Easy Computation of Difficult to Measure Activation Radionuclides

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ABSTRACT

Electricité de France (EDF), radioactive waste producer, is responsible for managing waste from dismantling of its permanently shut-down nuclear power plants. The process has been opened for a few years for 9 units. The main constraint of dismantling is the waste disposal and EDF is required to obtain a certification (or acceptance certification) form French governmental disposal agency (ANDRA) before any waste container production.

Such a certification which is a detailed technical file, is the proof that the container, the waste conditioning method and the waste composition itself, especially the activity of each radionuclide (RN), comply with all the requirements of the disposal safety studies.

Taking into account that EDF has already prepared numerous files describing a container and the means to fill it, the main problem to cope with now is the assessment of each RN present in each container ready to be shipped to the disposal. The general case of difficult-to-measure (DTM) RN management and specially the high difference between waste from plants in operation and waste from dismantling plants, are pointed out.

Starting from a global neutron flux cartography at 100% power, a specific global strategy of DTM activation RN assessment for each type of waste is developed. As Co-60 is the only tracer, which is almost always the case in EDF dismantling, a simple way to compute the global scaling factors of mix of different waste initial composition is presented for that purpose. A new concept is introduced, the "pseudo-scaling factor" which interesting geometric property allows a very simple industrial application container by container.

If the neutron flux cartography is too detailed, a method of merging cells is introduced to decrease the number and the time of computation without any impact on the result quality.

A method is also proposed to balance the fact that exact localization of each waste of each composition cannot be given very precisely in the neutron flux cartography. Then, we see that the knowledge of global mass of each composition allows us to limit this over assessment.

An example of application of the global methodology is shortly presented about Creys-Malville French fast-breeder.

INTRODUCTION

Regulatory French context - "Bataille" Act and SFR III 2 e

Unless it involves the return of residual matter from processing to their country of origin, radioactive waste intended for final storage is not authorized to cross French borders and the

"Bataille" Act has confirmed the ANDRA (French governmental radioactive waste agency) monopoly as the operator to be used for the storage of radioactive waste in France.

This act also gave ANDRA responsibility for the specifications which must be applied to the waste and the Safety Fundamental Rule SFR III 2 e describes the "certification" process at the Storage Center.

For a specific type of raw waste, a properly defined conditioning of this waste (container and equipment + possible processing) and a method for assessing the activity of each package produced, ANDRA validates the general conformity to their specifications for the Storage Center by giving a “certification”.

The characteristics of each package, and in particular the activity declaration of numerous RN, are sent to ANDRA electronically. EDF's data processing tool connects to ANDRA's computer network and it is only after the package has been electronically validated by ANDRA by return that arrangements can be made for the package to be sent to the Storage Center.

Package "Important item for the disposal safety”

As the waste package is an "important item for the safety of the Basis Nuclear Installation (BNI) devoted to the storage of which ANDRA is the licensee", EDF is "supplier" of the ANDRA BNI under the terms of the French Nuclear Quality order. For this reason, the producer of the waste (EDF) cannot delegate their activity declaration liability to a third party. The activity declaration is therefore one of the items which is required in order to satisfy compliance with the regulatory traceability provisions and the quality assurance in the area of nuclear safety.

The development of the activity assessment strategy and the calculation methodology used is therefore a key stage prior to the certification process, which is itself a prerequisite for any shipment. The assessment method which permits the activity declaration is a virtually unseen, yet central, part of the certification application processing file for waste activated on dismantling. This certification cannot be an extension of the certifications devoted to operating NPP, as is the case for most instances of contaminated waste which are based on measuring statistics originating from the operational period.

The activity assessment is the main point in the generic certifications that we want to use in order to share the certification files with plants in operation. In effect, the assessment of RN activity which is difficult to measure with the aid of the scaling factors in relation to a gamma tracer is still the only really new piece.

The generic nature is normally applied to the type of waste, its conditioning and the measurement technique of the gamma emitters on the package or its contents, but the creation of activation scaling factors is specific to the unit being dismantled and the material involved.

General methodological context

We will only look at the "common" stainless steel in the "Suspended Metallic Components" in the Creys-Malville reactor. The approach already makes reference to the method [1] which implements the activation calculations. This method was developed in order to obtain the ANDRA "certification for Bugey 1 Graphite Sleeves", before their final disposal.

Dismantling plants compared with plants in operation

The simplified and highly restrictive approach used for the standard activated waste for low and intermediate level (LLW-ILW) is based on the fact that they only comprise a very low proportion of LLW-ILW waste from nuclear plants in operation. Such a method does not enable management of the activation waste originating from the dismantling of the plants.
As is effectively the case for standard activated waste originating from the operation of the plants, for dismantling it is difficult to confirm if the global "activation" share is "marginal" in relation to the global nature of the filters, resins and easily contaminated maintenance waste. The procedure described herein itself originates from a case which resulted in a positive "feedback", as it was the outcome of the certification on the sleeves in Bugey 1 and their shipment completed a few years ago. The notable methodological items of their certification are described in [1].
The procedure is specific to each item of large material in each dismantling unit, as the first generation of EDF dismantling does not present enough homogenous characteristics for extrapolating the calculation of one on the other without excessive safety margins. The explanation is due to the fact that the assessment of the scaling factors does not go via a simple increase in fluxes, as both the numerator (that is, activity calculated by RN) and the denominator (that is, activity calculated in Co-60) are overestimated, and this cannot be used to guarantee the overestimation of the scaling factor itself (which is the result of their division).

PRIMACY OF THE ROBUST CALCULATION OF SCALING FACTORS

The "robust" methodology which is used traverses the development of the global activation Co-60 scaling factors whilst avoiding multiplication of the calculations on each basic spatial cell of the flow field at 100% power. The scaling factor calculation is much less sensitive to uncertainties associated with neutron fluxes than the separated calculations of the difficult to measure RN (the numerator) and Co-60 (the denominator).

The principle which maintains the quality and limits the number of calculations therefore consists of a merging of the basic flux cells within the limit of sufficient uniformity of the orders of magnitude of the values of each component in the flux vector. A description of the uniformity criterion, as well as the Binary Tiling method used to achieve the result in a simple manner, will be explained.

Darwin-Pepin, reference code

ANDRA has requested that the activation calculations originate from the validated code as a reference code according to the French Safety Authority. One of them is named "DARWIN-PEPIN code”, and is developed in association with CEA and EDF. It is why EDF insists that their suppliers use this code in its most recent version. The calculations are performed on all of the RN corresponding to the requirements of the ANDRA specifications.

Fitting on the RN measurements by reverse impurity calculation

Prior to the actual calculation of the scaling factors, in order to adjust as many impurities as possible using the activity measurements and to protect us from too large overestimation originating from methods with high Detection Limit, the procedure described in [1] can be applied. As the solution of the activation equations is a linear function of the "vector of the initial

compositions", by "inversion", an "initial composition" vector can be found at the source of the measured spectrum. We can therefore access, via the point measurements (samples) or global measurements (spectrometry on large objects), the calculated impurities which are likely to replace the over estimated values of the measured impurities.
This fitting can be highly effective : paper [1] shows that where the ICP-MS non-radioactive cobalt measurement (Mass Spectrometry.) gave a Detection Limit of 1 ppm, the reverse calculation gives between 2 and 3 ppb on average. In order to achieve this, both the results of the measurements and a sufficiently accurate level of modeling, from a spatial perspective, are required in order to provide a sense of the calculation/measurement fitting or even enough measurements to be able to authorize a statistical approach.

A new concept, the pseudo scaling factor

In order to maintain the fitting with the best estimate of cobalt possible, the final result is described in the form of a list of pseudo scaling factors at a single date which is characteristic of the end of the effective operation of the plant. The unit of the pseudo scaling factor is the Cobalt ppm and the end scaling factor to be used is the pseudo scaling factor divided by the number of reasonably underestimated ppm of Cobalt.

This notion means that the procedure can be simplified without neglecting the fact that the cobalt cannot be chosen as overestimated as the Co-60 intervenes in the scaling factor's denominator. Its practical use is apparent for processing packages which contain several materials, which relates to packages where the complex metallic waste could not give rise to the separation of special alloys (such as stellites) from the common stainless steels.

Pseudo scaling factor and its property

For a given set of waste, the number of input parameters specific to the activated content of the package, in order to perform the activity calculation, has been reduced to a minimum without jeopardising the extent of the result. We must know the α value of the "packages" which corresponds to the proportion by mass of the "common" material, and $[Co]_S$ which corresponds to the cobalt content of the "special" material ("special" material, defined below) by mass proportion (1-α). Each mass content M is comprised of a mass α M of common material and a mass (1-α) M of special material. The common material (C), which corresponds here to stainless steel, is allocated a cobalt content $[Co]_C$ which is a constant that is chosen once for all items in a reasonably underestimated manner, (in an RN calculation via scaling factor, the denominator should be under estimated so that the assessment can be reasonably overestimated). The special material (S) has a cobalt content $[Co]_S$ (underestimated as little as possible), which depends on the package in question and only needs to be specified in the spreadsheet enabling the final calculation.

A_{RN} represents the activity in Bq/g of the RN and ^{60}Co represents the activity in Bq/g of Co-60.

$$Sf_{RN} = \frac{A_{RN}}{^{60}Co} \ , \ PSf_{RN} = \frac{A_{RN}}{\left(\frac{^{60}Co}{[Co]}\right)} \ \text{and} \ Sf_{RN} = \frac{PSf_{RN}}{[Co]}$$

This general concept, which is regularly defined on a rough item of waste, conserves its significance when it is applied to a package. In this instance, we use the average cobalt content of the package: $[Co] = \alpha\ [Co]_C + (1-\alpha)\ [Co]_S$

It can be demonstrated that the "pseudo scaling factor" of a package may be considered as the barycenter of the "pseudo scaling factors" of the two materials, the barycentric coefficients being those of the mass proportions of the package's two constituent reference materials: $PSf = \alpha\ PSf_C + (1-\alpha)\ PSf_S$ with $Sf_C = \frac{PSf_C}{[Co]_C}$ and $Sf_S = \frac{PSf_S}{[Co]_S}$

Considering that the activated waste contained in a package has seen a comparable neutron flux in terms of the spectrum (same form of flux) and that it has had an identical irradiation history, the quantity of Co-60 formed in the material is proportional to its initial cobalt content: $\frac{^{60}Co|_S}{^{60}Co|_C} = \frac{[Co]_S}{[Co]_C}$

Every calculation made, we can deduce the desired result :

$$Sf \times [Co] = \alpha \times Sf_C \times [Co]_C + (1-\alpha) \times Sf_S \times [Co]_S$$

PRACTICAL EXAMPLE OF A "B.R.A.I.C" DEVELOPMENT

This chapter develops a detailed example of the "Best Radiological Activation Inventory per Calculation" (BRAIC) for dismantling requirements. The meaning of the term "best" is a reference to a reasonable over assessment, taking into consideration the inaccuracies of the modeling system used for the flux, as well as the inventory of the difficult to measure RNs which are calculated using the measurement on the package of the "tracer" Co-60. The Co-60 base will finally only be impacted by the measurement error and the over estimation in case a dose rate is used if the gamma spectrum is considered to be 100% in Co-60.

The first objective is, whilst remaining over-estimated, the limitation of the over-assessment so as not to waste the upper limits (called capacities) allocated to the different RN in their final storage safety report. This limitation of the over-assessments is based on the fact that the Co-60 has been measured on the package and that the result of the calculation of the scaling factors suffers fewer uncertainties than the direct activity calculation.

Purpose and general procedure

We describe now the BRAIC which assesses the activation of the "common" stainless steels, which represent a major part of the waste, originating from the "Suspended Metallic Components" from the Creys-Malville reactor. Our initial objective is to supply a complete set of scaling factors, which are sometimes presented as "correlation factors", when covered by statistical procedures. It is, in effect, the complete set of "pseudo scaling factors" which is the reference result as it enables a calculation performed independently from the underestimated choice of the cobalt.

When the number of under-lying measurements is sufficient, the statistical procedures are often the only ones available when the activity (fuel leak and/or activation of structures) is deposited by a fluid on the surface of the waste. This definition of the contamination is traditionally presented as a counterpoint to the activation even if it often involves a displaced activation. As the Co-60 measurement is acquired by the method described in the Activity Assessment Folder of the package in question, the product of the scaling factors by the value of the Co-60 of the package, described at the date of validity of the scaling factors, enables all of the activation RNs on this date to be easily obtained.

Component coordinates and masses subject to neutron flux

R is the distance of the core axis in cm and the altitude Z is given in cm. Each system is included in a tile [R1, R2] x [Z1, Z2] which describes a revolution volume and we will see later how the resultant lack of spatial precision is balanced by an over assessment method of the activation even if the tube exceeds the required size.

As calculating the activation of a material in the neutron flux of each of the 106,106 cells of the main systems represents more than 9 months of CPU with Darwin-Pepin in Linux version 2.1.1 (the fastest implementation available to date on PCs), a simplified yet thorough procedure for calculating the scaling factors must be developed in order to reasonably guarantee any over-assessment which would be costly in terms of safety margins of the disposal.

SIMPLIFICATION USED TO LIMIT THE CALCULATIONS

The most common simplification is that which consists of only applying the arithmetic average activation in an area of space (merging several units as defined by the flow calculation) and the activation caused by the neutron flow as an average over this area.

N.B.: By the term "arithmetic average" we systematically cover a barycentric average weighted by the volumes of the elements. This is only justified if the area has sufficiently homogenous neutron flux because, there may be several orders of magnitude difference between the neutron populations for an energy band given between the upper part and the lower part of the area in question or between its internal and external section.

Binary tiling process and its stop criterion

In our particular case of cylinder symmetry, the tile of space is described as a Cartesian product [R1,R2]x[Z1,Z2] has large as possible on which we should test if a single average activation calculation may have sense. The principle of the test consists in the verification that a sufficient proportion of the initial cell set composing the tile remain close enough from the geometric average computed with all the initials cells. The geometric average vector flux is here understood as the vector of each energy band composed of the geometric average of the same energy band weighted by the volume proportion cell. On each energy band of an initial cell, we compute the following ratio : value divided by the geometric average value of the set composing the tile. If on each energy band and if each ratio is between $1/\sqrt{N}$ and $\sqrt{N}$, the initial cell is close enough from the virtual center of the tile according the N-criterion.

If 95% of the cells composing the tile is close enough from the center according the 10-criteria and 66% of the cells composing the tile is close enough from the center according the 4-criteria, the arithmetic average of all the flux vector composing the tile makes sense for scaling factor computation and the set of cells of the tile can be replaced by a single macro-cell which vector flux is the (weighted by volumes) arithmetic average of those of the initial cells.

If it is not the case, the process carry on by dividing the tile in 2 tiles: for example horizontally, [R1,R2]x[Z1,(Z1+Z2)/2] and [R1,R2]x[(Z1+Z2)/2,Z2] that have to be iteratively tested until the homogeneity of the flux allows to use an arithmetic average value. This merging process allows us to reduce drastically the number of computation cell for activation calculation code.

N.B.: The choice of dividing by 2 is definitely not the optimum. There are other methods which follow the same stop criteria. It must be understood that the development of a "minimal" division in terms of the number of tiles is a complex mathematical problem, the resolution of which will gain no more than a factor 2 in the reduction of the number of Darwin-Pepin activation calculations. As the "binary tiling" already enables a gain of factor 50 or 100, most of the gain is already achieved without the introduction of a more complex division mechanism.

UNCERTAINTIES IN THE ACTUAL POSITIONING OF THE ACTIVATION

Strategy for a reasonable uncertainty purpose

We have seen previously that the initial size used for each "system" can not only be marred by an uncertainty, but that neutron flux code cylindrical 2D modeling remains an approximation of the 3D reality and that the distribution of masses of common stainless steel of actual components is not evenly distributed in the total volume of the circumscribed global tube.

These reasons mean that the material may not be considered evenly distributed in the defined global tube. We must therefore take into consideration a restriction which consists of choosing a mass distribution which is not prorata of the volume of the areas originating from the Binary Tiling, but which integrates a bias which systematically favours the volumes of tiling where the local scaling factor (scaling factor calculated from each tile) is the highest.

Successive removal of tiles with lower scaling factor

The most intuitive way, for each RN, consists of sorting the tiling items in ascending order of their local scaling factor and removing the tile where this local scaling factor is the smallest. This operation is repeated until a stop criterion is obtained which enables assessment of the sufficient character of the bias thus introduced.

Criterion used to reasonably limit the over-assessment

The difference measuring the offset between the average scaling factor over-estimating the stainless steel activities with the average scaling factor weighted by the global volume, may be measured by calculating the difference between the logarithm of the averaged scaling factor (weighted by the size of the tiles) over the whole of the initial tube and the same logarithm of the averaged scaling factor which is now calculated on the volumes which remain after exclusion of the volumes corresponding to a local scaling factor which is weaker than the others.

This difference between a global average and an average on a restrictive sample must be divided by the standard deviation of the distribution. We can therefore interpret it as a test in relation to the hypothesis H_0 for the equality of the average of the sample, with the global average in the case of a uniform distribution of the stainless steel mass activated in the defined tube.

Mathematical interpretation (described without formula)

In the context of the lognormal distribution of scaling factors (positive values), the difference in the logarithmic averages divided by the standard deviation σ of the sample enables the level of overestimation originating from the deletion of the least restrictive tiles to be shown in number of σ. In effect, a zero difference would correspond to what would happen in 50% of cases with a random sort, whilst a value of 2.33 σ corresponds to a case which is more restrictive than 99% of the configurations. We have used 99% as a minimum stop criterion; the simple uniform distribution corresponds to 50%. The following sensitivity study demonstrates that it involves a fairly wide maximization.

N.B.: 100% corresponds to the choice of the most restrictive tile which is supposed to gather all of the activated mass.

In practical terms, the discretization from the tile means that, in numerous cases, all of the tiles are removed, apart from the highest, without having achieved the 2.33 criterion σ as it is part of the final tile. In this case, we obtained the maximum which corresponds to the maximum local scaling factor. This situation of particularly high over assessment is, however, avoided in the highly disruptive cases by the 2.33 σ strategy which formally raises awareness of a parametric statistic test for estimating the coherence of an average originating from a sample with the average of the total distribution.

It must be noted that the over-estimation at 99% is conducted for each RN taken separately and that the Co60 used in the denominator to calculate the over-estimated scaling factor corresponds to the specific over-estimation of the RN in question. This procedure is therefore still highly over-estimating.

Table I: Global scaling factors and sensitivity to maximization percentage

Co-60 Sf	100%	99%	95%	50%	Co-60 Sf	100%	99%	95%	50%
Ag108m	1.67E-07	1.26E-07	1.25E-07	1.16E-07	Nb93m	2.55E-05	2.05E-05	2.06E-05	2.04E-05
Ag110m	4.66E-05	2.56E-05	2.40E-05	1.71E-05	Nb94	4.63E-06	4.02E-06	4.02E-06	4.00E-06
Ar37	1.05E-36	1.05E-36	1.05E-36	5.83E-37	Ni59	1.79E-03	4.57E-04	4.21E-04	3.00E-04
Ar39	1.56E-26	1.56E-26	1.56E-26	8.58E-27	Ni63	2.04E-01	4.76E-02	4.35E-02	2.92E-02
Ar42	2.46E-42	2.46E-42	2.46E-42	9.58E-43	P32	3.32E-15	2.10E-15	2.09E-15	2.07E-15
Be10	2.45E-07	1.39E-07	1.35E-07	1.22E-07	P33	4.16E-23	3.61E-23	3.50E-23	3.38E-23
Bi207	9.92E-36	9.92E-36	9.92E-36	4.29E-36	Pb202	2.18E-31	2.18E-31	2.18E-31	9.35E-32
Bi208	5.95E-26	3.00E-26	2.93E-26	2.85E-26	Pb205	3.09E-12	2.32E-12	2.30E-12	2.21E-12
Bi210m	2.81E-22	1.63E-22	1.58E-22	1.51E-22	Pb210	3.26E-20	1.99E-20	1.93E-20	1.88E-20
Br82	3.32E-07	2.83E-12	1.09E-12	8.19E-14	Pd107	3.25E-19	2.10E-19	2.10E-19	2.08E-19
C14	3.24E-04	8.19E-05	7.54E-05	5.20E-05	Pm144	1.71E-37	1.71E-37	1.71E-37	7.36E-38
Cd109	8.88E-11	5.47E-11	5.36E-11	5.22E-11	Pm145	9.03E-33	9.03E-33	9.03E-33	3.91E-33
Cd113m	1.08E-23	1.08E-23	1.08E-23	5.47E-24	Pm146	3.91E-29	3.91E-29	3.91E-29	1.83E-29
Ce144	1.48E-38	1.48E-38	1.48E-38	7.72E-39	Pm147	9.76E-16	8.55E-16	8.36E-16	8.07E-16
Cl36	8.54E-17	6.04E-17	5.93E-17	5.85E-17	Po209	8.60E-32	8.60E-32	8.60E-32	4.03E-32
Co57	5.66E-08	3.57E-08	3.56E-08	3.54E-08	Pt193	1.27E-36	1.27E-36	1.27E-36	6.67E-37
Eu150	2.96E-13	1.87E-13	1.87E-13	1.86E-13	Rb87	3.56E-38	3.56E-38	3.56E-38	1.56E-38
Eu152	9.67E-03	1.72E-03	1.57E-03	1.04E-03	Re186m	5.77E-15	3.66E-15	3.59E-15	3.51E-15
Eu154	2.76E-03	1.47E-03	1.20E-03	9.24E-04	Rh102	7.53E-29	7.53E-29	7.53E-29	3.27E-29
Eu155	1.57E-08	1.08E-08	1.05E-08	1.04E-08	Rh102m	4.48E-30	4.48E-30	4.48E-30	1.95E-30
Fe55	1.87E+00	4.91E-01	4.53E-01	3.41E-01	Ru106	2.43E-25	2.43E-25	2.43E-25	1.23E-25
Fe60	2.81E-16	1.82E-16	1.80E-16	1.73E-16	S35	9.68E-09	2.44E-09	2.24E-09	1.53E-09
Gd148	1.02E-42	1.02E-42	1.02E-42	3.96E-43	Se75	1.84E-05	1.39E-05	1.39E-05	1.39E-05
Gd150	3.11E-18	1.97E-18	1.96E-18	1.95E-18	Se79	2.55E-08	2.18E-08	2.18E-08	2.17E-08
Gd153	8.20E-10	5.73E-10	5.61E-10	5.53E-10	Si32	3.32E-15	2.10E-15	2.09E-15	2.07E-15
H3	1.95E-06	4.93E-07	4.54E-07	3.13E-07	Sm145	6.26E-33	6.26E-33	6.26E-33	2.69E-33
Hf178n	5.08E-15	3.21E-15	3.20E-15	3.19E-15	Sm146	1.87E-25	1.18E-25	1.18E-25	1.17E-25
Hf182	1.42E-18	1.35E-18	1.30E-18	1.25E-18	Sm151	2.26E-14	1.61E-14	1.61E-14	1.57E-14
Ir192n	1.32E-34	1.32E-34	1.32E-34	6.83E-35	Sr90	7.41E-26	7.41E-26	7.41E-26	3.53E-26
K40	9.82E-44	9.82E-44	9.82E-44	5.05E-44	Ta179	4.12E-12	2.60E-12	2.59E-12	2.58E-12
Kr81	3.22E-25	3.22E-25	3.22E-25	1.65E-25	Tb158	6.43E-45	6.43E-45	6.43E-45	2.66E-45
Kr85	1.85E-19	1.85E-19	1.85E-19	9.50E-20	Tc97	3.53E-28	3.30E-28	3.31E-28	1.71E-28
Lu174	2.92E-33	2.92E-33	2.92E-33	1.40E-33	Tc98	1.57E-20	7.88E-21	7.74E-21	7.56E-21
Lu176	2.87E-25	2.52E-25	2.46E-25	2.38E-25	Tc99	2.28E-05	2.03E-05	2.02E-05	2.01E-05
Mn53	8.55E-13	5.40E-13	5.39E-13	5.36E-13	Tl204	6.80E-15	5.01E-15	4.98E-15	4.87E-15
Mn54	1.97E-07	1.25E-07	1.25E-07	1.23E-07	V49	4.33E-13	2.73E-13	2.73E-13	2.71E-13
Mo93	7.87E-05	6.44E-05	6.44E-05	6.40E-05	Zn65	2.13E-10	1.31E-10	1.28E-10	1.24E-10
Nb91	3.70E-10	2.33E-10	2.33E-10	2.32E-10	Zr93	1.73E-14	1.23E-14	1.21E-14	1.19E-14
Nb92	1.15E-15	7.33E-16	7.31E-16	7.24E-16					

CONCLUSION

By the "Binary Tiling" of the main Suspended Metallic Components, we therefore decrease from more than 100,000 calculations to 1,352, that is, less than 2% of the maximum number of calculations, whilst conserving the quality of the computed scaling factors. So the corresponding CPU times remained obviously reasonable even using usual PC tools.

The Co-60 scaling factor over-estimated to 99% of the possible configurations (in the manner described above) for each of the different activation RN is calculated on each of the main activated systems of the Suspended Metallic Components. The global scaling factor of each reference material is calculated by including the mass contributions of this material from each system.

Thanks to the pseudo scaling factor concept, the declaration of each package with the software including that of the activity can be industrially performed even if numerous packages contain several types of reference materials with very different proportions.

As a consequence of these methods, we have pointed out two results:

(1) The package's activity assessment remain conservative for each RN because no under assessment would be acceptable in the safety analysis in storage.

(2) Nevertheless, the activity assessment obtained remains also not too conservative and it is what is desired because a systematic over-assessment may use up nearly all of the disposal capacities of some long-lived RN.

We should remain that these capacities are allocated to the ANDRA storage by the French Governmental Safety Authority and act as a base for the Storage Center’s Safety Report.

All the presented computational methodology is directly related to the operational safety of the storage and very long term impact analysis in accordance with the different scenarios for return to future generations.

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