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Nuclear criticality safety — Geometrical dimensions for subcriticality control — Equipment and layout

Sûreté-criticité — Dimensions géométriques pour garantir la sous-criticité — Dimensions d'équipements et cotes d'implantation

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Foreword

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This document was prepared by Technical Committee ISO/TC 085, *Nuclear energy, nuclear technologies and radiological protection*, Subcommittee SC 05, *Nuclear installations, processes and technologies*.

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

Nuclear criticality safety is achieved by methods of control in accordance with ISO 1709. The application of some of these methods of control (such as geometry, interaction…) can lead to requirement(s) on geometrical dimension limits. This document covers subcriticality control based on geometrical dimensions, called subcriticality dimensions, related to equipment and layout.

Stages presented in this document are summarized in the flow diagram in Annex A and an example of this standard application is presented in Annex B.

Nuclear criticality safety — Geometrical dimensions for subcriticality control — Equipment and layout

1 Scope

This document provides guidance, requirements and recommendations related to determination of limits on subcriticality dimensions and to their compliance with:

— geometrical dimensions specified in the design (design dimensions), or,

— actual dimensions.

This document is applicable to nuclear facilities containing fissile materials, except nuclear power reactor cores. This document can also be applied to the transport of fissile materials outside the boundaries of nuclear establishments. Subcriticality dimension control based on dimensions and layout of fuel assembly, fuel rods and fuel pellets are not covered by this document.

This document does not specify requirements related to the control of fissile and non-fissile material compositions.

The Quality Assurance associated with the fabrication and layout of the unit based on specifications (e.g. drawings elaborated during design) is a prerequisite of this document. The Quality Assurance is important to ensure the consistency between the unit geometry, its general purpose and its intended function.

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 11311, *Nuclear criticality safety — Critical values for homogeneous plutonium-uranium oxide fuel mixtures outside of reactors*

ISO 12749-3, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 3: Nuclear fuel cycle*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12749-3 and the following apply.

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

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

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

3.1
actual dimension
actual value of subcriticality dimension, obtained by direct or indirect measurement (e.g. a mould of set dimension used for the fabrication or a template) or guaranteed by the manufacturing process previously qualified, including estimated measurement uncertainties

Note 1 to entry: Actual dimensions are usually called as-built dimensions after procurement and before commissioning.

3.2
calculation model dimension
geometrical dimension used in subcriticality calculations of a unit

3.3
dimensional margin
appropriate dimensional margin considered in the nuclear criticality safety assessment

3.4
design dimension
geometrical dimension defining the unit geometry (item dimension or layout dimension) provided before manufacturing

3.5
item dimension
geometrical dimension of a component or of equipment

EXAMPLE For a tank, item dimensions can be the tank diameter, height and material thickness.

3.6
layout dimension
geometrical dimension defining the position of several items relative to each other and in their environment

EXAMPLE For a storage of several tanks, the layout dimensions are the distances between tanks, the number of tanks in x and y directions and the distance of tanks to walls.

3.7
subcriticality dimension
geometrical dimension (item dimension or layout dimension) controlled for which a limit shall be respected to ensure subcriticality of a unit

Note 1 to entry: A subcritical dimension is a different term, usually referring to a fissile material dimension that relies on single-parameter control to avoid making a unit critical. Examples are subcritical cylinder diameter, subcritical slab thickness and subcritical volume.

Note 2 to entry: The subcriticality of a unit may be ensured by other types of controls in addition to dimensional controls (e.g. mass control, density control).

3.8
subcriticality limit
limit value of subcriticality dimension which is respected in order to ensure subcriticality of a unit

3.9
unit
part of a process or of a facility, taken into account in the nuclear criticality safety assessment, composed of single item or group of items containing fissile material and by their surrounding materials not containing fissile materials

Note 1 to entry: Unit dimensions are composed of item dimensions and layout dimensions.

EXAMPLE A unit can be a glove box or a reprocessing process including the loading area, the chemical reactor and the various outlets.

3.10
unit lifetime
expected operating life taken into consideration for unit design and in the nuclear criticality safety assessment

4 Subcriticality dimensions

4.1 In the nuclear criticality safety assessment, the unit geometry is defined by:

— dimensions of items containing fissile media;

— dimensions of materials surrounding fissile items;

— layout dimensions;

— dimensions and layout of mobile items.

4.2 Some of these dimensions or distances can be required to be subcriticality dimensions. Accordingly, subcriticality dimensions shall be identified and controlled. The compliance of the actual dimensions with the subcriticality limits shall be verified to ensure subcriticality of a unit according to Clause 7. The determination of subcriticality limits is presented in Clause 6.

4.3 Limits of subcriticality dimensions may be justified using data from handbooks and/or standards (for simple cases) or from specific subcriticality calculations. For the later, requirements in Clause 5 apply.

EXAMPLE ISO 11311 contains critical values for homogeneous plutonium-uranium oxide fuel mixtures outside of reactors. That standard supports determination of subcriticality dimensions.

4.4 For conflicting effects (e.g. neutron reflection vs. interaction between two fissile items), a specific assessment can be necessary to define whether maximum or minimum values (or both) shall be ensured.

A particular attention must be paid to the definition of the subcriticality dimension in order to avoid mistakes (e.g. centre-to-centre vs. edge-to-edge).

4.5 Subcriticality limits shall take into account all configurations for which the nuclear criticality safety assessment relies upon specific dimensions. These configurations shall include normal conditions, including conditions affecting geometry such as ageing effects or pressure and temperature deformations, and abnormal conditions. Subcriticality limits may include maintenance operations.

NOTE It is possible to account for different dimensions to demonstrate subcriticality in normal and abnormal conditions.

5 Performing specific subcriticality calculations

5.1 When specific calculations are performed, the need and ability to control dimensions relevant for nuclear criticality safety (during design, before commissioning, during routine or essential maintenance and as required for Quality Assurance) shall be taken into account in defining calculation model dimensions. The choice of assumptions used in calculations should be guided by the need:

a) to define an overall conservative calculation model bounding reality so as to:

   — simplify the calculation model,

   — anticipate the potential evolutions of the design that may occur in downstream project phase(s),

b) to reduce the number of dimensions to control in order to focus on dimensions relevant to nuclear criticality safety, so as to minimize potential errors during verifications and to avoid unnecessary administrative controls.

5.2 The need to account for manufacturing and layout tolerances, defined as design constraints (6.2.1), for the definition of calculation model dimensions should be assessed.

5.3 Potential geometric distortions due to normal and abnormal conditions should be taken into account when performing subcriticality calculations.

6 Subcriticality limits

6.1 Identification and limitation of subcriticality dimensions

6.1.1 The identification of subcriticality dimensions shall be assessed by nuclear criticality safety staff. The justification of these dimensions can be guided in part or whole by:

— sensitivity calculations on dimensions and analysis of calculations results;

— handbooks or standards;

— expert judgment.

6.1.2 The subcriticality dimensions and their corresponding limits should be identified early in the design phase in order to be discussed, shared and considered by analysts qualified in design or people involved in design, suppliers and operators. In particular, the subcriticality dimensions should be determined prior to the procurement phase in order to be taken into account by suppliers for unit construction / fabrication.

6.1.3 During design, conditions affecting the unit geometry presented in 6.2.1 and 6.2.2 should be considered for the determination of each subcriticality limit.

6.1.4 Prior to the verification of actual dimensions with their subcriticality limits, normal and abnormal conditions affecting the unit geometry presented in 6.2.2 shall be taken into account for the determination of each subcriticality limits.

NOTE It is possible to account for different dimensions and/or dimension values to demonstrate subcriticality for various configurations in normal and abnormal conditions.

6.2 Conditions influencing the subcriticality limits

6.2.1 General

6.2.1.1 Conditions impacting subcriticality dimensions of a unit shall be considered in the subcriticality limit determination. Dimensions may change under the effect of such conditions. The estimation of the impact of the conditions presented in 6.2 on a subcriticality limit shall be guided in part or whole by:

a) a manufacturing standard;

b) expert judgment;

c) specific studies or lessons learned for the stresses and the ageing effects on unit dimensions.

6.2.1.2 Design constraints should be accounted for, unless more accurate information is obtained from actual dimension measurements. The design constraints correspond to the manufacturing and layout tolerances.

6.2.1.3 Additional dimensional margins should be taken into account for the determination of the subcriticality limits to cope with:

— difficulties during the verification such as:

 — possible changes in subcriticality dimension values due to late update during the design;

— larger measurement uncertainties not initially expected;

— the impracticality to verify by measurement, during commissioning,

— excessive ageing factors that could not be considered in the nuclear criticality safety assessment.

Some additional margins should be taken into account if design constraints are unknown.

6.2.1.4 During the design phase, if the estimation of the impact of conditions presented in 6.2.1 on subcriticality dimensions values is not available, additional margins should be taken into account in order to ensure the actual dimensions are compliant with the subcriticality limits.

6.2.2 Normal operations and abnormal conditions

6.2.2.1 General

To verify the compliance of actual dimensions with their subcriticality limits, the following shall be considered for the determination of subcriticality limits to be ensured:

a) normal operation stresses and ageing factors;

b) abnormal condition stresses.

The impact of normal or abnormal conditions on subcriticality dimensions may not be considered if subcriticality under these conditions is not justified by limiting dimensions.

6.2.2.2 Normal operation stresses and ageing factors

6.2.2.2.1 The present and expected future distortions due to the operation stresses or ageing factors shall be taken into account when impacting subcriticality dimensions. They correspond to:

a) mechanical stresses due to the operating conditions, such as pressure or temperature;

b) abrasion due to repeated frictions;

c) corrosion due to chemical reactions;

d) other ageing effects that may affect a dimension, such as fatigue.

6.2.2.2.2 The distortions due to corrosion, abrasion and other ageing effects during the unit lifetime shall be considered. If the lifetime of the equipment is extended, the impact of distortions on unit dimensions shall be revised accordingly in order to determine any impact on subcriticality limits.

6.2.2.2.3 The need to perform specific or periodic testing and/or inspection in order to validate the estimation of the impact of normal operating stresses and ageing effects on subcriticality dimensions shall be assessed and, if required, should be performed at suitable times during the life of the unit.

6.2.2.3 Abnormal condition stresses

6.2.2.3.1 The potential impact on the actual dimensions due to identified hazards (e.g. distortion in case of earthquake, fire, load drop, pressure increase) shall be accounted for when determining the subcriticality limits.

6.2.2.3.2 The need to perform specific or periodic testing and/or inspection to identify excessive ageing factors (corrosion, erosion, wear) shall be assessed.

7 Actual dimension control

7.1 Compliance of actual dimension values with the subcriticality limits

7.1.1 During design and prior to fabrication, the compliance of the design dimensions with their subcriticality limits should be verified.

7.1.2 The actual dimensions shall be verified to comply with associated subcriticality limits:

— prior to commissioning a new or old unit;

— following a modification to an existing unit which could affect the subcriticality dimensions of a unit;

— following carrying out maintenance operations on a unit which could affect the subcriticality dimensions of a unit;

— following any upset condition that has the potential to affect the subcriticality dimensions of a unit;

— at any period identified in 6.2.2.2.3.

7.1.3 The number of measurement points for the dimensional control of actual dimensions shall be justified. When several measurements are made, the value taken into account for the verification (e. minimal, maximal, average …) shall be justified.

7.1.4 The verification shall be documented. This documentation should present the ongoing subcriticality limits to be respected during the unit lifetime and the actual dimensions. This documentation should present a bounding value of the expected evolution of actual dimension during the unit lifetime in order to update subcriticality limits (impact of conditions such as corrosion …).

7.2 Management of non-compliance

7.2.1 Nuclear criticality safety staff shall participate in the assessment of non-compliances.

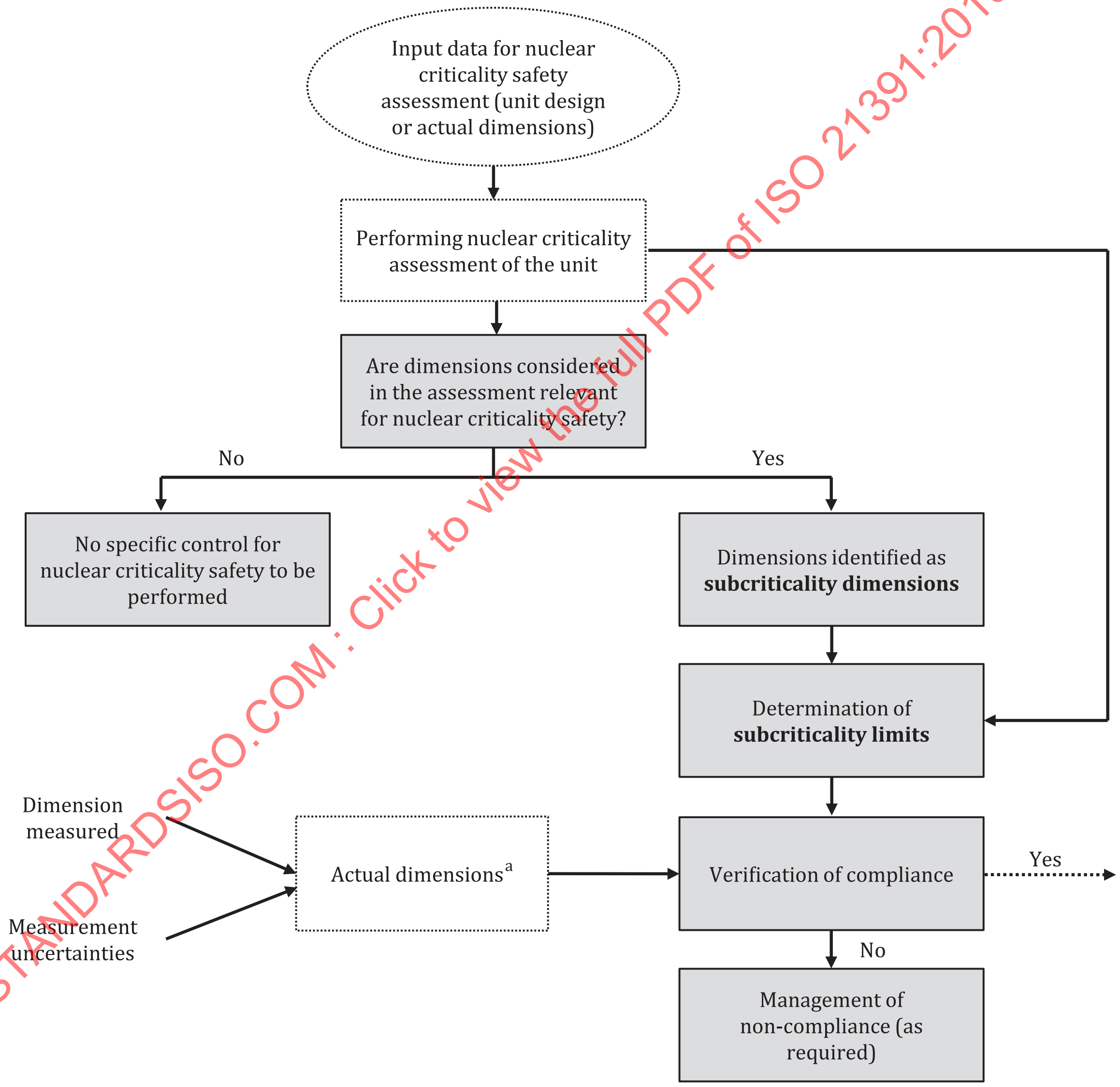
7.2.2 In cases where operations have commenced or are ongoing, the need to cease operations shall be evaluated if subcriticality cannot be ensured.

7.2.3 When the unit geometry is not changed to manage non-compliance, the assessment of the remaining non-compliance effect on nuclear criticality safety shall be documented.

Annex A
(informative)

Main stages for subcriticality limits determination

This flow diagram presents the main stages for determining subcriticality limits and verifying the unit design and actual dimensions with the limits. The stages covered by this document are presented in the grey blocks.



[a] In the design phase, the verification of compliance could be performed by comparing the subcriticality dimension limits with design dimensions provided by drawings, suppliers.

Figure A.1 — Flow diagram presenting the main stages of this document

Annex B
(informative)

Example

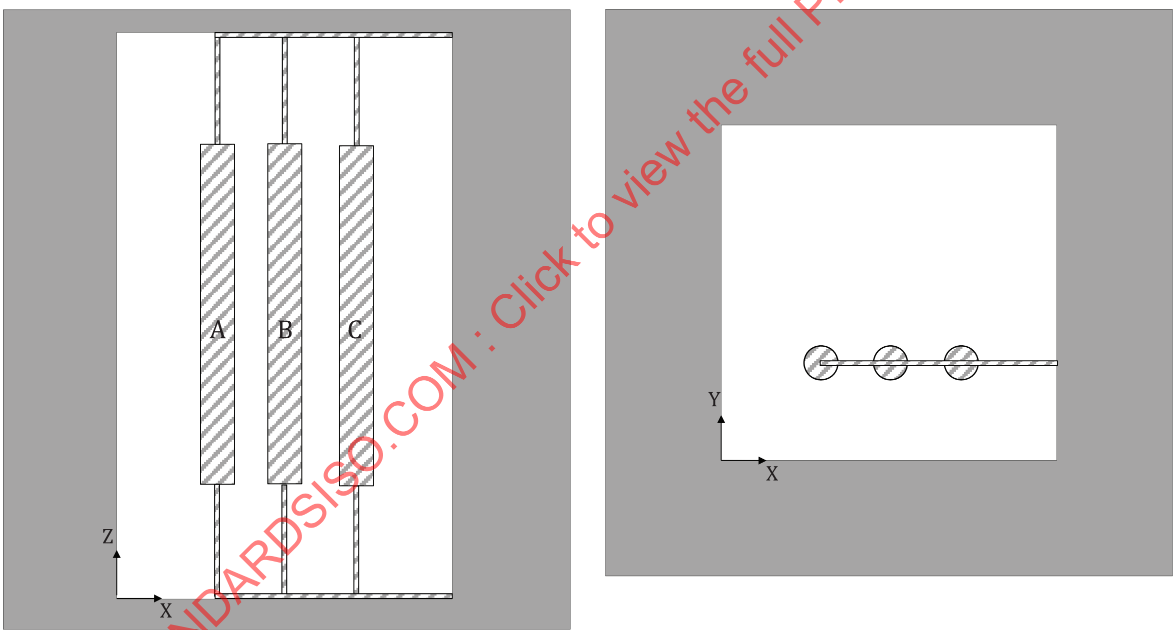
Purpose

This annex provides an example of identification of subcriticality dimensions and determination of their limits, concluding with compliance of the measured actual dimensions with the subcriticality limits.

Unit description

The unit considered in this annex is a solvent-extraction process of uranium. The unit comprises three stainless steel columns of U nitrate ($UO_2(NO_3)_2$).

The unit is pictured in Figure B.1. The dimensions considered in the nuclear criticality assessment (item and layout dimensions) are presented in Figure B.2. The nuclear criticality safety assessment accounts for the possibility of precipitation as an abnormal condition. Thus, the conservative fissile medium considered for this condition is UO_2F_2.



Key

fissile solution $UO_2(NO_3)_2$ or UO_2F_2

concrete

Figure B.1 — Unit representation

Calculation model description

The calculation model performed to demonstrate subcriticality is a simplified representation of the unit. Heights of columns are considered infinite and the small pipes, connecting columns to each other, are not modelled. This model is supposed to bound the actual unit. The calculation model is detailed in the picture below.

NOTE The definition of the calculation model for a nuclear criticality safety assessment is not covered by this document. Thus, in this example, the calculation model is supposed to be conservative.

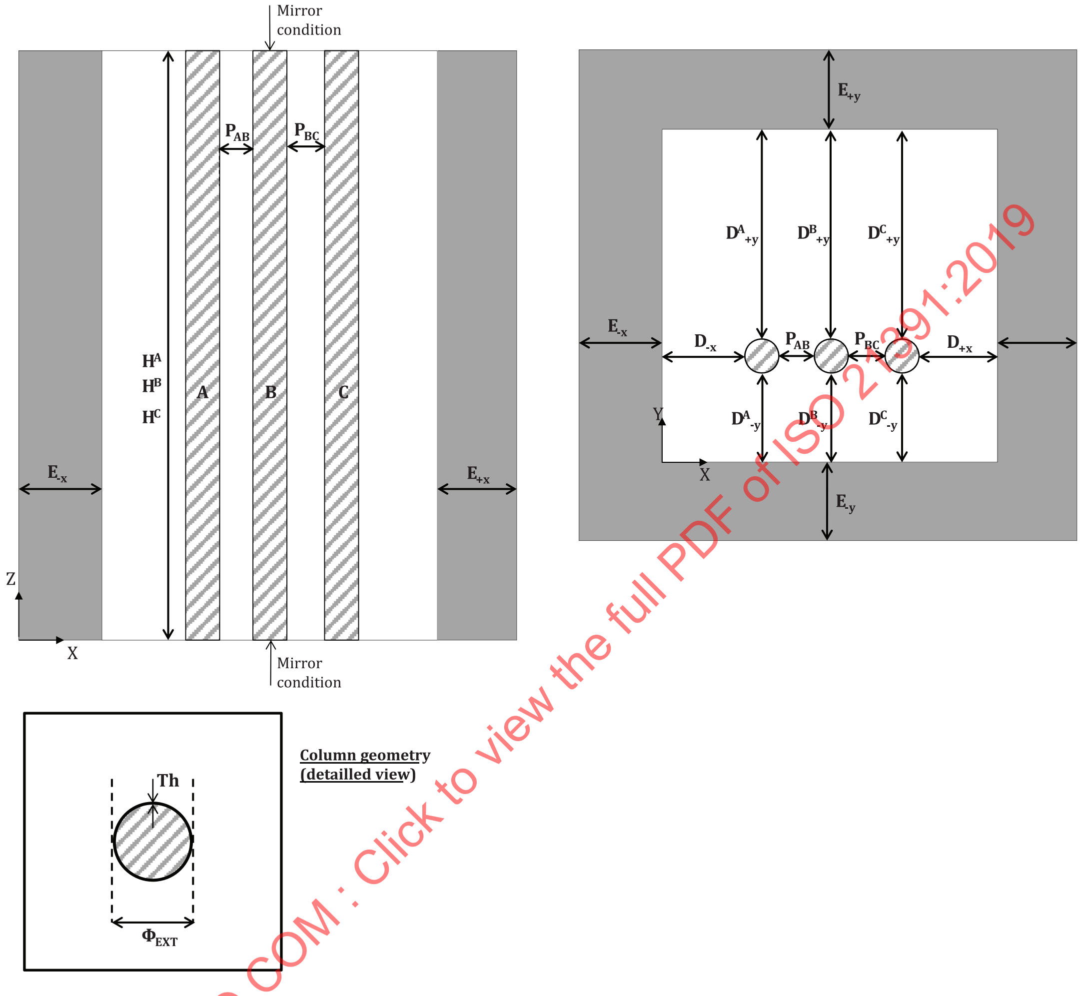


Figure B.2 — Unit representation

In normal conditions, the thickness of stainless steel (Th), a neutron absorber, is not taken into account in the calculation model. Subcriticality is justified by modelling the external diameter (Φ_{EXT}) of columns containing fissile solution...

In abnormal conditions, when the possibility of uranium nitrate precipitation is assessed, it is required to account for the thickness of stainless steel to justify the subcriticality of the unit.

The calculation model dimensions are listed in the table below.

Table B.1 — Calculation model dimensions

Dimension name	Dimension description	Calculation model dimension value cm
Items dimensions		
Φ^{A}_{EXT}	External diameter of column A	16
Φ^{B}_{EXT}	External diameter of column B	16
Φ^{C}_{EXT}	External diameter of column C	16
Th^{A}	Stainless steel thickness of column A	In normal condition: 0 In abnormal condition: 0,4
Th^{B}	Stainless steel thickness of column B	
Th^{C}	Stainless steel thickness of column C	
H^{A}	Height of column A	Infinite
H^{B}	Height of column B	
H^{C}	Height of column C	
Layout dimensions		
P_{AB}	Distance edge-to-edge between columns A and B	50
P_{BC}	Distance edge-to-edge between columns B and C	50
D_{-x}	Distance between the wall and column A - X axis	100
D_{+x}	Distance between column C and the wall - X axis	100
D^{A}_{-y}	Distance between –Y side of the wall and column A - Y axis	100
D^{A}_{+y}	Distance between column A and +Y side of the wall - Y axis	200
D^{B}_{-y}	Distance between –Y side of the wall and column B - Y axis	100
D^{B}_{+y}	Distance between column B and +Y side of the wall - Y axis	200
D^{C}_{-y}	Distance between –Y side of the wall and column C - Y axis	100
D^{C}_{+y}	Distance between column C and +Y side of the wall - Y axis	200
E_{-x}	Concrete thickness in -X side	100
E_{+x}	Concrete thickness in +X side	100
E_{-y}	Concrete thickness in -Y side	100
E_{+y}	Concrete thickness in +Y side	100

Identification of subcriticality dimensions

The identification of subcriticality dimensions is based on the nuclear criticality safety assessment of the unit (including criticality calculations results).

All dimensions taken into account are identified as subcriticality dimensions except the dimensions listed below:

— height of columns (H^{A}, H^{B} and H^{C}): the height of columns is not relevant because a variation of the height will not impact the k_{eff} value;

— thickness of concrete (E_{-x}, E_{+x}, E_{-y} and E_{+y}): the concrete thickness modelled is maximized to increase neutron reflection (full reflection). Thus, a decrease of this thickness will decrease the k_{eff} value and an increase of this thickness will not impact the k_{eff} value.

Determination of subcriticality limits

Conditions affecting subcriticality dimensions are listed below:

— design constraints (manufacturing and layout tolerances);

— corrosion of column materials;

— pressure increase;

— earthquake.

Some additional dimensional margins should be considered in the determination of subcriticality limits. In this example additional dimensional margin are not considered for small values such as thickness.

For each subcriticality dimension, it is required to determine if the limit to be respected is a maximal or a minimal limit (or both, *i.e.* an interval).

Therefore, based on the calculation model dimensions and the estimation of the impact of conditions affecting subcriticality dimensions, their limits can be determined. The table below presents the subcriticality limits.

The estimation of the impact of conditions may be determined by calculations, expert judgement, lessons learned from other units.