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

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

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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Introduction

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

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

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

1 Scope

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

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

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

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

2 Normative references

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

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

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

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

3 Terms and definitions

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

3.1 Accident

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

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

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

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

3.3
air exchange rate
ratio between the ventilation air flow rate of a containment enclosure or a compartment, during normal operating conditions, and the volume of this containment enclosure or compartment

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

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

3.6
barrier
structural element that defines the physical limits of a volume with a particular radiological environment and that prevents or limits releases of radioactive substances from this volume

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

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

See **containment enclosure** (3.10).

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

3.8
containment/confinement
arrangement allowing users to maintain separate environments inside and outside an enclosure, blocking the movement between them of process materials and substances resulting from physical and chemical reactions that are potentially harmful to workers, to the public, to the external environment, or for the handled products

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

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

3.10
containment enclosure
enclosure designed to prevent either the leakage of products contained in the pertinent internal environment into the external environment, or the penetration of substances from the external environment into the internal environment, or both simultaneously

See **cell** (3.7).

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

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

3.12
containment/confinement system
system constituted of a coherent set of physical barriers and/or dynamic systems intended to confine radioactive substances in order to ensure the safety of the workers and the public and the protection of the environment and to avoid releases of radioactive materials in the environment

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

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

3.14
decontamination factor
measure of the efficiency achieved by a filtration system and corresponding to the ratio of the radiological contents of the inlet and outlet of the filtration system

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

3.16
dynamic confinement
action allowing, by maintaining a preferential air flow circulation, the limitation of back-flow between two areas or between the inside and outside of an enclosure, in order to prevent radioactive substances being released from a given physical volume

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

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

EXAMPLE 1 Internal events:

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

EXAMPLE 2 External events:

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

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

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

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

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

3.21
fire damper
fire blocking valve
device that is designed to prevent, generally by automatic action under specified conditions, the ingress of fire through a duct or through the walls of a room

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

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

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

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

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

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

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

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

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

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

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

3.31
process ventilation system
ventilation system that deals specifically with the active gases and aerosols arising within process equipment (such as reaction vessels, piping networks, evaporators and furnaces)

NOTE The ventilation of the containment enclosures in which such equipment is generally located (e.g. hot cells, glove boxes, fume cupboards or high-radioactivity plant rooms) are not considered part of the process ventilation system.

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

3.33
safety flow rate
flow rate that guarantees air flow through any occasional or accidental opening, sufficient to either limit the back-flow of contamination (radioactive or other) from the working volume, or to avoid the pollution of clean products within the working volume

3.34
ventilation
organization of air flow patterns within an installation

NOTE Two systems are commonly used:

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

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

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

3.36
ventilation system
totality of network components such as ducts, fans, filter units and other equipment, that ensures ventilation and gas cleaning functions as defined in this International Standard

4 Functions ensured by the ventilation system

4.1 General

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

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

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

4.2 Main functions

The ventilation ensures the main following functions, without ranking.

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

— Between equipment, enclosures (or cells) and rooms of the same building (i.e. internal dynamic confinement), the ventilation ensures a hierarchy of pressure in order to impose a circulation of air from volumes with a low potential hazard of radioactive contamination to volumes with a high potential of radioactive contamination hazard. This dynamic confinement is also able to isolate or circumscribe, to process and to control the contamination as closely as possible to its source, at least in the reactor building and, therefore, it complements the other systems provided to protect the workers or the public against the hazards of ionizing radiations [see isolation function b) below].

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

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

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

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

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

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

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

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

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

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

5 Architecture and description of the different ventilation systems

5.1 Ventilation of the volumes within the primary containment envelope

5.1.1 General

These systems are located mainly inside the reactor building.

The ventilations systems concerned are

— either designed only for normal situations (see 5.1.2), or

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

5.1.2 Ventilation systems designed for normal operations

5.1.2.1 Ventilation systems located inside the reactor building

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

These systems ensure three main functions:

— conditioning the atmosphere;

— cleaning the atmosphere of the reactor building when people enter in the reactor building;

— purification of the reactor building atmosphere.

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

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

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

— internal and external dynamic confinement during normal operations or for minor incidents that do not lead to an increase in mass and energy in the reactor building;

— purification or gas cleaning of the reactor building atmosphere for minor incidents that do not lead to an increase in mass and energy in the reactor building;

— monitoring of gases and aerosols in the atmosphere of the reactor building during normal operations or for minor incidents that do not lead to an increase in mass and energy in the reactor building;

— isolation during accidental situations to maintain the integrity of the primary containment envelope and leak tightness.

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

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

5.1.2.3 Ventilation systems used as off-gas treatment systems

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

— purification of the process off-gases prior to their discharge into the environment;

— isolation during accident situations in order to rapidly halt radioactive releases to the environment;

— cleaning and protection by avoiding the mixing of gases in the off-gases systems with those of the room's atmosphere.

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

5.1.3 Ventilation systems designed for accident conditions

5.1.3.1 General

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

Two kinds of systems are described in 5.1.3.2 and 5.1.3.3.

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

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

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

— cleaning the atmosphere, consisting mainly to reduce the hydrogen by detection and mitigation (e.g. recombiners, systems for the homogenization or dilution of combustible gases);

— monitoring the atmosphere (pressure, temperature, humidity, hydrogen content, contamination content);

— purification of the atmosphere;

— isolation of radioactive materials contained in the reactor building atmosphere;

— confinement of radioactive products.

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

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

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

They ensure the following functions:

— confinement of radioactive materials;

— isolation of radioactive materials located inside the reactor building;