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Fermilab
ES&H Section

R.P. NOTE 116

GUIDELINES FOR EMPLOYING INTERNAL EXPOSURE CONTROLS DURING THE CUTTING OF ACTIVATED MATERIALS AT FERMILAB

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GUIDELINES FOR EMPLOYING INTERNAL EXPOSURE CONTROLS DURING THE CUTTING OF ACTIVATED MATERIALS AT FERMILAB

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Elaine Marshall

INTRODUCTION

Occasionally, members of the Radiation Physics Technical Support Group must cut through a piece of radioactive material or equipment so that it can be properly packaged for shipment to a low-level waste depository. These materials are of dissimilar shapes and sizes with varying activity levels. Administrative levels are presently in place, limiting the exposure rate at a distance of 1 foot from the material to less than 10 mR/hr. However, this limit is based on external exposure control considerations and the internal exposure controls aspects were not investigated prior to the establishment of this limit.[1] The infrequency of these operations and the administrative limit serve to render improbable the potential for an internal dose equivalent exceeding 100 mrem/year. This is supported by past air sampling which has not provided any evidence of uptakes by personnel.

The intent of this document is to establish guidance to be factored into the development of administrative limits for the cutting operations conducted to support Fermilab's low-level radioactive waste program. Because exposure rates at 1 foot from a material are readily measured with portable instrumentation and do not require additional processing, it is appropriate to define the maximum exposure rate at 1 foot that a material could have and still be cut without requiring internal exposure controls.

There are few data available to relate the exposure rate of the material to the airborne radioactivity concentration during cutting or other similar activities. As such, this study is based on current policy[2,3,4] which imposes internal exposure controls, including respiratory protection, when airborne radioactivity levels exceed 10% of the Derived Air Concentration (DAC). By correlating the maximum exposure rate at 1 foot from the material to airborne radioactivity concentrations, the maximum exposure rate at 1 foot can be estimated such that an Airborne Radioactivity Area need not be designated and the accompanying internal exposure controls not imposed during cutting operations.

DAC FRACTION

Past inventories have shown that the majority of the materials requiring cutting are made of manufactured steel and have various sizes and shapes. The radionuclides present and their abundance in such materials have been estimated from past experience. It is estimated that 60% of the activity is due to the presence of cobalt-60 and the remaining fraction is due to manganese-54. In order to not be classified as an Airborne Radioactivity Area, the sum of the DAC fractions must be less than 0.1:

$$0.1 \geq \frac{\text{Co}-60\text{ Activity}}{\text{DAC}_{\text{Co}-60}} + \frac{\text{Mn}-54\text{ Activity}}{\text{DAC}_{\text{Mn}-54}} \qquad [1]$$

Appendix B of 10CFR835[5] assigns inhalation classes to the various radionuclides based on their physical form. The physical form of the cobalt present in the waste materials results in an inhalation classification of Y for cobalt-60. The physical form of the manganese present in the waste materials results in an inhalation classification of W for manganese-54. From Appendix A of 10CFR835[6], the corresponding inhalation DACs are:

Cobalt-60	$1\text{E-}8\ \frac{\mu\text{Ci}}{\text{ml}}$
Manganese-54	$3\text{E-}7\ \frac{\mu\text{Ci}}{\text{ml}}$

Substituting into Equation 1:

$$0.1 \geq \frac{0.6 * \text{A}}{1\text{E}-8\frac{\mu\text{Ci}}{\text{ml}}} + \frac{0.4 * \text{A}}{3\text{E}-7\frac{\mu\text{Ci}}{\text{ml}}} \qquad [2]$$

where A is equal to the total activity present divided by the volume. Thus, when Equation 2 is solved for A, the airborne radioactivity levels must be less than:

$$\text{A} = 1.63\text{E}-9\frac{\mu\text{Ci}}{\text{ml}}\ .$$

ACTIVITY CONCENTRATION IN MATERIAL

To relate the airborne radioactivity levels during the cutting operation and the exposure rate of the material, the activity concentration in the material must be calculated.

Assuming that all of the activity present in the air volume is due to the cutting operation, the specific activity of the material in the item being cut can be calculated. Note that this method is independent of cut size or the volume into which the activity is released. It does, however, assume that the material is uniformly activated. This is not generally the case, but it does add a measure of conservatism into the calculation since the dose rate is measured at the "hottest spot".

$$\text{Specific Activity [steel]}\left(\frac{\text{Ci}}{\text{g}}\right) = \frac{\text{Maximum Activity Concentration in Air}\left(\frac{\text{Ci}}{\text{m}^3}\right)}{\text{Suspension Factor}\left(\frac{\text{g}}{\text{m}^3}\right)} \qquad [3]$$

The suspension factor is a measure of the particulate loading in the air or the mass concentration in air of the solid material released by the cutting process. For the purposes of this exercise, the suspension factor was taken to be 1 mg m^{-3} or 0.001 g m^{-3}. After reviewing the industrial monitoring of steel grinding operations conducted at Fermilab over the past several years, this value was determined to be a judicious estimate of particulate loading.[7] Using the maximum activity concentration calculated in the previous section and this value of the mass suspension factor, the specific activity of the steel released into the air under these conditions of 0.1 DAC is found to be:

$$\text{Specific Activity [steel]}\left(\frac{\text{Ci}}{\text{g}}\right)=\frac{1.63\text{E}-9\,\frac{\mu\text{Ci}}{\text{cm}^3}*\frac{1\text{E6 cm}^3}{\text{m}^3}*\frac{\text{Ci}}{1\text{E6}\,\mu\text{Ci}}}{0.001\,\frac{\text{g}}{\text{m}^3}}$$

$$\text{Specific Activity [steel]}\left(\frac{\text{Ci}}{\text{g}}\right)=1.63\text{E}-6\,\frac{\text{Ci}}{\text{g}}$$

From the specific activity of the material, the activity concentration in the steel can easily be determined:

$$\text{Activity Concentration [steel]}\left(\frac{\text{Ci}}{\text{m}^3}\right)=\text{Specific Activity [steel]}\left(\frac{\text{Ci}}{\text{g}}\right)*\text{Density}\left(\frac{\text{g}}{\text{m}^3}\right) \qquad [4]$$

The nominal density of steel is 7.8 g cm^{-3} [8] or 7.8E6 g m^{-3}. Substituting this into equation 4, the activity concentration in the steel is thus equal to

$$\text{Activity Concentration [steel]}\left(\frac{\text{Ci}}{\text{m}^3}\right)=1.63\text{E}-6\,\frac{\text{Ci}}{\text{g}}*7.8\text{E6}\,\frac{\text{g}}{\text{m}^3}$$

$$\text{Activity Concentration [steel]}\left(\frac{\text{Ci}}{\text{m}^3}\right)=12.7\,\frac{\text{Ci}}{\text{m}^3}$$

DOSE EQUIVALENT RATE

As the goal of this study was to relate exposure rates at 1 foot from the material to airborne concentration, the last step is to calculate the exposure rate at 1 foot from the material that would result in an airborne concentration equal to 10% of the DAC when cut. Dose equivalent rates, and thus, exposure rates, are calculated from the source geometry and activity.

One of the largest pieces that would actually be cut would be a piece of plate steel 1.22 m X 2.44 m and 0.013 m thick (4 ft. X 8 ft. and 1/2 in. thick). The majority of the pieces are much smaller than this. The steel would be a planar radiation source and for the purposes of this exercise was estimated to be a disc 1 m in diameter centered on the cut . Using this and the activity concentration of the material (calculated previously), the dose equivalent rate can be calculated using the following equation:

$$\dot{H}_{\text{T}}=\dot{H}_{\text{Co}}+\dot{H}_{\text{Mn}}$$

where the dose equivalent rate for each radionuclide is derived from Equation 5 taken from Cember[9]:

$$\dot{H} = \pi\Gamma\frac{C_v}{\mu}(1 - e^{-\mu t})\ln\left(\frac{r^2 + h^2}{h^2}\right) \quad \frac{\text{rem}}{\text{hr}} \qquad [5]$$

where C_V = Activity concentration of the material (Ci m^{-3})
G = Specific gamma ray constant (R m^2 Ci^{-1} hr^{-1})
r = radius of disc (m)
h = distance at which measurement taken (m)
t = thickness of material (m)
m = linear attenuation coefficient of material (m^{-1})

To calculate the dose equivalent rate for each component, the following constants were used.

	Specific Gamma Ray Constant[10]		Linear Attenuation Coefficient*
	$\left(\frac{\text{mSv m}^2}{\text{MBq hr}}\right)$	$\left(\frac{\text{R m}^2}{\text{Ci hr}}\right)$	m^{-1}
Co-60	3.703E-4	1.37	40.8
Mn-54	1.382E-4	0.511	50.8

*The attenuation coefficients were interpolated from a table of mass attenuation coefficients[11] for iron and multiplied by the density of steel (7.8 g cm^{-3}). For Co-60, the mass attenuation coefficient was taken as that for the 1.332 MeV gamma that is emitted.

Solving for the component dose equivalent rates results in 426 mrem/hr at 1 foot for Co-60 and 99 mrem/hr at 1 foot for Mn-54. Total dose equivalent rate is then 525 mrem/hr at 1 foot. As both of these radionuclides are beta/gamma emitters with quality factor of 1, the comparable exposure rate would be 525 mR/hr at 1 foot.

CONCLUSION

To not exceed 10% of the DAC, the maximum exposure rate at 1 foot of a material being cut to allow packaging for shipment to a low-level radioactive waste depository would have to be less than 525 mR/hr, a very conservative estimate for the reasons explained in the text. Materials with exposure rates less than this value would not require designating the area as an Airborne Radioactivity Area or imposing internal exposure controls, such as respiratory protection, during the cutting operations. This value is more than 50 times greater than the current administrative limit (10 mR/hr at 1 foot) which is based on external exposure considerations and is much greater than what can be found at Fermilab's waste packaging facilities.

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[2] Fermilab Radiological Control Manual. Article 235, Posting Contamination, High Contamination and Airborne Radioactivity Areas. Rev. March 1995.

[3] Fermilab Radiological Control Manual. Article 335, Contamination, High Contamination and Airborne Radioactivity Areas. Rev. March 1995.

[4] Occupational Radiation Protection: Final Rule. 10CFR835.603. *Federal Register*, Volume 58, Number 238. December 14, 1993.

[5] Occupational Radiation Protection: Final Rule. Appendix B. *Federal Register*, Volume 58, Number 238. December 14, 1993.

[6] Occupational Radiation Protection: Final Rule. Appendix A. *Federal Register*, Volume 58, Number 238. December 14, 1993.

[7] Summary of Industrial Hygiene Monitoring Results obtained from Maureen Huey. Supported by Personal Communication with T. Miller, August 18, 1995.

[8] Table 5.4 Density of Common Materials in Health Physics and Radiological Health Handbook. Edited by B. Shleien (Silver Spring, MD: Scinta, Inc., 1992).

[9] Cember, Herman. Introduction to Health Physics. (New York: Pergamon Press, 1983).

[10] Table 6.1.2 Specific Gamma Ray Dose Constants at 1 M in Health Physics and Radiological Health Handbook, Edited by B. Shleien (Silver Spring, MD: Scinta, Inc, 1992).

[11] Table 5.1 Mass Attenuation Coefficients in Health Physics and Radiological Health Handbook, Edited by B. Shleien (Silver Spring, MD: Scinta, Inc, 1992).