

Introduction:

A contamination control program is an important component of any radiation safety program. Doses to workers and members of the public arising from contamination in the workplace – and contamination carried out of the workplace – must be maintained ALARA. An effective contamination control program is highly dependant on an effective contamination monitoring program. Surface contamination levels on working surfaces and equipment, protective clothing, personnel, items leaving the working areas and the surfaces in neighboring areas must all be monitored.

The objectives of a contamination monitoring program include:

- 1) Maintain exposures to workers and members of the public ALARA.
- 2) Monitor the effectiveness of containment and working procedures.
- 3) Assist in preventing the spread of contamination from controlled areas to other areas such as low level counting rooms
- 4) To provide information for planning for work and for internal dosimetry programs.

There are generally two types of monitoring that are useful in radiation safety programs:

- A. Baseline Monitoring – in which the value (eg. surface contamination level) is low enough that it does not present a concern in and of itself but the parameter is monitored to detect changes (usually increase) that might be indicative of a trend or deteriorating condition.
- B. Operational Monitoring – in which values are such that the condition being monitored may present a hazard or require that decisions be taken or protective measures introduced.

In the latter case, it is necessary to have a specific limit or limits against which to compare monitoring results – Surface Contamination Limits. It is necessary, then, to answer the question “how much is too much?”

Doses Resulting From Surface Contamination:

Doses from surface contamination may result from directly from four exposure pathways:

- External irradiation from radioactive material transferred to the surface of the skin
- Inhalation of re-suspended material
- Ingestion of radioactive material transferred to hands
- Absorption of radioactive material through the skin.

Surface contamination is normally classified as removable (or “loose”) versus non-removable (or “fixed”). The former is generally defined as the fraction of the contamination on a surface which is easily removed by wiping. By examining the exposure pathways above, it is obvious that removable contamination presents the greater hazard. However, that does not mean that “fixed” contamination can be ignored. Direct external exposures can result from fixed contamination and fixed contamination can become loose through application of energy to the surface (welding, grinding, abrasion) temperature cycling, chemical reactions, or just time.

Surface contamination limits are generally focused on the removable component. The current CNSC surface contamination limits for laboratories are presented in the handout.

For beta (and energetic electron) emitting contaminants – by far the most commonly encountered – the dominant exposure pathway is often external exposure to the skin. Understanding these doses is important for two reasons - both to understand the derivation of surface contamination limits and to be able to calculate doses resulting from accidental skin or clothing contamination incidents.

Doses from Skin Contamination:

Figures 1 and 2 (from ICRP 89 [1] show the structure of the skin. The sensitive component is taken as the inner-most layer of the epidermis – the stratum basale or “basal layer”.

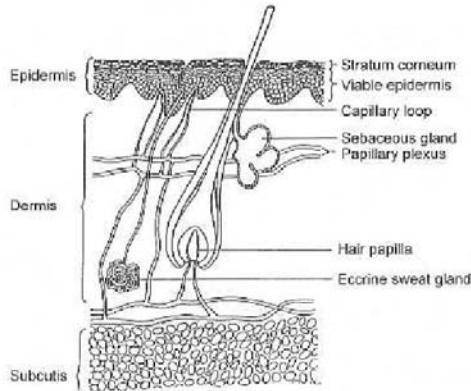


Figure 1: Schematic of integumentary system

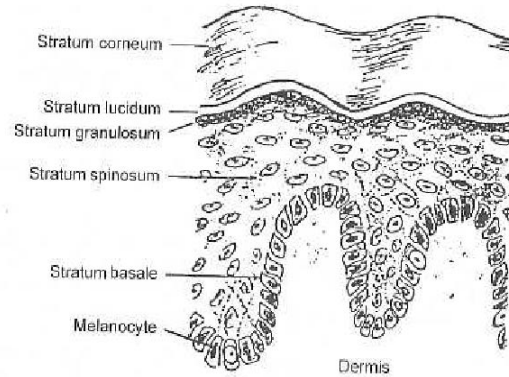


Figure 2: illustration of the stratified cellular epidermis

As shown in Figure 3 (also from ICRP 89), the mean epidermal thickness varies from one are to another on the body. Overall, the ICRP recommends an average value of 70 μm . The density of the epidermis is approximately 1.1 g/cm^3 so that the density thickness is approximately 7 mg/cm^2 . This is the appropriate value to use when averaging over the body – as is the case in determining the individual dose equivalent superficial $H_s(d)$ (often called shallow or surface dose) by calculation or measurement with a dosimeter. However, the dose from skin contamination is highly dependant on depth and it is important to use the epidermal thickness appropriate to the are of the body that is contaminated.

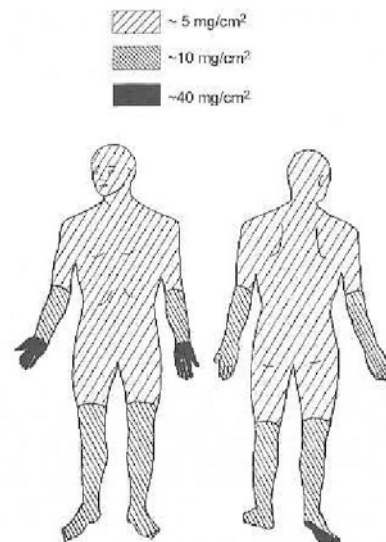


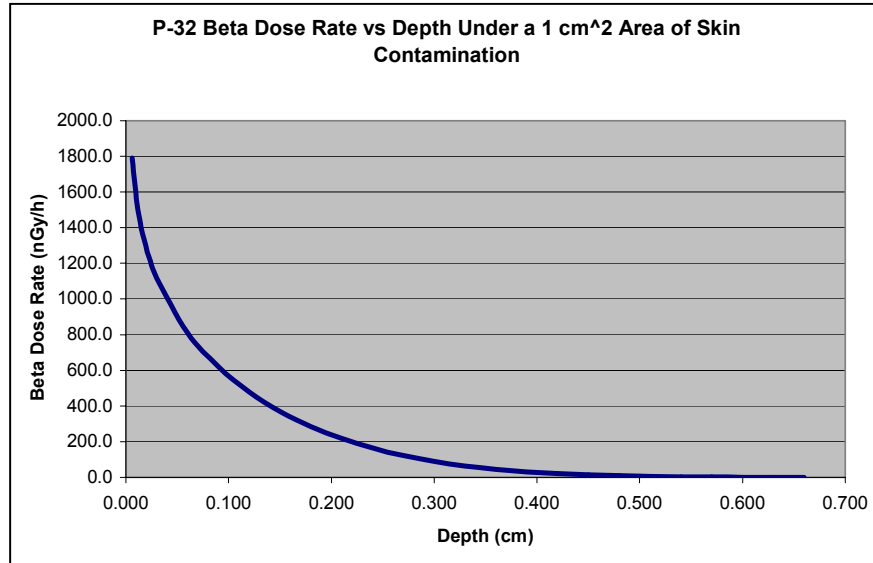
Figure 3: Variation in mean epidermal thickness (adults)

The dose at various depths in tissue (represented by water) below circular 1 cm^2 and 100 cm^2 areas of contamination has been calculated by Cross et all [2] for most radionuclides of interest. Two examples of the data tables are presented below – P-32 and Tc-99m, and plots of the data are shown. The data presented in this form is extremely useful as it allows for estimation of a dose conversion factor for the specific depth of irradiation. Occasionally, it may be necessary to calculate a skin dose resulting from contamination on protective clothing such as a high energy beta emitter on a rubber glove. In this case, the glove can also be approximated reasonably as water, and the dose conversion factor can be

determined for the depth of the basal layer under the glove and the epidermis. For example, a medium weight rubber glove may have a density thickness of about 30 mg/cm^2 . In this case we are interested in the dose rate at 70 mg/cm^2 , which can be interpolated or read from the graph.

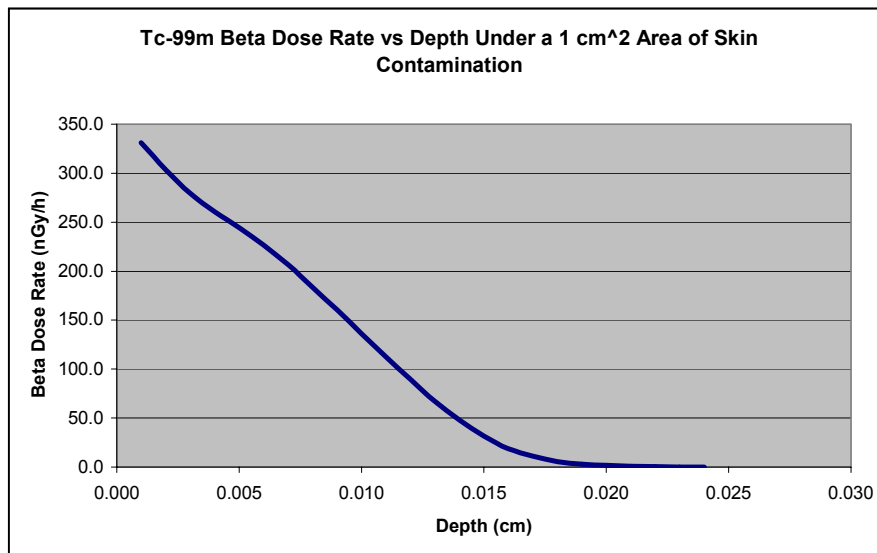
P-32

Depth (cm)	Dose Rate (nGy/h)
0.006	1790.9
0.012	1499.9
0.018	1331.0
0.024	1211.2
0.030	1116.9
0.060	811.5
0.090	620.6
0.120	478.4
0.150	369.8
0.180	284.9
0.210	217.7
0.240	164.3
0.270	122.3
0.300	89.5
0.330	64.3
0.360	45.3
0.390	31.2
0.420	20.9
0.450	13.6
0.480	8.5
0.510	5.1
0.540	2.9
0.570	1.6
0.600	0.8
0.630	0.4
0.660	0.1



Tc-99m

Depth (cm)	Dose Rate (nGy/h)
0.001	331.2
0.002	303.5
0.003	279.3
0.004	260.7
0.005	244.2
0.006	226.9
0.007	206.7
0.008	183.6
0.009	160.4
0.010	136.1
0.011	112.7
0.012	89.6
0.013	67.2
0.014	48.0
0.015	31.5
0.016	18.7
0.017	11.0
0.018	5.5
0.019	3.1
0.020	1.7
0.021	1.0
0.022	0.5
0.023	0.2
0.024	0.1



Dose Conversion Factors have also been tabulated in various forms. For example, see Table 13.10 of the Health Physics and Radiological Health Handbook.

Derived Working Limits for Surface Contamination:

A methodology for determining Derived Working Levels (DWLs) for surface contamination is described in ACRP-7 [3]. It requires an analysis of the following exposure pathways:

- external irradiation of skin due to contamination on the surface
- ingestion of a fraction of contamination from contaminated skin
- inhalation of re-suspended contamination
- uptake of the radionuclide via absorption through the skin
- skin dose from a radionuclide retained in the skin.

Surface	Pathways Considered	Dosimetric Parameters
Personal Skin Contamination	External irradiation Inhalation Ingestion Uptake through skin	Occupational dose limit Exposure time of 8760 hours
Personal Clothing	External irradiation Inhalation Uptake through skin	Occupational dose limit Exposure time of 4000 hours
Protective Clothing	External irradiation Inhalation Skin Uptake	Occupational dose limit Exposure time of 2000 hours
Controlled Area Surfaces	External irradiation Inhalation Skin Uptake	Occupational dose limit Exposure time of 2000 hours
Uncontrolled Area Surfaces and Equipment Leaving a Controlled Area	External irradiation Inhalation Ingestion Uptake through skin	Standard is 1/20 th of that for Controlled Area Surfaces. (Practice is 1/10 th)

External Irradiation

$$DWL = \frac{H_L}{T_c (DCF)_e} \text{ Bq} \cdot \text{m}^{-2}$$

Where

$$H_L = \text{annual dose limit} = 500 \text{ mSv } y^{-1}$$

$$T_c = \text{exposure time}$$

$$= 8760 \text{ hours } y^{-1} \text{ for skin contamination}$$

$$= 4000 \text{ hours } y^{-1} \text{ for contamination of personal clothing}$$

$$= 2000 \text{ hours } y^{-1} \text{ for contamination of protective equipment and controlled area surfaces}$$

$$(DCF)_e = \text{external dose conversion factor to basal layer of skin}$$

Inhalation

$$DWL = \frac{ALI}{I_a R_s} \text{Bq} \cdot \text{m}^{-2}$$

Where

ALI = Annual Limit on Intake (Occupational)

I_a = inhalation rate ($\text{m}^3 \text{y}^{-1}$)

= $3600 \text{ m}^3 \text{y}^{-1}$ for contamination of skin and personal clothing

= $2400 \text{ m}^3 \text{y}^{-1}$ for contamination of protective equipment and controlled area surfaces

R_s = resuspension factor for particulate material from surfaces

= $5 \times 10^{-5} \text{ m}^{-1}$ (for most materials)

Ingestion

$$DWL = \frac{ALI}{A_s f_a N_c} \text{Bq} \cdot \text{m}^{-2}$$

Where

ALI = Annual Limit on Intake (Occupational) by ingestion

A_s = area of skin being considered - normally taken as the area of the hands

= 0.03 m^2

f_a = fraction of activity on the skin that is ingested

= 0.1

N_c = number of contamination events per year - normally taken as once per working day

= 250

Uptake by Skin

$$DWL = \frac{H_L}{(DCF)A_s f_u N_c} \text{Bq} \cdot \text{m}^{-2}$$

Where

H_L = Annual Dose Limit

= 20 mSv y^{-1}

DCF = Dose Conversion Factor for the critical organ or tissue

f_u = fraction of activity on the skin surface that is taken up into the body through the skin

= 0.1 for tritiated water, 0.002 for radioiodine

N_c = number of events per year

= 250 based on once per day

Retention in Skin

For radionuclides retained in the skin to a significant degree, it is necessary to model the behaviour and calculate the resulting dose from the volume irradiation. ACRP 7 describes and references some of the work that has been done, such as that by Johnson for I-125.

Uncontrolled Areas

For Uncontrolled Areas, ACRP recommends that the application of the equation for the ingestion pathway be modified as follows:

$$DWL_{UA-I} = \frac{ALI}{A_s f_a N_c} \text{Bq} \cdot \text{m}^{-2}$$

Where

ALI = Annual Limit on Intake (Occupational) by ingestion / 20 (ratio of occupational to public dose limit)

A_s = averaging area for contamination measurements (nominally set to 0.01 m^2)
= 0.01 m^2

f_a = fraction of activity on surface that is ingested
= 0.1

N_c = number of contamination events per year - normally taken as once per working day
= 250

In addition, it is recommended that each of the exposure pathways be considered and that a scaling factor of 1/20 be applied to the derived limit for a Controlled Area. The scaling factor of 1/20 is only valid for exposure pathways where the DWL is limited by effective dose (inhalation, ingestion, and skin uptake). For the pathways where the DWL is limited by skin dose (external exposure and retention in skin), the relevant scaling factor is 1/10, which is the ratio of the public skin dose limit to the occupational skin dose limit.

The Table below summarizes the calculation performed for I-125.

Calculated Derived Working Limits for I-125 Contamination (Bq cm^{-2})

Surface	External Exposure	Inhalation	Ingestion	Skin Uptake	Retention in Skin
Personnel Skin Contamination	3.0 E 3	1.1 E 3	1.3 E 2	4.5 E 2	1.4 E 2
Personal Clothing	6.5 E 3	1.1 E 3	NA	4.5 E 2	1.4 E 2
Protective Clothing	1.3 E 4	1.7 E 3	NA	4.5 E 2	1.4 E 2
Controlled Area Surfaces	1.3 E 4	1.7 E 3	NA	4.5 E 2	1.4 E 2
Uncontrolled Area Surfaces (and equipment leaving a controlled area)	1.3 E 3	8.3 E 1	2.0 E 1	2.2 E 1	1.4 E 1

References:

1. ICRP 89, Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values, Annals of the ICRP Vol. 32, No. 3-4, 2002
2. Cross, Tables of Beta-Ray Dose Distributions in Water, AECL, 1992.
3. ACRP-7, Report on Derived Working Limits for Surface Contamination, the Advisory Committee on Radiation Protection, 1993