
**Nuclear criticality safety — Solid
waste excluding irradiated and non-
irradiated nuclear fuel**

*Sûreté-criticité — Déchets solides à l'exclusion du combustible
nucléaire irradié et non irradié*

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies and radiological protection*, Subcommittee SC 5, *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 considerations can play a significant role in the production, management, transport and disposal of waste containing fissile nuclides. Such waste can present particular challenges from a nuclear criticality safety perspective.

- The fissile content of waste can vary significantly. Most waste has a relatively low fissile content; however, there is the potential for waste to contain some items with significantly higher fissile inventory or for fissile nuclides to move and/or increase in local concentration. Typically, there are also large variations associated with the moderators, absorbers and scattering materials which make up the waste matrix.
- The uncertainties associated with the quantity, distribution, concentration and elemental fractions of fissile nuclides associated with a waste material can be large. Typically, there is also significant uncertainty associated with the moderators, absorbers and scattering materials that may comprise the waste matrix.
- Very large volumes of waste requiring criticality assessment can arise. Often the average fissile concentration can be low, but the total fissile mass can be significant.
- The physical and chemical form of waste can be very diverse, with a wide variety of potential effects on nuclear criticality safety (e.g. moderation, neutron poisons, neutron reflectors, etc.).
- The timescales that require nuclear criticality safety to be demonstrated for waste may be very long (and could be as large as hundreds of thousands of years or more when considering final disposal). Over such timescales, there is the potential for key parameters to change - for example, nuclide proportions as a result of radioactive decay, chemical changes in the waste matrix, re-distribution of fissile nuclides and moderators, separation of poisons. There is the potential for significant variability in the distribution of fissile nuclides within the waste volume at the time of disposal.
- There is often a requirement to transport waste within the public domain, which can be subject to differing limits and constraints when compared with where the waste was produced.

The purpose of this document is to support nuclear criticality safety throughout the waste life cycle while taking into account the potential to have a significant negative impact on other important areas such as:

- Radiological safety: For example dose control, risk of nuclear material ingestion/inhalation, the potential for contaminated wounds when handling waste, etc. If the nuclear criticality safety limits are set with little consideration of the other areas, resulting in large criticality safety margins, there is the potential for reworking waste to ensure compliance, incurring unnecessary radiological risk.
- Environmental considerations: For example additional handling, processing and storage leading to additional discharges, use of services such as electricity and water, generation of additional contaminated and non-contaminated packaging materials, generation of increased waste volumes.
- Conventional safety: For example additional risks of acute or chronic physical injuries.
- Cost: For example excessive or disproportionate costs which might be better spent reducing risk elsewhere. Final disposal space (e.g. deep geological disposal or shallow/ surface disposal) is an expensive, finite resource – with costs being directly linked to the volume of waste produced. Cost may also arise from, for example, the numbers of packages produced and the number of package movements required.
- Delay: For example potential for excessive delay due to development of overly complicated engineered solutions or safety arguments.

The criticality safety specific requirements and guidance within this document are to be applied with an awareness of this wider context to ensure that an appropriate balance between the criticality safety considerations and these other important factors is achieved.

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Nuclear criticality safety — Solid waste excluding irradiated and non-irradiated nuclear fuel

1 Scope

This document provides specific requirements and guidance on the nuclear criticality safety of waste containing fissile nuclides, generated during normal operations. This document is intended to be used along-side and in addition to ISO 1709.

This document applies specifically to the nuclear criticality safety of solid nuclear wastes. It also applies to residual quantities of liquids and/or slurries which are either intimately associated with the solid nuclear waste materials or arise as a result of processing or handling the waste.

This document does not apply to bulk or process liquids (including higher concentration process solutions) or irradiated or un-irradiated fuel elements.

NOTE The term fuel element is sometimes applied to fuel assembly, fuel bundle, fuel cluster, fuel rod, fuel plate, etc. All these terms are based on one or more fuel elements. A cylindrical fuel rod (sometimes referred to as a fuel pin) for a light-water-reactor is an example of a fuel element.

All stages of the waste life cycle are within the scope of the document. This document can also be applied to the transport of solid nuclear waste outside the boundaries of nuclear establishments.

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 1709, *Nuclear energy — Fissile materials — Principles of criticality safety in storing, handling and processing*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1709, 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 waste

<nuclear criticality safety> any kind of solid material containing or contaminated with fissile nuclides for which no further use is foreseen, not including irradiated or un-irradiated fuel elements

Note 1 to entry: This also includes:

- a) solids containing or contaminated with fissile nuclides for which no further use is foreseen, but for which further work to prepare the waste for final disposal is programmed, e.g. volume reduction;

- b) residual quantities of liquid or slurry type wastes which are either intimately associated with the solid nuclear wastes, or generated as a result of processing or handling the waste.

3.1.1

waste life cycle

<nuclear criticality safety> all phases in the life of the waste

Note 1 to entry: These phases can include, but are not limited to:

- pre-generation: the planning, design or operational stage of a process or facility before any waste is produced;
- generation: the processes that lead to generation of waste;
- initial handling: the initial handling of waste, prior to movement to a storage location or interim waste processing;
- local or interim storage: storage of waste for a short period when compared with the longer-term fate of the waste;
- interim waste processing: operations undertaken to further process the waste, prior to final disposal;
- transportation: the deliberate physical movement of waste to either some interim waste processing location, interim storage facility, or the location of final disposal;
- final disposal: emplacement of waste in an appropriate facility without the intention of retrieval (note that the term disposal implies that retrieval is not intended; it does not mean that retrieval is not possible).

Note 2 to entry: Typically, final disposal is split into two phases:

- operational: when the facility is being filled with waste and/or waste movements are taking place;
- post-closure: after the last addition of waste material, no more waste movements. Materials are in a long-term, quiescent state.

3.1.2

waste matrix

non-radioactive materials within waste in which radioactive substances are dispersed, including (but not exclusive to) any encapsulation or immobilisation material

Note 1 to entry: There is no expectation that the dispersal of the radioactive substances is homogeneous throughout the waste matrix.

[SOURCE: ISO 19017:2015, 2.23, modified — added “including (but not exclusive to) any encapsulation material”.]

3.2

nuclear criticality safety strategy for waste

high level plan as to how the nuclear criticality safety of the waste will be managed throughout the waste life cycle

4 Nuclear criticality safety strategy for waste

4.1 General

This document requires that a nuclear criticality safety strategy for waste is developed to make all relevant stakeholders aware of how nuclear criticality safety of solid waste are managed over the waste life cycle. This clause specifies requirements and recommendations for preparing, defining and maintaining a nuclear criticality safety strategy for waste.

4.2 Developing the strategy

A nuclear criticality safety strategy for waste shall be developed and documented.

Developing a nuclear criticality safety strategy as early as practicable will reduce the potential redesign or rework of nuclear criticality safety assessment and controls at a later stage. Documentation of the strategy allows for it to be reviewed; it also forms part of the audit trail as the waste is managed over its entire waste life cycle potentially including multiple owners, handling and processing stages and significant periods of time.

The nuclear criticality safety strategy for waste should be developed at the facility/plant design stage before any waste is created so risk and waste volume reduction options can be considered.

In the instances of existing wastes, which may have been created without a formal nuclear criticality safety strategy for waste, the earliest practicable stage can be regarded as the current stage at the time of application of this document.

4.3 Consulting with stakeholders

The nuclear criticality safety strategy for waste should be developed in consultation with all relevant recognized stakeholders.

If the strategy is developed without the input of all relevant recognized stakeholders, there is the potential that the strategy may not be optimised or will have to be revised at a later stage. However, identifying all relevant stakeholders can be difficult and depends on, amongst other things, the stage the project is at when the nuclear criticality safety strategy is developed. Therefore, it is appropriate to reflect this potential uncertainty in the wording of this recommendation.

Relevant stakeholders could include, but are not necessarily limited to:

- organisations who will handle, process, store, transport or dispose of the waste over the waste life cycle;
- the relevant regulatory body or bodies.

4.4 Strategizing over the waste life cycle

The nuclear criticality safety strategy for waste shall take into account nuclear criticality safety throughout the planned waste life cycle.

If the nuclear criticality safety strategy does not consider the entire planned waste life cycle, there is the potential for incurring higher criticality risk at a future stage, or higher non-criticality risk/costs, for example by having to repackage waste.

It is important that the strategy does not just consider local arrangements but, for example, considers transport and/or final disposal requirements (where applicable). Transportation in the public domain can lead to different regulatory limits than for within a nuclear facility (for example the IAEA criteria, see Reference [1]). Final disposal limits may also be different than would be adequate for local arrangements.

4.5 Radioactive waste characterization

The nuclear criticality safety strategy for waste shall allow for radioactive waste characterization that is proportionate to the criticality hazard of the waste across the full waste life cycle.

Radioactive waste characterization reduces uncertainties and allows for a more realistic assessment. This can reduce costs and allow better comparison between nuclear criticality safety and other important considerations. If proportionate radioactive waste characterization is not built into the strategy, it might be necessary to carry out radioactive waste characterization in conditions that were not originally planned for. It is important for the radioactive waste characterization strategy to consider the full waste life cycle, as, for example, a compound or nuclide which might not be relevant to nuclear criticality safety at an early stage in the waste life cycle could be relevant for final disposal.

The radioactive characterization of the waste should be recorded. There are clear benefits to this as it is likely the waste will transfer through a number of owners and is managed over many years so a lack of documentation could lead to the waste being re-characterized. An example radioactive waste characterization sheet is included in [Annex A](#). There is no formal requirement to use this particular form to capture information about the radioactive waste characterization; it is merely included as an example.

Parameters to consider in radioactive waste characterization include nuclide inventories for the radioactive materials, including fissile nuclides, and of the waste matrix. Best estimate values, along with an associated range and uncertainty, can be useful to help the balance of risk arguments when comparing nuclear criticality safety against other important considerations. Examples of issues to consider if radiometric methods are used are given in [Annex B](#).

The examples given in [Annex B](#) highlight the complexity and potential uncertainties associated with using radiometric methods for radioactive waste characterization. Radiometric instrument expertise may be required to define appropriate measurement techniques and/or to interpret results. When using such methods to comply with any nuclear criticality safety limits derived for waste (see [5.2](#)), it is important that such uncertainties are accounted for in the nuclear criticality safety assessment.

4.6 Review and update of strategy

The nuclear criticality safety strategy for waste should be reviewed when appropriate and updated accordingly.

Subsequent to the initial strategy being prepared, if further information arises (e.g. a process change or further radioactive waste characterization data become available), or external factors (e.g. regulatory requirements) change, then review and, if appropriate, update of the strategy will ensure that these developments are accounted for.

The frequency for a review of the strategy should be justified.

5 Nuclear criticality safety assessments of waste

5.1 General

This clause specifies requirements and recommendations for preparing a nuclear criticality safety assessment for waste.

When preparing such an assessment, a deterministic approach or a probabilistic approach may be applied.

For example, if an unsafe situation is demonstrated to be possible but highly unlikely, e.g. if many waste items each containing an unlikely high quantity of fissile nuclides are needed to be brought together before criticality is possible, it may be justified in the nuclear criticality safety assessment that this unsafe situation does not need further detailed assessment. If this approach is taken, then it should be justified in the nuclear criticality safety assessment what a highly unlikely event is assumed to be.

There may be different approaches to the development of a nuclear criticality safety assessment for the operational and post-closure phases of a disposal facility since the factors affecting criticality can be actively controlled during the operational phase but not during the post-closure phase. For example, container integrity is important during the operational phase of disposal but may not be as important for the post-closure phase. The opportunity is taken here to give guidance on the approach that may be applied to the following requirements depending on whether the facility is in an operational phase or post-closure phase.

5.2 Deriving criticality safety limits

Local nuclear criticality safety limits derived for waste shall be set taking into account the waste strategy.

If the extent of the waste life cycle as defined in the nuclear criticality safety waste strategy for waste is not taken into account when defining nuclear criticality safety limits, there is the potential that further waste processing or repacking will be required in the future.

There are various parameters that could be used to set nuclear criticality safety limits. Examples of such parameters may be, but are not limited to, fissile nuclide mass per waste item or package, total quantity (mass or volume) of waste material if a bounding fissile material content per unit volume of waste has been justified or fractions of fissile nuclides to matrix components (i.e. concentration).

There may be a benefit in having separate limits for the operational phase of the final disposal facility, where the waste can still be accessed, and the post-closure phase.

5.3 Variations in the inventory

The nuclear criticality safety assessment of waste shall account for uncertainties and variations in the fissile nuclide inventory and waste matrix.

It is important that safety margins used to cover uncertainties in the fissile nuclide inventory and waste matrix are justified appropriately (see [Clause 6](#)).

There may be a benefit in having separate levels of uncertainties and variations in the fissile nuclide inventory for a final disposal facility in the operational phase and the post-closure phase.

In addition to the advice on factors affecting criticality (see ISO 1709) some topics that may be relevant when evaluating the nuclear criticality safety of waste are given in [Annex C](#).

5.4 Radioactive decay

The waste nuclear criticality safety assessment of waste shall account for changes to the nuclide inventory via radioactive decay.

Changes in the nuclide inventory and relative proportions over time have the potential to affect nuclear criticality safety margins.

There is no requirement to act on changes to the fissile nuclide inventory via radioactive decay if it is justified that such changes will lead to a k_{eff} decrease.

If credit is taken for radionuclides as a diluent/neutron absorber, it is important that the nuclear criticality safety assessment justifies that any specified parameter values or limits will continue to be met over the timescales for which they are credited. Such timescales could be in excess of hundreds of thousands of years given the long half-life of ^{235}U .

There may be a benefit in having separate approaches for accounting for changes to the nuclide inventory via radioactive decay when considering a final disposal facility in the operational phase and the post-closure phase.

5.5 Consequences of a criticality accident

If a nuclear criticality accident cannot be excluded, the waste nuclear criticality safety assessment of waste shall take account of the consequences of a criticality accident at various stages in the waste life cycle.

NOTE The consideration, or exclusion, of a criticality accident at a particular stage of the waste life cycle is carried out using other processes that are not within the scope of this document.

The potential consequences of a criticality accident can vary over the waste life cycle. An understanding of the potential criticality consequences over the waste life cycle allows for the criticality risk to be

better understood. This may be important when balancing nuclear criticality safety considerations with other factors (see [Clause 6](#)).

If a waste storage or disposal location is heavily shielded (for example, underground) the potential direct dose uptake from a criticality accident may be low or zero. However, other potential effects may have to be accounted for, such as a release of radioactivity to the environment directly, or in the long term after the criticality event (e.g. by degrading the engineered or natural barriers containing the waste in a disposal facility, since a criticality event can release large amounts of kinetic energy).

There may be a benefit in having separate approaches for accounting for the consequences of a criticality accident when considering a final disposal facility in the operational phase and the post-closure phase.

6 Balancing nuclear criticality safety of waste with other considerations

While this document does not give guidance on how to balance other factors with nuclear criticality safety concerns, a nuclear criticality safety expert shall be involved in any balancing of the nuclear criticality safety of waste and other considerations.

It is important that the assumptions and the intended safety margins (and resulting levels of safety) of the nuclear criticality safety assessment are understood by those balancing nuclear criticality safety and other considerations.

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Annex A (informative)

Example radioactive waste characterization sheet

Table A.1 — Information potentially relevant to nuclear criticality safety at various stages of the waste life cycle

Phases	Information to provide
Waste generation	The process of generating nuclear waste (fabrication process, reprocessing facility, maintenance, decommissioning operations, etc.)
	Nature (metal, organic, etc.), physical and chemical forms (solid/liquid) of the waste containing fissile nuclides that are used at the facility
	Fissile properties: nature of fissile elements (U, Pu, mixed, etc.), isotopic composition, physical and chemical forms (metal, oxide, etc.) of fissile elements or compounds within the waste
Interim waste processing	Waste treatment (eventually): operations undertaken at the facility (vitrification, compaction, blocking concrete for heterogeneous wastes, concentration, etc.)
	Waste conditioning
	Conditioning description (barrel, big bag, tank, concrete container, etc.) and associated dimensions
	Nuclear criticality safety (by waste family): ^a 1. Nature of fissile properties (U, Pu, mixed, etc.), isotopic composition, physical and chemical form (metal, oxide, etc.), degree of moderation (organic wastes, concrete...), homogeneity or heterogeneity of fissile nuclide 2. Waste package characterization: measurement method and indication of medium and maximal value associated to the nuclear criticality safety analysis (weight of fissile nuclides, package geometry, concentration, degree of moderation) as well as production requirements and limits.
Interim storage	Storage conditions and events likely to have an influence on the important parameters for the nuclear criticality safety demonstration
Transport	Transport limits
Final disposal	Final disposal requirements
^a All such information should be entered on the following sheet of waste packages.	

Table A.2 — Example of a completed waste characterization sheet

Phases	Information to provide
Waste generation	<u>Process of generating nuclear waste:</u> Maintenance or decommissioning operations
	<u>Nature, physical and chemical forms:</u> Solid metallic or organic waste (filters, gloves, vinyl, metallic equipment, etc.)
	<u>Fissile nuclides:</u> Pu, oxide
	<u>Waste treatment:</u> Pre-compaction (eventually)
	<u>Waste conditioning:</u> 200 L drums; Ø ≈ 600 mm; H approximately 800 mm
Interim waste processing	<u>Nature of fissile properties:</u> Pu, oxide, heterogeneous
	Degree of moderation: organic wastes (eventually)
	<u>Waste package characterization:</u> Measurement method: Gamma spectrometry
	Average and maximum values: Average ^{239}Pu : 1,0 g (equivalent)
	Maximal ^{239}Pu : 10,0 g (equivalent)
Interim storage	<u>Storage conditions:</u> Storage on 6 levels, drums in contact
	Limit value : ^{239}Pu : 50 g Pu/drum
Transport	<u>Transport limits</u> 5 g ^{239}Pu /drum
	Final disposal requirements: 25 g ^{239}Pu /drum