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Nuclear energy — Nuclear fuel technology — Scaling factor method to determine the radioactivity of low- and intermediate-level radioactive waste packages generated at nuclear power plants

Énergie nucléaire — Technologie du combustible nucléaire — Méthode des ratios pour déterminer la radioactivité des colis de déchets de faible et moyenne activité produits par les centrales nucléaires

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Contents

Page

Foreword

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Introduction

Burial disposal of low- and intermediate-level radioactive waste has been practiced in several countries. Before disposal, the radioactivity of specific nuclides in waste packages have to be declared in accordance with limits and criteria derived from safety assessment of the disposal facility. Some of these nuclides are difficult to measure from the outside of the waste packages, because they are beta or alpha emitting nuclides.

There are a number of activity determination methods. The scaling-factor method is widely applied in order to evaluate these difficult-to-measure nuclides. The scaling-factor method is based on a correlation between easily measurable gamma emitting nuclides and difficult-to-measure nuclides. This International Standard presents guidelines on the empirical scaling-factor method for evaluating the radioactivity of nuclear power plant's low and intermediate level waste.

Nuclear energy — Nuclear fuel technology — Scaling factor method to determine the radioactivity of low- and intermediate-level radioactive waste packages generated at nuclear power plants

1 Scope

This International Standard gives guidelines for the common basic methodology of empirically determining scaling factors to evaluate the radioactivity of difficult-to-measure nuclides in low- and intermediate-level radioactive waste packages.

This International Standard gives common guidelines for the scaling factors used in the characterization of contaminated wastes produced in nuclear power plants with water-cooled reactor. This International Standard is also relevant to other reactor types, such as gas-cooled reactors. Methodologies for determining scaling factors based on theoretical considerations (i.e. not based on experimental measurement) are not covered by this International Standard.

2 Terms and definitions

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

2.1
difficult-to-measure nuclide
nuclide whose radioactivity is difficult to measure directly from the outside of the waste packages by non-destructive assay means

EXAMPLE Alpha emitting nuclides, beta emitting nuclides, and characteristic X-ray emitting nuclides.

2.2
key nuclide
gamma emitting nuclide whose radioactivity is correlated with that of difficult-to-measure nuclides and can be readily measured directly by non-destructive assay means

NOTE Also called “easy-to-measure nuclide” or “marker nuclide”.

EXAMPLE ^{60}Co and/or ^{137}Cs.

2.3
scaling factor
factor or parameter derived from mathematical relationship used in calculating the radioactivity of difficult-to-measure nuclide from that of key nuclide determined from sampling and analysis data

2.4
waste package
product of conditioning that includes the waste form and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared for handling, transportation, storage and/or disposal

NOTE Adapted from IAEA *Radioactive Waste Management Glossary*. 2003 Edition[1].

2.5
representative sample
sample taken from a process of the material in that process or that quantity of material which is considered to possess the average characteristics of the material

NOTE 1 Adapted from ISO 921:1997[2].

NOTE 2 Samples of waste are used to determine the scaling-factor parameters for the target waste stream. A representative sample is meant to closely resemble the characteristic nuclide content and activity proportions of the target waste stream.

2.6
composite sample
mixture of samples from different containers such that the mass ratio of the samples is equal to the ratio of the material masses contained in the containers

NOTE Adapted from ISO 921:1997[2].

EXAMPLE Series of samples taken over a given period of time and weighted by collection rate; or a combined sample consisting of a series of discrete samples taken over a given period of time and mixed according to a specified weighting factor, such as stream flow or collection rate.

2.7
corrosion product nuclide
nuclide produced by activation of corrosion products temporarily deposited on in-core surfaces

EXAMPLE ^{60}Co, ^{63}Ni.

2.8
fission product nuclide
nuclide produced either by fission or by the subsequent radioactive decay of nuclides thus formed

NOTE Adapted from ISO 921:1997[2].

EXAMPLE ^{137}Cs, ^{90}Sr.

2.9
alpha emitting nuclide
nuclide emitting an alpha particle when it decays

EXAMPLE Most actinides and transuranic nuclides.

2.10
transuranic nuclide
nuclide with atomic numbers above 92

2.11
dry active waste
solid waste generated in various waste streams in a nuclear power plant, including protective clothing, replaced equipment, parts, plastics, polyvinyl chloride sheets, and high efficiency particulate air filters removed during plant operation and maintenance

2.12
homogeneous waste
radioactive waste that shows an essentially uniform distribution of activity and physical contents

EXAMPLE Flowable wastes such as concentrates, solidified liquids and spent resins, in which the radioactivity may reasonably be assumed to be uniformly distributed over the volume or flowable wastes uniformly mixed with a solid matrix.

2.13
heterogeneous waste
radioactive waste that does not meet the definition of homogeneous waste, including solid components and mixtures of solid components, such as dry active waste and cartridge filters

3 Principle

The empirical scaling-factor method is a method for evaluating the radioactivity of defined difficult-to-measure nuclides from the radioactivity of key nuclides, based on the correlations between difficult-to-measure nuclides and key nuclides. To achieve this, it is important to understand the nuclide production mechanisms, the physico-chemical behavior of nuclides and observe radiochemical analysis data. Statistical calculation is a supplemental technique used for the quantitative evaluation of scaling-factor parameters from groupings of radiochemical data.

The difficult-to-measure nuclides of primary interest are those with very long half-lives that persist in a disposal site long after the period of institutional control. Their declarations are often important for the assessment of the health and safety of the disposal site. Some national programs for low-level radioactive-waste disposal establish specific limits on the concentrations of these nuclides in individual waste packages as well as on their total content in the disposal site. These are specific acceptance criteria which are set by the national regulatory system or waste management programs and are derived from the safety assessment of disposal facilities. The information about the activity concentration and total activity are also required for the transport of radioactive material.

Scaling factors provide a mechanism for estimating the quantities of difficult-to-measure nuclides in individual waste packages based on limited radiochemical analysis of samples from the bulk waste stream. This is achieved by observing the consistent and reproducible relationships between individual nuclides in samples from a stream, which, with reasonable confidence, can be assumed to represent the entire stream.

4 Sampling

4.1 General

Scaling factors in the context of this International Standard are based on a database of samples. Therefore, it is quite important to conduct appropriate sampling and create a database of analytical results. Described in 4.2.1 and 4.2.2 are two basic concepts employed for the collection of radioactivity data that serve as the basis for the scaling-factor method.

4.2 Representative sampling

Two common approaches to ensuring representative samples are

— homogenized sampling,

— accumulated sampling.

4.2.1 Homogenized sampling

This sampling applies to waste that can be considered as homogeneous. In order to ensure that the activity contained in the sample is uniformly distributed, the waste is sufficiently mixed before sampling or within the sample process. Satisfactory accuracy can be ensured even for scaling factors obtained from a small number of samples.

a) Waste is uniformly stirred and sampled from storage tanks.

b) Composite samples can be prepared by proportionally mixing waste.

4.2.2 Accumulated sampling

In this approach, waste samples are collected in suitable number or manner to represent the characteristic features of a population of waste samples. This is applicable to both homogeneous waste streams and heterogeneous waste streams.

4.2.3 Activity concentration range of waste samples

When sampling a defined waste stream in the case of accumulated sampling, it is important to obtain radioactive waste samples having a wide range of activity concentrations in order to ensure effective correlations between difficult-to-measure nuclides and key nuclides for waste from that stream.

4.3 Rejection of outliers

If an outlier is found within analysis results, the cause should be identified and the outlier can be corrected or abandoned based on the study of distribution of data and origin of data. If the cause of such an outlier is not identified, statistical methods can be applied optionally for rejection of outliers.

4.4 Records of samples

The following information should be recorded together with the measurement data of individual samples:

— sample identification number;

— plant name;

— reactor identification and building identification;

— reactor type (e.g. boiling water reactor, pressurized water reactor, heavy water reactor, etc.);

— waste stream identification;

— type of waste (e.g. spent resin, concentrates, metal, smear, etc.);

— date of waste sampling;

— date of waste analysis;

— organization that conducted analysis;

— radioactivity and detection limits of each nuclide (the activity concentration of each nuclide should be corrected for decay to the generation date of waste);

— moisture content of the waste (to be measured if necessary for ^{3}H evaluation).

5 Evaluation methodology for scaling factor

5.1 Applicability of scaling-factor method

The scaling-factor method relies on correlations or predictable relationships between nuclides. The crucial step is deciding whether a correlation exists, i.e. whether the scaling-factor method is applicable.

The applicability of the scaling-factor method for a given difficult-to-measure nuclide and a key nuclide pair can be checked by either or both of the following ways:

— consider their production mechanism, physicochemical behavior and observation of their correlation diagrams;

— use statistical methods to check for existence of a correlation.

5.2 Evaluation by linear relationship

The radioactivity of the difficult-to-measure nuclide is predicted by multiplying its scaling factor by the concentration of the key nuclide. The scaling factor is determined as the geometric mean of analyzed values.

$$a_{\mathrm{d}} = f_{\mathrm{SF}} \times a_{\mathrm{k}} \tag{1}$$

where

a_{d} is the activity concentration of the difficult-to-measure nuclide in either activity per mass or activity per volume, e.g. expressed in Bq/kg or in Bq/m^3;

f_{SF} is the scaling factor, see Equation (2);

a_{k} is the activity concentration of the key nuclide in either activity per mass or activity per volume, e.g. expressed in Bq/kg or in Bq/m^3.

The geometric mean can be used to calculate scaling factors for the evaluation of activity concentrations in the following manner:

$$f_{\mathrm{SF}} = \sqrt[n]{\left(a_{\mathrm{d},1}/a_{\mathrm{k},1} \times \cdots \times a_{\mathrm{d},i}/a_{\mathrm{k},i} \times \cdots \times a_{\mathrm{d},n}/a_{\mathrm{k},n}\right)} \tag{2}$$

where

$a_{\mathrm{k},i}$ is the activity concentration of the key nuclide in sample i ($i = 1 \ldots n$), e.g. expressed in Bq/kg if the activity is expressed per mass;

$a_{\mathrm{d},i}$ is the activity concentration of the difficult-to-measure nuclide in sample i ($i = 1 \ldots n$), e.g. expressed in Bq/kg if the activity is expressed per mass;

n is the number of samples.

5.3 Evaluation by nonlinear relationship

The following method using linear regression of logarithms of measurement data can be applied for the evaluation of difficult-to-measure nuclides where there is a nonlinear relationship between the difficult-to-measure nuclide and key nuclide. For example, when the nuclide ratio shows a dependence on concentration, there can be a nonlinear relationship.

$$a_{\mathrm{d}} = \alpha \times \alpha_{\mathrm{k}}^{\beta} \tag{3}$$

This corresponds to

$$\ln(a_{\mathrm{d}}) = \alpha' + \beta \times \ln(a_{\mathrm{k}}) \tag{4}$$

where

a_{d} is the activity concentration of the difficult-to-measure nuclide to be determined, e.g. expressed in Bq/kg if the activity is expressed per mass;

a_{k} is the activity concentration of the key nuclide, e.g. expressed in Bq/kg if the activity is expressed per mass;

α, α' are constants ($\alpha' = \ln\alpha$);

β is the regression coefficient.

5.4 Selection of key nuclides

The key nuclides used in evaluating the activity concentrations of difficult-to-measure nuclides are selected based on the following factors. Gamma-emitting nuclides shall meet the basic characteristics and it is recommended that they meet at least one of the additional characteristics.

a) Basic characteristics:

- can be measured by non-destructive means when present in waste packages,
- having activity levels above the detection limit,
- having a correlation with required difficult-to-measure nuclides,
- having a relatively long half-life (e.g. years rather than days).

b) Additional characteristics:

- having a nuclide production mechanism similar to that of difficult-to-measure nuclides, and/or
- having physical properties (particularly solubility) similar to those of difficult-to-measure nuclides.

Specifically, ^{60}Co is normally used as a key nuclide for corrosion-product nuclides and activation-product nuclides from reactor coolant and ^{60}Co and/or ^{137}Cs as key nuclides for fission product nuclides and alpha-emitting nuclides.

5.5 Integration and classification methodology for scaling factor

Data collected from various waste streams can be combined for the determination of particular Scaling Factors providing that it can be demonstrated that the data are all part of the same general population of data. That is, based on a comparison of means and variance, it can be established that the data populations are not different.

Data can be integrated over extended waste streams given that no significant trends or no significant changes in operating status are occurring.

5.5.1 Integration and classification of corrosion product nuclides

5.5.1.1 Consideration by type and design of nuclear power plant

The correlation of difficult-to-measure nuclides such as corrosion product nuclides to key nuclides strongly depends on the composition of the materials involved.

Therefore, if the compositions of materials are not significantly different among several plants, the associated radiochemical analysis data can be merged to establish a single scaling factor. Different reactor types (e.g. boiling water reactor, pressurized water reactor) generally produce different scaling factor parameters for the same combination of nuclides from similar waste streams because of differences in the compositions of some in-core materials and water chemistry.

5.5.1.2 Consideration by waste stream

Many corrosion product nuclides show a common production mechanism and transport behavior in the plant. Thus, classification by waste stream might not be necessary for those corrosion product nuclides in a given plant design.

