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A COUNT RATE BASED CONTAMINATION CONTROL STANDARD FOR ELECTRON ACCELERATORS

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Accelerators of sufficient energy and particle fluence can produce radioactivity as an unwanted byproduct. The radioactivity is typically imbedded in structural materials but may also be removable from surfaces. Many of these radionuclides decay by positron emission or electron capture; they often have long half lives and produce photons of low energy and yield making detection by standard devices difficult.

The contamination control limit used throughout the United States nuclear industry and the Department of Energy is 1000 disintegrations per minute. This limit is based on the detection threshold of pancake type geiger-mueller probes for radionuclides of relatively high radiotoxicity, such as cobalt-60. Several radionuclides of concern at a high energy electron accelerator are compared in terms of radiotoxicity with radionuclides commonly found in the nuclear industry. Based on this comparison, a count-rate based contamination control limit and associated measurement strategy is proposed which provides adequate detection of contamination at accelerators without an increase in risk.

INTRODUCTION

Current United States Department of Energy (DOE) Federal regulations (Title 10, Code of Federal Regulations, Part 835-10CFR835) do not adequately address limits for certain accelerator produced radionuclides (1). The removable contamination limits in 10CFR835 are based in large part on the fact that nuclear fission products and related activation products typically decay by modes which produce beta particles as well as photons. These beta particles are charged and are readily detected by a thin window pancake (5 cm diameter) Geiger-Mueller type detector, or frisker. Measurements are usually made on a substrate used to test for the quantity of radioactivity removed by dry transfer from a 100 cm^2 (1 dm^2) surface. The common response function is that 100 counts per minute (cpm) over background in a relatively low photon background corresponds to 1000 disintegrations per minute (dpm). This response function is suitable for radionuclides with relatively restrictive intake limits due to radiotoxicity, such as cobalt-60 (^{60}Co), and conveniently supports the limit for beta/gamma emitting radionuclides in 10CFR835 Appendix D of 1000 dpm-dm^{-2}.

PROBLEM

However, field analysis of certain radionuclides to the prescribed level of 1000 dpm-dm^{-2} is extremely difficult using conventional and practical techniques. An example is the radionuclide beryllium-7 (^7Be), which decays by electron capture and does not emit a charged particle but emits a 478 keV photon 10.4% of the time it decays. A conventional radiation detection instrument, such as a frisker (pancake GM probe), is relatively insensitive to ^7Be. It has a very low efficiency for photons of this energy, detecting approximately 3%

We now consider the question of whether this limit is appropriate for radionuclides such as ^7Be by considering the reduced detection efficiency and the reduced radiotoxicity. One way of comparing the risk of equal contamination levels of ^7Be and ^{60}Co is to compare the Annual Limits on Intake (ALIs) for each radionuclide. The inhalation ALI is the quantity of radioactive material which, if inhaled during an occupational work year, produces an effective dose of 0.05 Sv. The most restrictive inhalation ALI for ^{60}Co is 1.1×10^6 Bq and the inhalation ALI for ^7Be is 7.4×10^8 Bq (2). Thus, the same quantity of radioactivity, if inhaled, results in effective doses which are a factor of 670 apart.

METHODS AND MEASUREMENTS

The Thomas Jefferson National Accelerator Facility Radiation Control Group (Jefferson Lab RCG) has studied the problem of ^7Be contamination on surfaces and in certain systems which process air and water at Jefferson Lab. The RCG has established response functions for conventional "frisker type" detectors for measurements on substrates from systems unique to Jefferson Lab. These response functions were determined by comparing ^7Be activity, quantified using

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Table 1. Radionuclide Categories

Category 1 Electron Capture, Gamma Decay Only	Radionuclide	Major Decay Characteristics	Nuclide ALI/ ^{60}Co ALI	Predicted DPM per 100 CPM
	^{7}Be	10.4% 477 keV gamma	667	30,000
	^{51}Cr	9% 320 keV gamma	667	37,000
	^{54}Mn	100% 835 keV gamma	27	2,300
	^{57}Co	87% 122 keV gamma	23	1,700
Category 2 **Positron (β^+) / Gamma Emitters**	**Radionuclide**	**Major Decay Characteristics**	**Nuclide ALI/ ^{60}Co ALI**	**Predicted DPM per 100 CPM**
	^{56}Co	20% 1490 keV β^+	6.7	600
		40% 511 keV gamma		
		100% 847 keV gamma		
		66% 1240 keV gamma		
	^{58}Co	15% 474 keV β^+	23	1,600
		30% 511 keV gamma		
		99% 810 keV gamma		
	^{65}Zn	1.5% 327 keV β^+	10	3,700
		3.4% 511 keV gamma		
		49.0% 1115 keV gamma		

representative samples under controlled laboratory conditions and checked *in situ* using gamma spectroscopy measurements, to field frisker measurements of the same materials.

The response function is that 100 cpm over background (in a relatively low photon background) corresponds to approximately 30,000 dpm of ^{7}Be on substrate tested at Jefferson Lab. If one then applies the aforementioned factor of 670 for radiotoxicity to the ^{60}Co based limit of 1000 dpm-dm^{-2}, the result would be a ^{7}Be contamination control limit of 670,000 dpm-dm^{-2}. Thus, using 100 counts per minute over background as a ^{7}Be limit would still result in contamination control limits about 22 times (670,000/30,000) more restrictive than the equivalent control limit for ^{60}Co. Nevertheless, the RCG considers this conservatism to be acceptable and the value 30,000 dpm-dm^{-2} to represent a reasonable control limit for Jefferson Lab operations. This level is also convenient, as it can be used simultaneously in the field for beta/gamma emitters as well as ^{7}Be.

Other non-beta emitting nuclides similar to ^{7}Be such as cobalt-57, manganese-54 and chromium-51 (^{51}Cr) can be identified in radioactivity removable from surfaces at Jefferson Lab. These nuclides are typically found in mixtures that produce response functions during field frisking which are generally as sensitive as that for ^{7}Be. A review of the energy versus efficiency response function normalized to Cs-137 photons, provided by one manufacturer (3) for this type of detector, indicates that the lowest response is between approximately 200 keV and 400 keV. As a result, the combination of low photon yield and low response for ^{51}Cr and for ^{7}Be decay photon energies makes these nuclides generally the most difficult to detect among these non-beta emitting radionuclides.

ANALYSIS

A comparison of the decay modes and radiotoxicity as compared to ^{60}Co of radionuclides of concern (often detected in various quantities and ratios as removable contamination) is offered in Table 1. There are other radionuclides which are not mentioned here because they are relatively easy to detect due to their high photon energy and/or yield or high energy charged particle emission. It is evident (and not unexpected), that as radiotoxicity increases, detection by frisker generally becomes more favorable; the detector has an increased response due to charged particle emission and/or increased photon emission energy and yield.

Table 2 compares derived limits (7) with activity expected at the 100 cpm-dm^{-2} counting level. As evident, the quantities of radionuclides present are well below limits derived on the basis of external exposure or ingestion (7).

There is no condition where there is an increase in risk represented by the presence of 100 cpm of removable contamination from these radionuclides compared to that represented by 100 cpm of ^{60}Co. Consequently, the quantity of radioactivity corresponding to 100 counts per minute over background using field frisking equipment represents a reasonable removable contamination control limit for the radionuclides of concern at Jefferson Lab.

International documents reviewed by the RCG state that it is "inappropriate to use the standard working limits for low yield 'photon only' emitting low radiotoxicity sources." These documents indicate that licensees should ask their respective regulators for relief from standard working limits for low radiotoxicity radionuclides (4). Other references indicate that standards should be based on acceptable working conditions and risk (5). A 30,000 dpm-dm^{-2} limit is identified for

Table 2. Derived Limits vs. Calculated Activity

Nuclide	Derived Limit[a] ($dpm\text{-}dm^{-2}$)	Activity per 100 cpm ($dpm\text{-}dm^{-2}$)
^{51}Cr	1.8×10^{8}	37,000
^{54}Mn	1.8×10^{7}	2,300
^{56}Co	1.8×10^{6}	600
^{57}Co	1.8×10^{7}	1,700
^{58}Co	1.8×10^{6}	1,600
^{65}Zn	1.8×10^{7}	3,700

[a] selected on the basis of most restrictive limit

beta/gamma emitting radionuclides (such as ^{60}Co) in at least one international reference (6). The same reference also suggests contamination control values for low radiotoxicity radionuclides up to about 300,000 $dpm\text{-}dm^{-2}$ based on "facility specific situations".

CONCLUSIONS

Other DOE accelerator facilities should consider a similar request to the Department of Energy to allow the use of a limit of 30,000 $dpm\text{-}dm^{-2}$ for ^{7}Be removable surface contamination in lieu of the implied limit in 10CFR835 Appendix D of 1000 $dpm\text{-}dm^{-2}$ for beta/gamma emitting radionuclides. Accelerator facilities regulated by other entities should review their requirements and their expected radionuclide source term and consider the use of a field frisking technique which provides for count rate based limit for removable surface contamination. This technique may allow for the presence of both charged particle emitting radionuclides, non-charged particle, photon only emitting radionuclides, and those which decay by various mixed modes and which contribute to the frisker response in a way that keeps the risk due to radiation exposure no greater than, and in most cases less than, the risk associated with 1000 $dpm\text{-}dm^{-2}$ of ^{60}Co contamination.

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