Experimental Study on Source Efficiencies for Estimating Surface Contamination Level

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Abstract. Source efficiency was measured experimentally for various materials, such as metals, nonmetals, flooring materials, sheet materials and other materials, contaminated by alpha and beta emitter radioactive nuclides. Five nuclides, ^{147}Pm, ^{60}Co, ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y, were used as the beta emitters, and one nuclide ^{241}Am was used as the alpha emitter. The test samples were prepared by placing drops of the radioactive standardized solutions uniformly on the various materials using an automatic quantitative dispenser system from Musashi Engineering, Inc. After placing drops of the radioactive standardized solutions, the test materials were allowed to dry for more than 12 hours in a draft chamber with a hood. The radioactivity of each test material was about 30 Bq. Beta rays or alpha rays from the test materials were measured with a 2-pi gas flow proportional counter from Aloka Co., Ltd. The source efficiencies of the metals, nonmetals and sheet materials were higher than 0.5 in the case of contamination by the ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y radioactive standardized solutions, higher than 0.4 in the case of contamination by the ^{60}Co radioactive standardized solution, and higher than 0.25 in the case of contamination by the alpha emitter the ^{241}Am radioactive standardized solution. These values were higher than those given in Japanese Industrial Standards (JIS) documents. In contrast, the source efficiencies of some permeable materials were lower than those given in JIS documents, because source efficiency varies depending on whether the materials or radioactive sources are wet or dry. This study provides basic data on source efficiency, which is useful for estimating the surface contamination level of materials.

KEYWORDS: Radioactive surface contamination, Source efficiency, Beta ray, Radiation survey meter, Radioactive waste.

1. Introduction

It is important to estimate the surface contamination level of materials used in a radiation-controlled area and/or moved from a radiation-controlled area to an uncontrolled area, for radiation control in facilities that use radioisotopes. To measure and estimate the surface contamination level of materials, source efficiencies and instrument efficiencies are used as important parameters. Instrument efficiency depends on the characteristics and energy of the radiation sources, the structure of the detector, and geometrical condition between the detector and the radiation sources. Source efficiency depends on the characteristics and energy of the radiation sources and the surface condition and type of the contaminated materials. In Japan, radiation surface contamination level is measured and estimated according to Japanese Industrial Standards (JIS) documents, such as “Evaluation of surface contamination-Beta-emitters (maximum beta energy greater than 0.15 MeV) and alpha-emitters (JIS Z 4504)”[1], “Portable radiation surface contamination meters and monitors (JIS Z 4329)”[2], “Installed articles surface contamination monitoring assemblies for beta emitters (JIS Z 4337)”[3], “Hand and foot monitors and personnel surface contamination monitors for alpha and/or beta emitters (JIS Z 4338)”[4].

In JIS document [1], the recommended source efficiencies are 0.5 in the case of contamination by beta emitters whose maximum energy is greater than 0.4 MeV and 0.25 in the case of contamination by alpha emitters and beta emitters whose maximum energy is greater than 0.15 MeV and less than 0.4 MeV; if the source efficiencies are known, that is, experimental data exist, these source efficiencies may be used. In the case of contamination by beta emitters whose maximum energy is greater than 0.15 MeV and less than 0.4 MeV, the source efficiencies are conservative being half those in the case of contamination by beta emitters whose maximum energy is greater than 0.4 MeV. To achieve

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radiation control rationally for surveying radiation surface contamination, it is important to acquire the source efficiencies data for various materials used in a radiation-controlled area experimentally. However, there are limited data on experimental source efficiencies data, except for flooring material data [5] and the NRC report [6]. In this study, to achieve radiation control rationally, the source efficiencies of various materials, such as metals, nonmetals, flooring materials, sheet materials and other materials were determined experimentally.

2. Materials and methods

2.1 Test sample preparation

The materials of the test samples were selected from those that may be used in radiation-controlled areas: aluminum, iron, lead and stainless steel (smooth, rough and painted) as metals; glass, acryl, vinyl chloride, rubber and wood as nonmetals; lonleum, p-tile, concrete coated with epoxy resin and concrete coated with water paint as flooring materials; polyethylene sheet (0.1 mm thickness) and flame resisting sheet (0.1 mm thickness) as sheet materials; smear-test filter paper; and cloth. The tested materials are listed in Table 1.

Table 1: List of tested materials

Metal	Nonmetal	Flooring material	Sheet material	Others
Aluminum	Glass	Lonleum	Polyethylene sheet (0.1 mm thick)	Smear-test filter paper (drop)
Iron	Acryl	P-tile	Flame resisting sheet (0.1 mm thick)	Smear-test filter paper (wipe off)
Lead	Vinyl Chloride	Concrete coated with epoxy resin		Cloth (drop)
Stainless steel (smooth)	Rubber	Concrete coated with water paint		Cloth (wipe off)
Stainless steel (rough)	Wood			
Stainless steel (painted)				

The test samples were prepared using sample plates of 50 mm diameter and 6 mm depth. Except for the p-tile, lonleum, sheet materials, smear-test filter paper and cloth, all the materials were used to fill the sample plates. For the p-tile and lonleum, the flooring materials were put on the surface of concrete used to fill the sample plates. For the sheet materials, smear-test filter paper and cloth, the materials were put on the surface of the empty sample plates.

Five nuclides, ^{147}Pm, ^{60}Co, ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y, were used as the beta emitters, and one nuclide, ^{241}Am, was used as the alpha emitter. The test samples were prepared by dropping the radioactive standardized solutions uniformly on the various materials using an automatic quantitative dispenser system from Musashi Engineering, Inc. The radioactivity of the radioactive standardized solutions were certified by the DKD or JCSS calibration facility. After dropping the radioactive standardized solutions, the test materials were allowed to dry for more than 12 hours in a draft chamber with a hood. The radioactivity of each test material was about 30 Bq. To estimate the radioactivity of the test samples, the weight differences of the radioactive standardized solutions between before and after dropping were measured using a precision electric balance. For the smear-test filter paper and cloth, wipe off test samples were prepared additionally. First, polyethylene sheet test samples were prepared by dropping the radioactive standardized solutions on them and drying the sample. The smear-test filter paper and cloth wipe off test samples were prepared by wiping off the surface of the polyethylene sheet test samples. The radioactivity of the wiped off test samples were estimated from the radioactivity differences of the polyethylene sheet samples between before and after wiping off.

2.2 Radiation measurement of test samples

Beta rays or alpha rays from the test materials were measured with a 2-pi gas flow proportional counter from Aloka Co., Ltd. The 2-pi gas flow proportional counter was calibrated using wide-area standard sources certified by the DKD or JCSS calibration facility. Instrument efficiency was estimated by measuring the radioactivity of wide-area standard sources set at the same distance between the detector and the test sample surface.

3. Results and discussions

3.1 Source efficiencies for beta emitters

The source efficiencies of the metal materials (i.e., aluminum, iron, lead and stainless steel (smooth, rough and painted)) for the beta emitters were estimated experimentally and are shown in Fig. 1. The source efficiencies of the nonmetal materials (i.e., glass, acryl, vinyl chloride, rubber and wood) for the beta emitters were estimated experimentally and are shown in Fig. 2. The source efficiencies of the flooring materials (i.e., lonleum, p-tile, concrete coated with epoxy resin and concrete coated with water paint) for the beta emitters were estimated experimentally and are shown in Fig. 3. The source efficiencies of the sheet materials (i.e., polyethylene sheet and flame resisting sheet), smear-test filter paper and cloth for the beta emitters were estimated experimentally and are shown in Fig. 4.

Figure 1: Source efficiencies of metal materials contaminated by beta emitters

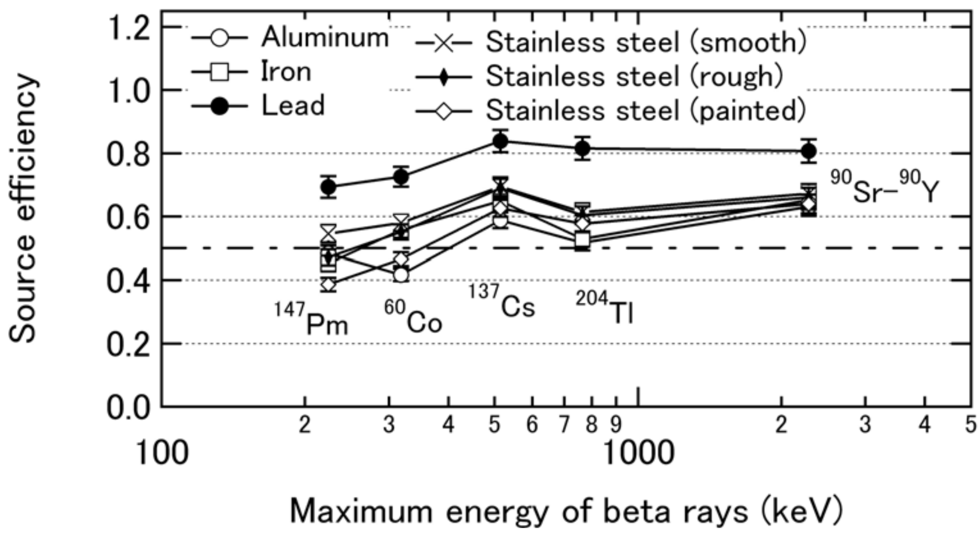


Figure 2: Source efficiencies of nonmetal materials contaminated by beta emitters

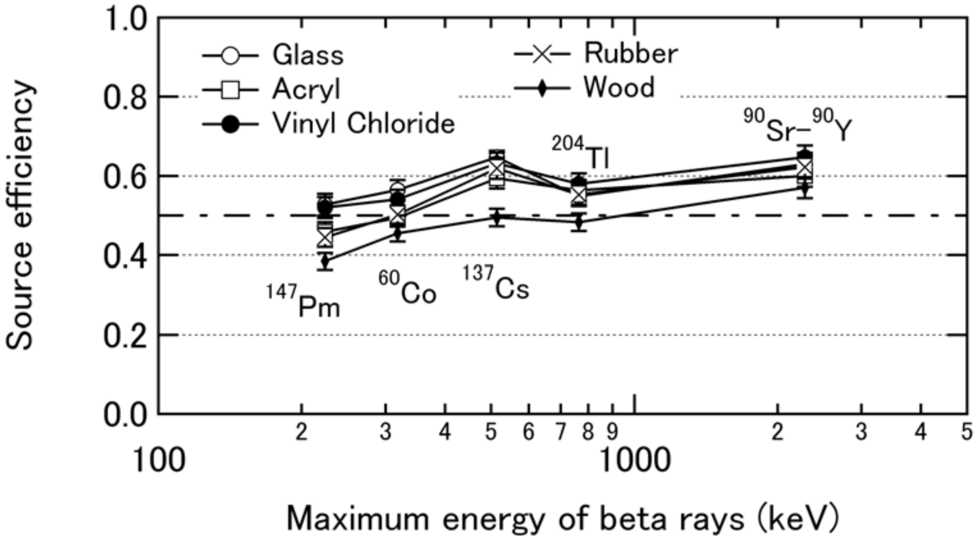


Figure 3: Source efficiencies of flooring materials contaminated by beta emitters

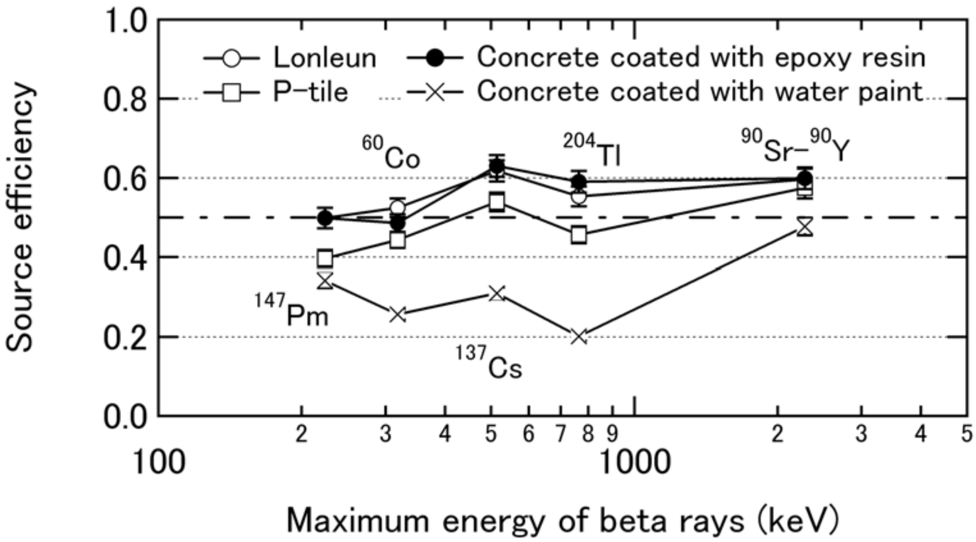
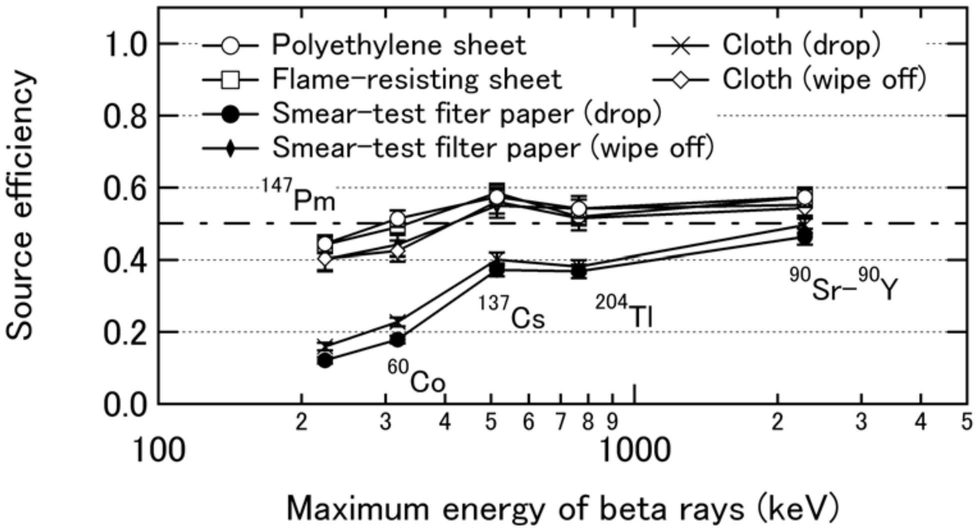


Figure 4: Source efficiencies of other materials contaminated by beta emitters



The source efficiencies of the metal materials were higher than 0.5 in the case of contamination by the ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y radioactive standardized solutions and higher than about 0.4 in the case of contamination by the ^{60}Co and ^{147}Pm radioactive standardized solutions. The source efficiencies were higher with high-density materials, such as lead, owing to the backscattering effect. The source efficiencies of the nonmetal materials except for the permeable material (wood) were higher than 0.5 in the case of contamination by the ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y radioactive standardized solutions and higher than about 0.4 in the case of contamination by the ^{60}Co and ^{147}Pm radioactive standardized solutions. The source efficiencies of wood were lower than those of the other nonmetal materials, because radioactive standardized solutions penetrated into the wood. For the flooring materials, the source efficiencies of the lonleum and concrete coated with epoxy resin were higher than about 0.5 for all the radioactive standardized solutions. The source efficiencies of the p-tile were higher than about 0.4 for all the radioactive standardized solutions. The source efficiencies of the concrete coated with water paint were lower than those of the other flooring materials, because radioactive standardized solutions penetrated into the concrete material. For the sheet materials, the source efficiencies of both the polyethylene and flame-resisting sheets were higher than 0.5 in the case of contamination by the ^{60}Co, ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y radioactive standardized solutions and higher than about 0.4 in the case of contamination by the ^{147}Pm radioactive standardized solution.

The source efficiencies of the smear-test filter paper and cloth with wiped off dried radioactive standardized solutions were higher than 0.5 in the case of contamination by the ^{137}Cs, ^{204}Tl and ^{90}Sr-^{90}Y radioactive standardized solutions and higher than 0.4 in the case of contamination by the ^{60}Co and ^{147}Pm radioactive standardized solutions. On the other hand, the source efficiencies of the smear-test filter paper and cloth with the radioactive standardized solutions dropped directly were much lower than those of the wipe off test samples, because the radioactive standardized solutions penetrated into the sample materials strongly. For permeable materials, the source efficiencies depend on whether the materials or radioactive sources are wet or dry.

In JIS document [1], the recommended source efficiencies are 0.5 in the case of contamination by beta emitters whose maximum energy is greater than 0.4 MeV and 0.25 in the case of contamination by beta emitters whose maximum energy is greater than 0.15 MeV and less than 0.4 MeV. For the non permeable materials, the experimental source efficiencies in this study were higher than the JIS recommendation. On the other hand, for the permeable materials, there were some cases in which the experimental source efficiencies in this study were lower than the JIS recommendation. Co-60 is the main nuclide for contamination in nuclear power plants. The numerical data of the source efficiencies of ^{60}Co are shown in Table 2.

Table 2: Source efficiencies of materials contaminated by ^{60}Co

Metal material		Nonmetal material		Flooring material		Other material	
Material	**Source efficiency**	**Material**	**Source efficiency**	**Material**	**Source efficiency**	**Material**	**Source efficiency**
Aluminum	0.42±0.02	Glass	0.56±0.02	Lonleum	0.52±0.02	Polyethylene sheet (0.1 mm thick)	0.51±0.02
Iron	0.56±0.02	Acryl	0.49±0.02	P-tile	0.44±0.02	Flame resisting sheet (0.1 mm thick)	0.49±0.02
Lead	0.73±0.03	Vinyl Chloride	0.54±0.02	Concrete coated with epoxy resin	0.49±0.02	Smear-test filter paper (drop)	0.18±0.01
Stainless steel (smooth)	0.58±0.03	Rubber	0.50±0.03	Concrete coated with water paint	0.26±0.01	Cloth (drop)	0.23±0.01
Stainless steel (rough)	0.55±0.02	Wood	0.46±0.02			Smear-test filter paper (wipe off)	0.44±0.03
Stainless steel (painted)	0.47±0.02					Cloth (wipe off)	0.42±0.03

3.2 Source efficiencies for alpha emitters

The source efficiencies of the metal materials (i.e., aluminum, iron, lead and stainless steel (smooth, rough and painted)), nonmetal materials (i.e., glass, acryl, vinyl chloride, rubber and wood), flooring materials (i.e., lonleum, p-tile, concrete coated with epoxy resin and concrete coated with water paint), sheet materials (i.e., polyethylene sheet and flame resisting sheet), smear-test filter paper and cloth for the alpha emitter (i.e., ^{241}Am) were estimated experimentally and are shown in Table 3.

Table 3: Source efficiencies of materials contaminated by ^{241}Am

Metal material		Nonmetal material		Flooring material		Other material	
Material	**Source efficiency**	**Material**	**Source efficiency**	**Material**	**Source efficiency**	**Material**	**Source efficiency**
Aluminum	0.28±0.02	Glass	0.47±0.02	Lonleum	0.50±0.03	Polyethylene sheet (0.1 mm thick)	0.49±0.02
Iron	0.40±0.02	Acryl	0.49±0.02	P-tile	0.17±0.01	Flame resisting sheet (0.1 mm thick)	0.47±0.02
Lead	0.47±0.02	Vinyl Chloride	0.48±0.02	Concrete coated with epoxy resin	0.51±0.03	Smear-test filter paper (drop)	0.07±0.01
Stainless steel (smooth)	0.44±0.02	Rubber	0.34±0.02	Concrete coated with water paint	0.06±0.01	Cloth (drop)	0.09±0.01
Stainless steel (rough)	0.41±0.02	Wood	0.37±0.02			Smear-test filter paper (wipe off)	0.42±0.03
Stainless steel (painted)	0.41±0.02					Cloth (wipe off)	0.41±0.03

The source efficiencies of the metal and nonmetal materials were higher than 0.25. For the flooring materials, the source efficiencies of lonleum and concrete coated with epoxy resin were higher than 0.5. On the other hand, the source efficiencies of the p-tile and concrete coated with water paint were lower than those of the other flooring materials, because radioactive standardized solutions penetrated into the materials.

The source efficiencies of the smear-test filter paper and cloth wiped off of dried radioactive standardized solutions were higher than 0.4. On the other hand, the source efficiencies of the smear-test filter paper and cloth with radioactive standardized solutions dropped directly were much lower than those of wipe off test samples, because the radioactive standardized solutions penetrated into the sample materials strongly. For the permeable materials, the source efficiencies depend on whether the materials or radioactive sources are wet or dry.

In JIS document [1], the recommended source efficiencies are 0.25 in the case of contamination by alpha emitters. For non permeable materials, the experimental source efficiencies in this study were higher than the JIS recommendation. On the other hand, for permeable materials, there were some cases in which the experimental source efficiencies in this study were lower than the JIS recommendation.

4. Conclusion

Source efficiency was measured and estimated experimentally for various materials, such as metals, nonmetals, flooring materials, sheet materials and other materials, contaminated by alpha and beta emitter radioactive nuclides.

For non permeable materials, the experimental source efficiencies for both alpha and beta emitters in this study were higher than the JIS recommendation. For permeable materials, the experimental source efficiencies in this study depended on whether the materials or radioactive sources were wet or dry. In some cases, the experimental source efficiencies in this study were lower than the JIS recommendation. This study provides basic data on source efficiency, which is useful for estimating the surface contamination level of materials.

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