NON-DESTRUCTIVE MEASUREMENTS OF NUCLEAR WASTES

VALIDATION AND INDUSTRIAL OPERATING EXPERIENCE

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ABSTRACT

After a short survey of the means employed for the non-destructive measurement of specific activities (γ and X-ray) in waste packages and raw waste, the performances of the device and the ANDRA requirements are presented.

The validation of the γ and X-ray measurements on packages is obtained through determinig, by destructive means, the same activity on coring samples. The same procedure is used for validating the homogeneity measurements on packages (either homogeneous or heterogeneous).

Different operating experiences are then exposed for several kinds of packages and waste.

Up to now, about twenty different types of packages have been examined and more than 200 packages have allowed the calibration, validation, and control.

1. Introduction

Characterization and control assays performed on request of the waste producer, waste manager or safety authorities, include the determination of mass activity either in raw waste or in conditioned or immobilized waste packages.

For the purpose, the Service de Caractérisation, d'Evaluation des Confinements et d'Analyses (SCECA), through the Laboratoire d'Expertise et de Caractérisation des Confinements (LECC) and the Section d'Analyses des Effluents et Déchets (SAED), has developed, for its own use and for producers, some mobile devices suitable for all waste production, regardless of the type of waste, matrix, and package.

Operating experience is available on several dozen packages:
- CEN—Cadarache packages (homogeneous and heterogeneous cemented waste),
- STE_3 bitumen packages,
- STEL bitumen packages, and
- SSM packages (ANDRA).

This paper briefly discusses the means employed, the French requirements for radioactive homogeneity and mass activity measurement; then describes the validation tests required for all types of waste and finally presents some examples of industrial measurements.

2. Examination Means

The means used comprise mainly:
- a "high purity Germanium" gamma detector (range: 10 keV to 10 MeV; resolution: 1 keV at

122 keV and 2 keV at 1. 33 MeV),

- a "low-energy germanium" gamma detector (range: 3 keV to 1 MeV; resolution: 230 eV at 5. 9 keV and 540 eV at 122 keV),
- a 4096-channel analyzer,
- a microcomputer,
- specialized spectrum analysis software,
- an optical detector alignment system,
- accessories for liquid nitrogen,
- lead shielding for collimation,
- a radioactive sealed source for calibration, and
- a turnable for waste packages (permissible load = 10 tons; rotation speed = 1 revolution per minute).

All these examination means are mobile and can thus be used to perform measurements directly in the producer's facilities, reducing measurement costs by eliminating the need to ship radwaste packages to the laboratory.

The turnable is specifically used for heterogeneous packages and to test the containment properties of overpacks and concrete shells.

Table 1 shows the application scope and the main device performance specifications.

3. French Homogeneity and Mass Activity Determination Requirements for Radwaste to be Delivered to ANDRA

Current ANDRA regulations define homogeneity requirements, embedding thresholds, and the maximum permissible activities for the main isotopes.

Waste package homogeneity

The homogeneity of a homogeneous radwaste package is defined by a maximum mass concentration difference of $\pm 25\%$ from the mean activity.

To be acceptable, the mass activity in any 100-litre volume inside a heterogeneous waste package must not exceed one-fifth of the total activity.

Embedding threshold

This is the mass activity above which waste must be conditioned; two types of thresholds are specified:

- a total emission threshold:
  e. g. $\alpha = 5\times 10^{-3}$ Ci/t
  $\beta\gamma = 1$ Ci/t;
- individual thresholds for each isotope with a half-life exceeding 180 days.

Maximum permissible activity

This activity is defined for each radionuclide;

e. g. 1300 Ci/t of ^{60}Co
130 Ci/t of ^{137}Cs
total $\alpha = 0.1$ Ci/t.

The current requirements on measurements levels for raw waste, packages, and leachates are shown in Table 2 for homogeneous waste.

4. Validation Tests on Measurements

These validation tests were carried out concurrently on raw waste and conditioned waste; the validation concerns both βγ and α(^{241}Am) emitters and emission ratios for pure β and α emitters, e. g. ^{60}Co/^{63}Ni; ^{137}Cs/^{90}Sr; ^{241}Am/total α.

4. 1 Validation on raw waste

Two objectives were assigned:

- validation of sampling and of the destructive techniques necessarily used for pure β emitters in order to define the ratios; and
- sample optimization for measurements (mass, measurement representativity, uncertainties).

These aims are illustrated by the results shown in Tables 3 and 4. In Table 3, graphite is used as an example; non-destructive measurements on about 30 samples were used to validate:

- the minimum number of samples to examine (3),
- the dissolution technique, and
- the definition of the main ratios.

In Table 4, the example chosen illustrates the optimization of sample mass for ion exchange resins and the processing of primary samples.

The following remarks are applicable to these examples:

- for each type of waste, the preparation and dissolution techniques of raw samples must be validated; and
- the optimum mass for raw solid waste is about 10 grams.

4. 2 Validation of conditioned waste packages

Several steps were necessary to validate the non-destructive measurements on packages:

- comparison of measurements on the package and its core samples using the same technique;
- comparison of measurements on the package and the samples (taken from the coring samples) by non-destructive means;
- comparison of non-destructive and destructive results; and
- comparison of different measurement procedures (immobilized package, rotating package, different detectors).

Comparison between the package and its core sample

By coring without water, the laboratory can take several samples from the package, to control the activity level and distribution, and to perform different tests (compression, leaching, etc.).

An example of activity comparison on a cemented concentrates package is given in Table 5. These measurements were carried out by non-destructive means. The good correlation of measurements can be seen.

Comparison between the package, the core samples and their slices

The purpose of these non-destructive validation tests is to confirm that the self-shielding coefficients, the geometry and the scale effect allow the technique to be used for any test of characterization, control, and inspection.

An example of this type of validation is given in Table 6. These results come from control measurements on cemented concentrates from a nuclear power plant. The deviations between the different measurements do not exceed 10 to 15%.

Comparison between destructive and non-destructive measurements

The aim here is to allow a complete cross-checking of measurements on mass activities of all the isotopes concerned by the requirements on conditioned waste: βγ, pure β, and α emitters.

The example in Table 7 shows the results of control measurements on an old 700-litre package (cemented concentrates, weighing 1.4 ton). The measurements allow a good evaluation of the mass activity of this package.

Comparison between the different types and means of non-destructive measurements

Although the calibrations and validations above allow a good cross-checking of the measurements, the influence of the measurement mode on heterogeneous packages must be assessed.

Table 8 shows the results given by measurements on steady and rotating packages, both homogeneous and heterogeneous. It is clear that heterogeneous packages must be rotated to measure them. With overcoated packages, the containment must also be tested by measuring possible diffusion of activity in the overcoating.

The use of several types of detectors and the need for evaluating α activity through measuring ^{241}Am with low-energy detector also call for validation of this technique.

An example is given in Table 9; the cross-checking of ^{241}Am measurements by a γ-emitter such as ^{137}Cs validates this type of measurement.

These tests, calibrations, destructive and non-destructive measurements allowed validation of the device employed for determining the mass activity of packages and raw waste in compliance with ANDRA requirements.

The second step involves industrial operating experience.

5. Industrial Measurement Operating Eeperience

The measurements and operating experience presented below concern:
- homogeneity measurements on homogeneous and heterogeneous packages to be shipped to the surface storage site,
- determination of conversion tables for decommissioning waste,
- water filter measurements in routine operation before immobilization in concrete shells,
- special waste measurements: after incident, or waste waiting for transportation, old waste removed from storage, and
- measurement for experimental operation when starting new facilities.

5.1 Homogeneity measurements on packages before shipping to surface storage sites

These measurements are mainly carried out at the Cadarache Nuclear Research Center but also for control. Two examples are given: the first one concerns a package from Cadarache (homogeneous waste): Table 10 illustrates the technique used and the results obtained for a βγ emitter (^{137}Cs) and an α emitter (^{241}Am), for the latter radionuclide, Fig. 1 shows the ^{241}Am spectrum obtained by low-energy detector for one measurement point.

The second example concerns a heterogeneous package: Table 11 shows an application of the regulation that limits the activity inside any 100-litre volume to one-fifth of total activity. The percentage of relative activity (100 %) corresponds to 5 % of total mass activity.

5. 2 Conversion tables for decommissioning waste

In addition to actual dismantled waste, decommissioning generates technological waste (gloves, cotton, etc.). To ensure rational operation, routine controls are performed and it is very useful to define conversion tables relating routine dose rate measurements to total activity and typical spectrum.

An industrial example is given below, with all its steps:
- the first step consists in non-destructive measurements on several series of packages issued from the different zones of the facility being decommissioned, (Table 12);
- the second step is to determine the typical spectra and the different waste characteristics (density, dose rate), (Table 13); and
- the last step consists in computing the conversion coefficients applicable to each type of waste (Table 14).

These steps are carried out as the decommissioning work progresses.

5. 3 Routine measurements on water filters before immobilization in concrete shells

Water filters from nuclear power plants are waste with activities varying over a wide range, from a few mCi to several tenths of Curies per filter.

Although this kind of filter has a typical spectrum in normal operation, variations are observed during plant starting or in case of serious cladding failure; it is then necessary to measure filter activity before immobilizing them in concrete shells.

An example of routine measurement is given in Table 15. This example shows the activity dispersion according to filter location, as well as the fluctuations of isotopic ratios:

e. g. $^{134}Cs/^{137}Cs$: 1. 46 to 1. 61 $\times 10^{-2}$
$^{60}Co/^{137}Cs$: 1. 74 $\times 10^{-2}$ to 1. 7 $\times 10^{-3}$
$^{60}Co/^{125}Sb$: 0. 195 to 1. 567.

5. 4 Measurements on special waste

The number of non-destructive measurement needed for this type of waste increases with the need for storage and the requests to ANDRA for special packages.

Three examples illustrate this operating experience:
- measurements on a settling tank from a nuclear power plant: this vessel was placed in a container for failed assemblies, surrounded by concrete shielding. Table 16 shows the results of γ and low-energy γ measurements;
- measurements on a control rod after replacement: Figure 2 shows the contents of this package. Table 17 shows both the measured spectrum including some minor radionuclides such as ^{124}Sb, and the activity of the two major isotopes: ^{58}Co and ^{60}Co (activity between 3,800 and 4,000 Ci); and
- measurements on packages to be removed from storage because of radium α-activity. In

addition to the overall activity per package, it was necessary to measure the distribution in the drum and in the absorbents placed at the top and bottom of the drum. Table 18 shows an example of measurement for this type of package.

5. 5 Industrial measurements performed when starting new facilities

Non-destructive measurements are performed on bitumized packages during the experimental operation periods.

The industrial targets are:
- validation of the activity evaluations made by the operator from measurements of raw waste;
- validation of the industrial measurement system based on dose rate measurement; and
- verification that the results comply with the specifications and guaranteed process parameters.

Table 19 shows an example of the measurements performed and of the evaluations given by the operator. The deviations between the evaluations, the full-scale non-destructive measurements and the dosimetries ranged from 15 to 20 % for packages containing 60 to 400 Ci of βγ emitters.

Conclusions

These validation results and industrial measurements show that the measurements performed by the Laboratoire d'Expertise et de Caractérisation des Confinements comply with current ANDRA specifications for homogeneity and for mass activity of packages. Nevertheless, the only α-emitter that can be routinely measured at the present time is ^{241}Am. This determination will be used for relating with neutron measurements (active or passive) and for non-destructive validation of all the devices needed to assess mass activity for β, γ and α emitters.

Non-destructive βγ measurements will remain necessary to determine pure β emitters and validate the destructive techniques employed for this type of isotope.

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Table 1 Application fields and performance

1. Application fields

Complete packages:
- Drume
- Shells
- Homogeneous or heterogeneous wastes in different matrices

Samples:
- Core-samples, filters, control rods, unconditioned dismantling wastes, graphite, raw wastes, wastes with radium, etc.

2. βγ - X-ray activity · performance

βγ: up to 1000 Ci/package or raw waste

X-ray: up to 50 Ci/package or raw waste

3. Detection limits

βγ activity: 10^{-3} to 10^{-4} Ci/t per emitter

X-ray: (^{241}Am) : 10^{-2} to 10^{-3} Ci/t

Table 2 Sensitivity and detection limit required for activity measurements for raw and conditioned wastes

Specification	Activity level	Emitter	Detection limit	Uncertainty of results
Embedding limit	10^{-3}Ci/t	α	5×10^{-9}Ci/m^3	50%
Acceptability limit	0.1 Ci/t	α	5×10^{-7} Ci/m^3	10~20%
Maximum limit	1 Ci/t	α	5×10^{-6} Ci/m^3	5~10%
Embedding limit	0.1 Ci/t	βγ	5×10^{-7}Ci/m^3	50%
Embedding limit	1 Ci/t	βγ	5×10^{-6} Ci/m^3	10~20%
Acceptability limit (medium)	10 to 20 Ci/t	βγ	10^{-4} Ci/m^3	5~10%
Maximum limit	1000 Ci/t	βγ	10^{-2} Ci/m^3	5%
Acceptability limit	2 Ci/t	H_3	5×10^{-7} Ci/m^3	20%
Embedding limit	10^{-4} Ci/t	γ long half-life	(10^{-10}- 10^{-11}) Ci/m^3	50%
Acceptability limit	10^{-1} Ci/t	γ long half-life	(10^{-7}- 10^{-8}) Ci/m^3	10~20%
Embedding limit	10^{-3} Ci/t	β long half-life	10^{-9} Ci/m^3	50%
Acceptability limit	10^{-1} Ci/t	β long half-life	(10^{-7}- 10^{-8}) Ci/m^3	10~20%
Maximum limit	10 Ci/t	β long half-life	(10^{-5}- 10^{-6}) Ci/m^3	5~10%

Table 3 Graphite sample measurements

Non-destructive βγ activity measurements

^{60}Co: 1 to 12	kBq/g (0.3 - 3.2×10^{-1} Ci/t)
^{133}Ba: 0.05 to 0.1	kBq/g (0.15 - 0.3×10^{-2} Ci/t)
^{134}Cs: 0.01	kBq/g (0.3×10^{-3} Ci/t)
^{137}Cs: 0.01 to 0.15	kBq/g ((0.03 - 4.5)$\times10^{-3}$ Ci/t)
^{154}Eu: 0.4 to 0.8	kBq/g ((1.2 - 2.4)$\times10^{-2}$ Ci/t)

Destructive measurements

^{3}H: 340 - 400	kBq/g (9.2 - 10.8 Ci/t)
^{14}C: 6 - 25	kBq/g (0.2 - 0.7 Ci/t)
^{63}Ni: 1 - 7.5	kBq/g (0.3 - 2.0×10^{-1} Ci/t)
^{93m}Nb: < 0.1	kBq/g (< 0.3×10^{-2} Ci/t)
^{36}Cl: 0.4 - 1.5	kBq/g ((1.2 - 4.5)$\times10^{-2}$ Ci/t)
^{60}Co: 2 - 15	kBq/g ((0.6 - 4.0)$\times10^{-1}$ Ci/t)
^{133}Ba: 0.05 - 0.2	kBq/g ((0.15 - 0.6)$\times10^{-2}$ Ci/t)
^{134}Cs: 0.01 - 0.1	kBq/g ((0.3 - 3)$\times10^{-3}$ Ci/t)
^{137}Cs: 0.01 - 0.1	kBq/g ((0.3 - 3)$\times10^{-3}$ Ci/t)
^{154}Eu: 0.4 - 0.8	kBq/g ((1.2 - 2.4)$\times10^{-2}$ Ci/t)
^{155}Eu: 0.15 - 0.4	kBq/g ((0.4 - 1.2)$\times10^{-2}$ Ci/t)

Ratios for different isotopes

^{14}C/total βγ activity	: 1.7 ± 0.7
^{63}Ni/total βγ activity	: 0.5 ± 0.1
^{63}Ni/^{60}Co	: 0.58 ± 0.16

Table 4 Validation and optimization for sampling

1. Destructive and Non-destructive measurements for ion exchangre resins (IER)

Radionuclide	Total sample (non-destructive)	Sample fractions (destructive) 10 g	Sample fractions (destructive) 13 g
^{54}Mn	25.5 ± 0.8	17.7 ± 1.3	37.6 ± 2.6
^{58}Co	28.0 ± 0.7	19.0 ± 6.8	40.0 ± 8.2
^{60}Co	54.0 ± 7.6	38.0 ± 2.3	79.3 ± 4.2
^{110m}Ag	52 ± 1.5	62.3 ± 4.8	63.0 ± 4.8

2. Validatiom of sampling to optimize the measurements (destructive analysis)

Dry weight	^{54}Mn	^{60}Co	^{110m}Ag
6.4 g	36.6 ± 4.4	73.4 ± 6.2	71.0 ± 8.0
12.6 g	33.5 ± 3.3	76.4 ± 5.8	68.1 ± 6.8
14.6 g	34.5 ± 3.6	76.8 ± 5.5	64.8 ± 6.5
22.4 g	33.7 ± 3.0	72.2 ± 4.9	63.2 ± 4.9
31.9 g	32.2 ± 2.6	72.5 ± 4.7	64.2 ± 5.5
51.2 g	30.4 ± 2.6	66.2 ± 4.2	56.7 ± 4.6
Moyenne	33.5 ± 3.0	72.9 ± 5.0	64.7 ± 6.0
Deviation from Mean:			
Maximum	1.09	1.05	1.10
Minimum	0.91	0.91	0.88

Table 5 Comparison between full scale package and core sample
(activity relative to full scale package in mCi)

Radionuclide	Core sample	Full scale package
^{60}Co	0.34 ± 0.051	0.30 ± 0.046
^{134}Cs	0.078 ± 0.012	0.080 ± 0.012
^{137}Cs	71 ± 11	80 ± 12

Table 6 Non-destructive measurement validation from different size of samples (concentrates in cement)

Radionuclide		Full scale package (220 l - 370 kg)	Core sample (800×60 mm - 15 kg)	Leaching sampling (80×80 mm - 0.6 kg)
^{54}Mn	Bq mCi	(4.2 ± 0.6)×10^{8} 11.4 ± 1.6	(3.1 - 3.2)×10^{8} 8.4 - 8.8	(4.5 - 4.8)×10^{8} 12.3 - 12.9
^{60}Co	Bq mCi	(1.6 ± 0.2)×10^{9} 43.2 ± 5.4	(1.35 - 1.39)×10^{9} 36.5 - 37.4	(1.51 - 1.53)×10^{9} 40.8 - 41.4
^{134}Cs	Bq mCi	(1.1 ± 0.2)×10^{8} 3.0 ± 0.5	(9.25 - 9.62)×10^{7} 2.5 - 2.6	1.13×10^{8} 3.05
^{137}Cs	Bq mCi	(9.3 ± 1.4)×10^{8} 25.1 ± 3.8	(9.10 - 9.17)×10^{8} 24.6 - 24.8	(1.03 - 1.05)×10^{9} 27.8 - 28.4
Total	Bq mCi	(3.1 ± 0.5)×10^{9} 84.0 ± 12	(2.70 - 2.75)×10^{9} 72.0 to 74 ± 7	(3.1 - 3.2)×10^{9} 84 ± 8 to 86 ± 8

Table 7 Comparison between destructive and non-destructive measurements (activity relative to full scale package in mCi)

Radionuclide	Full scale package	Core sample	Ssmple 5 - 15 g	Test samples ≃10 g
^{60}Co	0.30 ± 0.046	0.34 ± 0.051	0.35 ± 0.05	0.30 ± 0.05
^{134}Cs	0.080 ± 0.012	0.078 ± 0.012	0.081 ± 0.012	0.075 ± 0.015
^{137}Cs	80 ± 12	71 ± 11	85 ± 12	78 ± 10
^{241}Am	1.4 ± 0.2	—	1.3 ± 0.1	1.6 ± 0.2
^{90}Sr	—	—	—	0.19 ± 0.03

Table 8 Type of measurements for heterogeneous and homogeneous packages

Homogeneous package measurement

Radionuclide	Static measurement	Measurement with turntable
^{60}Co	0.30 ± 0.046	0.32 ± 0.048
^{134}Cs	0.08 ± 0.012	0.09 ± 0.016
^{137}Cs	80 ± 12	79.7 ± 12

Heterogeneous package measurement

Radionuclide	Static measurement	Measurement with turntable
^{60}Co	6.70 ± 0.6	7.20 ± 0.6
^{134}Cs	1.5 ± 0.1	1.9 ± 0.2
^{137}Cs	15.3 ± 1.5	37.9 ± 4

Table 9 Equipment and sample comparison

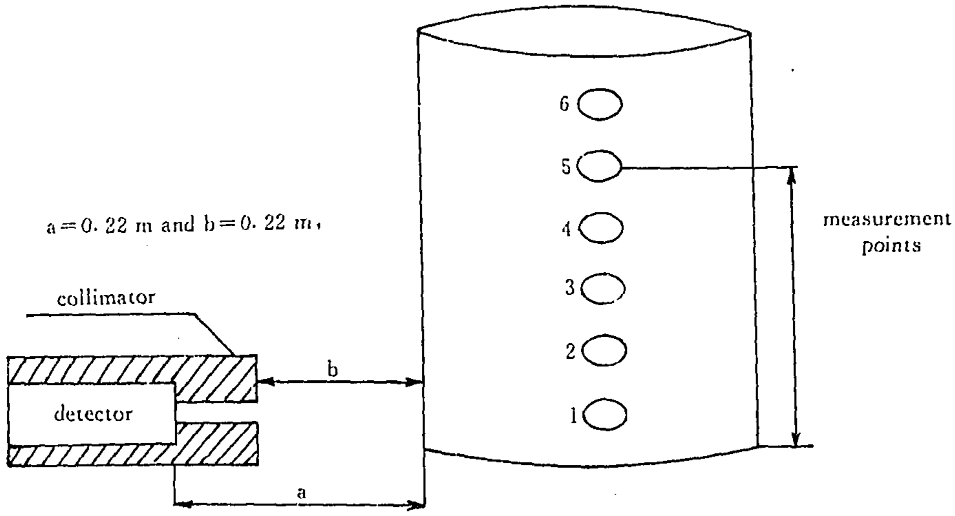
Comparison of measurements by different devices: (^{241}Am) homogeneous Package measurement

Samples (packages)	γ probe	X-ray probe
1	$1.4 \times 10^3 \pm 300$	$1.6 \times 10^3 \pm 350$
2	$2.7 \times 10^4 \pm 6000$	$2.5 \times 10^4 \pm 5500$

Comparison of measurements from different types of samples (MBq/drum)

Type of samples	^{241}Am	^{137}Cs
Full scale package (1.4 t)	1.4×10^3	2.9×10^3
Coré sample (16 kg)	Non measured	2.66×10^3
Section of core sample (1 kg)	0.9×10^3	2.84×10^3
Destructive measurement of sample (10 g)	1.6×10^3	2.80×10^3

Table 10 Results for homogeneity control (700 l PACKAGE No. 1901)



Measurement points	Height (m)	Relative activity (%)	
		^{137}Cs	^{241}Am
1	0.15	82 ± 8	92 ± 9
2	0.30	76 ± 8	78 ± 8
3	0.45	87 ± 9	84 ± 8
4	0.60	100 ± 10	100 ± 10
5	0.75	91 ± 9	79 ± 8
6	0.90	97 ± 10	79 ± 8

Table 11 γ scanning of heterogeneous package
(% of relative activity)

Measurement points	^{60}Co	^{137}Cs
Surface	100	100
Medium	250	510
Bottom	30	15

Table 12 Measurements of dismantling waste: raw waste measurements

Reference of drums	Routine control measurements	^{22}Na kBq	^{54}Mn kBq	^{60}Co kBq	^{134}Cs kBq	^{137}Cs kBq
4751	Undetectable	—	—	< 37	—	< 37
4752	1700	—	—	20190 ± 1700	—	2375 ± 236
4753	700	7.0 ± 1.4	337 ± 31	365 ± 31	98 ± 10	14393 ± 1400
4754	700	—	—	6016 ± 52	—	2915 ± 280
4756	3300	—	2527 ± 235	3197 ± 277	673 ± 68	101800 ± 9500

Table 13 Dismantling waste
density — dose rate — % of activity for different isotopes

Checking cart \ Reference of drums	4571	4752	4754	4753	4756
Density	Not measured	0.22 g/cm^3	0.26 g/cm^3	0.24 g/cm^3	0.24 g/cm^3
Origin	Hot changing room	Decontamination	Decontamination	Reactor containment	Reactor containment
Maximum contact dose rate	< 0.1 mrad/h	40 mrad/h at mid-height	4 mrad/h at mid-height 10 mrad/h at bottom	4 mrad/h at mid-height 10 mrad/h at bottom	4 mrad/h at mid-height 10 mrad/h at bottom
Relative activity					
^{22}Na	—	—	—	0.05%	
^{54}Mn	—	—	—	2.20%	2.3%
^{60}Co	50%	90%	68%	2.50%	3.1%
^{134}Cs	—	—	—	0.60%	0.6%
^{137}Cs	50%	10%	32%	94.65%	94.0%

Table 14 Dismantling waste
(conversion table: count to activity in kBq)

Type of wastes	Conversion factors
Decontamination	13.3 kg ± 20% FOR 1 count per second
Reactor barrier	27.2 kBq ± 20% FOR 1 count per second

Table 15 Process wastes (filters)
(activity measurements; MBq/filter)

Sample number	^{60}Co	^{125}Sb	^{154}Eu	^{134}Cs	^{137}Cs
1	42.2 ± 7.0	106 ± 25	89 ± 21	99 ± 14	6150 ± 750
2	129 ± 17	82.3 ± 14.0	71 ± 10	113 ± 17	7400 ± 900
3	190 ± 32	950 ± 210	1260 ± 320	1273 ± 177	84700 ± 10700
4	218 ± 35	1117 ± 159	1140 ± 285	1560 ± 288	106300 ± 10700
5	130 ± 20	635 ± 77	571 ± 70	1143 ± 158	76700 ± 9700

Table 16

Activity in a settling tank

Radionuclide	Activity in settling tank
^{241}Am	30.0 ± 7.5
^{125}Sb	20.6 ± 4.0
^{154}Eu	40.0 ± 6.0
^{134}Cs	42.0 ± 6.0
^{137}Cs	4220 ± 630
^{60}Co	13.6±2.0

Activity calculated at measuring time (05/09/89)

Radionuclide	Activity (TBq)
^{58}Co	69 ± 12
^{60}Co	73 ± 12

Table 17 Control rod spectrum

Radionuclide	Activity (TBq)
^{58}Co	69 ± 12
^{60}Co	73 ± 12

Table 18

Gamma-scanning of 200-liter drum for wastes containing radium

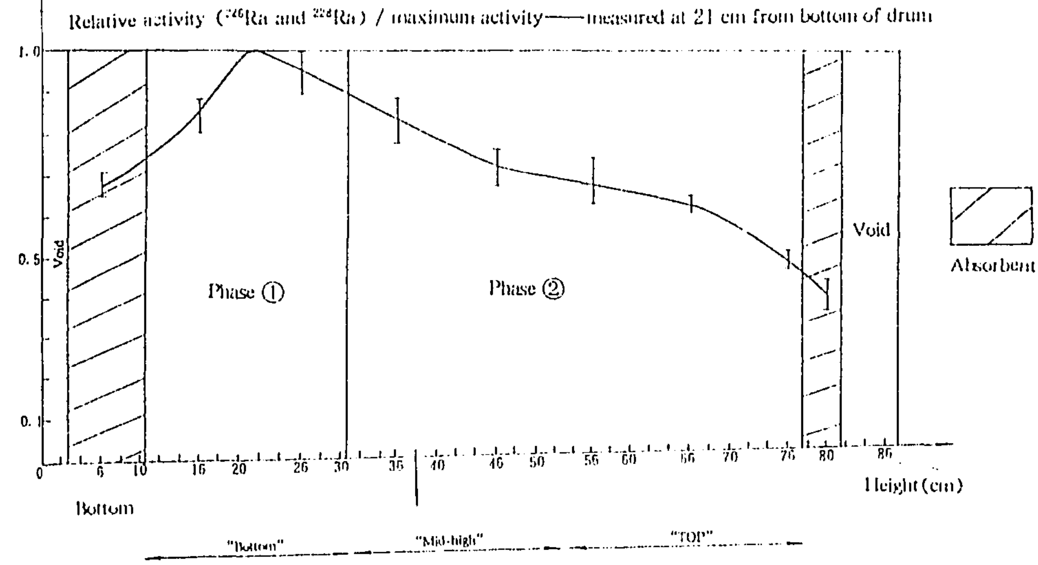


Table 19 Non-destructive measurements for startup of the STE3 bituminization facility at La Hague

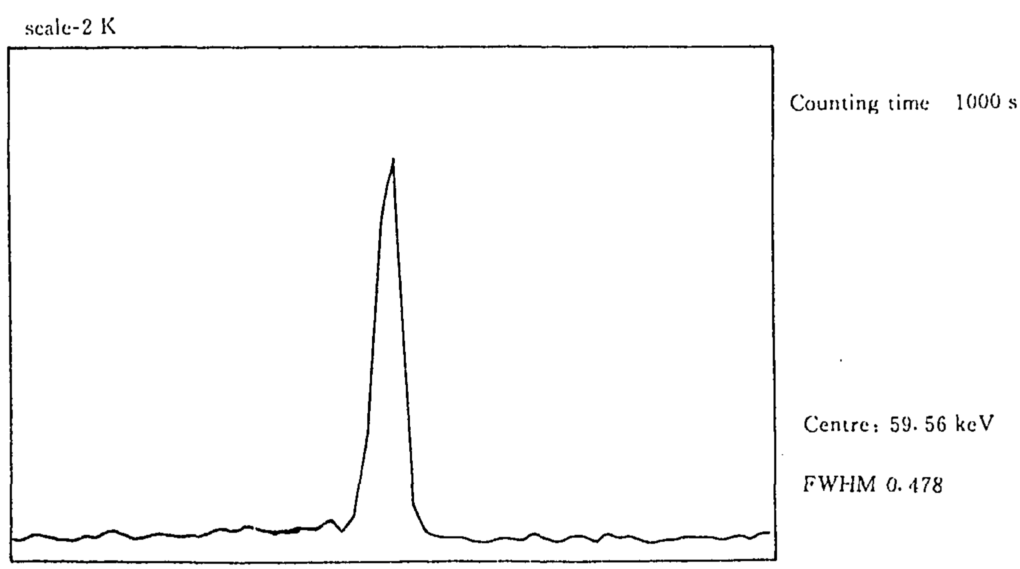
Package number	$^{106}Ru + ^{106}Rh$ (Ci)		Total βγ (Ci)		Dosimetry (rad/h)	
	LH	CAD	LH	CAD	LH	CAD
1099	26.01	23.0	64.1	58.5	45.0	38.3±1.8
1159	24.5	21.0	59.0	53.2	42	ND
992	147.1	122.1	340	314	102	101.3±1.2
993	141.0	118.0	333	292	ND	96.7±2.9

Non-destructive measurments (CAD)

Evaluation according to the operator's specifications (LH)

Validation of acceptance requirements (activity content in packages)

Fig. 1 Americium-241 Peak for the First Measurement Point for Package No. 1901



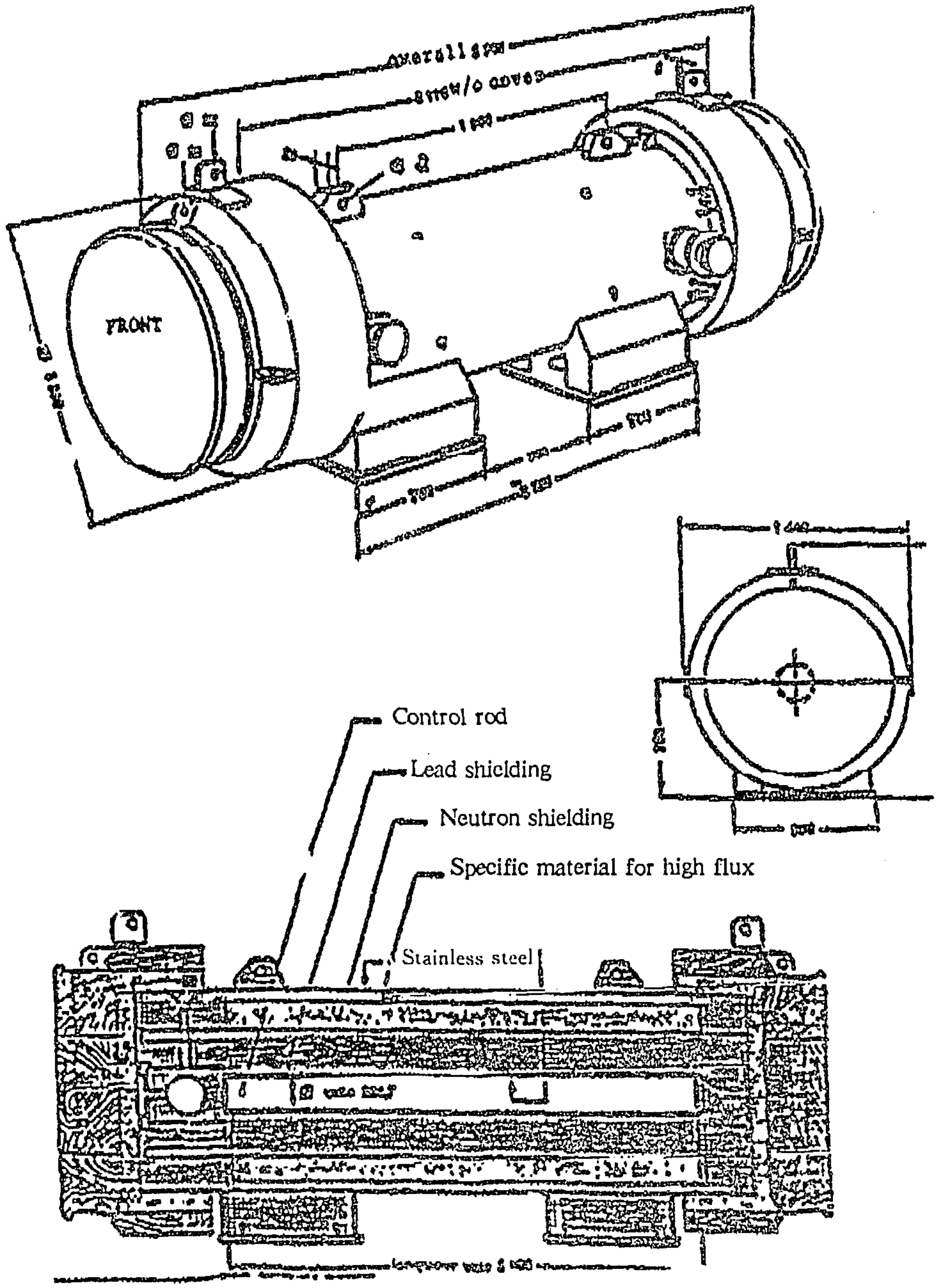


Fig. 2 Package Composition