^{85}Kr, iodine (^{131}I, ^{129}I, etc.), aerosols (^{134}Cs, ^{137}Cs, ^{106}Ru, etc.), alpha emitter aerosols (^{235}U, ^{239}Pu, etc.), activated corrosion products aerosols (^{60}Co, ^{58}Co, ^{59}Fe, etc.), tritium, carbon 14. But most of the particles that have an impact on the workers or members of the public during accidents are alpha, beta or gamma emitters aerosols in particular iodine. In order to protect people from these products, High Efficiency Particulate Air (HEPA) filters and iodine traps are generally used. Generally, for those facilities, tritium impact during accidents is negligible compared to the impact of aerosols or iodine products. For those facilities, ISO 17873, ISO 26802 and ISO 16647 apply. These standards are very oriented towards facilities with aerosol or iodine contamination, which represents the main risk for nuclear facilities other than fusion facilities.

— For fusion facilities with tritium, some of the design solutions and requirements that are standardized for fission-type facilities cannot be applied for fusion facilities without optimization since the contribution of tritium to the impact on the workers or members of the public is one key driver, even considering its extremely low radiotoxicity. In addition, fusion facilities have much lower long term waste issues, as well as no risk of long term chain reaction with runaway energies leading to request core cooling functions for long periods of time, as well as active components to maintain these functions. Other specificities consist in using cryogenic systems and superconducting magnets.

Considering these specificities, this document describes in particular all the design and operation issues associated with the confinement systems and the ventilation systems:

— requirements for the static containment barriers;

— requirements for the dynamic confinement systems e.g. negative pressure range, air change rates, filtration of radioactive materials;

— design against external hazards (earthquake, loss of electrical power, etc.);

— design against internal hazards (fire, flooding, other pressurization sources, etc.).

However, some potential adaptations have been already identified in this document with regards to tritium issues:

— the filters needed to remove aerosols are passive; the ones needed to cope with tritium usually rely on active systems: the variety of support systems depends strongly on the technology considered for the detritiation (coolers, heaters, demineralised water, power, etc.);

— while static containment is a way to protect workers against internal exposure for aerosols, we need additional dynamic confinement in order to cope with tritium permeation;

— air change rates in rooms or processes should be adapted to the volatility of tritium;

— the in-room volumes taken by HEPA filters is much smaller than the volume needed for detritiation systems; while it is relatively easy to add an additional HEPA filter to improve radioactive aerosols safety, it might not be possible to implement an additional detritiation system:

  — For instance, in areas very contaminated with aerosols, there are sometimes up to 3 HEPA filters in series in order to improve the overall efficiency and reliability. This could not be always possible for detritiation systems.

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- Another example relates to the fact of having rooms inlet filters in order to avoid a backflow of contaminated air in case of overpressurization of the room. This could not be completely applicable to tritium facilities.
- Another example is the implementation of HEPA filters between two rooms with a different contamination zoning in nuclear facilities; this could be impossible for tritium facilities.

4.2 Inventories to identify for fusion facilities confinement

Ventilation systems are used to strongly reduce radionuclide releases under normal circumstances, incident situations and to mitigate the consequences of accidents. For new nuclear fusion plants, design stages shall also include the identification and the evaluation of the source term for accident situations, including accidents considered as design extension conditions. 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 fusion facilities, tritium is not the only radionuclide to deal with, as structures are exposed and activated to neutrons up to 14,1 MeV.

Examples of the main nuclides to cope with are:

- fusion fuel tritium isotopes:
  - gaseous tritium-containing hydrogen isotopologues (HT, DT, T_2);
  - oxidised isotopes under vapor/liquid form (HTO);
  - tritiated organic species ($C_xH_yT_z$);
  - tritiated nitrogenic species ($N_xH_yT_z$);
  - tritium adsorbed on non-radioactive aerosols or bulk materials;
- activated structural materials (bulk materials, aerosols, dust):
  - from tungsten alloys (^{187}W, ^{185}W, ^{181}W, ^{188}Re, ^{182}Ta);
  - from copper alloys (^{64}Cu, ^{62}Cu, ^{60}Co);
  - from steel (^{56}Mn, ^{55}Fe, ^{58}Co, ^{60}Co);
  - from beryllium (^{10}Be) and from uranium impurity traces in beryllium (leading to traces of Cs, Sr, I, Ru, Ar, Xe, etc. nuclides);
  - from other liquid metals such as lead (Pb or Po isotopes), or lithium and their impurity;
  - from the above structural materials on which tritium can be adsorbed or incorporated, leading to tritiated materials;
- activated materials in coolant or purge gas: ^{16}N, ^{17}N, ^{14}C;
- activated gases: mainly ^{41}Ar, noble gases nuclides injected to stabilise the plasma.

At last, tritium may be concomitant with almost all of these other radioactive materials (e.g. $^{14}CTH_3$).

All these nuclides can be found under gas form, vapour form, liquid form, aerosols or activated structural solid forms, leading to a complexity of the confinement systems aiming at coping with them.

In addition, some toxic or carcinogenic products (deuterium, hydrogen, beryllium, hydrazine, mercury, boron, lithium…) may be used depending on the technology chosen for the materials facing the plasma, or the ones chosen for chemical processes of fluids.

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4.3 Specific systems or loads used in fusion facilities

The confinement systems are exposed to several thermal or mechanical loads that would not exist in fission-type facilities.

— plasma events: that may generate disruption, runaway electrons, or plasma displacements; these loads shall be considered to design the first containment barrier;

— electromagnetic loads: these loads are even stronger than pressure loads for some systems and require a robust design of the systems exposed to these loads;

— vacuum losses: loss of vacuum events can lead to lose vacuum progressively, resulting in a pressure increase, that dynamic confinement systems have to compensate in order to avoid a loss of the confinement function of radioactive materials; these events can also lead also to air/oxygen entrance in circuits, notably the vacuum vessel, enabling the possibility to create explosion loads;

— cryogenic events: Magnet systems are also specific in fusion facilities, because of the use of superconducting technology which require cryogenic technology. These systems use large quantities of cryogenic liquid helium or nitrogen. In case of scenarios leading to a release of these liquid gases, their volume instantaneously increases such as to create pressure and thermal loads able to challenge on confinement systems;

— internal remote maintenance and transportation events: the maintenance situations of heavy and big activated materials require enclosures such as casks for which dose rates lead to require remote maintenance and remote transportation; these create needs for shielding and confinement of the casks or of the rooms in which the casks are transported, as well as require remote cask rescue technology.

4.4 General description of confinement systems for fusion facilities

4.4.1 General

The confinement function is one of the main fundamental safety function of fusion tritium facilities. This function requires to confine hazardous materials via 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.

The confinement systems of hazardous materials of fusion facilities consists of two different confinement systems. For future fusion reactors, a safety analysis based on mature input data shall nevertheless indicate whether or not two confinement systems are enough regarding the nature of the risks associated with levels of dispersible and radiotoxic radionuclides other than tritium, one of the least radiotoxic nuclides that exist on earth.

a) A first confinement system, located as close as possible to the hazardous materials, aiming at protecting the personnel working closely to the hazardous materials inside the facility from airborne releases of these materials. This first confinement system is composed:

   — by one or several static containment devices with leak rates specifications, such as the vacuum vessel and its extensions, the tritium processes, the glove boxes, the waste containers, the radwaste or hot cells coatings (such a liner) or walls when hazardous materials is stored without first confinement system, additional static confinement provisions to restore a system during maintenance;

   — as necessary, by the associated dynamic confinement systems aiming at ensuring a negative pressure inside this first confinement system and an adequate filtration of the nuclides of interest.

b) A second confinement system designed to protect workers inside the facility not involved in the activities with hazardous materials and to limit releases into the other rooms of the buildings and therefore to limit releases towards the environment. This second confinement system is composed:

   — by one or several static containment devices with leak rates specifications, such as rooms and building walls;

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— as necessary, by the associated dynamic confinement systems aiming at ensuring a negative pressure inside this second confinement system and an adequate filtration of the nuclides of interest. This is done 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 HEPA filters, traps, storage for decay, etc.) via adequate pressure cascades.

The overall architecture of the confinement systems can be composed of only one system or different standalone systems designed to achieve different functions. In the following paragraphs, systems are described with their related functions.

Both first and second systems are based on static and dynamic confinement provisions, supported by adequate supporting functions as well as by adequate nuclide detection systems.

As primary parameters for the confinement function, the following needs to be defined:

— leak rates of "static" barriers (e.g. processes, liners, glove boxes, penetrations, buildings walls);

— pressure cascades between processes and rooms, between facility rooms according to their contamination risks in permanent or accidental conditions, and between rooms and the environment;

— filtration of hazardous materials:

  — decontamination factor of radioactive aerosols HEPA filtration;

  — detritiation factor for tritium;

  — decay time for short lived noble gases nuclides;

  — adsorption units for specific vapour nuclides.

These static and dynamic confinement function helps also in performing other safety or non–safety functions: an inventory control, by isolating in processes or in rooms, in a safe and tight way, the hazardous materials likely to be spread, which leads to avoid or limit the spread of the contamination to the other surrounding volumes and the environment; this helps in the accounting of these hazardous materials:

— the monitoring of the releases of the facility by organizing air flows in such a manner as to allow meaningful measurements;

— the cleaning of the processes or rooms by changing adequately the atmosphere and therefore by minimizing the hazards associated with an accumulation of dangerous products, and reducing the risks of spread of these products.

This helps to define secondary parameters needed for confinement:

— contamination concentration levels in processes, rooms and at releases points, in permanent or accidental conditions;

— air flows in rooms, and air change rates versus the nature of risks;

— detection time and isolation time for I&C systems;

— ambient conditions (pressure, temperature, humidity).

Detection systems are part of these confinement systems when they actively restore confinement (e.g. when they switch from one configuration to another configuration).

The design should be based on the possible compromise between a static containment and the different types of dynamic confinement systems presented in Clause 6. 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 fusion facilities with two confinement systems. Annex A gives several schematic diagrams of typical fusion facilities confinement system designs.

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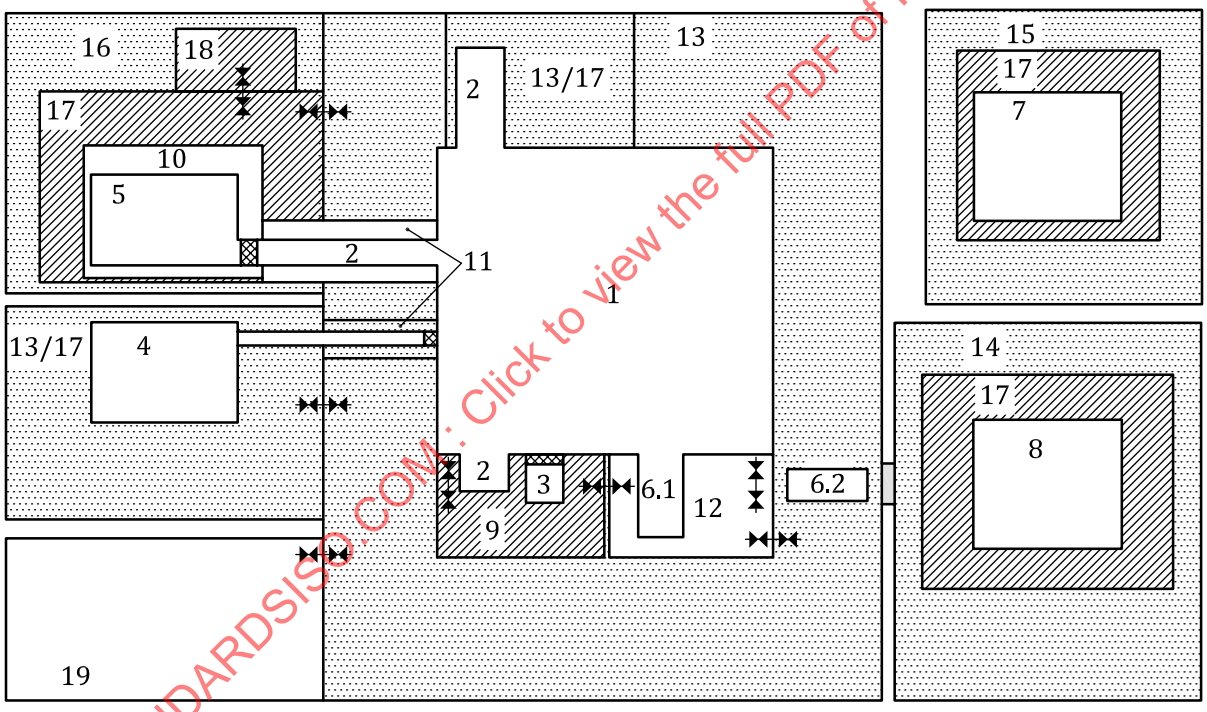
The Table 1 and Figure 1 present the general layout of confinement systems used in fusion facilities.

Table 1 — Typical examples of static containment barriers and/or systems

	Material form	
Type	**Solid**	**Liquid and gas**
Primary confinement	Glove box, container, walls, hot cells, containment enclosure and associated ventilation networks	Vacuum vessel and its boundaries (neutral beam, pressure limiter, piping, bellows), piping and tanks, glove box, port cells during maintenance, hot cells, containment enclosures and their associated process and/or enclosure ventilation networks
Secondary confinement	Adjoining room(s) and associated ventilation networks	Cryostat, port cells (when vacuum vessel is closed), adjoining room(s) and associated ventilation networks, nuclear building walls

To be noted that two confinement systems are implemented; a third one can be also present in specific risks upon a risk based graded approach, but that each confinement system may comprise several containment barriers, equipped when necessary with their specific dynamic confinement systems.

Figure 1 provides examples of typical barriers for the first and second confinement systems.



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Key

1st confinement system barriers

1 vacuum vessel
2 extension of the vacuum vessel
3 auxiliary systems connected to the vacuum vessel
4 cooling systems with radioactive products
5 fuel cycle systems
6 6.1 transport cask connected to the vacuum vessel
6.2 transport cask moving
7 solid or liquid waste containers or components
8 hot cells
9 port cells in plasma operation

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10 glove boxes
11 guard pipes / double envelope

2nd confinement system barriers

12 port cells in maintenance
13 main fusion building
14 maintenance / hot cells building
15 radwaste building
16 fuel cycle building
17 process rooms

Rooms or buildings without specific containment barriers requirements

18 adjacent process rooms
19 other adjacent building without radioactive materials

Figure 1 — Example of schematic drawing of a confinement systems

4.4.2 First confinement system

4.4.2.1 First containment barrier

In fusion facilities, radioactive inventories are not located only in the vacuum vessel but also, distributed all along the fuel cycle systems as well as in cooling systems and maintenance and radioactive waste buildings.

Vacuum vessel boundary is the first confinement barrier as shown in the centre of Figure 1 and requires strong and robust containment provisions in order to enclose all the plasma events (disruptions, runaway electrons, plasma displacements, etc.) as well as accident conditions inside it (in-vessel loss of coolants, explosion, etc.).

The process pipes and tanks, cooling the primary systems of the machine or part of the tritium production systems (test blankets, breeding blankets) are part of the first confinement barrier for radioactive inventories within the process fluids. The parts of the process systems of in-vessel components that are outside of the vacuum vessel also provide the first barrier for inventories within the vacuum vessel. Depending on the hazardous inventories, these pipes are constituted by double envelope with or without a ventilated and detritiated interspace.

Fuel cycle systems (see 4.4.4) constitutes the first containment barrier, but they also incorporate sometimes a second detreated containment barrier such as a glove box (see 4.4.2.2).

Other auxiliary systems, such as behind diamond window with isolation valve, stainless steel waveguide, closure plate, cooling lines, steering mirror actuator and seals, are part of extension of first containment barrier.

Casks transporting the radioactive materials during maintenance are also parts of the first containment barrier.

Hot cells in maintenance facilities, used are the first barrier with the associated transport cask to move in vessel component from vacuum vessel to remote maintenance area located in hot cells.

These systems shall be designed such as to prevent radioactive materials to be released in areas where personnel are present, including in accidental situations.

4.4.2.2 Second or third containment barriers

For specific cases, in particular where maintenance is performed and the first containment barrier is likely to be opened, additional containment barriers are enclosing parts of the first containment barrier.

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Airlock to vacuum vessel where transport could be docked to remote in vessel equipment is part of the second barrier. Process pipes, auxiliary system and hot cells are surrounded by a second or third barrier such as glove box, hard shells or liners.

Other examples of additional containment barriers could be formed by the aluminium waveguide, gyrotron window with possible second valve and pumping systems.

These systems shall be designed such as to prevent radioactive materials to be released in areas where personnel are present, including in accidental situations.

4.4.2.3 Dynamic confinement for the first confinement system

Some of the containment barriers used in the first confinement systems require specific dynamic confinement systems. This is the case of the vacuum vessel but also of the maintenance areas (e.g. port cells or hot cells), or the glove boxes.

These dynamic confinement systems shall be adapted to the routine operations risks, including during their maintenance, and be designed such as to limit impact on personnel and members of the public from the spread of radioactive or toxic materials. The purpose of these systems is to create a negative pressure cascade and to limit release into other systems or into the environment.

These systems are generally both detritiation systems for which the flow rate is adapted to the presence of personnel: when personnel are not present, low flow lines are used while when personnel are present, higher flow rates are used, e.g. during maintenance.

Local detritiation systems are also used for specific containment barriers in which high level of airborne tritium is present or would lead to increase tritium routine discharges.

As fusion fuels are hydrogen isotopes, some local ventilation systems are also used to ensure dilution of explosible gases in order to avoid deflagration, or to mix the ambiances in order to avoid local deflagration and to reduce the risks of detonation (e.g. use of a local air mixer). See 8.6.

Ventilation systems are also used to as air coolers for removing the energy from specific systems (e.g. the heat dissipated by cubicles in cubicle rooms).

Liquid detritiation systems are also used for removing the tritium from liquid streams and further to use this tritium in fuel cycle systems.

4.4.3 Secondary confinement system

The goal of the secondary confinement system 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 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,

— the associated ventilation systems which ensure a dynamic confinement function, including possible detritiation and room decontamination functions.

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

The design of the secondary confinement shall consider the maximum quantity of radioactive substances that are present in a dispersible form inside the primary containment, the quality of the containment barrier(s)

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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.

It should be noted that the secondary confinement constitutes the last barrier in the event of any type of 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 accident (e.g. the total loss of electrical supply). In most designs, auxiliary buildings are included in the secondary confinement.

4.4.4 Fuel cycle systems

Most of tritium fusion facilities incorporate fuel cycle systems in order to process, store and further recycle the tritium isotopes used as fuel, instead of discharging it. These systems host a high tritium inventory and therefore their structures, pipes and tanks are themselves their own containment barriers of their first confinement system (see 4.4.1). These containment barriers are therefore safety important.

These systems also have tritium recycling and reprocessing functions. These intrinsic functions are not safety important when they are limited to process the tritium, sort and store the tritium isotopes for a further re-use.

Nevertheless, the functions of controlling the tritium isotopes inventory are safety important as well as the parts that lead to routine or accidental discharges into the environment.

4.4.5 Tritium material compatibility

Tritium gas has the availability to be adsorbed easily in many types of surfaces and to permeate into materials, including metals, and to be desorbed slowly depending on the adsorbing material properties. Its desorption can then be in the form of tritium gas, tritium vapour or even tritiated organic form depending on the adsorbing materials. Therefore, the initial study of the tritium material compatibility shall be performed for confinement systems directly in contact with large tritium concentrations.

Some materials such as stainless steel have already proven their adequate tritium compatibility, while some others (e.g. concrete) have shown a bad compatibility, leading to “tritium memory effects”, i.e. relatively long-term desorption (leading to tritiated waste) and workers exposure to tritium. Therefore, tritium compatible materials, anti-permeation barriers or adequate coatings (metal coatings lead to less memory effects than polymer coatings such as paintings) should be used for confinement systems permanently in contact with high tritium concentration levels.

5 Functions and safety aspects for confinement and ventilation systems

5.1 General

The ventilation of fusion facilities 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.

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5.2 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 hazard of radioactive contamination. 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 rooms with radioactive materials 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 rooms hosting radioactive materials and likely to contain it with regard to the activity released 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; this is a specificity of tritium fusion facilities since it needed to avoid large airflows to be processed due to limitation in volume able to be processed by detritiation technologies, see Annex B.

c) Purification (or gas cleaning), by conveying the collected gases including any dust, aerosols and volatile components such as tritium, towards defined and controlled points for collection, processing and elimination where possible (by using filters, traps, storage for decay, etc.) via adequate pressure cascades.

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, in particular, the elimination of any gas necessary to create the risk of an explosion hazard by ensuring the processing of the gaseous atmosphere such as to prevent deflagration (e.g. use of igniters, of recombiners, of dilution techniques with inert gases, of air-mixing techniques). This function is generally ensured by large air change rates in rooms. Nevertheless, as a specificity of tritium fusion facilities, it is needed to assess air change rates in the potentially tritiated rooms connected to stack discharge systems since these air change rates contribute to increase the flow discharged into the environment and therefore create large tritium releases (see 7.2.8)

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. In addition, air conditioning helps in controlling room air humidity, and, as a specificity of tritium fusion facilities, helps in limiting the creation of liquid tritium in permanently tritiated rooms and drainage circuits (via condensation) or in detritiation systems that would collect and condense air tritiated humidity.

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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, design extension conditions, and selected beyond-design basis accidents. In this context, these accidents should be considered during the design of the confinement function.

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

5.3 General principles

Confinement 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[25], by extension to tritium fusion facilities, DEC accidents should be considered during the design of containment / confinement systems.

Before beginning any detailed confinement system design, a hazard assessment shall be made so that design safety principles and actual targets can be adequately defined. 5.4 provides an outline of the hazard assessment process as it relates to ventilation design.

As far as possible, this approach is based on the experience derived from the design and operation of existing tritium facilities.

The hazard assessment addresses the functional aspects of the confinement 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 fusion tritium facilities to cope with DEC and some BDBA accidents. Particular care is given to the design of the confinement 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.

5.4 Risk assessment procedure

5.4.1 Preliminary analysis

The design of an appropriate confinement system requires a preliminary analysis that considers 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 7.2.2.2. 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 in accordance with the recommendations given in ICRP 103[19];

b) discharge limits from the ventilation system as a whole, and the decontamination efficiency requirements prior to discharge;

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c) the need to use the ventilation systems to mitigate design basis accidents. If DEC accidents are considered, then ventilation systems should be used to mitigate these 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 confinement systems (see 8.7);

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

i) loads and events combinations that challenge the operation and the design of the confinement systems. These combinations shall consider 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 considered when designing confinement 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 treatment systems such as 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, 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 consider 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;

— limitation of the creation of low level tritiated waste water (optimisation of ambient air humidity, optimization of air change rates, optimisation of detritiation system parameters);

— the necessity to apply a defence in depth approach, and to avoid designing to the limits coming from general safety objectives of the facility in order to allow flexibility in the operation of the facility in case of unexpected situations;

— the implementation of design criteria for the main parameters of the confinement systems, such leak rate for containment barriers, HEPA filters or detritiation efficiency for HVAC and detritiation systems.

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5.4.2 Risk evaluation

For each element considered, the confinement systems shall be designed, using a safety risk assessment consistent with that given by IAEA safety principles[20]).

This safety risk assessment includes the combination of 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), together with an adequate use of probabilistic methods in order to identify the postulated events categories as well as the sequences leading to aggravating events via multiple failures.

It is important not to primarily exclude some combinations of loads and, 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.

Loads combination rules shall be indicated in the safety documents of the plant. Subclause 4.28 of the IAEA Safety Standards Series SSG-53 (see Reference [22]) gives minimum load combinations for all the containment/confinement systems, including ventilation systems.

For DBA, including design extension conditions, it shall be verified that the design and operation of ventilation systems meet the facility safety objectives, that shall be ALARA, and that they do not lead to cliff-edge effects or to unacceptable consequences to workers, the public or the environment. If one of the functions of the ventilation systems defined in 5.2 is used to limit the consequences of such accidents, then this function shall be designed to cope with these accidents.

To be noted that the wording BDBA (beyond design basis accidents) is not applied anymore by IAEA, IAEA preferring the wording design extension conditions (DEC). These DEC are postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process for the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits. Therefore, these DEC can use assumptions and methods that can be less conservative than for DBAs (but still considering uncertainties). This expression cover accidents scenarios that were also considered as beyond design basis accidents for former designs, but that shall be considered in the design process of the facility in order to limit radioactive releases within acceptable limits.

For fission facilities, IAEA made the distinction between:

— the DEC with no significant core degradation has to be considered for the design, with consequences not requiring off-site protective actions, and with radiological consequences comparable to those established for design basis accidents.

— while the DEC leading to core melting have to be considered in the design (in particular for confinement systems) such as to avoid cliff edge effects and to limit necessary off-site protective actions in time and space, and for the situations leading early large releases have to be practically eliminated from the design by appropriate design provisions;

For fusion applications, as there is no issue of core degradation and as fusion hazardous inventory is lower in terms of radiotoxicity than the one for fission NPPs by several orders of magnitude, it can be concluded that the practical elimination of some situations in the fusion design is not required, but that all DEC shall be considered such as to avoid cliff edge effects and to limit necessary off-site protective actions, but using less conservative assumptions and methods.

Therefore, for the DEC specific case in fusion facilities, an analysis should be carried out in order to check the absence of cliff-edge effects from combined situations and multiple failures and to establish the margins and the lines of defence between ventilation or confinement systems design parameters and those needed for coping with these DECs (e.g. fire with several in-depth defence lines). It shall be verified that the design and operation of confinement systems meet the facility safety objectives, that shall be ALARA, and that they do not lead to cliff-edge effects or to unacceptable consequences to workers, the public or the environment.

For fusion facilities, examples of DEC are:

— the scenarios where several confinement systems can be affected by one or several independent failures, leading to a confinement bypass (e.g. scenarios leading to the break of the vacuum vessel together with

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the opening of relief panels to discharge the energy to the environment, pipe whipping effects from high energy line breaks);

— multiple failures scenarios leading to a high release of mass or energy higher than the ones used in the design of building systems leading to a non-compensated breach in the last confinement system (e.g. failure of cryogenic fluids together with loss of coolant scenarios, explosion scenarios, generalised fire scenarios);

— combination of smaller accident scenarios (e.g. combination of Loss of coolant events and Loss of vacuum accidents);

— common causes failures that may affect redundant trains.

The consideration of additional failures to any incident or accident situations, independent from the initiating scenario, is possible, but if the additional failure is applied on a safety important component independent from the initiating event, the scenario is less plausible. Therefore, when the initiating scenario was already an hypothetical accident, the resulting scenario may be considered in the "DEC" category. DEC scenarios are studied in the scope of design under the defence in depth principle, in order to exclude cliff edge effects scenario and keep the last confinement barrier unaffected. Those DEC scenarios are then reassessed with those new assumptions in order to confirm the absence of cliff-edge effects.

For DEC, an analysis should be carried out in order to check the robustness, and to establish the margins, as well as the lines of defence between confinement or confinement systems design parameters and those needed for coping with these DEC (e.g. fire with several failed in-depth defence lines). If one of the functions of the confinement systems is needed to avoid unacceptable consequences of such accidents, then this function shall be designed to cope with these DEC accidents.

In order to consider the feedback from Fukushima events, stress tests shall be considered in order to identify extreme natural events (extreme winds, extreme flooding, extreme earthquakes…) that may endanger the confinement function and that may further lead to cliff edge effects. The loads associated with these extreme events are site-dependant and shall be discussed with the local safety authorities.

5.4.3 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 is called upon to perform the safety function; this has to be considered with care since there is not enough experience feedback to provide accurate reliability data for a probabilistic safety assessment for fusion facilities;

— the time following an initiating event at which, or period throughout which, it is 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, geographic separation, diversity) or of more conservative codes and standards.

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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 Architecture and description of the different confinement systems

6.1 General

The confinement of hazardous materials shall be based on static and dynamic confinement for both first and second confinement systems:

a) a first system, designed to protect workers close to the radioactive materials, and therefore located as close as possible to the materials, provided in particular by static containment barriers such as the vacuum vessel and its extensions, piping, the tritium processes (including glove boxes), the maintenance hot cells and by dynamic confinement via the associated ventilation systems as necessary;

b) a second system, designed to protect the other workers and members of the public, and to limit releases into the environment, provided by static containment barriers such as the walls of the rooms and buildings and by dynamic confinement via the associated ventilation systems as necessary.

The overall architecture of the confinement system can be composed of only one system or different standalone systems designed to achieve different functions. In this paragraph, systems are described with their related functions.

The dynamic confinement should manage aerosol and gas contamination, including tritium. Due to their respective flowrate capacity required for these different forms of contamination, the dynamic confinement consists of:

— a radioactive aerosol oriented ventilation system, generally called HVAC in most designs, used during normal operation;

— a tritium oriented ventilation system (detritiation system), used both during normal operation and during incident and accident conditions.

6.2 Static confinement of radioactive material

6.2.1 Containment barriers and systems

The boundaries of containment barriers shall be leaktight such as to avoid the need for the personnel outside the barriers to wear during normal operations specific personnel protection equipment.

These containment barriers shall be designed to maintain their confining function against all the internal and external events to which they are exposed (see 4.3, 4.4 and Clause 8).

As a tritium specificity, static containment is important but not enough by itself to confine tritium since, as a natural phenomenon, its chemical and physical properties allow it to permeate into containment barriers in prolonged high exposure situations, leading to further contamination and waste issues. This explains the need for dynamic confinement systems in order to reduce its concentration in barriers.

6.2.2 Isolation function (static containment)

This isolation function is useful for volumes (mainly containment building) during a DBA/DEC 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.

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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 with radioactive or toxic materials. 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, hermetically 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 containment barriers 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 risks associated with radioactive inventories and the risks presented in the safety demonstration. For rooms requiring a dynamic confinement function using detritiation systems, stringent leak rates should be implemented in order to avoid to process large airflows volumes within DS, otherwise this would produce large tritiated condensed water volumes, and would reduce the DS efficiency by creating a competition between tritiated vapour (HTO) and air humidity (H_2O) for some technologies sensitive to humidity or to the air velocity (e.g. molecular sieves).

Typical examples of leak tightness rates for containment barriers for the peak pressure and temperature ambient conditions are given in Annex D.

The containment 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 D.

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 (depending on the safety demonstration) and by the wind effects on the structure.

To minimize these winds pressurisation effects induced by the most severe winds, both static containment and dynamic solutions can be used, either by adopting an adequate leak rate for the secondary confinement envelope (see Annex D for leak rates), and/or to implement an initial negative pressure compensating the wind pressurising effects.

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.

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Finally, regarding static containment parts belonging to ventilation systems with confinement function, the parts of these systems located outside the second containment envelope shall either satisfy additional requirements related to their leak tightness and safe closure in order to limit external leaks, or the full 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 D gives typical leak rate values for ventilation components. ISO 10648-2 provides leak rates classification methods.

6.3 Ventilation of the volumes within the first confinement system

6.3.1 General

These systems are mainly located outside of the primary containment envelope.

The ventilation systems concerned are

— either designed for only normal situations;

— or designed for ensuring both safety and protection function in the event of a Design Basis Accident.

The dynamic confinement systems concerned are:

— vacuum vessel exhaust process (process ventilation system) designed for high contamination to handle vacuum vessel exhaust effluent in normal operation;

— vacuum vessel pressure limiting system consisting of a line, a discharge tank and detritiation system prior to discharge stack;

— local and/or centralised detritiation system collecting fuel process off gas.

6.3.2 Vacuum vessel exhaust process

The vacuum vessel and attached equipment (e.g. neutral beam injectors when available) are served by an exhaust vacuum process, generally a roughing system comprising cryogenic and mechanical pumps: the various technologies used by these pumps are determined as a function of the pumping pressure (e.g. below 50 Pa for cryopanels) and hydrogen isotope throughput requirements of the respective pumps (e.g. cryogenic viscous flow compressors). The unburned fuel exhausted from vacuum vessel is composed of a complex mixture of impurities and fuel (hydrogen isotopes). This mixture is purified with different stage of chemical or physical purification (separators, filters, etc.). The purified fuel is returned to fuelling cycles. The residual impurities, after purification, may be then sent to the stack.

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 vacuum vessel. The functions ensured by this system regarding confinement function are:

— 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 primary envelope.

— purification or gas cleaning of the vacuum vessel exhaust for minor incidents that do not lead to an increase in mass and energy in the vessel.

6.3.3 Primary containment pressure limiter

Even though under vacuum during normal situations, there are incident or accident conditions leading to pressurise the vacuum vessel above the atmospheric pressure, leading then to leaks from the vacuum vessel (and connected equipment) to adjacent volumes. In order to avoid exceeding the vacuum vessel design pressure, specific systems are implemented to maintain the induced pressure below this design pressure, therefore protecting the first containment barrier. These systems, often called vacuum vessel pressure suppression system, become themselves an extension of the first containment barrier during these

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accidents. These systems are located outside the primary containment envelope. They consist generally of discharge tanks under vacuum, connected to the vacuum vessel, able to take the energy induced by LOVA and/or LOCA accidents in order to avoid breaching the primary containment envelope.

It is necessary that they function in the event of a DBA inside the containment envelope and that their potential failure do not lead to cliff edged consequences in a DEC event.

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

— energy dissipation inside a primary envelope such as to discharge the energy in discharge tanks;

— condensation of water vapour in discharge tanks;

— confinement of radioactive products inside the boundaries of such system;

— filtration and cleaning of the radioactive materials prior to their release;

— anti-deflagration function.

6.3.4 Local and/or centralised detritiation system

These systems are located outside the containment. It is necessary that their functions are maintained in normal operation and in the event of a DBA/DEC in the containment envelope.

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

— dynamic confinement in the primary envelope;

— cleaning the atmosphere, consisting mainly to exhaust and purify air in leakage of the enclose;

— purification of the atmosphere might be initiated to recover from a DBA/DEC as quickly as possible.

6.3.5 Ventilation of the volume between first and second containment barriers of the first confinement system

These systems concern examples of volumes such as glove boxes or double envelope pipes (e.g. guard pipes). These volumes are likely to collect leaks (expected or not), leading to liquid, gas or aerosol contamination or to the creation of hazardous atmosphere such as explosive atmosphere, or to collect gases and vapour through unavoidable hydrogen isotopes permeation. When potential collection of these hazardous substances can occur in these volumes, these volumes are ventilated such as to detect leaks from the primary barrier, to confine radioactive materials and to reduce the risks of hazards due to the substances contained in the volume.

The ventilation of these volumes, depending on their use, may have the following functions:

— dynamic confinement of the volume, some of the volumes may be at negative pressure and even be under vacuum for process reasons,

— cleaning the atmosphere, in order to reduce the hazards,

— monitoring of the atmosphere,

— purification of the atmosphere, via detritiation or aerosol contamination removal.

6.3.6 Cryogenic systems

The use for superconducting technology requires to maintain some gases such as helium and nitrogen at very low temperatures (around 4 K for helium, around 80 K for nitrogen) inside magnets and coils, requiring cryogenic systems. In case of scenarios leading to a release of these liquid gases, their volume instantaneously increases (by a factor that could reach 2 or 3 orders of magnitude) such as to create high pressure loads and cold thermal shock loads inside rooms and buildings. These loads are able to challenge on confinement systems if no pressure escape pathway is found to decrease the pressure.

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8.2 addresses the control provisions needed to cope with these risks.

A study of the potential radioactive content of these systems (tritium from permeation, radionuclides from helium activation, etc.) shall be undertaken. In case these systems contain radioactive materials and are routed outside confined buildings, the safety analysis shall proportionate the additional static confinement requirements to the risks of releasing radioactive materials from these systems outside buildings.

6.4 Ventilation of the volumes within the second confinement system

6.4.1 General

The ventilation systems for the volumes within the secondary confinement usually operate during normal and accidental situations, even during DBA/DEC.

The secondary confinement is comprised of all the buildings and rooms that help to collect radioactive materials in order to filter them. These buildings are either specific to the collection of leaks 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.

6.4.2 Rooms and building ventilation systems

These systems are located inside the second containment. Their functions are maintained during normal operations and most of the systems are not designed to operate under the conditions of an accident.

The systems ensure the following functions:

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

— cleaning the atmosphere, consisting mainly to reduce aerosol concentration in atmosphere;

— monitoring the atmosphere (contamination content);

— homogenisation or dilution of combustible gases to avoid air pocket in case normal ventilation in not in operation.

6.4.3 Detritiation systems

These systems (see 7.2.2) are located inside the containment. It is necessary that they function in the event of a DBA/DEC in the process and buildings where tritium can be located and be spread. They are part of the ventilation systems, but dedicated to the operational function to detritiate and help in the recycling of tritium.

The systems ensure the following safety functions:

— dynamic confinement in the secondary envelope;

— purification of radioactive tritium and aerosol leakages in order to minimize the releases into the environment

— support the monitoring of tritium in ducts and the control of the global tritium inventory.

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6.4.4 Local ventilation systems

These systems are located inside rooms where both radioactive and hazardous risks may exist. It is necessary that they function in the event of a DBA/DEC in the containment envelope. They ensure the following functions:

— conditioning the atmosphere of the rooms in order to protect both safety systems (electronic and electrical systems) and workers (in order to facilitate maintenance operations and further to reduce human factor risks);

— cleaning the atmosphere, consisting mainly to reduce ambient contamination in atmosphere (e.g. by enhancing the flowrate in some rooms such as “elephant trunks” for specific maintenance conditions or following abnormal situations);

— monitoring the atmosphere (contamination content) for both normal situations and for situations where low flowrate ventilation systems (such as detritiation systems) are under operations;

— homogenisation or dilution of combustible/explosible gases (in particular hydrogen isotopes) to avoid heterogeneous concentration above explosive limits, for example. by local air mixing system, and thus to avoid potential explosion conditions.

6.4.5 Ventilation of the volumes located outside the secondary confinement

This subclause deals with 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 (e.g. tritium isotopes), waste and effluents treatment buildings. These systems usually operate during normal and accidental situations, even during an accident.

6.4.6 Miscellaneous ventilation systems not connected with containment envelopes

6.4.6.1 Ventilation systems for control rooms

These systems are designed to operate during normal situations and accidental conditions. 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.

As it is difficult to implement a detritiation system at the inlet of the control room ventilation layout in order to protect the workers located in the control room, the air inlet of the control room ventilation network shall be located such as to be exposed only to the least frequent winds, and preferably protected against direct releases from the facilities (e.g. opposite direction to the stack or other gaseous release points). The leaktightness of the rooms where long-term habitability is required has to be specified and periodically checked. The leak rates should be proportionate to the risks induced by the potential need for shutting down the air inlet ventilation system in case of an accident leading to a large tritium contamination of the site.

Concerning the air conditioning function, the control rooms host safety important components, generally from both electrical redundant trains. Whatever this air conditioning function is ensured by a ventilation network with cooling/heating loops or with local air conditioners, they shall be designed such as to maintain

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the adequate internal climatic conditions for the operation of these safety components, considering the full range of external weather conditions such as to avoid a common mode failure of these redundant trains.

6.4.6.2 Smoke removal ventilation systems

The use of smoke removal system shall be avoided in rooms likely to be directly or indirectly contaminated in routine or accident conditions since this would contribute to by-pass the exhaust filtration systems.

For rooms without potentiality of contamination (e.g. electrical building rooms), reference can be made to national or regional standards regarding systems for the evacuation of smoke (for example, the EN 12101 series or NFPA 92 Standard for Smoke Control Systems).

6.4.6.3 Ventilation systems ensuring the protection of safety systems

These systems are associated with the operation of the safety systems, such as electrical power supply (back-up power and normal), electronic control systems. These systems are designed to operate whatever the situation in the fusion facility. They are also classified as safety systems when their failure leads to the loss of adequate conditions of the safety systems.

The functions ensured by these systems are:

— cleaning function;

— conditioning function.

Nevertheless, the conditioning function can be highlighted due to the fact that they can support the safety systems.

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7 Requirements for the design of ventilation systems

7.1 General

According to Clauses 4 and 5, the ventilation systems ensure several functions that shall fulfil several general requirements.

In 7.2, the requirements for application to the dynamic confinement function are considered.

In 7.3, the specific requirements for filtration of radioactive materials, and in particular for tritium, are mentioned.

7.2 Dynamic confinement

7.2.1 General

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).

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7.2.2 Classification of the installation into potentially contaminated areas (confinement classification)

7.2.2.1 Introduction

The areas in which work on radioactive materials takes place should be classified according to the degree of radioactive risk 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 level of atmospheric contamination within these envelopes during normal operation;

  — tritium contamination;

  — other nuclides contaminations.

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

  — tritium contamination;

  — other nuclides contaminations.

— the possibility of not entering inside the primary containment envelope of the building hosting the vacuum vessel during normal operation, either for radiological reasons or other provisions (heat, safety, magnetic fields, accessibility);

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

— the presence of other contamination hazards in the rooms (e.g. toxic materials such as beryllium or hydrazine or lithium).

7.2.2.2 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 and type (aerosol or gas form) of the spread of contamination during normal operation or during a foreseeable accident, should be defined in accordance with the respective national safety authorities.

All these systems, defined on the basis of a safety analysis, provide 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.

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

Class	Expected normal and/or occasional contamination
C1	Means a clean area free from normal radioactive contamination, whether surface or airborne. Only an exceptional very low contamination level can be accepted.
C2	Means an area that is substantially clean during normal operation. Only in exceptional circumstances, resulting from an incident or accident situation is a low level of surface or airborne contamination acceptable, so appropriate provisions shall be made for its control.
C3	Means an area in which, in normal situations, some surface contamination could be present and with low levels of airborne contamination. In some cases, resulting from an incident or accident situation, there is a potential for surface or airborne contamination at a level higher than in C2 areas, so that suitable provisions shall be made for its control.
C4	Means an 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.

In order to better distinguish the rooms with airborne contamination from aerosols from the ones with airborne tritium, the Table 2 is split into 2 parts, one for the aerosols (named A*x*), one for the tritium (named T*x*), as shown in Table 3.

Table 3 — Normal/occasional expected contamination in volumes

Class (A*x*/ T*x*)	Explanation of the class
A1	Clean area free from normal radioactive aerosol contamination, whether surface or airborne. Only an exceptional very low contamination level can be accepted.
A2	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 aerosol contamination acceptable, so appropriate provisions shall be made for its control.
A3	Area in which, in normal situations some surface aerosol contamination can be present and with low levels of airborne aerosol contamination. In some cases, resulting from an incident or accident situation, there can be a potential for surface or airborne aerosol contamination at a level higher than in C2 areas; suitable provisions shall therefore be made for its control.
A4	Area in which permanent and/or occasional aerosol contamination levels are so high that there is normally no access permitted for personnel, except with appropriate protective equipment.
T1	Clean area free from normal tritium contamination, whether surface or airborne. Only an exceptional very low tritium contamination level can be accepted.
T2	Area that is substantially clean of tritium during normal operation. Only in exceptional circumstances, resulting from an incident or accident situation, is a low level of surface or airborne tritium contamination acceptable, so appropriate provisions shall be made for its control.
T3	Area with exhaust likely to be detritiated if a tritium contamination threshold is exceeded
T4	Area equipped with permanent detritiation in one-through mode
T4*	Area equipped with permanent detritiation in recirculation and one-through mode

NOTE 1 C1 to C4 classes from Table 2 deal with the whole contamination products, aerosols, gases as well as tritium, and both types have to be considered for establishing this classification. In Table 3, A*x* cases correspond to the cases where radioactive aerosols are the contaminant. T*x* cases correspond to the cases where tritium is the contaminant.

NOTE 2 Examples can be that one room can be A*i* for radioactive aerosols, T*j* for tritium, but the classification C considers the global contamination A*i* + T*j*, expressed in DAC. See Annex A for guidance.

NOTE 3 T1 and T2 cases are theoretical: they may exist in principle if the contaminant is only due to tritium but in this case, they can be considered as C1 and C2.

NOTE 4 Other classifications can also exist in parallel for rating the confinement needs for chemical products present in the facility.

7.2.2.3 Classification into radiological areas

In the event of a radiation exposure hazard (internal and external exposure), a complementary classification of the installation into radiological areas exist in all countries according to the ICRP 103[19] and IAEA[26] recommendations. The following radiological area designations are used: supervised, and controlled areas,

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the other adjacent areas being not restricted with regards to radiological risks. 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 if allowed by national regulations.

Definitions of these different radiological areas are given in national regulations. They can overlap with the previous containment-area classification, but the superposition of these two areas classifications shall be analysed in order to avoid incompatibility (a C4 class can only be a forbidden area, C3 and C4 classes are in a controlled area, etc.).

In all cases, the overall classification system (complying with these two classifications) shall consider and comply with the pertinent national radiation protection and safety regulations.

7.2.3 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, considering the influence of several factors.

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

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

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

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

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

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

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

According to the safety analysis, possible failures of ventilation systems components can lead to the need for redundancy of corresponding components.

7.2.4 Negative pressure

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

— rooms surrounding the fusion facility containment barrier;

— those in which there is the risk of having some contamination, and notably tritium leakages;

— those in which a specifically hazardous radioactive process is under operation (storage bed, 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, change chemical reactor packing);

— 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 downstream from the filtration systems, such that the filtration systems are not able to filter all gases.

Table 4 gives some examples of the usual values of negative pressures depending on the confinement class (see Tables 2 and 3). Examples of levels of contamination are given in Annex A.

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.

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It should be noted however that very high negative pressures can be required for glove boxes or containment enclosures (e.g. vacuum vessel, port cell to access vacuum vessel).

Table 4 — Guidance to negative pressure values

Nature of room or area	Negative pressure value[a]	Confinement class
Control rooms	Positive pressure	Unclassified
Non-controlled rooms or areas free from contamination	Atmospheric pressure or small overpressure	Unclassified
Supervised areas with very low levels of surface or airborne contamination in abnormal (exceptional) situations only These areas shall be uncontaminated in normal operations.	0 Pa to 60 Pa	C1
Controlled areas substantially clean during normal operation and with low level of surface or airborne contamination only in exceptional circumstances, resulting from an incident or accident situation	80 Pa to 100 Pa	C2
Controlled areas in which some surface or airborne contamination could be present at low levels in normal situations, and in some cases resulting from an incident or accident situation, there is a potential for surface or airborne contamination at a high level	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	All C4

[a] Compared to the reference pressure or, for rooms inside C3/C4 containment envelopes, the pressure inside this envelope.

7.2.5 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 in existing standards (see ISO 11933-4 and ISO 17873). For the particular case of gaseous tritium products, a minimal air velocity (safety flowrate) of 1,5 m/s is recommended due to the high volatility of tritium. 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.

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7.2.6 Basic air pattern and clean-up systems

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

C1 areas would normally not need to be filtered at the exhaust. Only appropriate air treatment should be foreseen when the corresponding rooms are occupied by workers. If the served C1 rooms participate to the collection of leaks from a containment barrier, then the C1 network should be connected to the stacks in order to monitor releases and to allow effluent release better dilution to the environment. Otherwise, the extract air can be ejected locally without filtration.

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 ePM1, ePM2 or ePM3 according to ISO 16890-1 or E or H according to ISO 29463-1, 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.

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.

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 when this risk exists, detritiation devices) adapted to the type of contamination.

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 considering 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 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 E or H according to ISO 29463-1, 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).

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Containments for T3 or T4 areas, such as glove boxes, hot cells, etc. 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, detritiation systems for the exhaust are appropriate for managing and controlling tritium routine releases. Releases shall be made through a stack allowing sufficient dilution (with an adequate height).

When in addition, there is aerosol airborne contamination corresponding to C3 or C4 classes, HEPA filters shall also be added on the exhaust (see Annex A for guidance).

If the deposition of radioactive materials on the main filtration devices during accidents leads to excessive external exposure of operators, 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.

If the deposition of radioactive materials on the main filtration devices during accidents leads to excessive internal exposure of operators in post-accident situations necessary to maintain the safe state, then adequate protection measures against tritium contamination shall be taken, such as installation of first confinement systems (double pipes, glove boxes, specific enclosures) around the tritiated sources, or use of specific protective personnel equipment designed against tritium.

7.2.7 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 A 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.

7.2.8 Optimization of air exchanges

7.2.8.1 General

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 five iterative steps described in detail in 7.2.8.2 to 7.2.8.6:

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

— consideration of reducing radioactive releases and internal doses for the workers; i.e. air cleaning needs in incident/accident situations;

— consideration of the specific risks such as management of explosible risks;

— study of the confinement function;

— 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 consider the design and the construction of the building.

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7.2.8.2 First step

This step provides for the definition of a minimal air exchange rate, considering 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.).

7.2.8.3 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 radionuclides.

— 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[1)]. Tables 5 and 6 below give guidance for the corresponding indications of air change rates with regards to global contamination risks and to the presence of personnel.

Table 5 — Guide to air exchange rates according to global contamination risks (C class)

Compartment	Typical air exchanges per hour	Area (confinement class)
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	1 to 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
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
Large primary containment without personnel entrance (e.g. vacuum vessel)	1 to 4 (depending entirely on process, leaktightness, volume of the containment enclosure and hazard)	C4

1) All these air exchange rate values can be reduced according to the approach defined in the third step (see 7.2.8.4), taking into account whether or not personnel are present in the rooms and an evaluation of the radiological consequences subsequent to an accident

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Table 6 — Guide to air exchange rates for rooms, according to whether or not personnel are present in the rooms in routine operations

Units are in air exchanges per hour

Compartment (typical examples)	Typical confinement class	Situations	Presence of personnel in enclosures with air cleaning needs	Presence of personnel in enclosures without air cleaning needs	Absence of personnel
Highly contaminated rooms (vacuum vessel, Hot cells, radwaste process rooms), specific tritiated enclosures, rooms adjacent to highly contaminated rooms	C3, C4	Normal	1 to 10 [a]	1 to 4 [a]	<<1
		Accident with short-lived nuclides	1 to 3 [a]	1 to 2 until personnel is evacuated, then 0,1 to 1 [a]	0,1 to 1
		Accident with long-lived nuclides	1 to 10 [a]	1 to 10 until personnel is evacuated, then 0,1 to 1 [a]	1 to 5
Tritium building, Tokamak building galeries	C2, C3	Normal	1 to 10	1 to 4	<<1
		Accident with short-lived nuclides	1 to 3	1 to 2 until personnel is evacuated, then 0,1 to 1	<<1
		Accident with long-lived nuclides	1 to 10	1 to 10 until personnel is evacuated, then 0,1 to 1	0,1 to 1

[a] Presence of personnel in highly contaminated rooms is not allowed, except in exceptional circumstances with personal protective equipment and subject to acceptance in national regulations.

7.2.8.4 Third step

Consideration of hazards and the specific constraints such as

— explosive and inflammable gases, for example H_2 isotopes;

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

— tritium 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 considered 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.

For rooms hosting circuits with hydrogen isotopes, or other explosible gases, higher air change rates should be implemented in order to limit explosion risks. Nevertheless, the use of high air change rates should be limited when these rooms also contain tritium contamination that is either permanent or likely to be released in quantities exceeding 4 000 DAC in accident, since it would lead to large tritium releases. In such cases, the use of efficient local air mixing systems should be recommended in order to homogenise quickly the potential release of explosive gases and therefore to limit explosion risks.

7.2.8.5 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.

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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.

7.2.8.6 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 considers

— 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 A;

— 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.

7.2.8.7 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, considering 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 considered 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 considered:

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.

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7.2.9 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).

7.2.10 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 consider 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 A gives some typical examples of ventilation diagrams.

7.3 Filtration

7.3.1 General

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.

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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, T3/T4) that have a high-risk contamination classification. Informative layouts are provided in Annex A.

7.3.2 HEPA filters

The design of HEPA filters for fusion facilities 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 E). 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 8.6.

7.3.3 Air detritiation system

Tritium nuclides contribute a major part of the radioactive inventory in the case of routine operations as well as in an accident, so the associated chemical process requirements shall be implemented very carefully. The detritiation process was deployed in several nuclear facilities. The success of such systems for reducing stack emission and work exposure to tritium has resulted in their deployment in every major fusion facility.

Tritium may be in various forms such as elemental, oxide, hydrocarbon and adsorbed in aerosols.

As a preliminary step, tritium in all forms is collected in process volumes or rooms into duct layouts qualified to withstand all the conditions of the rooms.

In order to protect and make easier the detritiation process steps, several devices can be implemented depending on the safety analyses regarding the streams to detritiate in routine or accident conditions:

— Generally, an HEPA filtration step in order to reduce the concentration of aerosols, tritiated or not, in the streams to detritate: this has a double positive effect, it reduces thanks to the HEPA filtration, the tritium under aerosol form and avoids to send aerosols to the detritiation core that would lead to a lower detritiation efficiency and waste effluents issues (especially in case of polluted environments such as in a fire event).

— In case of too hot collected streams, a cooling system of the stream can be implemented in order to maintain an optimal temperature of the stream to detritiate.

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— In case of collected streams with potential chemical products (e.g. acids), a specific chemical stage can be implemented (e.g. passivation columns).

Annex B provides examples of detritiation technologies.

In the detritiation core, two main steps are deployed: a tritium conversion step (transforming gaseous tritium into tritiated vapour), and a tritium vapour collection step:

The first processing step consists in sending the collected streams to chemical/thermal process (catalytic recombiner at high temperature) converting, and cracking the gaseous molecules into water vapor to transform the tritiated mixture into streams easier to detritiate. The tritium oxidation step is accomplished by heterogeneous catalytic reactors at several temperatures depending on the chemical tritiated forms (around 170 °C for elemental form, more than 300 °C for more complex chemical forms).

After this oxidation step, there may be a cooling step in order to improve vapour condensation.

The tritium vapour collection step is performed by;

— either molecular sieve-based adsorbers (tritium traps), that will need to be regenerated later in fuel cycle systems, removing then the tritiated vapour prior to its discharge in a stack (or reprocess into fuel cycle systems),

— or scrubber columns. The latter is a counter-current contactor between a gaseous stream containing tritiated water and another stream of liquid tritium-free water. This step divides the streams into a concentrated tritiated liquid, sent to liquid tritium treatment system in fuel cycle systems, and a detritiated stream sent to the discharge stack.

The requirement for tritium conversion and tritium collection shall be defined to reach the decontamination factor required for detritiation system. The tritium decontamination factor 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 considered with regard to this objective:

a) the decontamination factor required during routine situations and during accidents, associated with the different tritium chemical forms;

b) the qualification of detritiation system during the whole accident period;

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

The decontamination factor of detritiation system depend on oxidation and trapping efficiency. Sensibility to parameters depend on the selected technology. Oxidation efficiency is sensitive to:

— temperature control of the oxidation reactor bed;

— residence time (ratio of volume over the flowrate passing the reactor bed);

— ageing due to short- or long-term poisoning (such as halogens)

— chemical form of the tritium released during an accident (e.g. elemental, oxide and hydrocarbon).

Tritium trapping efficiency is sensitive to:

— Tritium inventory in the device prior to test and tritium concentration upstream (for molecular sieve);

— Ratio between water vapor to liquid water (Scrubber column).

Therefore, the following provisions shall be considered.

a) In order to limit, upstream from the tritium trap, the maximum temperature, which can degrade detritiation factor, a thermal study for all routine or accident conditions shall be performed in order to assess the need for a cooler to be installed upstream from the device. Relevant information shall be continuously available in order to control the parameter. It shall be demonstrated that the provisions

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with respect to the maximum value of each component, mixture or parameter are adequate either by design feature or by monitoring and control.

b) In order to ensure high efficiency and the optimum retention time of tritium inside the trap, the air-speed limit shall be lower than the value achieving this goal (i.e. 1 to 1,1 m/s for oxidation or tritium trapping). It shall be demonstrated that the provisions with respect to this value are adequate.

c) Stand-by detritiation system shall be tested as frequently as those in normal operation.

d) The chemical form of tritium 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 detritiation system, when used in stand-by mode, can guarantee their efficiency at an early stage of tritium release into a containment/enclosure. 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) Detritiation system function shall not be damaged by foreseeable fire risks (internal to the ventilation systems as well as in the rooms where the process 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 process and limit the releases into the environment due to the destruction of this detritiation system (e.g. appropriate fire dampers installed on the ventilation systems for the detritiation system and on the overall ventilation system of the surrounding room). Sensor can be in stand-by while used only during the periodic efficiency test.

g) When fire risks exist, provisions shall be adopted that prevent detritiation system destruction from external fire (e.g. insulation) and internal fire (e.g. appropriate fire dampers on the ventilation systems of the detritiation system and on the overall ventilation system of the surrounding room). Exhaust ventilation/detritiation ducts should be located at the lowest part of the rooms in order to continue the detritiation function the longest as possible.

h) Packed bed used for detritiation system shall be designed to increase surface contact between gas processed and trapping solid or liquid.

Decontamination factors for tritium in fusion facilities are generally (depending on the specific needs required by the safety analyses, these values can be higher or lower):

— 10 for gaseous or vapour tritium in accident situations that involve chemical products that are likely to reduce detritiation efficiency (e.g. halogenated products produced in fire conditions);

— 100 for all gaseous or vapour tritium form in routine or all other accident situations in which detritiation is required (e.g. tritiated water leaks, tritium leaks);

— 1 000 for tritium aerosols; corresponding filtration is ensured by at least one HEPA filter stage, more HEPA filters in series could bring higher decontamination factors.

It shall be noted that these values are not equivalent in terms of retention.

In a general way, halogenated products should be avoided in nuclear facilities using airborne detritiation systems, since these halogens, once released in rooms (e.g. in fire conditions), will generate chemical species in catalytic reactors that reduce the efficiency of detritiation systems.

Periodic in situ tests shall be performed for all stand-by detritiation systems. The periodic tests include tritium detritiation factor as well as the tests of all the parameters that support the detritiation efficiency (e.g. catalyst temperature sensors, air flows sensors, inlet water temperature and flowrate sensors, tritium detection sensors). For the detritiation systems that are routinely used to detritiate effluents, the ratio of tritium concentration between upstream/downstream the system is enough to quantify routinely the DF, together with period tests of all the parameters that support the detritiation efficiency. For all detritiation systems, periodic tests shall be performed according to the most severe condition in the facility (e.g. air saturated of water).

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According to IAEA recommendations (see Reference [25]), fusion facilities should be designed to cope with design extension conditions. Therefore, the filtration systems, in particular detritiation system, used to mitigate the consequences of such accidents should be designed with regard to these 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 and DEC, the detritiation system function (tritium oxidation and traps, with associated control and protection devices) should be based on redundant components, seismically classified and supported by a safety back-up power supply.

7.3.4 Other gas-trapping devices

Other gas-trapping devices, such as permeator, bed such as uranium or zirconium-cobalt, and cold trap 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. a 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.

8 Management of specific risks

8.1 Control of combustible gases in the buildings

For normal operations, as wells for abnormal/incident/accident situations, large amounts of combustible gases (e.g. hydrogen isotopes) 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 tritium/concrete interactions, tritium can also permeate to material, 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 DEC 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 [25]), the efficiency of the means of mitigation should cover the full amount of hydrogen isotopes in the systems, 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 use of local air mixers in rooms with low air change rates is a good practise in order to homogenise quickly such as to reduce below flammability limits of handled gases in the global volume.

The means of hydrogen mitigation provided can be the same for DBA/DEC conditions and for some BDBA 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.

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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 Control of cryogenic liquid/ gases in the buildings

Helium and/or nitrogen gases are used in cryogenic conditions in tritium fusion facilities with superconducting magnets. At such low cryogenic temperatures (around 4 K for helium, around 80 K for nitrogen), these gases are under a liquid form.

Several postulated initiating events assume the break of cryogenic circuits, leading to a discharge of the liquid cryogenic fluids to the areas where the circuits are located, and therefore leading to a large pressure increase in these areas (the expansion volume of these liquid to gas phases is multiplied by around 2 to 3 orders of magnitude). This phenomenon creates high pressure loads and cold thermal shock loads inside rooms and buildings, able to challenge on confinement systems if no pressure escape pathway is found to decrease the pressure.

The design of cryogenic circuits shall consider all the loads, in particular mechanical or thermal loads, that would lead to create a vaporisation of these liquid fluids inside the circuits or in the rooms. The design pressure of these systems shall consider a plausible increase of pressure inside the circuits from local or global vaporisation of these fluids inside the circuit. In that sense, the "confinement" of these fluids inside circuits (with expansion volume inside circuits, i.e. quench tanks) shall be ensured for all internal or external events when these events would cause the spread of radioactive materials in the facility. The cryogenic circuits should ensure the continuity of the safety barriers properties, e.g. for penetrations across confinement barriers.

Expansion volumes for these gases inside rooms, in case of circuit break or opening, shall be studied such as to avoid the pressure to exceed the building and rooms design pressure values. When the cryogenic systems are implemented in rooms that are likely to be contaminated, or when the pressurization effects can affect rooms likely to be contaminated, then these expansion volumes shall be located in confined buildings with leaktight properties.

When it can be proven that neither the cryogenic gases nor the rooms with potential pressuring effects from a cryogenic circuit break can be contaminated, then the discharge pathway can be directly connected to the environment without going through a confined volume.

The design of these escape expansion pathways should take consideration of the use of relief panels, rupture disks or flaps. If they ensure the continuity of safety barriers, these devices shall be able to reclose tightly such as to ensure the initial role of the safety barrier; if such pathway is implemented on, or crosses a safety barrier (fire sector or confinement barrier), the safety barriers properties shall be reconstituted.

These systems require an adequate management such as to be able to continue to confine hazardous materials of the facility and to continue to control fire risks.

8.3 Management of ambient conditions

8.3.1 Tritium airborne contamination

Tritium adsorption on surfaces and desorption from surfaces, as well as tritium permeation are natural physical phenomena that occur even at ambient temperatures.

These phenomena are of safety interest when outgassing would lead to tritium airborne contamination, and is related to temperature increase. This is particularly the case for tritiated components and waste.

Therefore, the control of ambient conditions shall be performed in areas where tritium is present in tritiated components and waste. In such a case, the air conditioning function ensured by ventilation systems helps in maintaining the room airborne contamination zoning.

NOTE The experience feedback has shown visible higher effects for room temperature higher than 50 °C.

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8.3.2 Air conditioning of safety-classified components

Rooms containing safety-classified components shall identified and be ventilated in order to maintain the range of temperatures required for the safe operation of these components[2)].

Requirements for the air-conditioning function of these rooms shall be consistent with the importance of the safety-classified components in the safety analysis, as well as dew point control.

The sizing of the heating and cooling capacities shall consider 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 equipment (including control rooms)	5 °C	15 °C	25 °C	35 °C
Pumps	5 °C	15 °C	25 °C	45 °C
Back-up power supply equipment (e.g. diesel generator)	10 °C	15 °C	35 °C	40 °C

For rooms with permanent tritium contamination levels (e.g. more than 0,1 DAC) or containing tritium handling systems, high levels of air humidity in rooms would lead to produce liquid tritium quantities once detritiated. Therefore, for such rooms, producing less tritiated water should take precedence to maintaining a comfort function regarding the air conditioning humidity for workers comfort.

8.3.3 Ventilation systems of the control rooms

8.3.3.1 General

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.

8.3.3.2 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:

- 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;

2) 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.

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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.

8.3.3.3 Specific requirements for the design

The following specific requirements shall be introduced for these systems:

— implementation of a positive pressure in the MCR ventilation systems to avoid air infiltration without filtration in the MCR;

— implementation of specific filtration systems equipped with aerosol filters (and for some cases with iodine filters e.g. for cases with adjacent fission facilities; in such a case, with implementation of air humidity control such as heater upstream from the iodine filters to reduce water adsorption phenomena to maintain the iodine filters efficiency in all weather conditions) on the air-inlet of the ventilation system of the control rooms used for managing accidental situations for the long-term habitability function;

— 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.

8.4 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.

8.5 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;

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— 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.

8.6 Prevention of fire hazard

8.6.1 Compartmentalization

To inhibit the spreading of a fire, the best strategy for prevention consists of creating fire compartments (FC), sometimes called fire sectors, 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 8.6.3.

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 considered 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.

8.6.2 Fire compartments (fire sectors)

Fire compartments shall fulfil the following requirements:

a) The walls and the material of construction of a fire compartment boundary (including its penetrations) shall be designed to resist to 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 consider the constraints due to maximum pressure variations (that could reach a few kPa as positive or negative 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 (such as HEPA filters, more rarely 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.).

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 target in terms of maximum tritium inventory and a maximum explosive gas inventory shall be established for fire compartments; specific safety prevention provisions shall be implemented in order to avoid these inventories to be spread in fire scenarios.

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g) 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:

— ensure the control of the dynamic confinement as long as possible during and after the possible fires considered in the safety analysis;

— minimize creating the risk of an explosive atmosphere within the containment areas or rooms, this point is a major key point in fusion facilities where hydrogen isotopes are handled, requiring to perform specific analyses aiming at calculating heterogeneous diffusion of these hydrogen isotopes;

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

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

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 consider the following.

  — 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 phenomenon, 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 considering the maximum leak rate of the fire compartment.

  — Air mixing systems shall be implemented in fire compartments where there is a risk of local concentration above the flammability limit, in order to reduce detonation risks.

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

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— 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 insulation materials shall be implemented on the ductwork between the fire dampers and the walls in order to reconstitute the fire compartment boundaries, except if it can be demonstrated that the fire compartmentalization is maintained.

— 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;

— 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.

8.6.3 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

8.6.4 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.

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— 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.

The interfaces between normal HVAC and ventilation systems equipped with detritiation systems implemented in the same rooms or in adjacent rooms shall be studied such as to avoid by-pass pathways of the detritiation systems. Specific I&C, based in particular on adequate room or duct contamination monitoring, shall be implemented in order to stop normal HVAC either when the safety demonstration does not foresee its maintain under operation, or when this normal HVAC is likely to release contamination without passing through the stacks and their stack radiological monitoring system.

Fire extinguishing systems shall be implemented in fire compartments enclosing radioactive substances where human intervention is not possible (e.g. because of magnetic fields, of external radiation or of atmospheric contamination, or other risks in the rooms), except if it can be demonstrated with qualified codes and robust assumptions that the fire duration can be limited naturally to a duration lower than the fire compartment resistance duration (e.g. by oxygen starvation).

8.7 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 / confinement 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 confinement 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 considering 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;

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— 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 balancing 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 confinement systems;

b) 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 balancing dampers on air intakes or exhausts and to a specific operation of ventilation systems;

c) 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;

c) with regard to earthquakes, safety-classified confinement systems should have a seismic classification (e.g. integrity, operability).

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 confinement systems, as well as the support systems necessary to operate the confinement systems (electrical systems, cooling systems, air compressed, demineralised water, radiological measurements, instrumentation and control, etc.) 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 consider the availability of the different components and equipment comprising the protection against internal

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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, as well as the support systems necessary to operate the confinement systems.

This addresses the need to distinguish operation modes:

— where plasma operations are done and the vacuum vessel under vacuum conditions;

— maintenance is performed on components without affecting confinement barriers; in such conditions, the workers may be present according to the room ventilation zoning, with specific provisions considering external exposure radiation zoning;

— maintenance is performed on confinement barriers with opening operations of confinement barriers; these situations incorporate notably the situations where:

  — the vacuum vessel is not anymore under vacuum and maintained at a negative pressure using detritiation systems;

  — plasma facing components are removed from the vacuum vessel and transported into other rooms, using transfer leaktight confinement devices;

  — other opening of confinement barriers outside the vacuum vessel (e.g. pipes containing tritium, glove boxes);

  for these situations, the abnormal or accident conditions that can occur during maintenance situations shall be studied such as to assess the contamination risks and external exposure risks on the workers with regards to the facility zoning.

For the maintenance situations, the additional risks involved in routine, abnormal or accident conditions that can occur shall be studied such as to reduce the contamination risks and external exposure risks on the workers with regards to the facility zoning and the potential releases,

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 confinement systems and their necessary support systems, limiting values for certain parameters that should not be exceeded in order to maintain the functionality (i.e. 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 confinement systems 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 (including detritiation) 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.

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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 confinement 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;

— emergency exercises.

9.4 Test procedures and maintenance

9.4.1 General

The confinement systems, their necessary support 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 9.4.2 to 9.4.5.

9.4.2 Qualification

The qualification process for all safety confinement systems and the systems supporting the confinement function shall be performed; evidences of this qualification shall be kept in a traceable process. This applies also to detritiation system qualification process for all conditions, e.g. tritium concentration, flowrate or pollutants presence, in which detritiation systems are supposed to operate.

9.4.3 Pre-commissioning inspection tests

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.).

The use of traces of tritium during pre-commissioning tests inside the fusion facility is not recommended.

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9.4.4 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:

— ventilation and detritiation networks, ducts, dampers or control valves and associated flow dynamics equipment, including motordriven fans and continuously adjustable compensation dampers;

— regulation and monitoring networks, gas trapping and filtration systems;

— fire dampers and fire detection systems;

— associated fluid (e.g. compressed air, inert gases, demineralised water used in scrubber columns) and electricity supplies;

— tightness of confinement barriers.

Acceptance tests shall be undertaken in conditions as representative as possible of the operational conditions specified for the design of the confinement systems, their necessary support systems and their associated monitoring and control equipment. 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 conditions of the confinement 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, partial or total failure of a support equipment, 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.

9.4.5 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 conditions of the confinement system (e.g. flow dynamics of the ventilation system). For this purpose, the operators shall adjust the leak detection, air flow rates and the negative pressures using appropriate regulation devices.

The verification of all of the confinement 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;

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

f) the instrumentation and control devices with all thresholds are in operation.

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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). The use of tritium during commissioning tests inside the fusion facility is not recommended. Nevertheless, if required to perform commissioning tests demonstrating the safety of the facility, such a use is submitted to the same risk's assessments than the ones during operation (contamination, workers exposure, waste, releases, etc.)

In addition to the air flow verification and filter testing described above, the complete confinement system should be tested to ensure that it meets the functional requirements both during normal operation, abnormal and accident conditions. For accidents, the representativity of the tested accident conditions shall be demonstrated. 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.

The design of the containment systems shall provide the capability for proving that the leak rates assumed in the safety analysis are maintained throughout the operating lifetime of the plant; it may be done by commissioning tests using the methods developed in ISO 10648-2. The commissioning tests can be performed at the full design pressure of the leak rates used in the safety analyses or at a reduced pressure.

Testing with a reduced pressure with regard to full design pressure is acceptable 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, depending on the proportionate risks associated with each containment barrier and the use of the leak rates in the safety analysis (i.e. in the safety analysis, the function of a leak rate in limiting direct radioactive releases in an overpressure accident event involving high levels of tritium is more important than its function of reducing low level tritiated effluents in normal situations).

9.4.6 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 barriers (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

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measurements. The methods, periodicities and accuracy of these tests shall be defined, considering 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 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 using the methods developed in ISO 10648-2. The in-service leak rate tests shall be performed periodically at least every ten years, and may be made at either

— a reduced 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 when commissioning tests have been performed at the design pressure; 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 is acceptable 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, depending on the proportionate risks associated with each containment barrier and the use of the leak rates in the safety analysis.

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 confinement 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 operation of ventilation

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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 depends 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, consider 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 document, 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

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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 consider the safety rules applied according to IAEA principles. According to the principles, some safety rules should be carefully assessed, 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, such as 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 for non detritiated streams, and the one(s) protecting the detritiation systems for detritiated streams;

— of a smoke detector downstream from the last extraction HEPA filter for non detritiated streams, and the one(s) protecting the detritiation systems for detritiated streams;

— 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 for non detritiated streams, and the one(s) protecting the detritiation systems for detritiated streams.

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 as well as the one(s) protecting the detritiation systems.

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, considering contradictory aspects such as:

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

— stratification of hydrogen isotopes concentration, which may be above deflagration risks or detonation risks limits, and

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

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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 Instrumentation and Control (I&C)

10.1 Control

The details of the control system are determined by the architecture of the confinement systems and its necessary support systems 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 consider common cause failures of control systems (notably in the case of fire, earthquake, flooding, site contamination). The I&C for the necessary support systems of confinement systems shall be submitted to the same safety requirements than the confinement systems themselves.

Critical confinement 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;

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— continuous monitoring of the status of fire detectors and dampers, motorized control dampers, regulation valves, detritiation systems support systems, 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 confinement 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;

— pressure drops in filters (HEPA filters, detritiation systems, etc.) and in tritium monitoring systems;

— 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 and rooms;

— activity concentration in specific ducts (i.e. servicing highly contaminated rooms, requiring actions on the ventilation systems) and across detritiation systems core components (upstream/downstream catalytic reactors, scrubbers, liquid flows to water detritiation systems.

These alarm indications shall be relayed to the control rooms for the confinement systems and be relayed to the emergency control room with indications of their source.

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Annex A
(informative)

Guidance on airborne contamination risks

A.1 Guidance on classification of type of ventilation for tritium fusion facilities

Table A.1 indicates a guidance on the classification of rooms derived from ISO 17873:2004, Annex B, adapted for tritium fusion facilities, according to the specific levels of airborne aerosols contamination (C_A) and tritium contamination (C_T), together with the global contamination ($C_G = C_A + C_T$). A comparison with ISO 17873 is made hereafter. Both contaminations are expressed in DAC number

Table A.1 — Classification of rooms for tritium fusion facilities

		Specific tritium classification		Specific classification for aerosol and nuclides else than tritium		Global classification (expressed in DAC)	
Specific permanent contamination (DAC)	Specific contamination in accidents (DAC)	Tritium confinement class based on C_T(T*x*)	Requirements on filtration	Aerosol confinement class based on C_A(A*x*)	Requirements on filtration	Global classification based on global contamination (DAC) $C_G = C_T + C_A$	Requirements
0	≤1	T1	/	A1	/	C1	Requirements similar to ISO 17873, except for filtration and adaptations for air change rates
<<1	≤80	T2		A2	Similar to ISO 17873	C2	
≤1	≤4 000	T3	with exhaust likely to be detritiated if a contamination threshold is exceeded	A3	Similar to ISO 17873	C3	
≤1	≥4 000	T4		Included in C4* class in ISO 17873		C4	
≤80	≤4 000	T4*	with permanent detritiation for in-leaks	A4*	Similar to ISO 17873	C4*	
≤4 000	≥4 000	T4**	with purge and permanent detritiation for in-leaks	A4**	Similar to ISO 17873	C4**	
>4 000	≥4 000	T4***	with recycling and permanent detritiation to extract in-leak	A4***	Similar to ISO 17873	C4***	

NOTE 1 The DAC number is calculated in this document from ICRP 103:2007, Appendix B[19].

NOTE 2 The contamination calculation considers the contribution from all nuclides, including tritium. As a convention, the confinement class can be written as A*x* if the classification is due to aerosols, T*x* if it is due to tritium, C if it is due to the global contamination from aerosols and tritium.

NOTE 3 The real class depends on the safety analyses associated with the spread of radioactive materials in the rooms.

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For instance, if the contamination in normal operation is less than 1 DAC for both tritium and aerosols else than tritium, and if the contamination in accident is 60 DAC for aerosols and nuclides else than tritium (corresponding to A2), and the tritium contamination in accident is 40 DAC (corresponding to T2), then the total contamination in the room is 100 DAC and the global room classification corresponds to the C3 category, see Table A.2. This notation is not mandatory but helps to identify the nuclides responsible for the classification.

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Table A.2 — Typical informative examples of rooms with permanent and accident contamination involving aerosols and tritium

	Permanent contamination		Accident contamination		Global accident contamination	Confinement class
	Aerosols and nuclides else than tritium	Tritium	Aerosols and nuclides else than tritium	Tritium		
External corridor barely connected to a nuclear building	<<1	<< 1	<<1	≤1	≤1	C1
External corridor connected to a nuclear building	<<1	<1	<1	<80	<80	C2
Internal corridor of tritium building	<<1	<1	<<1	<4 000	<4 000	T3
Internal corridor of Tokamak building	<<1	<1	<4 000	<4 000	<4 000 or >4 000	T3 or T4
Fuel cycle room with efficient 1st confinement system	<1	<1	<1	>4 000	>4 000	T4
Cooling loop room with efficient 1st confinement system, usual rooms adjacent to the vacuum vessel	<1	<1	<<4 000	<<4 000	<4 000	C3 or T3 or A3
PHTS room with efficient 1st confinement system	<1	<1	>4 000	>4 000	>4 000	C4 or T4 or A4
Tritiated waste storage rooms after waste detritiation	<1	<80	<1	<4 000	<4 000	T4*
Fuel cycle room with non-efficient 1st confinement system	<1	<80	<1	>4 000	>4 000	T4**
PHTS room with non-efficient 1st confinement system, specific rooms adjacent to the vacuum vessel	<1	<80	<4 000	>4 000	>4 000	C4** or T4**
Storage room for in-VV components or highly contaminated glove boxes with tritium and aerosols	>4 000	>4 000	>4 000	>4 000	>4 000	C4*** or T4*** or A4***
Purely tritiated glove box	<1	>4 000	<1	>4 000	>4 000	T4***

A.2 Associated recommended ventilation configuration

Table A.3 indicates the arrangement recommended for most of the confinement classes and associated filtration systems (the table is not comprehensive for all theoretical cases).

The following schemes are based on aerosols and tritium dissemination analysis and consequently show HEPA filters and detritiation systems, according to the permanent contamination (Pc) and accident situations contamination levels (Ac).

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

Table A.3 — Recommended ventilation layouts for different confinement classes

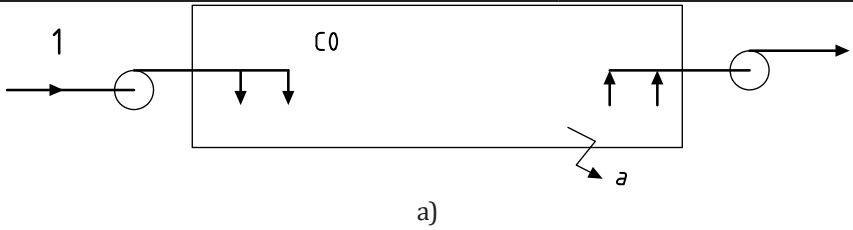
Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Non-contaminated areas	 a)	

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Table A.3 *(continued)*

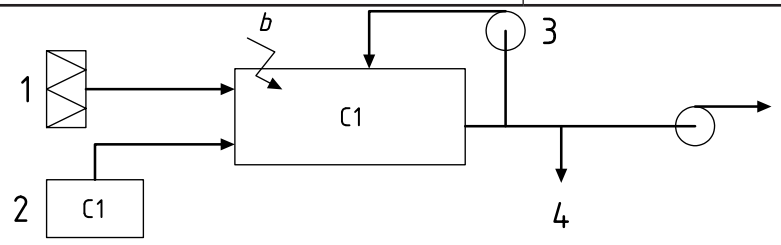
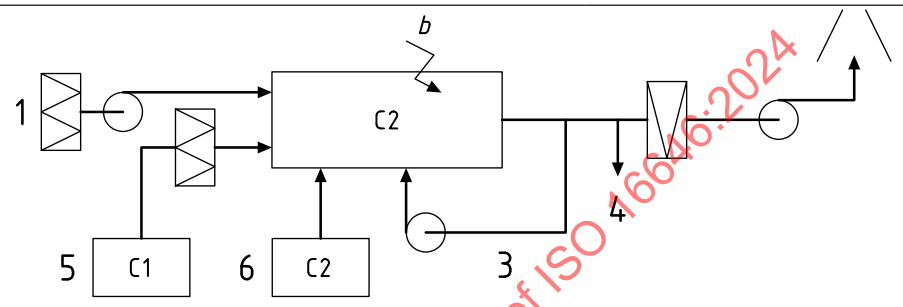
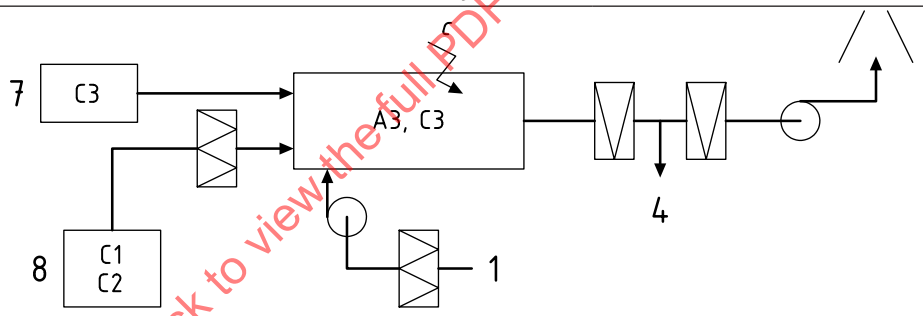
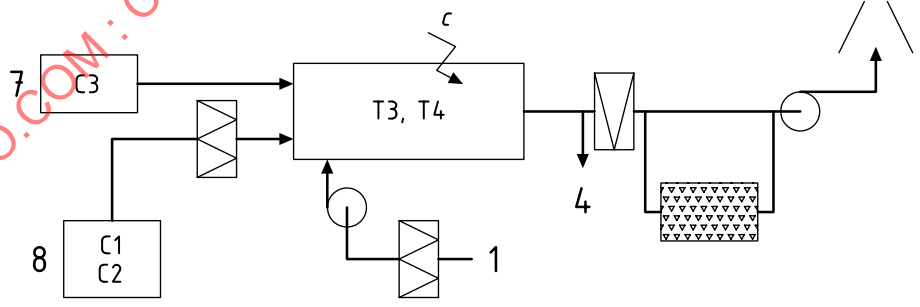
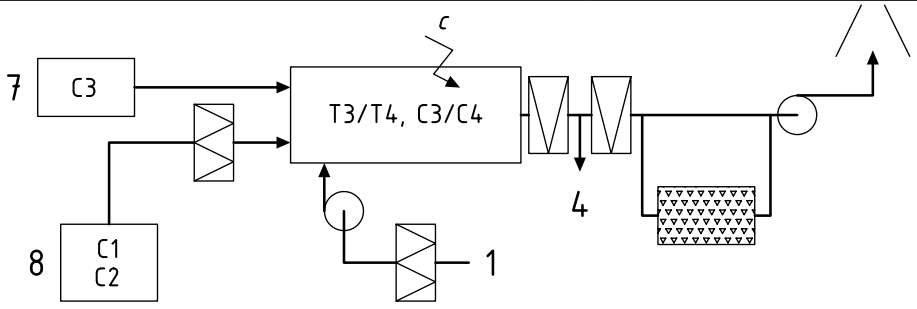
Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Pc: Not significant Ac: Low Cases concerned: A1, T1, C1	 b)	
Pc: Low for aerosol, tritium and global Ac: Medium for aerosol, tritium and global Cases concerned: A2, T2, C2	 c)	
Pc: Low for tritium and aerosol Ac: High for aerosol, low for tritium Cases concerned: A3, C3 if C_T low	 d)	
Pc: Low for tritium and aerosol Ac: High or very high for tritium, low for aerosol Cases concerned: T3/T4 if C_A low DS started on contamination threshold and all air inlet of the concerned rooms are stopped tightly.	 e)	
Pc: Low for tritium and aerosol Ac: High for tritium, high for aerosol Cases concerned: T3/T4, C3/C4 if C_A high DS started on contamination threshold and all air inlet of the concerned rooms are stopped tightly.	 f)	

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Table A.3 *(continued)*

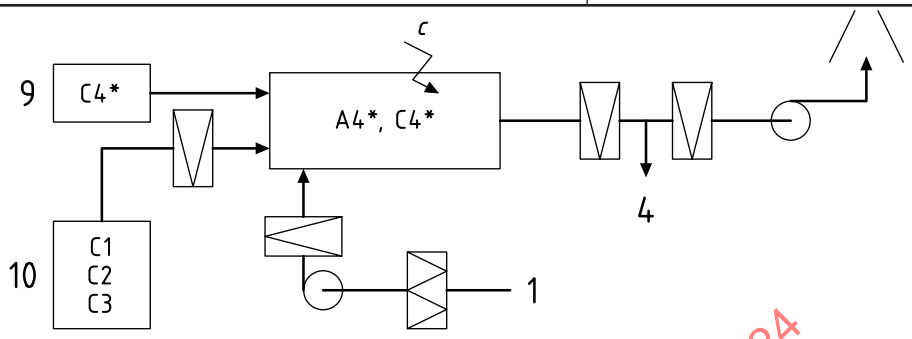
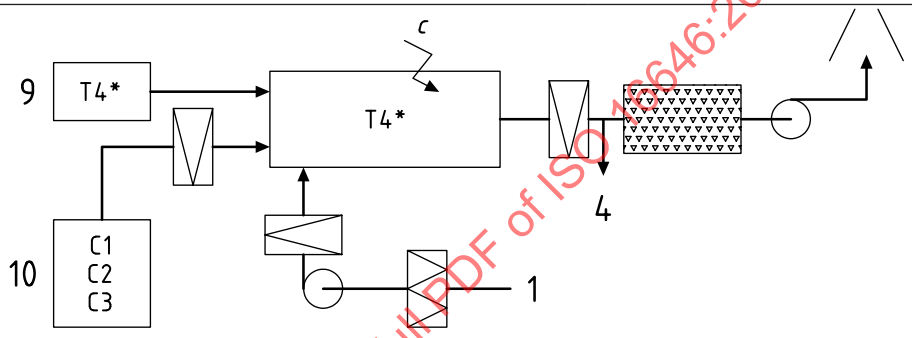
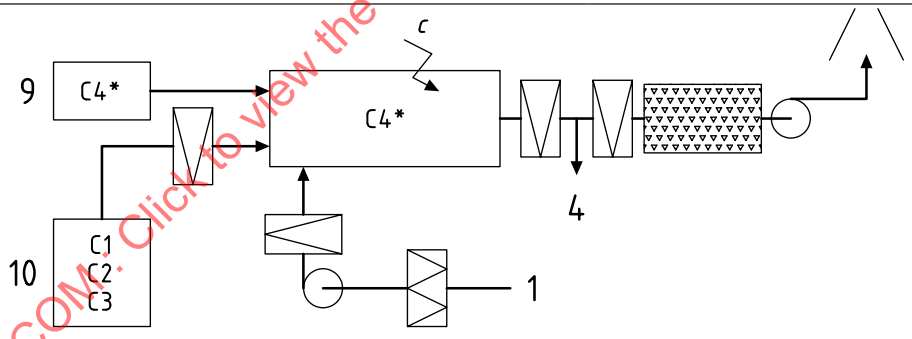
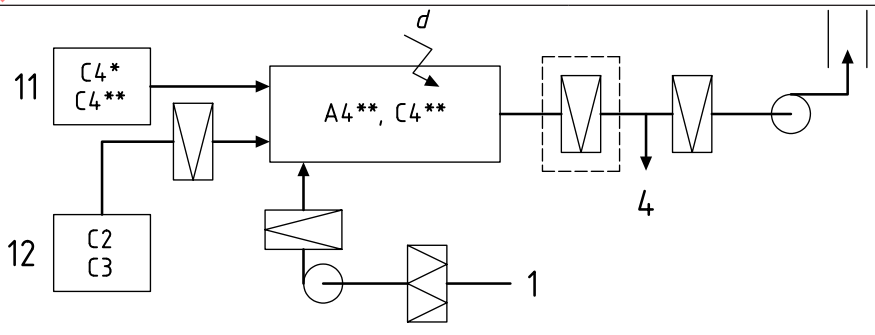
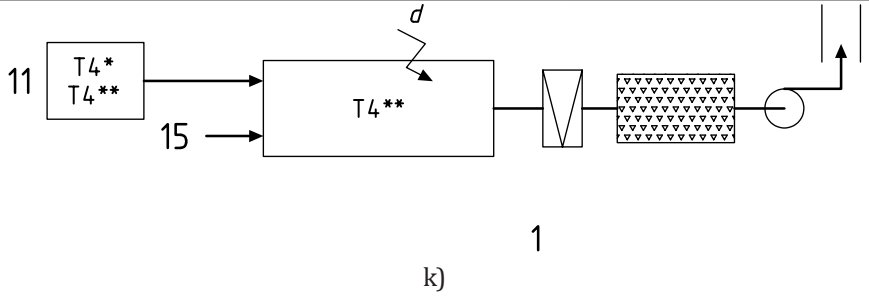
Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Pc: Medium Ac: High Cases concerned: A4*, C4* if C_T low	 g)	
Pc: Medium Ac: High Cases concerned: T4*, C4* if C_A low	 h)	
Pc: Medium Ac: High Cases concerned: C4*	 i)	
Pc: High Ac: Very high Cases concerned: A4**, C4** if C_T low	 j)	
Pc: High Ac: Very high Cases concerned: T4**, C4** if C_A low	 k)	

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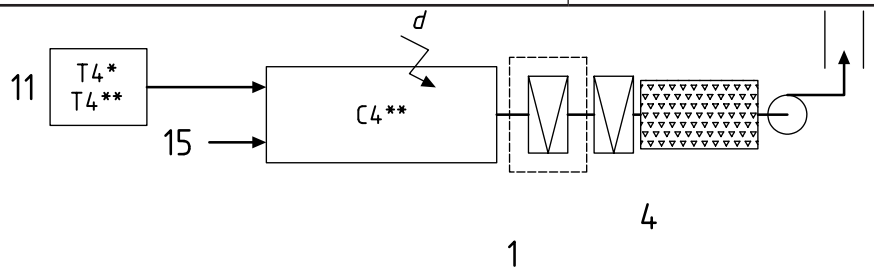
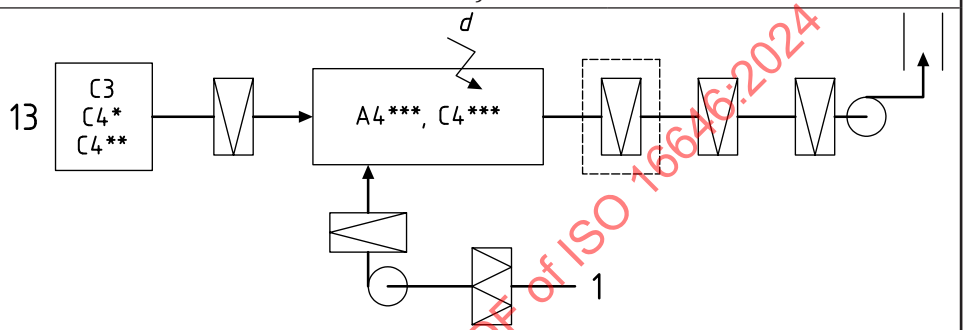
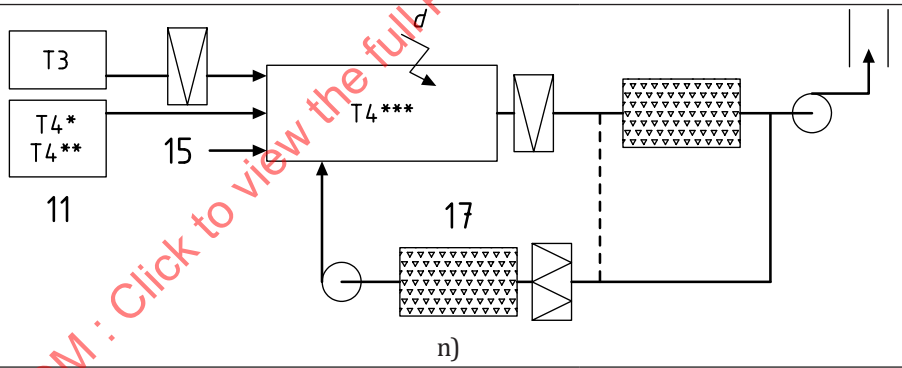
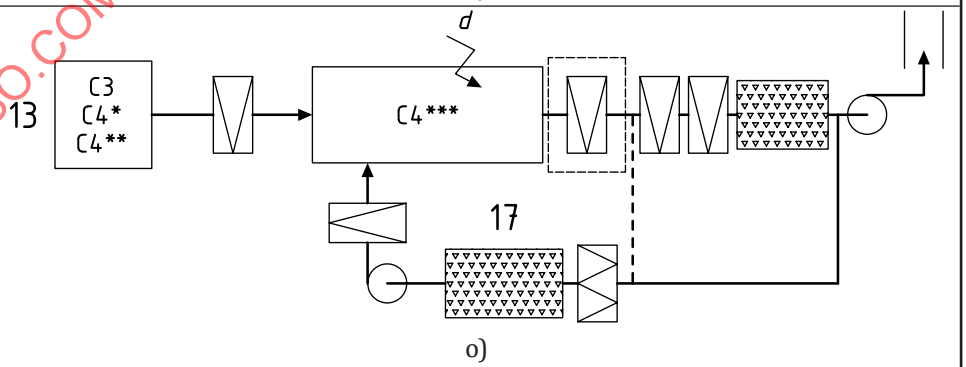
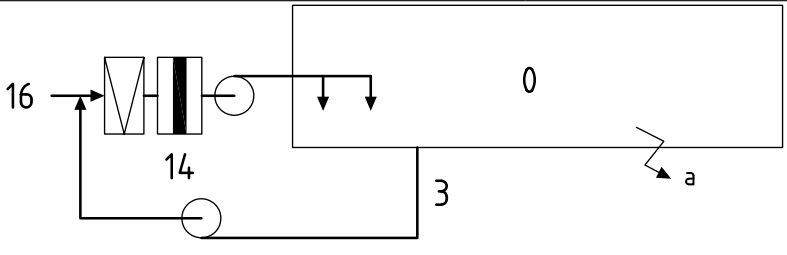
Table A.3 *(continued)*

Foreseen radioactive contamination	Organization of the ventilation systems	Filtration unit
Pc: High Ac: Very high Cases concerned: C4**	 l)	
Pc: Very high Ac: Very high Cases concerned: A4***, C4*** if C_T low	 m)	
Pc: Very high Ac: Very high Cases concerned: T4***, C4*** if C_A low	 n)	
Pc: Very high Ac: Very high Cases concerned: C4***	 o)	
Control rooms	 p)	

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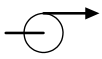
Key

Not significant	Concentration <<1 DAC
Low	Concentration <1 DAC
Medium	1 DAC ≤ Concentration < 80 DAC
High	80 DAC ≤ Concentration < 4 000 DAC
Very high	Concentration ≥4 000 DAC
Pc	Permanent contamination
Ac	Accidental contamination
0	Positive pressure in operating areas
1	Direct admission from outside of the building
2	Transfer from a C1 operating area, without filtration
3	Recycling
4	Potential transfer to the same or higher classification areas through an independent ventilation system
5	Transfer from a C1 operating area, through an industrial grade filter
6	Transfer from a C2 operating area, without filtration
7	Transfer from a C3 operating area, without filtration
8	Transfer from a C1 or C2 operating area, through an industrial grade filter
9	Transfer from a C4* operating area, without filtration
10	Transfer from a C1, C2 or C3 operating area, through a HEPA filter
11	Transfer from a C3, C4* or C4** operating area, without filtration
12	Transfer from a C2 or C3 operating area, through a HEPA filter
13	Transfer from a C2 or C3 operating area, through a HEPA filter
14	The iodine filters could be by-passed during normal operations
15	From purge gases (compressed air, inert gases)
16	The air inlet should be the least exposed to tritium releases, otherwise specific provisions to prevent tritium for entering inside the control rooms
17	Optional additional detritiation depending on the safety analyses
a	Cascade of higher pressures to non-contaminated areas
b	Cascade of lower pressures from non-contaminated areas
c	Cascade of lower pressures from non-contaminated or low contaminated areas
d	Cascade of lower pressures from low or medium contaminated areas
e	Cascade of lower pressures to operating areas
	Leakage
	Fan
	Main stack
	Collector to main stack
	Coarse or fine filter
	High efficiency filter

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