Practical limitations of monitoring personal contamination at a PWR

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Abstract

Although personal contamination events are usually of low radiological significance, at Sizewell B they have often been subject to intense managerial & regulatory interest. A recent internal review of Sizewell B's arrangements for the assessment and recording of personal contamination events included a re-evaluation of the protocol for the calibration of installed personnel monitoring equipment. This paper summarises the findings of the study. The practical implications of the findings are discussed.

Introduction

Personnel contamination monitoring at Sizewell B

All personnel that enter radiological controlled areas (RCA) at Sizewell B are monitored for contamination before leaving. A variety of instruments are used, typically whole body monitors, although hand & foot monitors or hand held probes are occasionally employed for low occupancy, low risk RCAs external to the main reactor block.

At the main exit from the RCA, and also in change facilities adjacent to areas where a significant risk of personal contamination exists, NE Technology IPM8 whole body monitors are used to detect contamination on clothing and skin.

Sizewell B, in common with the majority of UK nuclear establishments, normally uses a derived working level (DWL) for beta-gamma surface contamination of 4 Bq/cm^2, for the clearance of personnel and equipment from the RCA. This value derives from long-standing custom and practice [1].

Calibration of Installed Personal Monitors

Original Protocol

Historically activation products of steel, primarily ^{60}Co, ^{58}Co, ^{51}Cr and ^{54}Mn, have been the dominant radioactive contaminants at Sizewell B. Operational contamination instrument derived working levels have been determined using the assumption that any contamination detected is due to ^{60}Co.

The long-standing calibration procedures for installed contamination monitoring instruments at Sizewell B have used planar ^{36}Cl sources, with an assumed P-factor of 2. Alarm set points are calculated using equation 1 below [2].

(Equation 1)
$$C = \frac{Aa\Sigma}{P}$$

Where; C is the alarm level (cps).
A is the DWL (Bq/cm^2).
a is the area over which the contamination is averaged (cm^2)
Σ is the detector efficiency as a proportion of unity.
P is the P-factor relating surface activity to surface emission.

The detector efficiencies are determined with the sources in contact with the detector. Additional *ad-hoc* checks have been performed on random detector panels using ^{55}Fe and ^{99}Tc sources, to confirm expected response to electron capture nuclides and low energy beta emitters.

To take account of the fact that the beta maximum energy of ^{36}Cl (E_{max} 714 keV) is greater than that of ^{60}Co (E_{max} 310 keV), Sizewell B originally set the installed personnel monitors to alarm at 2 Bq/cm^2, thus compensating for the lower detector efficiencies at ^{60}Co beta energy.

The review of calibration procedures recognised that it would be preferable to use calibration sources closer in energy to the isotopes of interest. Use of ^{60}Co as a calibration standard was ruled out because its relatively short half-life (5.27y) would make it necessary to replace calibration sources on a regular basis. Technicium-99 was considered because it has a maximum beta energy (E_{max} 290 keV) close to that of ^{60}Co and a long half-life (2.12 x 10^{5}y). Certainly this nuclide is typically used for instrument calibrations on US light water reactors similar to Sizewell B.

However it was judged that, taking into account self- absorption and attenuation in clothing, the energy spectrum of ^{60}Co would in fact be closer to that of ^{14}C (E_{max} 156 keV). For this reason and also because of its long half-life (5760y) and the ready availability of traceable standards for periodic source re-calibration, ^{14}C was eventually selected as the new calibration standard.

Study Protocol

Detector Efficiencies

The variability in detector - clothing distance for various body parts was determined using 14 members of staff. Based on these measurements, ^{14}C efficiencies were determined using 100cm^2 activated foils, traceable to the UK National Standard. Background & foreground counts were determined over 100 seconds.

Setting an alarm level

Based on these efficiencies, various alarm levels were calculated & assessed for their practical application.

IPM8 response to contaminated clothing

The response of an IPM8 when presented with contaminated clothing was compared for alarm settings derived from calibrations based on ^{14}C and ^{36}Cl. 100 cm^2 cotton patches (fabric weight 12 mg/cm^2) were spiked with known amounts of ^{60}Co, ^{63}Ni or ^{54}Mn solution. The activity on each patch was confirmed by hand-held probe & γ - spectrometry (where appropriate).

These were then backed with polythene (to prevent spread of contamination) and worn on various body parts (Table 1) through an IPM. Each patch was passed through the IPM 3 times, and the number of alarms was recorded. The minimum detectable activity (MDA) was defined as lowest activity patch that could generate 2 out of 3 alarms.

Table 1: Locations where contaminated patches were worn.

Front	Rear
Lower shin	Lower calf
Knee	Knee
Thigh	Thigh
Waist	Buttocks
Abdomen	Centre of lower back
Chest	Middle of shoulder blades

Ten second counts were used throughout the patch tests, as this is the count time used operationally. Data is shown as mean ± 95% confidence levels where appropriate.

Results

Clothing – Detector separation

A great deal of variability in the detector-clothing distance was observed both between individuals and also along an individual's body. The data is shown in Figure 1.

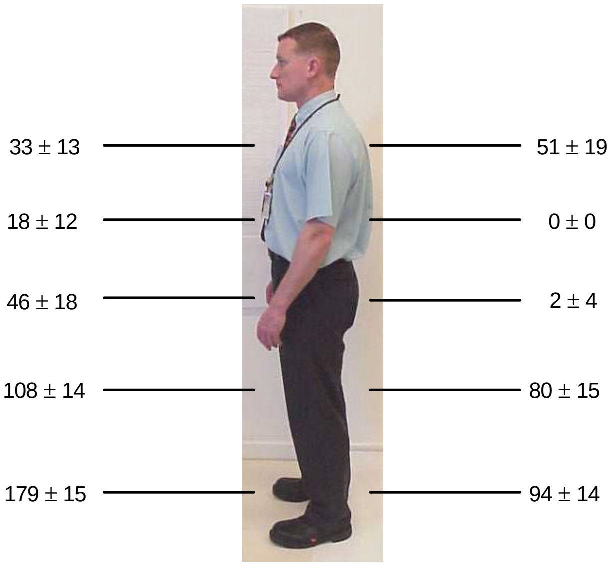

Fig 1: Clothing - detector distances (in mm) for various anatomical regions.

Carbon-14 efficiencies

Figure 2 shows the efficiency of an IPM8 body panel to ^{14}C at various source – detector distances. Contact efficiencies (e.g. representing the front abdomen, buttocks etc.) are 22 ± 3 %. At a distance of 80 mm (e.g. the knees) the efficiency has fallen to 1.4 ± 0.5 %.

From this data it is obvious that calibrating personal contamination instruments based on contact efficiencies was unrealistic because, at Sizewell B, the body parts that are most often contaminated (apart from the hands and feet) are the knees and ankles.

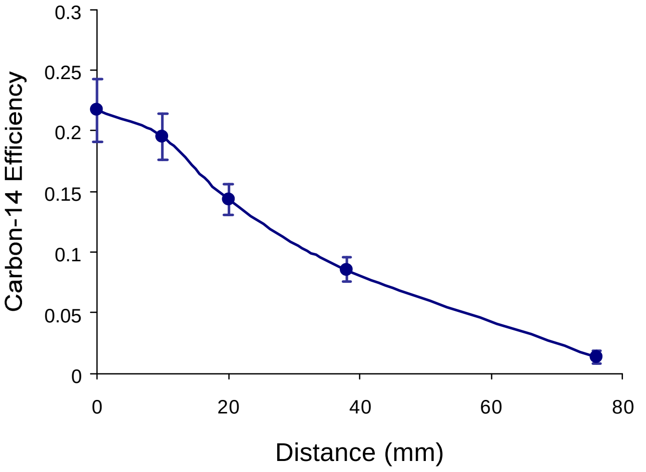

Fig 2: Variation in detector efficiency to ^{14}C with increasing source-detector distance.

Various alarm levels were calculated for the efficiencies determined in Figure 2. The lowest alarm level that could be set for reliable operation was based on the efficiency derived at 20 mm. Alarm levels based on efficiencies at distances greater than 20mm led to continuous high background or contamination faults.

Response to contaminated clothing

The characteristics of each contaminated cotton patch are shown in Tables 2 and 3.

Table 2: Spiked 100cm^2 cotton patches – ^{60}Co

Nominal Activity (Bq/cm^2)	Net cps by Eberline HP260 hand-held contam'n probe	Activity determined by γ - Spectrometry (Bq)
2	2 – 4	167 ± 22
4	4 – 6	317 ± 31
8	6 – 10	687 ± 49
20	12 – 18	1651 ± 83
40	30 – 40	3220 ± 148

Table 3: Spiked 100cm^2 cotton patches – ^{54}Mn

Nominal Activity (Bq/cm^2)	Net cps by Eberline HP260 contamination probe	Activity determined by γ - Spectrometry (Bq)
2	< 0.5	183 ± 22
4	0.5 - 1	327 ± 31
8	1 – 2	681 ± 49
20	2 - 3	1535 ± 79
40	3 – 4	3203 ± 138

The hand-held probe response to ^{60}Co was approximately 10 times greater than the response to ^{54}Mn contamination at the same specific activity (see Tables 2 & 3). No response was observed for any patch spiked with ^{63}Ni.

The minimum specific activities required to generate at least 2 out of 3 alarms are shown in Figures 3 & 4. For both radionuclides there is a significant variation in the MDA between the front and rear of the body and along the vertical axis. Generally, the lowest MDAs were found on the rear torso whilst the highest MDAs were observed on the front lower legs.

Figure 3 shows that in the case of ^{60}Co, alarm settings based on the ^{36}Cl calibration protocol were typically in the range of 20 – 40 Bq/cm^2 (i.e. 5 to 10 DWL), although an MDA of 8 Bq/cm^2 (2 DWL) was achieved in the small of the back. Calibration with ^{14}C & the resultant [reduced] alarm levels improved greatly the MDA for ^{60}Co. For example the MDA for the front waist was reduced from 20 Bq/cm^2 to 4 Bq/cm^2. However, despite the reduction in alarm levels, the MDA for the legs still remains at 5 to 10 DWL.

Similar results were observed for ^{54}Mn (Figure 4). The MDA for each body region was typically twice that of ^{60}Co. There was no response of the IPM8 to any patch spiked with ^{63}Ni, regardless of body region tested.

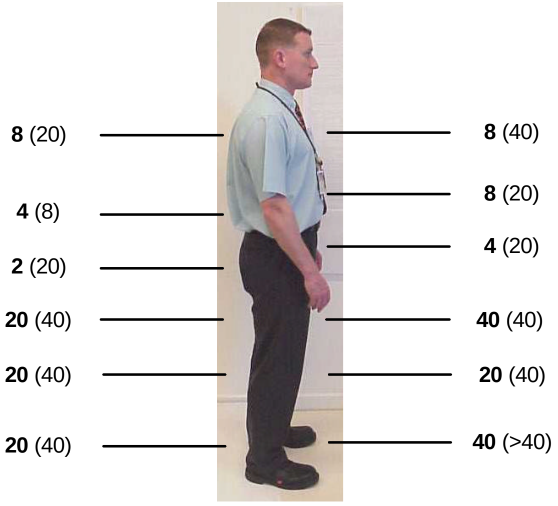

Fig 3: Minimum specific activity (Bq/cm^2) of ^{60}Co to generate at least 2 out of 3 alarms on an IPM8. Data in **bold** refers to ^{14}C based calibration. Data in parentheses refers to ^{36}Cl based calibration.

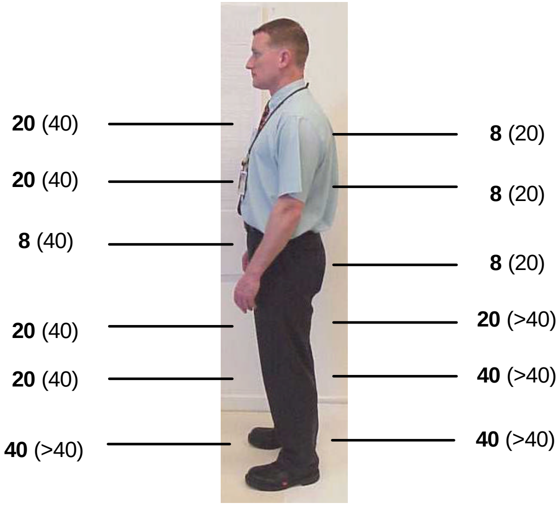

Fig 4: Minimum specific activity (Bq/cm^2) of ^{54}Mn to generate at least 2 out of 3 alarms on an IPM8. Data in **bold** refers to ^{14}C based calibration. Data in parentheses refers to ^{36}Cl based calibration.

Discussion

National Physical Laboratory Good Practice Guide Nº 29 [3] has recently recommended that, when determining alarm levels on installed contamination monitors, the employer should use an efficiency at least a factor of 2 lower than the contact efficiency, in order to account for variable distances between clothing and the detectors.

In practice, when using ^{14}C, we found that this recommendation equates roughly to the lowest practicable alarm level, despite the instruments being located in very low ambient background areas. Attempting to use lower alarm settings simply resulted in the instruments being in continuous “high background” fault alarm. Thus, the outcome of this calibration protocol revision has been a 5 to 8% reduction in the hand & foot alarm levels & a 50% reduction for the body panel detectors (summarised in Table 4).

Table 4: Summary of alarm settings

Detector	Alarm Settings (cps) **Old** (^{36}Cl based)	 **New** (^{14}C based)	% Change
Hand (β)	166	158	**-4.8**
Foot (β)	103	95	**-7.8**
Body (β)	41	20	**-51.2**

These reductions mean that it is now possible to achieve a ^{60}Co MDA of 2 to 4 Bq/cm^2 (i.e. 0.5 to 1 DWL) on anatomical regions that are in contact with the detector panel (e.g. buttocks, lower back, and abdomen). Although the ^{60}Co MDA for the lower legs is 40 Bq/cm^2 (10 DWL).

One implication of the study is that personnel may have been exiting the Controlled Area with contamination levels in excess of those allowed by Local Rules. Table 5 shows the personal contamination rate in the 12 months prior to, & immediately after, the alarm set point change; fortunately there is no evidence to suggest that this has been the case.

Table 5: Effect of alarm level change on PC event frequency

	Before (2000/2001)	**After** (2001/2002)
No. RCA Entries	85313	55334
No. PC Events	139	91
PC Event Rate (per 1000 RCA entries)	1.63	1.64

There are a number of reasons why the former set points were operationally adequate. Firstly in areas of significant contamination risk the operator usually passes through a number of diverse contamination monitoring points. Secondly, some personal contamination incidents involve multiple areas of the body. In these cases, it is contamination on the hands and feet (with very low MDAs) that is detected. Contamination on clothing with higher MDAs is then detected on the secondary survey by hand-held probe.

It is important to note that, from a practical radiological protection perspective, the release of personnel with levels of beta-gamma contamination between 4 and 40 Bq/cm^2 poses negligible radiological risk.

The reduction in the alarm level has not resulted in any increase in spurious alarms. Latterly Sizewell B has been experiencing some operational problems with failed fuel, with fission product activity being released to the Reactor Coolant System. Typical fission product maximum beta energies are higher than that of ^{60}Co, thus where fission product contamination is present then the revised alarm set points are conservative.

Despite these shortcomings, the installed personnel monitor is the instrument of choice for clearance monitoring of personnel. Installed monitors are responsive to a wider range of nuclides than many hand-held probes and they have far shorter monitoring times. Further improvements in the installed contamination monitor MDA could be achieved by design modifications. Improvements to the layout of detector arrays may yield lower MDAs but a more practical and cost-effective solution would be the introduction of individual alarm set points for each detector panel.

Conclusions

In order to detect personal contamination at levels that are required by Local Rules, we have revised our calibration procedures. Calibration of installed contamination monitors is now performed using ^{14}C as the standard and as a result, the instrument alarm levels have been lowered by up to 50%. Even at this level, some parts of the body still have ^{60}Co MDAs in excess of the clearance criteria, thus highlighting the need for strict contamination control at the work place, before persons approach the RCA barrier.

Acknowledgements

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References

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