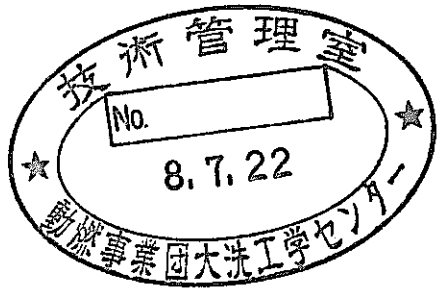
PNC TN9100 96-007

Realistic Contamination Control Methods at α and $\beta(\gamma)$ nuclide Coexistence Facilities

March, 1996



O-arai Engineering Center

Power Reactor and Nuclear Fuel Development Corporation in Japan

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α核種及びβ・γ核種が混在する施設の実際的な汚染管理手法

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概　　要

燃料破損のない軽水炉では，^{60}Co及^{54}Mn等のβ・γ核種に対して汚染管理が必要である。

これに対して，照射後燃料を取り扱っている施設では，α核種及びβ・γ核種の多くの種類に対して汚染管理を必要とする

大洗工学センターには，照射後燃料及び材料の破壊試験を実施している3施設がある。これらの施設では，核種組成比が比較的安定している。このため，日常の汚染管理を^{239}Pu, ^{241}Pu, ^{90}Sr等の代表的核種に着目しながら全β・γ放射能を測定することにより行っている。

核種組成比の調査，汚染管理の考え方及び現場における汚染管理の実際が報告されている。

（本資料は，科学技術庁の原子力研究交流制度の研究者，JICAの放射線安全管理実務者研修等において利用可能な公開資料としてとりまとめたものである。）

1）大洗工学センター　安全管理部　放射線管理課

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March, 1996

Realistic Contamination Control Methods at α and β(γ) nuclide Coexistence Facilities

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ABSTRACT

At the light water reactors with no fuel failure, radioactive contamination control is needed for β(γ) nuclides such as ^{60}Co and ^{54}Mn.

On the other hand, at the nuclear facilities where irradiated fuels (spent fuels) are handled, contamination control is needed for many kinds of α and β(γ) nuclides.

There are three facilities where destructive testing of irradiated fuels and materials is done at Oarai Engineering Center. The ratios of the nuclide composition are considerably stable at these facilities. Therefore, daily contamination control is executed by measuring total (gross) β(γ) activity with paying attention to the representative nuclides such as ^{239}Pu, ^{241}Pu and ^{90}Sr.

The investigation about the ratios of the nuclide composition, the basic idea of the contamination control, and the reality of the contamination control in the facilities are reported.

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1. Preface

At light water reactors with no fuel failure, contamination control is needed for ^{60}Co and ^{54}Mn which are radioactive corrosion products. It is easy to detect these nuclides, because they are $\beta(\gamma)$ nuclides and have moderate energies. We can measure their activities with a Geiger-Mueller counter and their γ energies with a germanium semiconductor detector.

On the other hand, at nuclear facilities where irradiated fuels are handled or at reactors with fuel failures, contamination control is needed for fission products and transuranic (TRU) materials, too. They extend to many nuclides. The types of radiation, the energies, and the limit values of radiation control are different, and several different measuring methods are required. There are some special nuclides we cannot identify or detect with daily measuring methods, for example ^{90}Sr and ^{241}Pu. Chemical pretreatment is needed to identify ^{90}Sr, because it is pure β emitter. Chemical pretreatment and a liquid scintillation counter are needed to detect ^{241}Pu, because it has very low β energy. Therefore, it is unrealistic to identify and detect all nuclides on daily contamination control. After the ratio of the nuclide composition is understood, dairy contamination control is executed by measuring total (gross) $\beta(\gamma)$ activity with paying attention to the representative nuclides. The following shows how to control the contamination at the α and $\beta(\gamma)$ nuclide coexistence facilities where the destructive testing of irradiated fuels and materials is done.

2. The investigation of nuclide composition

2.1 Analysis with ORIGEN code (Oak Ridge National Laboratory, Isotope Generation and Depletion Code)

The sources of contamination are mainly fuels and materials irradiated at Experimental Fast Reactor "JOYO." Nuclide composition of a standard fuel (a Mox fuel) before irradiation is shown in Table-1. The masses of ^{238}U, ^{239}Pu and ^{235}U are considerably large, but their activities are not so large. On the other hand, the mass of

^{241}Pu is considerably small, but its activitiy is large. The half-life of ^{241}Pu, which decays to ^{241}Am, is about 14 years, is shorter than those of other nuclides.

Main parameters of the analyses with ORIGEN code are burnup (irradiated period) and cooling-off period after irradiation.

The results of analyses are as follows.

(1) The isotope composition ratio of Pu (α)

Pu (α) means α emitters of Pu, such as ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{242}Pu. The isotope composition ratios of Pu (α) related to burnup and cooling-off period are shown in Figure-1 and Figure-2.

The isotope composition ratio of Pu (α) does not change largely, even if burnup and cooling-off period lengthen.

(2) The activity composition ratio of α nuclides

Main α nuclides are ^{242}Cm, Pu (α), ^{241}Am and ^{244}Cm nuclides.

Figure-3 shows the result of analysis related to burnup. The activity ratios of Pu (α) and ^{241}Am decrease slightly as the burnup lengthen and the activity ratio of ^{242}Cm increases slightly as the burnup lengthens.

Figure-4 shows the result of analysis related to cooling-off period. The activity ratio of ^{242}Cm decreases as the cooling-off period lengthens, because the half-life of ^{242}Cm is about 163 days. The activity ratio of Pu (α) increases at initial term but decreases slightly as the cooling-off period lengthens. The activity ratio of ^{241}Am increases at initial term and increases slightly as the cooling-off period lengthens.

(3) The ratio of ^{241}Pu (β) to total α activity

^{241}Pu is β emitter.

Table-2 shows the result of analysis related to burnup. Alpha nuclides are ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{241}Am, ^{242}Cm and ^{244}Cm. The ratio of ^{241}Pu (β) to total α activity decreases as the burnup lengthens.

Figure-5 shows the result of analysis related to cooling-off period. The ratio of ^{241}Pu(β) to total α activity is below 20.

Figure-6 also shows the result of analysis related to cooling-off period. This explains the reason of the variation of activity ratio shown in Figure-5.

(4) Main β(γ) nuclides except ^{241}Pu (β) in the irradiated fuels and materials

Table-3 shows main β(γ) nuclides except ^{241}Pu (β) in the irradiated fuels and materials. These nuclides are from fission products and activated materials.

Table-4 shows the ratios of ^{90}Sr activity to other β(γ) nuclide activities in the irradiated fuels and materials. The ratios of ^{90}Sr to ^{137}Cs activity are about 0.6 to 1.0, and they do not depend on burnup and cooling-off period. The half-lives of both nuclides are nearly equal to 30 years.

2.2 Measurement

The smear samples of surface contamination inside Cells in the following facilities were collected

FMF: Fuels Monitoring Facility

Non-destructive testing and disassembling of fuel assemblies

Non-destructive testing and destructive testing of fuel pins irradiated in reactors

Preparation of the samples for AGF and MMF

AGF: Alpha-Gamma Facility

Non-destructive testing and destructive testing of fuel pins irradiated in reactors

Characterization of nuclear fuel materials

MMF: Materials Monitoring Facility

Material testing of non-fuel materials including core structural materials irradiated in reactors

(1) Measurement of α-ray spectra

The procedure of measurement was as follows.

Smear sample

⇓

Electrodeposition sample

⇓

α-ray spectrometer (Silicon surface-barrier semiconductor)

(Figure- 7 shows outline of α-ray spectrometer system.)

It is impossible to resolve the energeies of following nuclides into each other, because their energeies are too close.

^{240}Pu (5.168 Mev) and ^{239}Pu (5.157 Mev)

^{241}Am (5.486 Mev) and ^{238}Pu (5.499 Mev)

The results of α-ray spectra are as follows.

Figure-8 shows α nuclide composition ratios in Cells.

Main detected nuclides at FMF were ^{240}Pu (or ^{239}Pu), ^{241}Am (or ^{238}Pu), and ^{242}Cm.

Main detected nuclides at AGF were ^{240}Pu (or ^{239}Pu) and ^{241}Am.

Main detected nuclides at MMF were ^{240}Pu (or ^{239}Pu) and ^{241}Am (or ^{238}Pu)

The detection rates of ^{242}Cm, of which half-life is about 163 days, were low at both AGF and MMF. They depend on the flow of samples which are from irradiated fuels and materials.

Figure-9 shows an example of α-ray spectrum measurement of the sample which is from Fuel Cladding Cell of MMF.

(2) Measurement of γ-ray spectra

The procedure of the measurement was as follows.

Smear sample

⇓

γ-ray spectrometer (Germanium intrinsic)

The results of γ-ray spectra are as follows.

Table-5 shows γ nuclide composition ratios in Cells in the each facility.

^{137}Cs, which is from fission product, was detected in all facilities and the existence ratios were high. ^{60}Co and ^{54}Mn, which are from activated materials, were detected at FMF and MMF where irradiated materials are handled

(3) Measurement of total α to total β(γ) activity ratio

The procedure of the measurement was as follows.

Smear sample

⇓

Evaporation sample

⇓

α: Proportional counter (gas flow type), β(γ): Geiger-Mueller counter

The results of total α to total β(γ) activity ratio are as follows.

Table-6, Table-7 and Table-8 show the ratios of total α to total β(γ) activity in Cells in the each facility. The average ratio of total α to total β(γ) activity is about 1 to 20.

2.3 Summary of the investigation

(1) α nuclides

α contamination is mainly composed of ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am and ^{242}Cm in the facilities.

The factors of nuclide composition changing are mainly burnup and cooling-off period. The cooling-off period is more effective than the burnup. As the half-live of ^{242}Cm is about 163 days, the existence ratio of ^{242}Cm depend on cooling-off period.

(2) β(γ) nuclides

In view of nuclide composition ratios and DACs (Derived Air Concentrations from Annual Limit on Intake), the important nuclides are mainly ^{241}Pu, ^{144}Ce, ^{106}Ru, ^{137}Cs, ^{90}Sr and ^{60}Co.

^{241}Pu is not detected with ordinary measuring methods because of its low β energy. It is presumed that ^{241}Pu activitiy is 20 times of total α activity, from the result of ORIGEN code analysis.

^{90}Sr is not identified with ordinary measuring methods because it is pure β nuclide, but it is presumed that the ratio of ^{90}Sr to ^{137}Cs activity is 0.6 to 1.0, from the result of ORIGEN code analysis. (Half-lives of ^{90}Sr and ^{137}Cs are nearly equal each other.)

(3) The ratio of total α to total β(γ) activity

Measurement

The ratio of total α to total β(γ) activity is about 1 to 20

Including undetectable ^{241}Pu (Considering the results of ORIGEN code analysis)

The ratio of total α to total β(γ) activity is about 1 to 40

3. The idea of the contamination control with paying attention to representative nuclides

The conservative, reasonable and realistic idea of contamination control was discussed based on the results of the above investigation.

3.1 Basic idea

It is generally conservative to presume the following assumption.

(1) Total α activitiy detected in the measurement is due to ^{239}Pu. (As shown in Table-9, ^{239}Pu has one of the most critical DACs in the existence α nuclides in the facilities.)

(2) Total β(γ) activity detected in the measurement is due to ^{90}Sr. (As shown in Table -10, ^{90}Sr has the most critical DACs in the detectable existence β(γ) nuclides in the facilities.)

(3) ^{241}Pu activitiy exits 20 times of the total α activitiy detected in the measurement. (This means that ^{241}Pu activity is nearly equal to the total β(γ) activity detected in the ordinary measurement.)

3.2 Routine contamination control

Routine contamination control is initially performed by measuring total β(γ) activitiy, which is easily detected.

The following is presumed.

All the detected activity is ^{90}Sr activity.

There is ^{241}Pu activitiy which is equal to the detected activity.

There is ^{239}Pu activity which is equal to one twentieth of the detected activity.

If the unexpected contamination is detected, total α activity and γ-ray spectrum are measured for exact evaluation.

4. The reality of contamination control

4.1 Area control according to designed contamination levels

A controlled area is posted as the following 3 areas called with names of colors.

Red area: The area having contamination

Amber area: The area having the possibility of contamination

Green area: The area having no contamination

Clothing and shoes are exchanged at the entrance of each area.

The contamination of persons and articles is checked at the exit of each area with a hand-foot (clothing) monitor, a gate monitor or a survey meter to prevent the spread of contamination. This checking is mainly performed by measuring total $\beta(\gamma)$ activity. If necessary, total α activity and γ-spectrum are measured.

The control values on measurement are as follows.

α: below 0.04 Bq/cm^2

$\beta(\gamma)$: below 0.4 Bq/cm^2

These control values are one tenth of the values prescribed in Japanese regulations. The values prescribed in Japanese regulations are used when articles are taken out from controlled areas. Considering undetectable ^{241}Pu (β), the control value of $\beta(\gamma)$ is practically equivalent to one fifth of the value prescribed in Japanese regulations.

The ratio of α to $\beta(\gamma)$ control value on measurement is 1 to 10. On the other hand, the ratio of total α to total $\beta(\gamma)$ activitiy in the facilities was about 1 to 20 in measurment. Therefore, when the level of contamination clears the control value of $\beta(\gamma)$ on measurement, the level of contamination shall clear the control value of α on measurement.

Figure-10 shows an example of the posting of a controlled area.

The spaces on the red area are hot cells, where contaminated and irradiated materials are treated with manipulators. Workers do not enter this area except special cases, for example, repairing instruments or replacement of instruments in the Cells.

Through the amber area, articles are sometimes carried out from the red area.

From the green area, manipulators are operated with remote control.

4.2 Daily contamination control of controlled areas

The contamination levels in the controlled area are regularly measured to recognize contamination conditions.

(1) Surface contamination measurement

The smear samples are collected at the fixed points once a week.

The total $\beta(\gamma)$ activities are measured.

If the contamination is detected, total α activity and γ-ray spectrum are measured.

The control values on measurement are as follows.

α: below 0.04 Bq/cm^2

$\beta(\gamma)$: below 0.4 Bq/cm^2

The ratio of α to $\beta(\gamma)$ control value on measurement is 1 to 10. On the other hand, the ratios of total α to total $\beta(\gamma)$ activity in the facilities were about 1 to 20 in measurment. Therefore, when the level of contamination clears the control value of $\beta(\gamma)$ on measurement, the level of contamination shall clear the control value of α on measurement.

Figure-11 shows an example of smear points. There are about 50 points. The controlled area is about 1,700 m^2.

(2) Measurement of activity concentration in the air (measurement of airborne concentration)

Continuous air sampling is performed with air samplers at fixed points. Continuous monitoring is also performed with dust monitors at some facilities.

Figure-12 shows an example of air sampling points for the measurements of air concentration of activity. There are about 20 sampling points. The controlled area is about 1,700 m^2.

The air filters of above instruments are exchanged once a week. If abnormal indication is found in the immediate measurement of total $\beta(\gamma)$ activity, the filter is measured with γ-ray spectrometer at once.

Total α and total β(γ) activities on the filters are officially measured after 72 hours from exchanging the filters in order to reduce the influence of the daughter activities of Radon and Thoron.

The control values, the average values of a week, on measurement are as follows.

α: below 10^{-9} Bq/cm^3

β(γ): below 10^{-8} Bq/cm^3

These values are sufficiently below the DAC values prescribed in Japanese regulations.

The ratio of α to β(γ) control value on measurement is 1 to 10. The ratios of total α to total β(γ) activity in the facilities were about 1 to 20 in measurement. Therefore, if the level of contamination clears the control value of β(γ) on measurement, the level of contamination shall clear the control value of α on measurement.

The undetectable β nuclide activity of ^{241}Pu is nearly equal to the detected total β(γ) activitiy and the DAC value of ^{241}Pu is 4×10^{-6} Bq/cm^3. Therefore, if the level of detected contamination clears the control value of β(γ), the level of contamination shall clear the DAC value of ^{241}Pu.

4.3 Contamination control in works

A radiological working plan is made before the work, and contamination control is based on this plan.

The paper related to making a radiological work plan is "PNC TN9100 96-006 Radiological Work Control at Nuclear Facilities."

5. Conclusion

In α and β(γ) nuclide coexistence facilities where the nuclide compositions are considerably stable, it is possible to establish daily contamination control by measuring total β(γ) activity with paying attention to the representative nuclides such as ^{239}Pu, ^{241}Pu and ^{90}Sr.

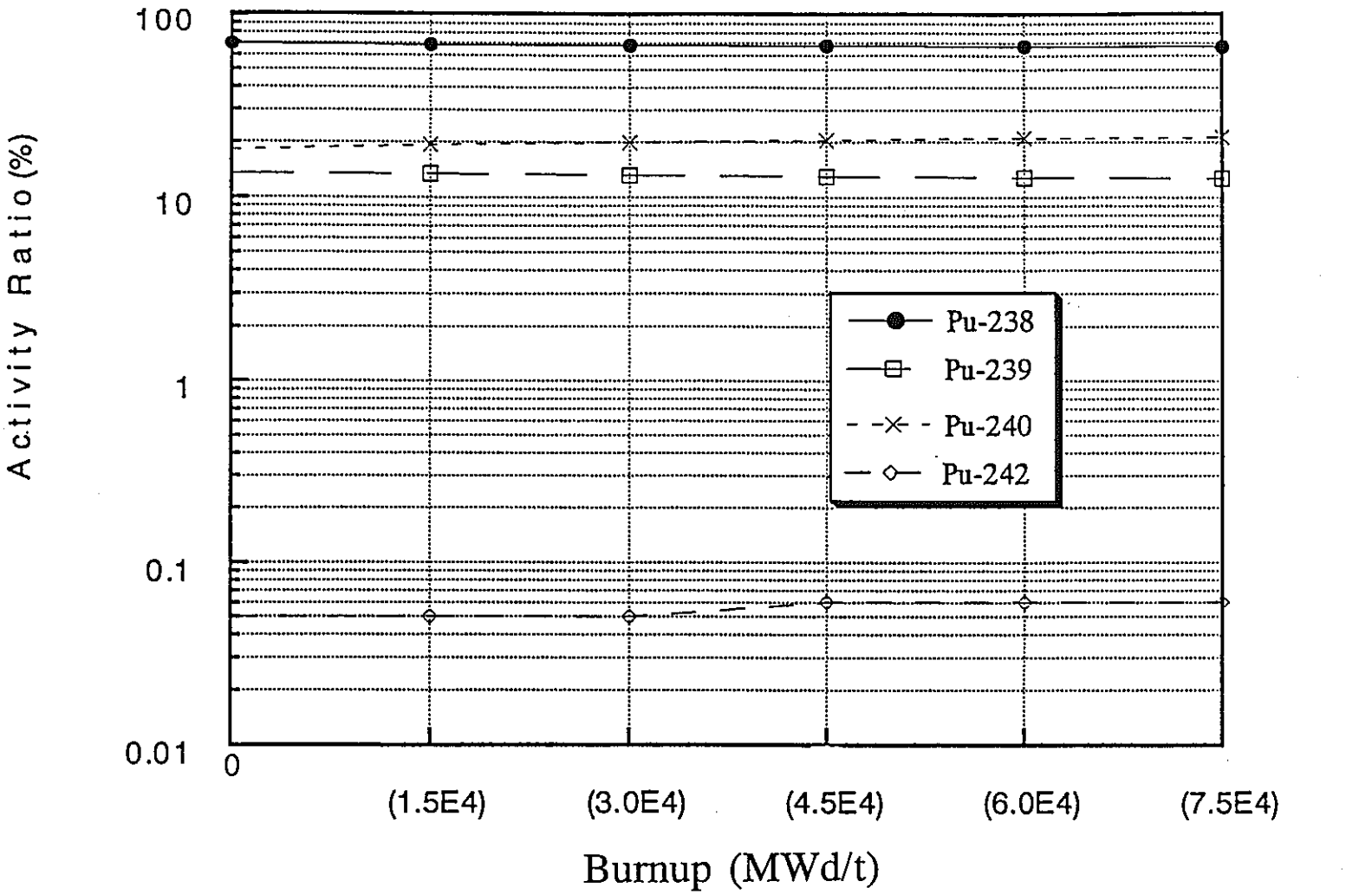
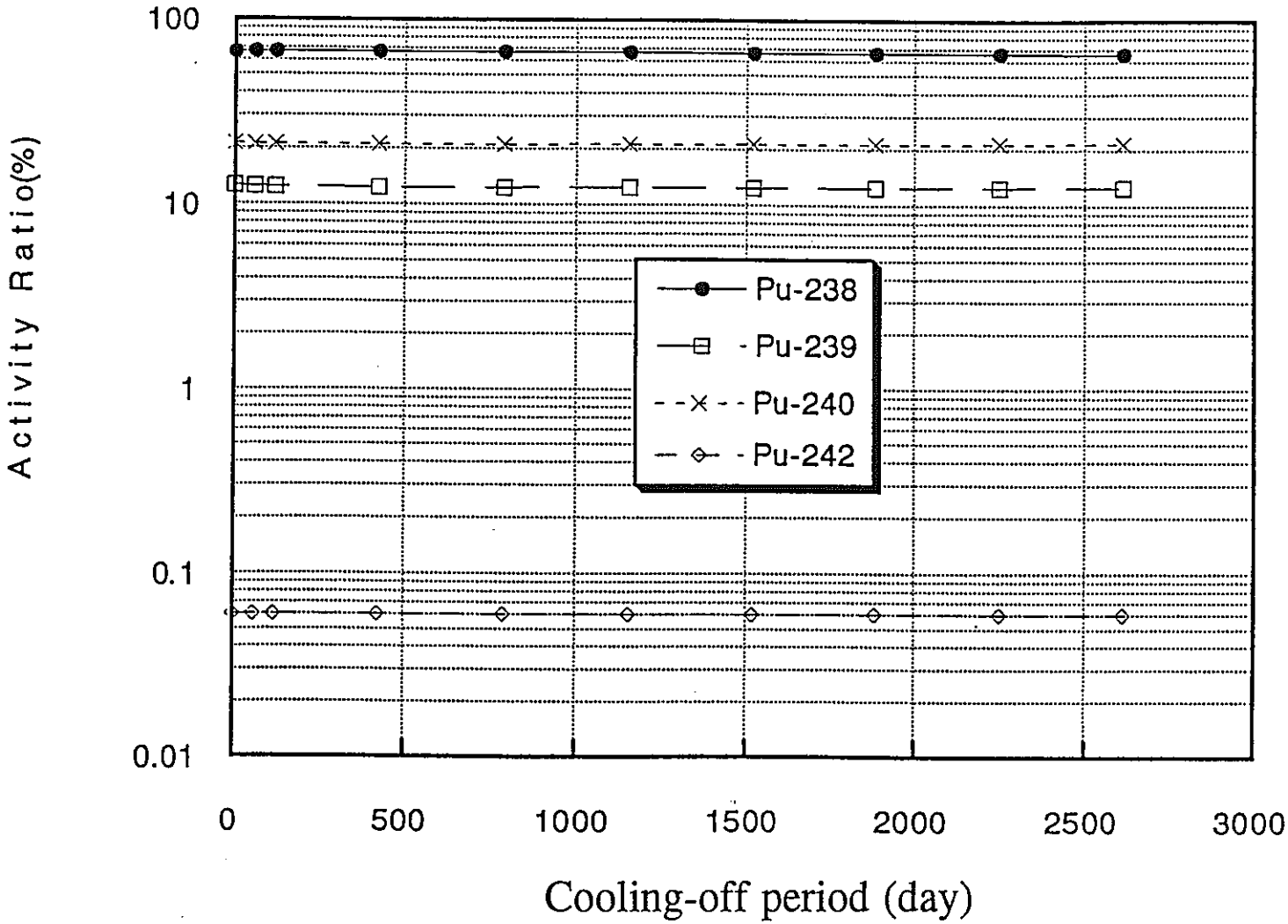


Fig.-1 The isotope composition ratio of Pu(α) related to burnup



Burnup (MWd/t): 75000

Fig.-2 The isotope composition ratio of Pu(α) related to cooling-off period

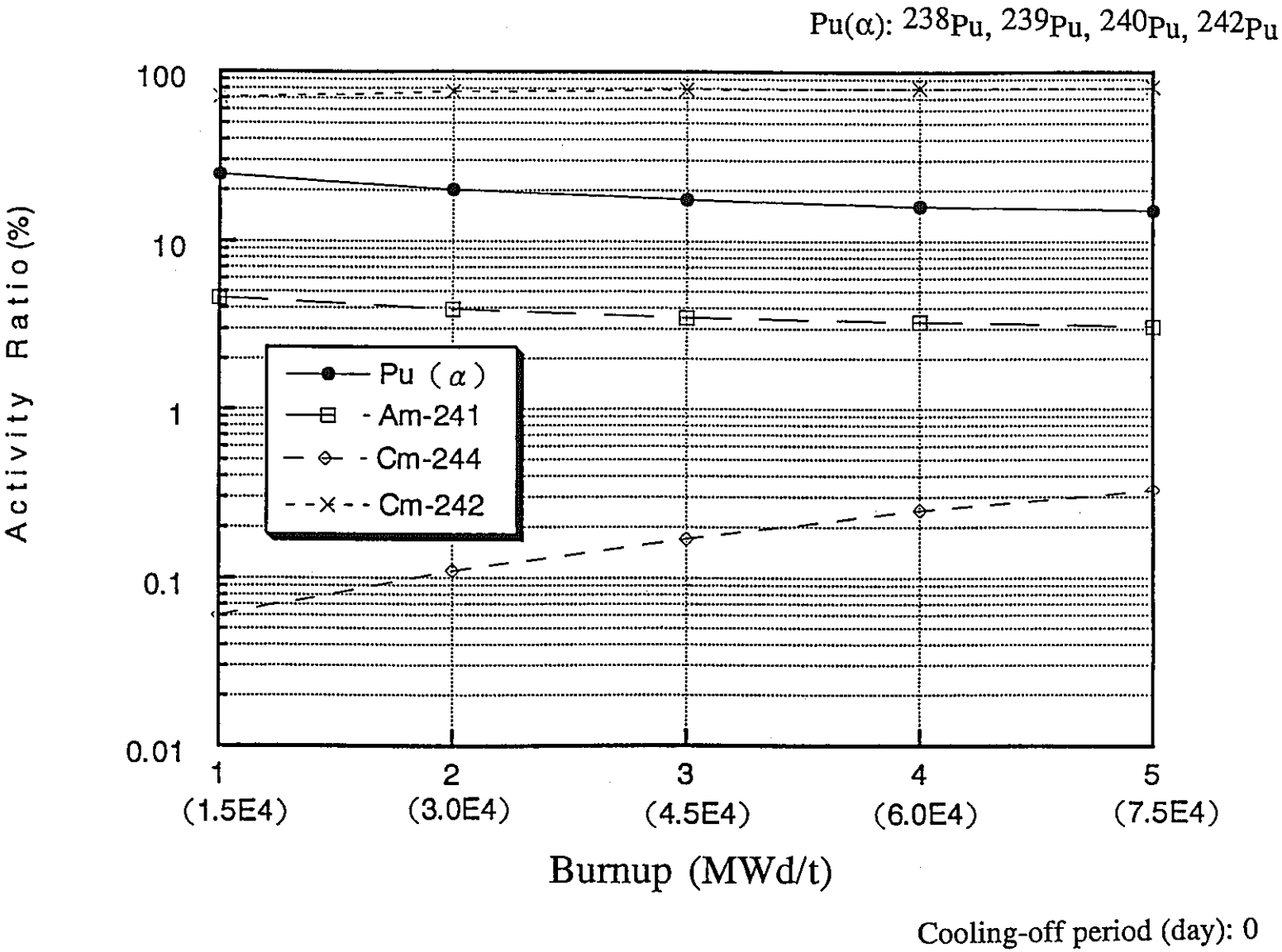


Fig.-3 The activity composition ratio of α nuclides related to burnup

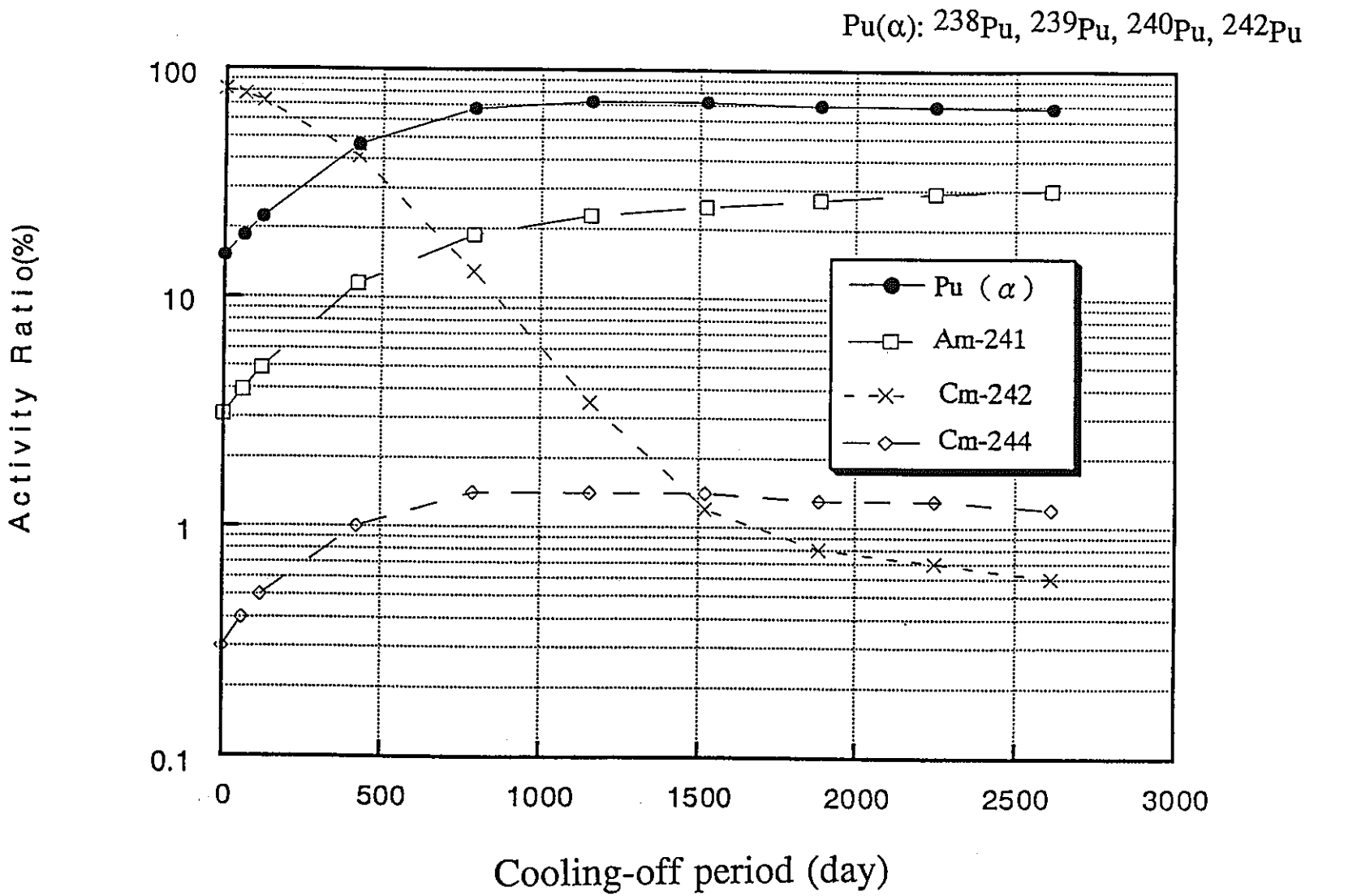


Fig.-4 The activity composition ratio of α nuclides related to cooling-off period

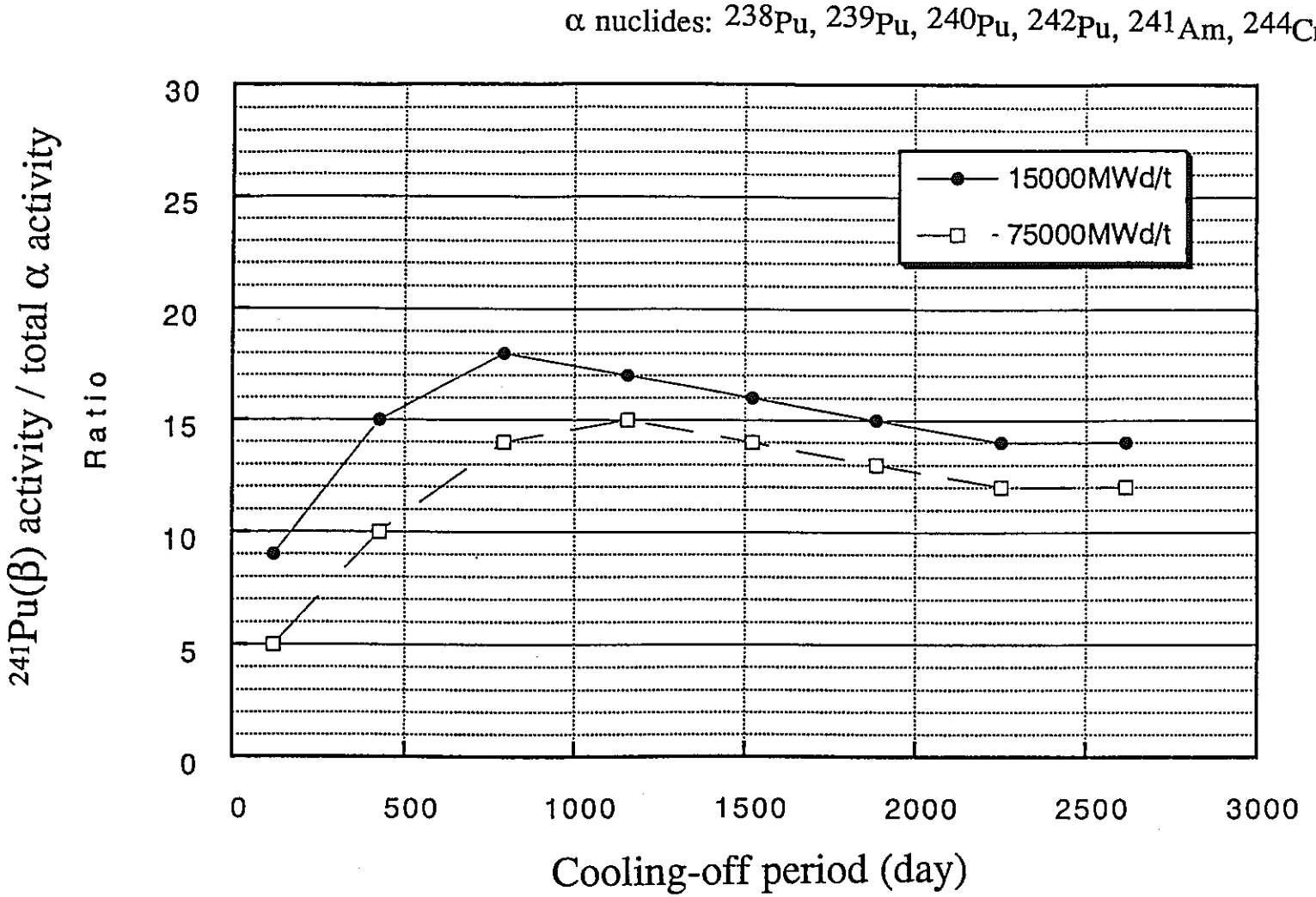


Fig.-5 The ratio of $^{241}Pu(\beta)$ to total α activity related to cooling-off period

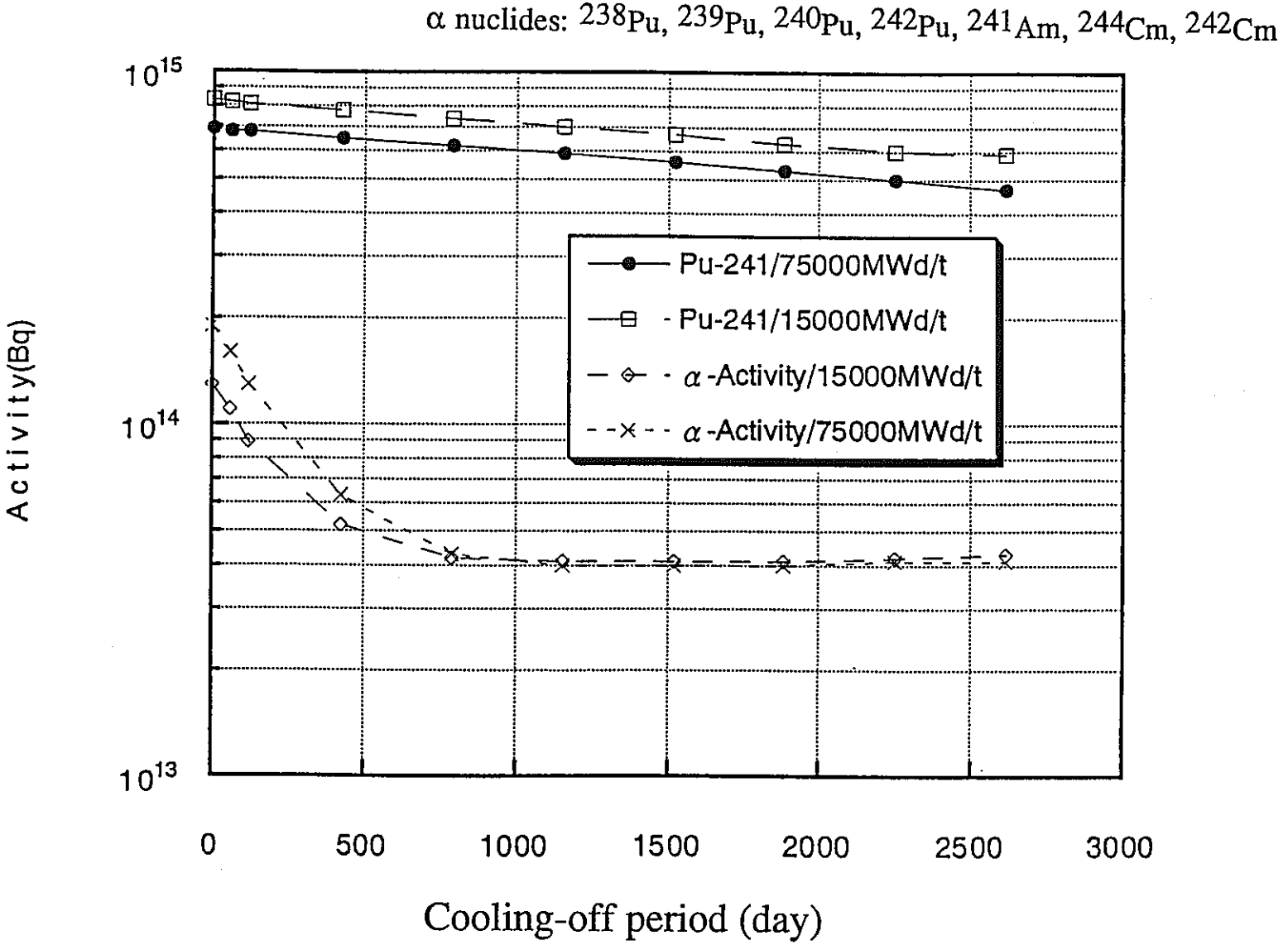


Fig.-6 The $^{241}Pu(\beta)$ activity and total α activity related to cooling-off period

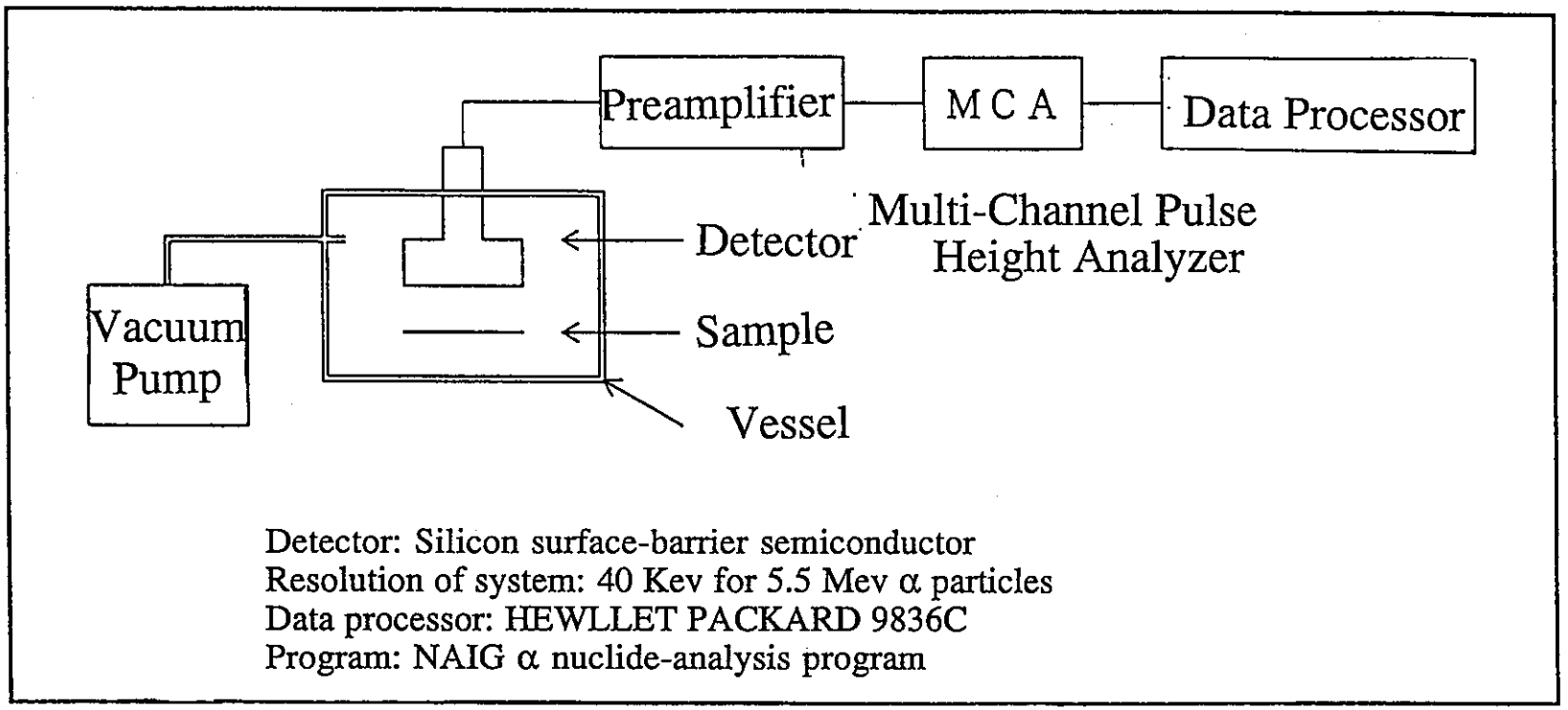


Fig.-7 Outline of α-ray spectrometer System

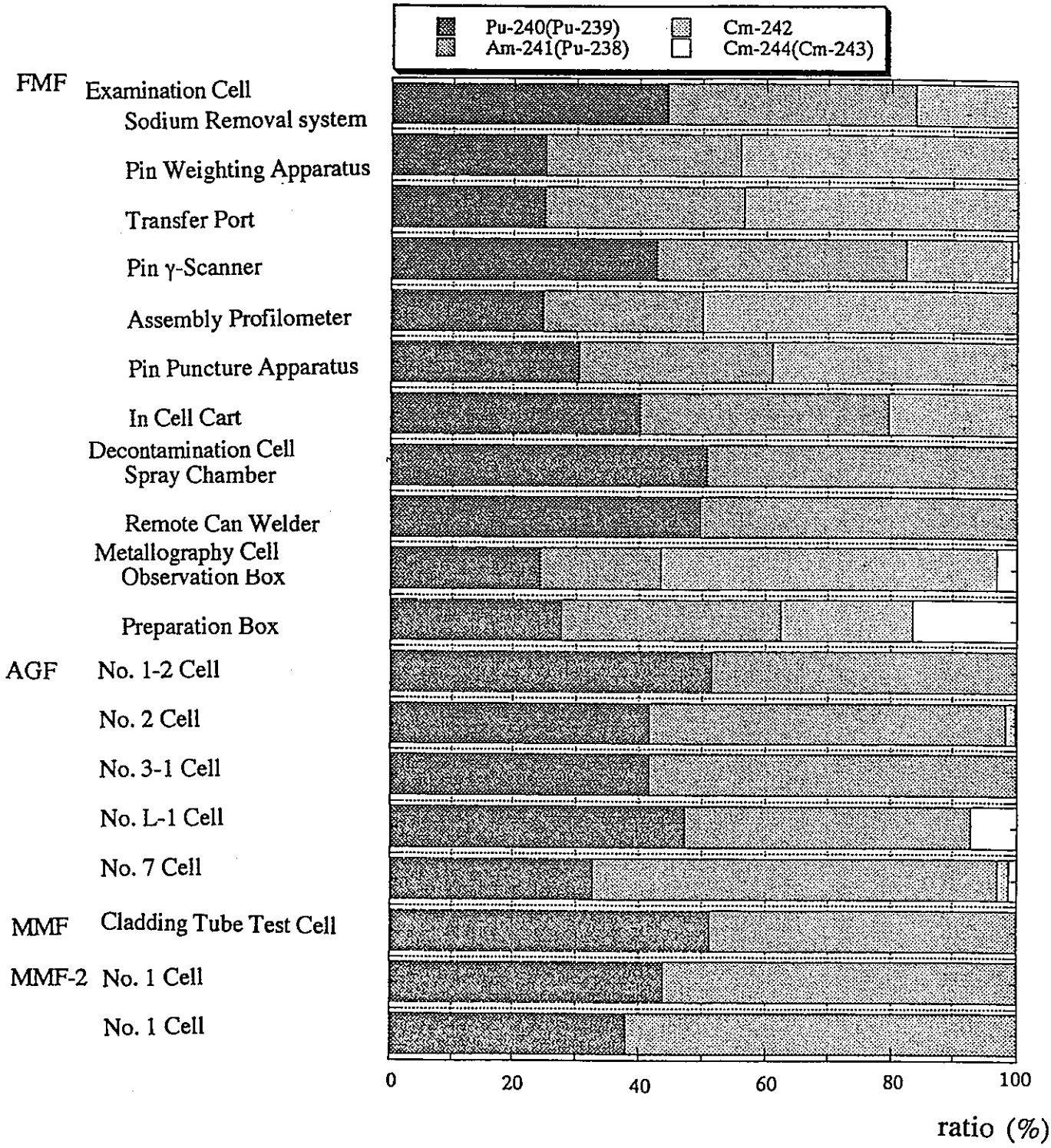


Fig.-8 α nuclide composition ratios in Cells

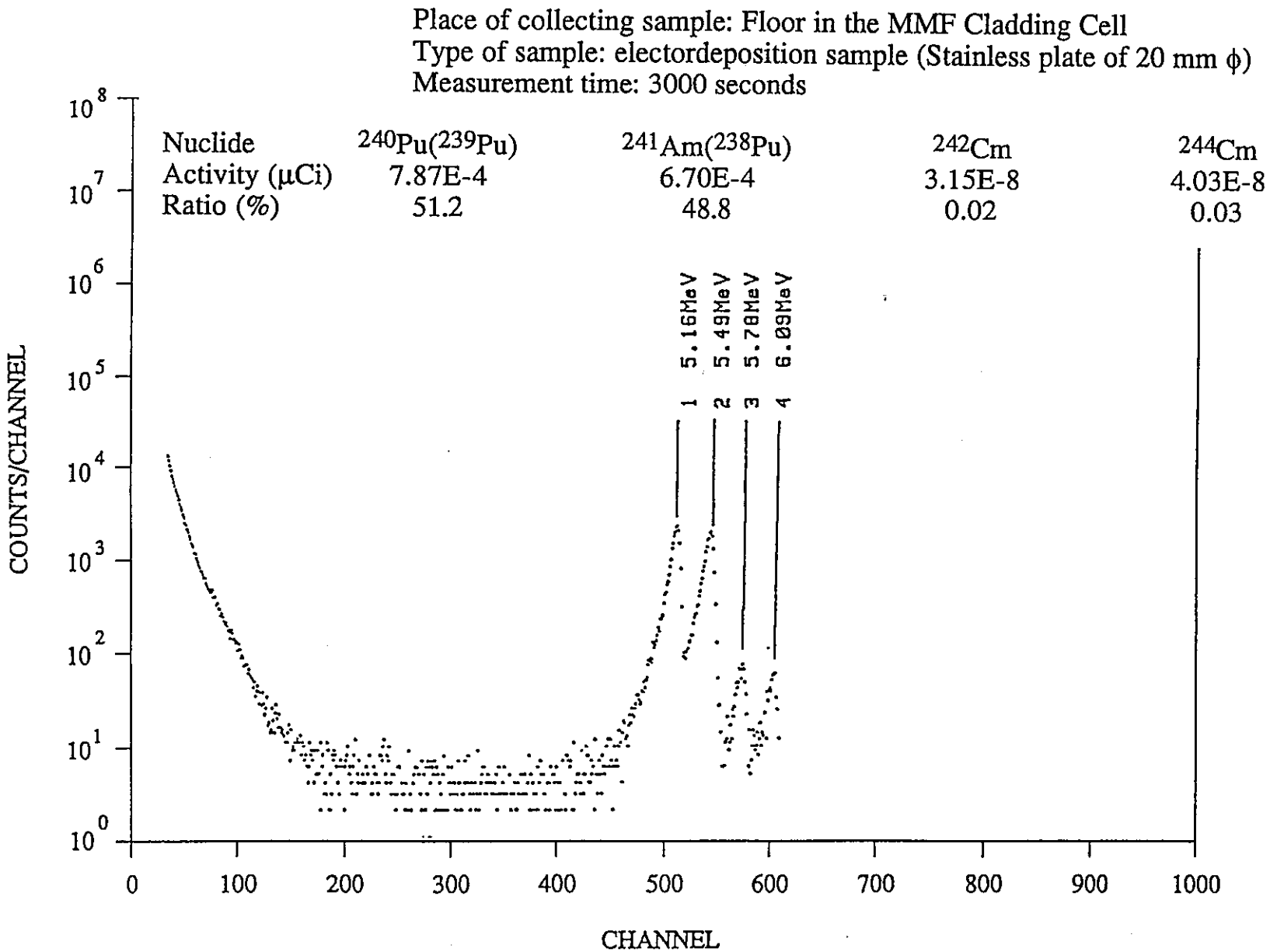


Fig.-9 Example of α-ray spectrum (MMF Fuel Cladding Cell)

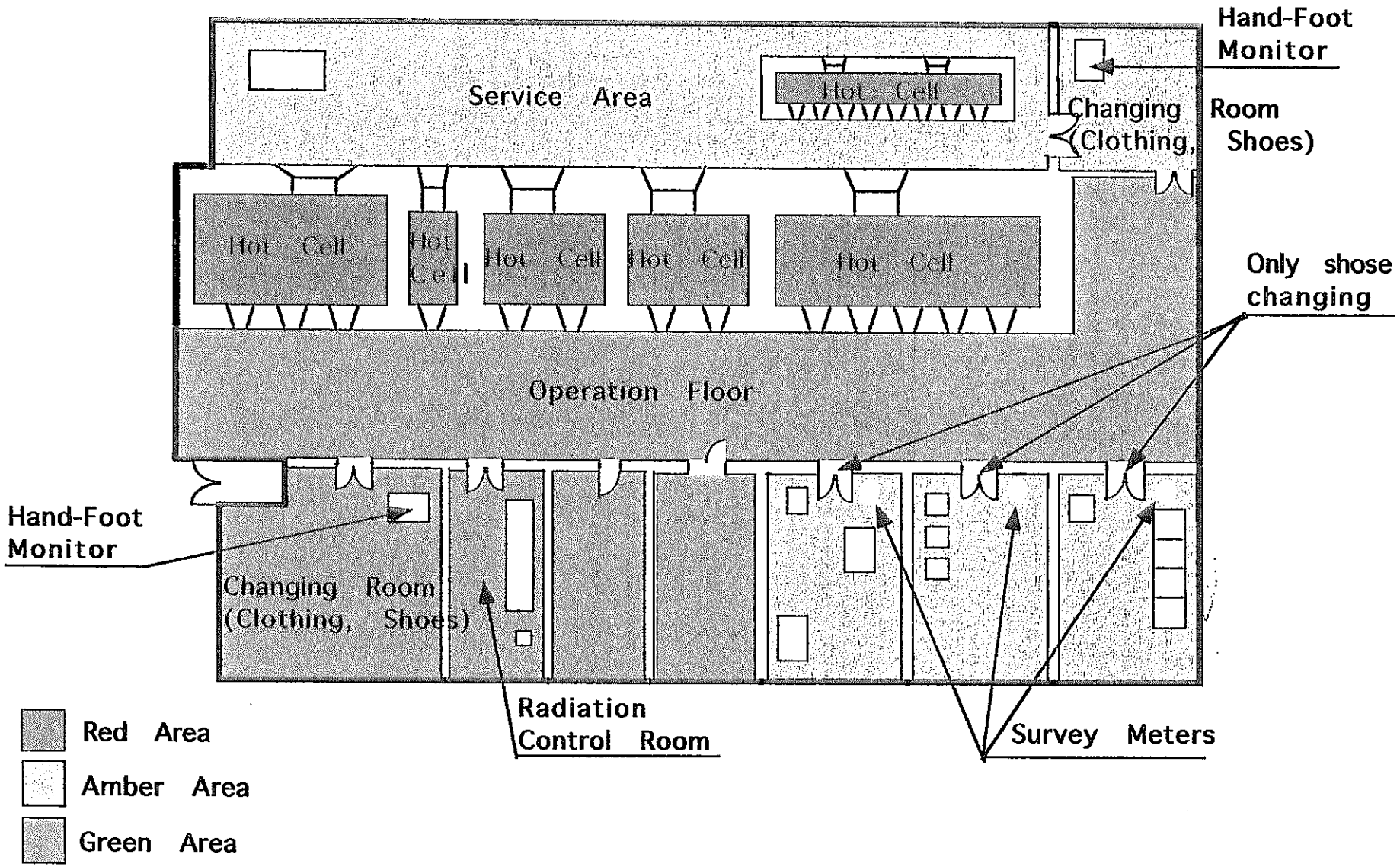


Fig.-10 Posting of a controlled area (Red, Amber, Green)

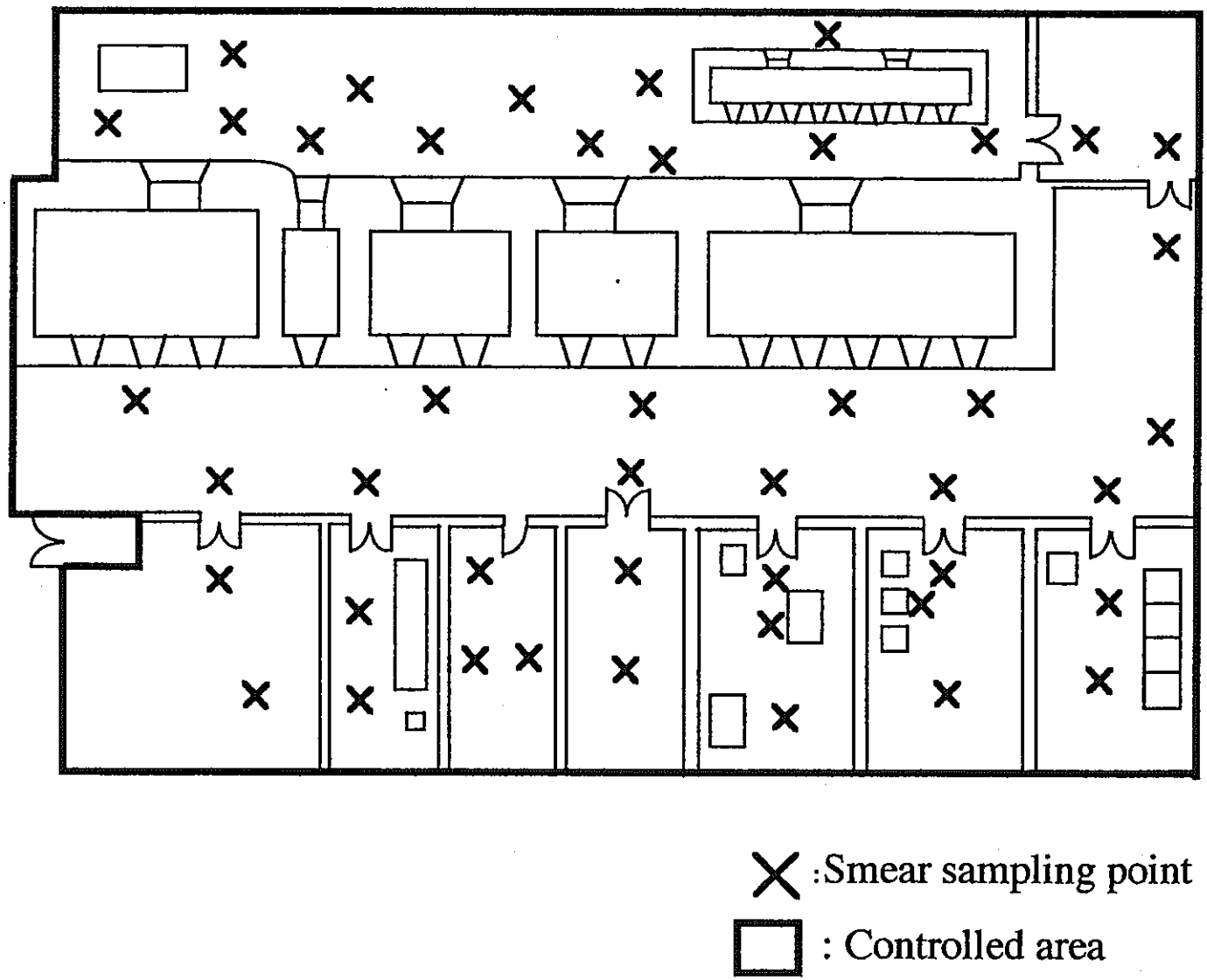
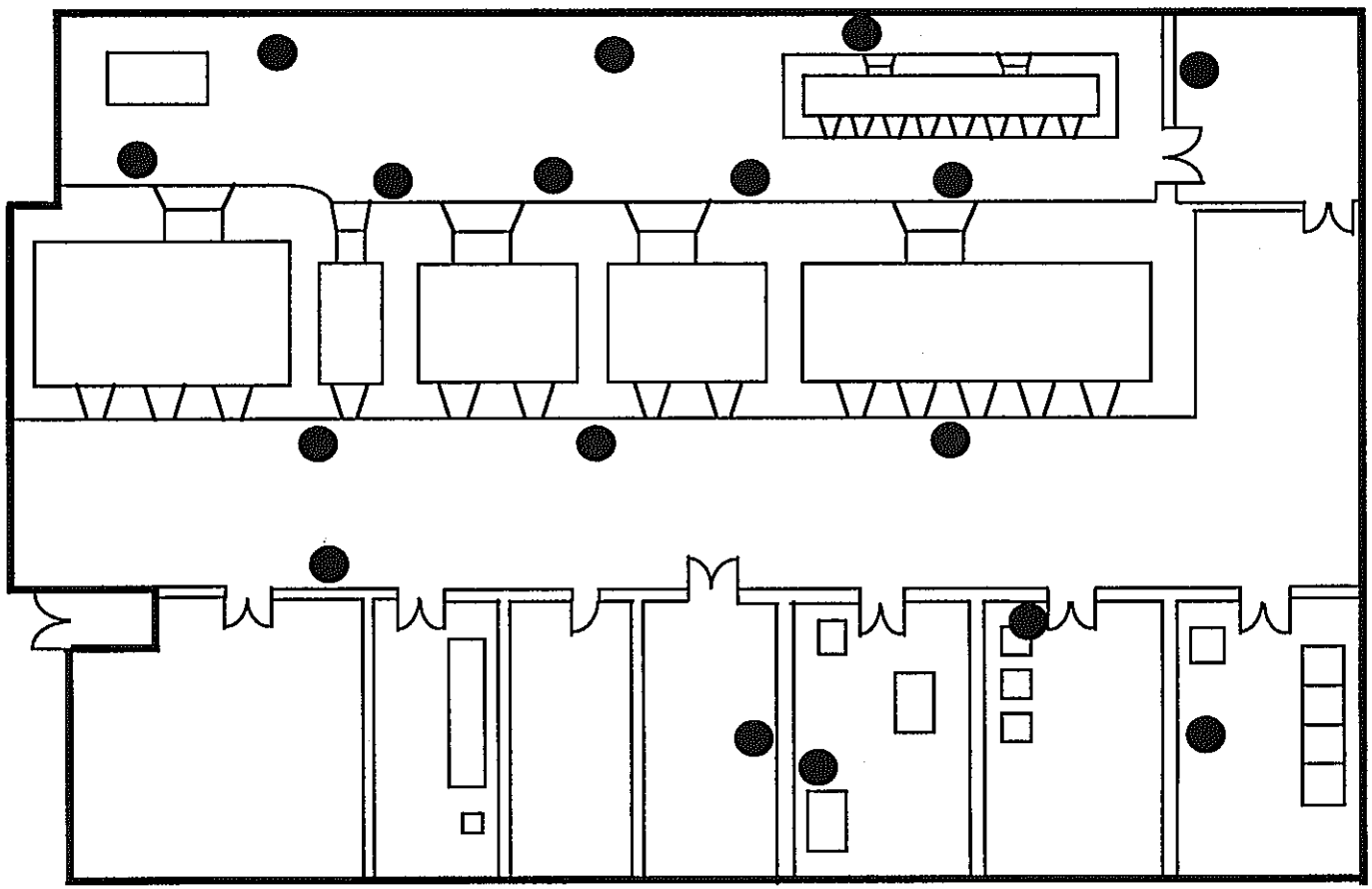


Figure-11 Measurement of surface contamination (an example)



● : Air sampling point

□ : Controlled area

Fig.-12 Measurement of airborne concentration (an example)

Table-1 Main nuclide composition of a standard fuel before irradiation

Nuclide	Mass(g) / fuel assembly	Activity (Bq)	Activity ratio (%)
^{235}U	1420	1.13×10^{8}	1.1×10^{-5}
^{238}U	6890	8.58×10^{7}	8.6×10^{-6}
^{238}Pu	36	2.28×10^{13}	2.29
^{239}Pu	1940	4.46×10^{12}	0.45
^{240}Pu	710	5.96×10^{12}	0.60
^{241}Pu	250	9.56×10^{14}	96.2
^{242}Pu	110	1.60×10^{10}	1.6×10^{-3}
^{241}Am	41	5.21×10^{12}	0.52

Table-2 The ratio of $^{241}Pu(\beta)$ to total α activity related to burnup

	Burnup (MWd/t)				
	1.5×10^4	3.0×10^4	4.5×10^4	6.0×10^4	7.5×10^4
$^{241}Pu(\beta)$ activity / total α activity	6.7	5.3	4.5	4.0	3.6

Cooling-off period (day): 0

α nuclides: ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{241}Am, ^{244}Cm, ^{242}Cm

Table-3 Main β(γ) nuclides except ^{241}Pu in the irradiated fuels and materials

Nuclide	^{144}Ce-Pr	^{106}Ru-Rh	^{95}Nb	^{95}Zr	^{137}Cs	^{54}Mn	^{90}Sr-Y	^{125}Sb	^{134}Cs	^{60}Co
Activity (Bq)	1.0×10^{15}	7.2×10^{14}	6.8×10^{14}	3.5×10^{14}	1.1×10^{14}	1.1×10^{14}	6.4×10^{13}	2.1×10^{13}	1.8×10^{13}	1.8×10^{12}
Type	FP	FP	FP	FP	FP	Activated Material	FP	FP	FP	Activated Material

Burnup: 75000Mwd/t, Cooling-off period: 120days

Table-4 The ratios of ^{90}Sr activity to other β(γ) nuclides activities in the irradiated fuels and materials

Nuclide	Burnup (MWd/t)	Cooling-off period (day)				
		0	120	425	790	1155
^{54}Mn	1.5×10^3	0.34	0.47	0.92	2.10	4.70
	7.5×10^3	0.45	0.59	1.20	2.64	5.90
^{60}Co	1.5×10^3	35.8	37.1	40.6	45.1	50.3
	7.5×10^3	34.3	35.5	38.8	43.2	48.2
^{137}Cs	1.5×10^3	0.58	0.58	0.58	0.58	0.58
	7.5×10^3	0.57	0.57	0.57	0.57	0.57
^{144}Ce	1.5×10^3	0.03	0.04	0.09	0.21	0.50
	7.5×10^3	0.05	0.06	0.13	0.31	0.72

^{90}Sr activity / another β(γ) nuclide activity from one fuel assembly including metallic materials.

Table-5 The ratios of γ nuclide composition in Cells (1)

Facility Name	Cell Name	Main Nuclide Composition Ratio (%)
FMF		
	Examination Cell Sodium Removal system	^{60}Co (39.9) · ^{137}Cs (35.2) · ^{144}Ce (11.4) · ^{54}Mn (4.2) · ^{241}Am (3.9) · ^{125}Sb (1.9) · ^{134}Cs (1.8) · ^{22}Na (1.7)
	Pin Weighting Apparatus	^{60}Co (58.7) · ^{137}Cs (24.1) · ^{144}Ce (9.4) · ^{54}Mn (4.6) · ^{241}Am (3.2)
	Transfer Port	^{137}Cs (33.0) · ^{60}Co (30.6) · ^{144}Ce (4.7) · ^{54}Mn (8.1) · ^{241}Am (7.3) · ^{58}Co (2.9) · ^{125}Sb (1.7) · ^{134}Cs (1.4) · ^{22}Na (0.3)
	Pin γ-Scanner	^{60}Co (47.0) · ^{137}Cs (20.0) · ^{54}Mn (13.9) · ^{144}Ce (10.1) · ^{241}Am (3.1) · ^{58}Co (3.0) · ^{125}Sb (1.7) · ^{134}Cs (1.1) · ^{22}Na (0.1)
	Assembly Profilometer	^{60}Co (51.9) · ^{54}Mn (21.7) · ^{137}Cs (10.9) · ^{241}Am (10.7) · ^{58}Co (3.2) · ^{144}Ce (1.6)
	Pin Profilometer	^{60}Co (60.5) · ^{137}Cs (17.0) · ^{58}Co (9.3) · ^{54}Mn (7.6) · ^{144}Ce (2.8) · ^{241}Am (2.0) · ^{134}Cs (0.8)
	Pin Puncture Apparatus	^{60}Co (70.0) · ^{137}Cs (26.0) · ^{54}Mn (4.0)
	In Cell Cart	^{60}Co (64.2) · ^{54}Mn (15.0) · ^{137}Cs (11.0) · ^{144}Ce (5.0) · ^{241}Am (4.8)
	Decontamination Cell Spray Chamber	^{60}Co (70.0) · ^{137}Cs (22.3) · ^{54}Mn (7.7)
	Remote Can Welder	^{137}Cs (60.5) · ^{144}Ce (34.6) · ^{134}Cs (4.9)
	Clean Cell	^{60}Co (98.7) · ^{54}Mn (1.3)
	Contact Repair Room	^{60}Co (54.6) · ^{144}Ce (29.2) · ^{54}Mn (11.9) · ^{137}Cs (4.3)
	Hot Repair Room	^{137}Cs (29.0) · ^{60}Co (25.0) · ^{144}Ce (21.7) · ^{54}Mn (16.1) · ^{58}Co (8.2)
	Metallography Cell Observation Box	^{137}Cs (39.8) · ^{58}Co (23.0) · ^{144}Ce (16.5) · ^{134}Cs (12.6) · ^{241}Am (2.9) · ^{207}Bi (1.9) · ^{125}Sb (1.8) · ^{22}Na (0.6) · ^{95}Zr (0.3) · ^{93}Nb (0.3) · ^{60}Co (0.2) · ^{54}Mn (0.1)
	Preparation Box	^{137}Cs (48.1) · ^{144}Ce (23.6) · ^{134}Cs (16.8) · ^{22}Na (5.8) · ^{241}Am (3.1) · ^{125}Sb (2.2) · ^{54}Mn (0.2) · ^{60}Co (0.2)
	Liquid Waste Tank Room	^{60}Co (95.4) · ^{54}Mn (4.6)
	Sampling Hood	^{137}Cs (23.6) · ^{60}Co (16.8) · ^{54}Mn (5.8)
	Port P-10	^{54}Mn (62.4) · ^{58}Co (24.1) · ^{137}Cs (7.6) · ^{60}Co (4.5) · ^{241}Am (1.4)

Table-5 The ratios of γ nuclide composition in Cells (2)

Facility Name	Cell Name	Main Nuclide Composition Ratio (%)
AGF	Loading Cell	^{137}Cs (95.1) · ^{134}Cs (4.9)
	No. 1-2 Cell	^{137}Cs (96.6) · ^{125}Sb (3.4)
	No. 2 Cell	^{137}Cs (90.6) · ^{241}Am (9.4)
	No. 3-1 Cell	^{137}Cs (91.1) · ^{241}Am (8.9)
	No. 3-2 Cell	^{137}Cs (95.1) · ^{241}Am (4.9)
	No. 6 Cell	^{137}Cs (82.6) · ^{241}Am (17.4)
	No. 7 Cell	^{137}Cs · ^{241}Am · ^{144}Ce · ^{155}Eu · ^{125}Sb · ^{134}Cs · ^{106}Ru
	L-1 Cell	^{137}Cs (100)
MMF	Cladding Tube Test Cell	^{137}Cs (95.2) · ^{134}Cs (4.8)
	Loading Cell	^{137}Cs (52.2) · ^{54}Mn (20.9) · ^{60}Co (15.2) · ^{58}Co (9.3) · ^{134}Cs (2.4)
	Machining Cell	^{54}Mn (53.6) · ^{58}Co (27.8) · ^{60}Co (17.9) · ^{95}Nb (0.7)
	Metallurgy Cell	^{60}Co (73.5) · ^{54}Mn (23.8) · ^{58}Co (2.7)
	Mechanical Test Cell	^{60}Co (92.7) · ^{54}Mn (6.2) · ^{58}Co (1.1)
	Microscope Cell	^{60}Co (80.2) · ^{54}Mn (16.2) · ^{134}Cs (3.6)
MMF-2	No. 1 Cell	^{144}Ce (35.8) · ^{95}Nb (27.9) · ^{137}Cs (14.6) · ^{95}Zr (13.3) · ^{106}Ru (4.2) · ^{134}Cs (2.9) · ^{125}Sb (0.6) · ^{58}Co (0.4) · ^{54}Mn (0.3)
	No. 2-1 Cell	^{152}Eu (77.0) · ^{154}Eu (19.0) · ^{137}Cs (4.0)
	No. 2-2Cell	^{137}Cs (56.8) · ^{60}Co (14.7) · ^{134}Cs (10.1) · ^{125}Sb (10.1) · ^{144}Ce (8.3)
	No. 3 Cell	^{60}Co (98.8) · ^{54}Mn (1.2)
	No. 4 Cell	^{60}Co (87.8) · ^{54}Mn (9.5) · ^{137}Cs (1.4) · ^{58}Co (1.3)

Table-6 The ratios of total α to total β(γ) activity in Cells (FMF)

Smear point		α (Bq)	β(γ) (Bq)	β／α
Examination Cell	Sodium Removal system	4.89×10⁴	6.09×10⁵	12.5
	Pin Weighting Apparatus	1.21×10⁴	2.70×10⁵	22.5
	Transfer Port	4.72×10³	1.25×10⁵	26.5
	Pin γ-Scanner	1.47×10⁴	1.82×10⁵	12.4
	Assembly Profilometer	3.70×10³	7.67×10⁴	20.7
	Pin Puncture Apparatus	7.65×10³	2.48×10⁵	32.4
	In Cell Cart	3.93×10³	8.24×10⁴	21.0
Decontamination Cell	Spray Chamber	1.08×10²	4.42×10³	40.9
	Remote Can Welder	3.52×10²	7.24×10³	20.6
Metallography Cell	Observation Box	1.16×10⁴	4.50×10⁵	28.1
	Preparation Box	6.27×10⁴	9.83×10⁵	15.7
			Average	23.0±8.6

Table-7 The ratios of total α to total β(γ) activity in Cells (AGF)

Smear point	α (Bq)	β(γ) (Bq)	β／α
No. 1-2 Cell	2.72×10^{1}	3.52×10^{2}	12.9
No. 3-1 Cell	3.98×10^{1}	5.76×10^{2}	14.5
No. 3-2 Cell	8.00×10^{1}	1.47×10^{3}	18.4
No. 6 Cell	2.10×10^{2}	4.45×10^{3}	21.2
No. 13 Cell	6.60×10^{0}	2.30×10^{2}	34.8
No. 14 Cell	1.06×10^{2}	2.22×10^{3}	21.0
No. 17 Cell	5.20×10^{0}	1.35×10^{2}	26.0
		Average	21.3±7.4

Table-8 The ratios of total α to total β(γ) activity in Cells (MMF)

Smear point	α (Bq)	β(γ) (Bq)	β／α
Cladding Tube Test Cell (P. No. 1)	5.93×10^{2}	9.80×10^{3}	16.5
Cladding Tube Test Cell (P. No. 2)	1.48×10^{2}	4.64×10^{3}	31.0
Cladding Tube Test Cell (P. No. 3)	7.55×10^{2}	1.02×10^{4}	13.5
G.B. for Cladding Tube Test Cell (P. No. 1)	2.20×10^{1}	7.13×10^{3}	32.4
G.B. for Cladding Tube Test Cell (P. No. 1)	1.50×10^{1}	4.13×10^{2}	27.3
G.B. for No. 1 Cell of MMF-2 (P. No. 1)	1.71×10^{1}	3.65×10^{2}	21.3
G.B. for No. 1 Cell of MMF-2 (P. No. 2)	4.70×10^{0}	1.13×10^{2}	24.0
G.B. for No. 1 Cell of MMF-2 (P. No. 3)	9.60×10^{0}	2.14×10^{2}	22.3
G.B. for No. 1 Cell of MMF-2 (P. No. 4)	1.18×10^{2}	1.91×10^{3}	16.2
		Average	22.7±6.6

Table-9 DAC values of main α nuclides

Nuclide	DAC (Bq/cm^3)	Half-life	Energy in Mev	Percent branching
^{238}Pu	9E-8	88 y	5.499	71.5
			5.456	28.5
^{239}Pu	8E-8	2.4E4 y	5.157	73.3
			5.144	15.1
			5.105	11.5
^{240}Pu	8E-8	6.5E3 y	5.168	73.5
			5.124	26.4
^{242}Pu	2E-7	3.8E5 y	4.856	23.0
			4.901	77.0
^{241}Am	8E-8	432 y	5.486	85.2
			5.443	13.1
^{242}Cm	3E-6	163 d	6.113	73.8
			6.070	26.2
^{243}Cm	1E-7	29 y	6.058	5.0
			5.992	5.8
			5.785	73.5
			5.741	10.7
^{244}Cm	1E-7	18 y	5.805	76.4
			5.763	23.6

DAC value: Derived Air Concentration from ALI prescribed in Japanese Regulation

Table-10 DAC values of main β(γ) nuclides

Nuclide	DAC (Bq/cm^3)	Half-life	β energy in Mev (%)	γ energy in Mev (%)
^{241}Pu	4E-6	14 y	0.021 (100)	
^{144}Ce-Pr	2E-4	285 d	0.318 (77) 3.00 (98)	0.134 (11)
^{106}Ru-Rh	1E-4	372 d	0.039 (100) 3.54 (79)	0.512 (21)
^{95}Nb	1E-2	35 d	0.160 (100)	0.766 (100)
^{95}Zr	3E-3	64 d	0.366 (55)	0.757 (55)
^{137}Cs	2E-3	30 y	0.512 (94)	0.662 (90)
^{54}Mn	1E-2	312 d		0.835 (100)
^{90}Sr-Y	5E-5	29 y	0.546 (100) 2.28 (100)	
^{125}Sb	7E-3	2.7 y	0.303 (40)	0.428 (29)
^{134}Cs	1E-3	2.1 y	0.658 (70)	0.605 (98)
^{60}Co	4E-4	5.3 y	0.318 (100)	1.173 (100) 1.333 (100)

DAC value: Derived Air Concentration from ALI prescribed in Japanese Regulation