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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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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 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

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.