SLAC-PUB-696
December 1969
(ACC)

OPERATIONAL HEALTH PHYSICS ASSOCIATED WITH INDUCED RADIOACTIVITY AT THE STANFORD LINEAR ACCELERATOR CENTER*

D. D. Busick and G. J. Warren

Health Physics Department
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

The machining of accelerator components having induced radioactivity presents an additional radiation problem associated with the internal deposition of radioactive particles in the human body. The assessment of the potential for exposing personnel to internally deposited radionuclides is more involved, due to the large number of variables, than assessing the potential for exposure to external ionizing radiation.

There have been many studies by various researchers concerned with methods for assessing internal radiation dose from radionuclides that have gained entry into the human body. However, there seems to be a singular lack of published data about the potential for producing environments which may cause significant internal deposition by ingestion of inhalation except in very general terms.

This paper deals specifically with the machining of hardware which has been activated at SLAC by exposure to a high energy e^- or e^+ beam and high energy secondary particles produced by the absorption of the primary beam. The composition of most beam line components is typically aluminum, copper or stainless steel. Such items as vacuum pipes, valves, beam dumps, targets, beam scrapers and bellows are typical of the types of hardware involved. Equipment such as large Faraday cups, calorimeters and secondary emission quantometers are also involved. Such devices are costly since a great many man-hours have gone into their design and fabrication. The desire to use such items for other than their intended purpose is therefore to be expected; of course, some modification may be required.

Given the task of modifying or repairing such equipment, what are the necessary safeguards? Are enclosures with controlled and filtered ventilation or close-capture ventilation required? Is personnel protection such as supplied air, respirators, coveralls, gloves and shoe-covers required?

The answers to these questions are not simple, at least if their use is to be justified on the basis of real hazard potential. If a "hot-machine shop" is available the usual answer is to perform such work there since enclosures and ventilation controls are probably already available for other more compelling reasons.

If a "hot-shop" is not available, what then are the alternatives? Portable enclosures with ventilation capability is one answer; or perhaps close-capture ventilation on a few selected machines is sufficient. Of course, if ventilation is required then some sort of air cleaning and radiation monitoring of the discharged effluent is also required.

Since engineering controls, such as the examples stated above, can fail we must also perform some sort of routine bioassay on the individual worker to complete the sort of logic which seems required if the nature of this kind of operation is in fact hazardous from the viewpoint of potential exposure.

---

*Work supported by the U. S. Atomic Energy Commission.

(Presented at Second International Conference on Accelerator Dosimetry and Experience, Stanford Linear Accelerator Center, Stanford University, Nov. 1969)

It would seem reasonable to propose some operational guidelines that are practical and offer a sufficient level of protection that will prevent the exposure of machine operators to levels of radioactive concentration that might be expected to cause internal or external contamination of personnel. Furthermore, these guidelines should be related to the specific activity, relative hazard of the material and the potential for a given machining operation to produce airborne material.

Good operational measurements on the release and dispersion of radioactive aerosols and particulates from metals containing induced radioactivity does not seem available in the published literature. Apparently this whole question seems to be resolved by individual organizations more or less arbitrarily. With the growing number of high energy accelerators, it would seem reasonable to expect that the relative importance of this question is also going to increase.

What does a project do about machining this kind of material if a "hot-shop" and/or portable engineering controls are not available? The answer of course is to provide or specify what is required and why it is needed for the performance of this task.

It is a rather simple task to specify what is required but it is not so easy to justify it on reasonable grounds! Also, the equipment to be modified or repaired may be physically small or it may be quite large and weigh many tons. This, of course, requires a rather large and well-equipped machine shop at a significant expense. The justification for such an arrangement should be firm and based on reasonable hazard potential.

As a basis for establishing guidelines the hazard potential for specific radionuclides can be assessed by having knowledge of the following values:

1. Identity of radionuclide (s)
2. Maximum Permissible Concentration in air (MPC_a)
3. Maximum Permissible Body Burden (MPBB)
4. Specific activity of induced radionuclides (SpA)
5. Physical properties of the parent material to be machined

Table 1 lists the various radionuclides that may be formed in stainless steel, aluminum and copper by exposure to high energy electrons and positrons together with MPC_a and MPBB values. Note that the majority of the radioelements are classed in Group 3 of the relative hazard tabulation found in Handbook 92 and ICRP Publication 5.

Morgan, Snyder and Ford[1] proposed a more complete grouping of radioisotopes according to relative hazard. Their classification is divided into three groups; very hazardous, intermediate and less hazardous. The isotopes listed in Table 1 fall within the intermediate and less hazardous groupings. However, this article assumes that the specific activity of each isotope is the theoretical maximum.

Another method that is useful in bracketing the relative hazard is to compare the MPC_a for specific radionuclides with the chemical toxity of ordinary copper or lead. To do this we must first restate MPC_a in terms of Threshold Limit Values (TLV), usually noted as mg/m^3.

$$mg/m^3 = \frac{MPC_a}{Sp\ A}$$

where

$$MPC = \mu Ci/m^3$$

$$SpA = \mu Ci/mg$$

TABLE 1

MAXIMUM PERMISSIBLE CONCENTRATION FOR 40 HOUR WEEK EXPOSURE AND MAXIMUM PERMISSIBLE BODY BURDENS FOR SELECTED RADIOISOTOPES PRODUCED AT SLAC

Isotopes	MPC_a $\mu Ci/cm^3$(5)	MPBB μCi(6)
^{48}V	6×10^{-8}	8
^{54}Mn	4×10^{-8}	20
^{52}Mn	1×10^{-7}	5
^{24}Na	1×10^{-7}	7
^{22}Na	9×10^{-9}	10
^{65}Zn	6×10^{-8}	60
^{60}Co	9×10^{-9}	10
^{58}Co	5×10^{-8}	30
^{57}Co	2×10^{-7}	200
^{59}Fe	5×10^{-9}	20
^{55}Fe	9×10^{-7}	1000
^{51}Cr	2×10^{-6}	800
^{46}Sc	2×10^{-8}	10
^{45}Ca	3×10^{-8}	30

Table II lists several of the materials that have established chemical toxicity together with their TLV's.[2]

TABLE 2

THRESHOLD LIMIT VALUES FOR SELECTED MATERIALS

Material	TLV mg/m^3
Al	15
Cr	0.1
Cu	0.1 - 1.0
Fe	15
Mo	5
Ti	15
U sol	0.05
U insol	0.25
Zr	5
Pb	0.20
Th_{nat}	0.27

Note that stable copper has a recommended TLV of 0.1 - 1.0 mg/m^3 for fumes and mist respectively and that Pb, U_{nat} and Th_{nat} are 2 to 2.7 times less toxic than copper, or at least so it would appear. Unlike MPC's, TLV's are often based on clinical symtoms which may reflect a serious impairment of some vital body function or they may be based on minor but observable reactions such as allergic reactions of the skin. In the case of copper, industrial experience with workers and animal experimentation has indicated mild to very serious reactions. Organs affected include the digestive system, liver, kidneys, lungs and blood. Acute and chronic effects have been cited.(2) So it would appear that a comparison between the chemical toxicity of copper and radioactive material is not unreasonable in view of the potential consequences of overexposure.

In Table 3 we have listed several commonly occurring radionuclides that may be found in significant quantities in a typical piece of accelerator hardware. Column 3 restates the MPC_a in terms of mg/m^3 by assuming a specific activity of 1 $\mu Ci/gm$. Column 4 indicates the required specific activity to approximate the chemical toxicity for stable copper as a mist or dust.

TABLE 3

MPC FOR SELECTED RADIOISOTOPES RESTATED AS mg/m^3
ASSUMING 1 $\mu Ci/gm$ SPECIFIC ACTIVITY

Isotope	MPC_a $\mu Ci/m^3$	mg/m^3	$\mu Ci/gm$ to equal 1.0 mg/m^3
^{54}Mn	4×10^{-2}	40	40
^{51}Ci	2	2000	2000
^{57}Co	2×10^{-1}	200	200
^{58}Co	5×10^{-2}	50	50
^{22}Na	9×10^{-3}	9	9
U_{nat}	7×10^{-5}	0.21	----
Th_{nat}	3×10^{-5}	0.27	----

If we now compare the dust or particle concentrations of common environments such as rain, fog, smoke, smog and, etc, we find that 0.1 - 1 mg/m^3 is, according to Hatch and Drinker,[3] about the range found in industrial cities of the U.S.A. Also, 1 - 10 mg/m^3 are typical values for very dusty operations such as foundry shakeout and mine atmospheres during drilling operation. According to Patty 15 mg/m^3 is about the upper limit of dustiness set for all innocuous dusts.

Experience at SLAC

The bulk of our machining experience at SLAC has been with copper and stainless steel. We have required that machining operations be performed by cutting techniques known to produce large chips without special containment provisions. Grinding and other procedures that produce fine particles have been generally discouraged.

Air sampling has been performed on each of these procedures with negative results. Small personnel air samples have been used to evaluate possible airborne concentration of radioactive particulates. In each case the air sampling rate was 10 1/min and the location of the sampling head was near the breathing zone of the machinist. A second air sampler was placed near the cutting tool in an attempt to evaluate airborne concentration near the cutting surface.

Radiation measurements have also been made with ion chambers at ~10 cm from material to be machined. Debris from drilling and filling operations were weighed and analyzed for major γ emitters for subsequent identification and specific activity determination. These values appear in Table 4. The measured gamma dose rate was 50 mR/hr per $\mu Ci/gm \pm 50\%$.

TABLE 4

PREDOMINANT γ EMITTING RADIOISOTOPES FOUND IN COPPER AND STAINLESS STEEL

	Isotope	Fractional Abundance	μCi/gm
Copper	^{57}Co	0.53	3.1×10^{-2}
	^{54}Mn + ^{58}Co	0.41	2.4×10^{-2}
	^{60}Co	0.06	3.5×10^{-3}
	Specific Activity μCi/gm		5.85×10^{-2}
	Dose Rate at 10 cm		2 mR/hr
Stainless Steel	^{57}Co	0.18	0.52
	^{54}Mn + ^{58}Co	0.12	0.35
	^{51}Cr	0.70	2.00
	Specific Activity μCi/gm		2.9
	Dose rate at 10 cm		220 mR/hr

If we assume that the external dose rate is a linear function of specific activity, then for ^{54}Mn the external dose rate would approach 1 - 3 R/hr before the radiotoxicity approaches the chemical toxicity for copper, from Table 4.

$$(40\,\mu\text{Ci/gm})\left(\frac{50\text{ mR/hr}}{\mu\text{Ci/gm}}\right) = 2000\text{ mR/hr} \pm 50\%$$

The determination of specific activity by external radiation measurement with survey rate meters is not a method of great precision. However, sufficient accuracy can be achieved for operational purposes given the proper conservative assumptions.

There are a variety of geometric shapes to consider as well as thin and thick specimens. Self absorption has been neglected in the following discussion.

Most machining operations are performed on relatively thin items, such as vacuum piping, flanges and target holders. The material may have absorbed some of the primary beam or perhaps been exposed by an isotopic source of secondary high energy photons and nucleons. We have also observed thermal neutron activation reactions in some areas.

As a first approximation consider a disc source of known or assumed uniform specific activity, diameter, thickness and distance from a sensor.

$$R_\gamma = \frac{q\Gamma}{a^2} \ln \frac{h^2+a^2}{h^2} \text{ r/hr}^{(4)}$$

where

R_γ = R/hr
q = mCi
a = radius of source
h = distance from center of disc to sensor
Γ = dose-rate constant
cm^2-R/mCi-hr

If we assume that the material is copper with the following physical dimensions and specific activity:

1. radius, 10 cm
2. thickness, 1 cm
3. distance, 10 cm
4. specific activity, 1 μCi/gm

The dose rate at 10 cm is calculated to be:

$$1.8 \times 10^{-2} \frac{\text{R/hr}\Gamma}{\mu\text{Ci/gm}}$$

Consider now a point source produced by the irradiation of a primary beam in a thick copper target. The radioactivity is assumed to be in a volume approximating a sphere whose radius is 5 cm. If we assume a specific activity of 1 μCi/gm and that the sphere approximates a point source, the radiation level at 10 cm will be:

$$R_\gamma = \Gamma q/r^2 \text{ r/hr } ^{(4)}$$

where

R_γ = R/hr
Γ = dose rate constant cm^2-R/hr - mCi
q = total activity mCi
r = distance from source

The dose rate from a point source is therefore:

$$4.7 \times 10^{-2} \frac{\text{R/hr}\Gamma}{\mu\text{Ci/gm}}$$

The ratio between the two models is within a factor of three for the same specific activity. The selection of the proper diameter in the case of a disc source would necessitate some assumptions based on survey meter readings, as to the proper dimensions to use. Certainly the difference between a point source and disc source can be ascertained. The error concerned with the proper selection of a disc radius is estimated to be within a factor of two.

Conclusion

An attempt has been made to place the problem of machining radioactive materials of relatively low specific radioactivity in proper perspective.

It would appear that the specific activity in irradiated copper, stainless steel or aluminum would have to reach proportions that would create external whole body radiation protection problems before measurable airborne exposure becomes significant.

It is not the intention of this report to argue that continued health physics surveillance is unnecessary when the machining of radioactive items is required. It is intended to help formulate guidelines for decision making with respect to the need for ventilated enclosures or close-capture ventilation for this kind of activity at SLAC as a personnel protection requirement.

The problem of long term buildup of radioactive contamination on machines and machine shop areas remains. Also, the problem of preventing or minimizing cross contamination of equipment used in "low background" counting equipment remains an essential factor for consideration.

References

1. K. Z. Morgan, W. S. Snyder and M. R. Ford, Relative Hazard of the Various Radioactive Materials, Health Physics: 10, 151 (1964).
2. Frank A. Patty (ed.), Industrial Hygiene and Toxicology, 2nd ed., John Wiley and Sons, Inc. New York, 1963.
3. P. Drinker and T. Hatch, Industrial Dust, 2nd ed., McGraw-Hill, New York 1954.
4. G. Hine and G. Brownell (ed.), Radiation Dosimetry, pp. 755-764, Academic Press Inc., New York, 1956.
5. U. S. A. E. C. manual, Standards for Radiation Protection, Chapter 0524, Annex A.
6. National Bureau of Standards, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure, Handbook-69, U. S. Government Printing Office, Washington D. C. 1959.