



**International
Standard**

ISO 16646

**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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html

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.

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).

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/>

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.

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](#)).

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.

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.

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 form to water form ($HQ + \frac{1}{2} O_2 \rightarrow HQO$)

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

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

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.

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.

- 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, T₂);
 - 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 (¹⁸⁷W, ¹⁸⁵W, ¹⁸¹W, ¹⁸⁸Re, ¹⁸²Ta);
 - from copper alloys (⁶⁴Cu, ⁶²Cu, ⁶⁰Co);
 - from steel (⁵⁶Mn, ⁵⁵Fe, ⁵⁸Co, ⁶⁰Co);
 - from beryllium (¹⁰Be) 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: ¹⁶N, ¹⁷N, ¹⁴C;
- activated gases: mainly ⁴¹Ar, noble gases nuclides injected to stabilise the plasma.

At last, tritium may be concomitant with almost all of these other radioactive materials (e.g. ¹⁴CTH₃).

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.

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;

- 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.

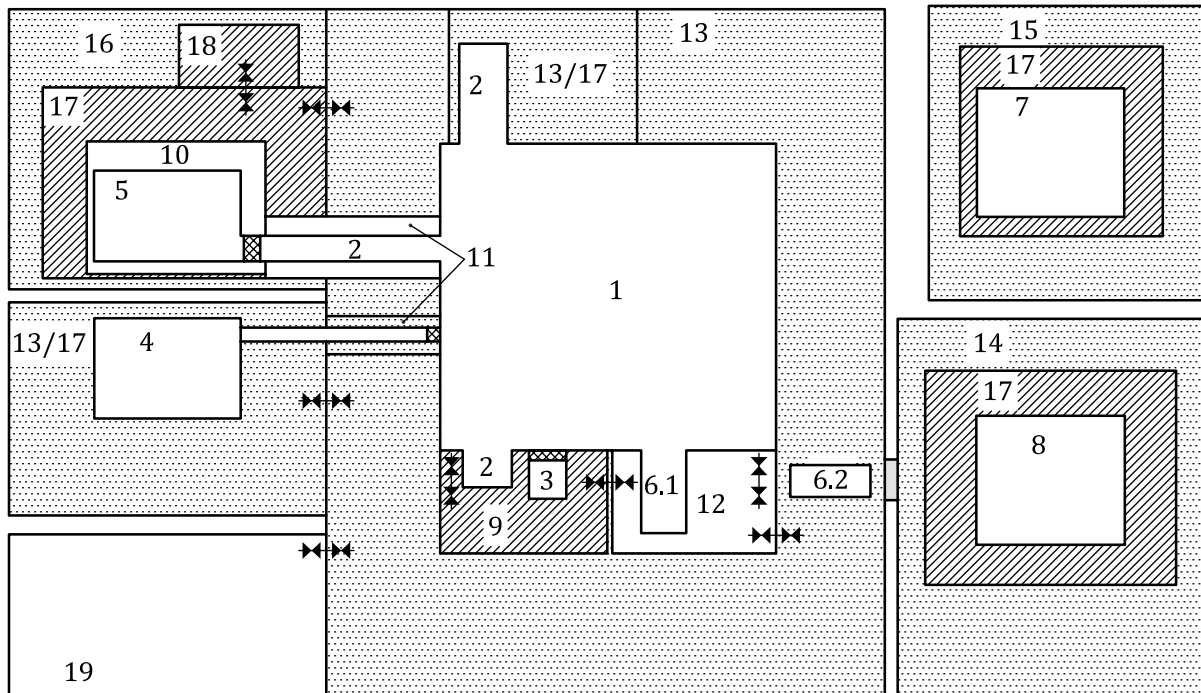
The [Table 1](#) and [Figure 1](#) present the general layout of confinement systems used in fusion facilities.

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

Type	Material form	
	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.



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

- 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.

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)

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.

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.

- 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;

- 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.

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 DEC (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

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.

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.