Initial Dose Magnitude Estimation for Individuals Involved in a Radiological Incident/Accident

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Note: *The following document builds upon and updates information contained in a document written by Steve Sugarman when he was the Health Physics Project Manager at the Radiation Emergency Assistance Center/Training Site (REACT/TS) entitled "Early Internal and External Dose Magnitude Estimation." The technical information contained in this update can be used to guide emergency responders, medical personnel, and others in occupational settings to conduct early radiation dose estimations.*

Author's note:

I originally wrote *Early Internal and External Dose Magnitude Estimation* in 2008 when serving as the Health Physics Project Manager at the Radiation Emergency Assistance Center/Training Site (REAC/TS), a response asset of the US Department of Energy, to provide general guidance for early estimation of radiation dose magnitude. Although not always possible, every effort was made to write in understandable terms so that the guidance could be used by a wide range of people. The document was posted on the REAC/TS website, and during my time at REAC/TS the document was periodically updated in an effort to keep it current and improve its usability – the most recent update to *Early Internal and External Dose Magnitude Estimation* being 2017.

In late 2017 I left REAC/TS to join Summit Exercises and Training LLC (SummitET®) where I am the Vice President of Operations and Corporate Health Physicist. Upon revisiting *Early Internal and External Dose Magnitude Estimation*, I realized new information that may be pertinent to the topic had become available. I've incorporated that information into an undated document: *Initial Dose Magnitude Estimation for Individuals Involved in a Radiological Incident/Accident*.

Initial Dose Magnitude Estimation for Individuals Involved in a Radiological Incident/Accident isn't intended to provide methods for definitive dose calculation, but to provide methods one may consider using for initial dose estimation when trying to determine the potential magnitude of the radiation doses to individuals involved in a radiation incident/accident. As with any job, it's advantageous to have multiple tools available to help with the task, but it's up to the user to determine if the proper tool is being selected and to apply that tool correctly to any given situation. The tools/methods described in this document are in no way intended to take the place of established/validated internal dose assessment (urinalysis, whole body counting, etc.) or external dose assessment (selection of proper dosimetry, in-depth reconstructions, etc.) techniques, nor are they to be used for regulatory and/or occupational dose assignment. Each situation should be evaluated for the applicability of the described tools with an understanding of the strengths and weaknesses that are inherent in each of them.

This document is intended to provide general guidance and isn't a peer-reviewed publication. I've attempted to give credit where credit is due throughout the document and have provided related document citations in the useful reference lists for each section. Should you have any questions, please feel free to contact me at SteveSugarman@SummitET.com.

Responding to a radiological accident/incident can be intimidating for many people. Be it due to impressions left by the portrayal of the effects of radiation espoused in popular culture (comic books, novels, etc.), images of the destructive power of the atomic bomb from Nagasaki or Hiroshima, or statistics about cancer causation provided by various sources (legitimate and non-legitimate), there seems to be something about radiation that makes people a little nervous. One only has to go as far as the January 2021 incident in Haddon Township, NJ, where a school was evacuated because a student brought a uranium-glazed Fiestaware® plate to class to see the impact that the word "radiation" can have on decision-making (Evacuation ordered after officials learn of 'potentially dangerous substance' (burlingtoncountytimes.com) and Scientists back Haddon Twp. youth who brought radioactive plate to school (burlingtoncountytimes.com)).

Assessing the potential radiation dose and associated impacts is an important part of the health physicist's (or radiation protection professional's) job. There are many things to be considered. Priorities have to be set, appropriate instrumentation should be selected, proper techniques have to be used, and - many times - a little detective work needs to be done. The information available soon after an accident/incident may not be sufficient to come up with a categorical dose assessment, but one should be able to gather enough information to develop an estimate of the magnitude of the radiation dose – or potential dose – to personnel involved in the event or who are otherwise expected to perform duties in the affected area.

One should not forget that in many cases first responders and medical care providers may not be accustomed to responding to situations involving exposure to, or contamination with, radioactive materials. According to an article in *Health Physics News* by Stephanie Carlson, MD, *Ask a Doc? What Do Physicians Know about Radiation Anyway?* (Volume 36, Number 8) there's a suggested general lack of knowledge within the medical community about ionizing radiation and its effects. It stands to reason that this lack of understanding, and perhaps a reticence or uncomfortableness with working around radioactive materials, may also apply to a large cross-section of the overall response community. They may need assistance from a radiation protection professional not only for advice and assistance with radioactive material controls and potential assessment of radiation doses, but for reassurance and helping to calm the fears many have when it comes to radiation. It's, therefore, essential to integrate radiation protection professionals into the radiation emergency response plans. Establishing a good working relationship between emergency responders – be they police, fire, EMS, or healthcare providers – and health physics personnel in advance of an incident will help to build trust, provide an opportunity for concerns to be addressed, and help the response go much more smoothly and efficiently than it otherwise may if this integration doesn't occur.

Just as first responders and medical personnel attempt to determine the history of the patient in order to determine the proper treatment, attempts should also be made to ascertain the generalities of the incident from a radiological point of view. Points of concern may include – but not be limited to – where was the involved person at the time of the accident? What was he/she doing? Aside from potential contamination issues, should exposure be a concern (to the individual and/or responders)? What radioisotopes were involved? How much radioactive

material was there? What type of protective clothing or respiratory protection was used? Where are the areas of contamination – wounds? Intact skin? Face? Only on clothes?

When a person has sustained an injury, there's one overriding general principle: Medical needs take priority over radiological concerns. Medical evaluation and stabilizing treatment should not be delayed in order to perform a thorough survey or to decontaminate an injured individual. Once the victim has been medically stabilized, radiological surveys and subsequent decontamination may begin.

Early Magnitude Assessment of External Radiation Dose

It's important to be able to quickly determine the magnitude of the radiation dose a person may have received in order to predict potential effects, and it can therefor play a role in early triage. This, however, isn't always an easy task. There are many variables the person doing the dose assessment must understand that come into play when doing initial dose estimation. Among the things to consider are time of exposure, distance from the source, source activity, potential shielding, and isotope. Some of these items are usually fairly straight forward, source activity and isotope, for instance. It's oftentimes much more difficult to pinpoint the distance the affected area was from the source or the duration of exposure. Due to distance vs. dose rate relationships and the extremely high dose rates that can be encountered, any inconsistencies can have tremendous impacts on the dose estimates.

For point sources, the inverse square law can be used to calculate gamma dose and dose rate. The inverse square law says that the dose or dose rate falls off with the inverse square of the distance ($1/R^2$). Another way to state this is "double the distance, quarter the dose." It can also be written as:

$$\textit{Equation 1: } (D_1) \times (R_1)^2 = (D_2) \times (R_2)^2$$

Where:
D_1 is the original distance
D_2 is the distance of interest
R_1 is the initial dose or dose rate
R_2 is the dose/dose rate of interest

Note: Knowing any three parameters allows for solving for the fourth.

The generally accepted rule of thumb used to determine whether, or not, the inverse square law can be used says that the distance from the source must be at least three times the longest dimension of the source. For small sources such as industrial radiography sources the distance required is a centimeter, or slightly less.

Other equations and information to calculate radiation doses can be found in Section 3 of *Health Physics and Radiological Health, 4th Edition* (2012).

To estimate gamma dose rates for exposures at a distance from the source, one can use the information found in the Gamma Constant column of Table 1 in conjunction with the following equation:

$$\textit{Equation 2: } D = \frac{\Gamma A t}{d^2}$$

Where:
*D is the dose**
A is the source activity
t is the exposure time
d is the distance
*Γ is the gamma-ray constant (mSv-cm^2/hr-MBq**)*

* the units for exposure and dose due to photons are considered to be equal
** multiply mSv/hr/MBq by 3.7 to get R/hr/mCi

It's often the case that one is concerned with doses at various depths in tissue. Table 1 can be utilized to determine doses to the first 0.07 mm and 1 mm of soft tissue and dose rates at 1 cm and 3 cm depths by using Equation 3 .

Equation 3: D = SAt

Where:
D is the dose
A is the source activity
t is the exposure time (min)
S is the surface dose rate constant for desired tissue depth (mSv/hr-MBq)

Keep in mind that observable injuries/illnesses associated with acute radiation exposures are related to threshold doses (Tables 2 and 3) and usually take time to fully develop. Early dose estimations should always be compared to physical dosimetry, if available, taking into account the onset of medical signs/symptoms (or lack thereof). In many cases, the true dose will be elusive and bracketing the dose may require ongoing communication between medical care personnel and health physics personnel. If the expected biological effects predicted by the initial dose estimates do not jibe with observed effects, the physician must weigh what he/she is seeing versus what was calculated by the health physicist.

The radiation protection professional must also be mindful of potential pitfalls associated with dose estimation in situations where the information may be somewhat nebulous in order to provide good support to responding personnel. As previously mentioned, among the things to consider are the accuracy of provided exposure times and distance-from-source estimates. Mock-ups, multiple in-depth interviews, or other means of reconstructing the accident scenario may provide additional information to further fine-tune the dose estimates being used to help guide medical care.

Table 1: Dose Conversion Factors

Approximate dose rates to the skin for 1 MBq in a sealed source - PHITS Simulations

		Dose to first 0.07mm			*Dose to first 1mm*				
Nuclide	Gamma Constant (mSv-cm^2/ hr-MBq)	Dose Rate Photon Only (mSv/h)	Dose Rate due to secondary electron buildup in encapsulation (mSv/h)	Dose Rate Total (mSv/h)	Dose Rate Photon Only (mSv/h)	Dose Rate due to secondary electron buildup in encapsulation (mSv/h)	Dose Rate Total (mSv/h)	Dose rate at 1cm tissue depth (mSv/h)	Dose rate at 3cm tissue depth (mSv/h)
Cs-137	0.927	0.95	3.99	4.94	2.90	1.28	4.18	0.48	0.065
Co-60	3.48	1.60	14.00	15.60	5.42	8.20	13.62	1.74	0.262
Ir-192	1.24	2.65	6.80	9.45	5.12	1.04	6.16	0.59	0.092
Ra-226	2.23*	2.15	11.30	13.45	5.30	4.80	10.10	1.28	0.157
Se-75	0.548	1.95	4.61	6.56	2.43	0.47	2.90	0.21	0.022

- 0.7 and 1 mm data from Encapsulated Gamma Source Contact Dose Conversion Factors: Updating NCRP-40 Guidance – Health Physics – February 2021 (Ed Waller and Eric Heritage)
- 1 cm and 3 cm data was provided by Ed Waller on 03/02/2016 via personal correspondence.
- Cs, Co, Ir, Ra 1 cm and 3 cm data closely resembles that published in NCRP 40.
- No data available in NCRP 40 for Se.
- Gamma constant information from *Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides* (Smith, Stabin – Health Physics – 2012) – converted from conventional US units listed in the reference
- * Converted from NCRP 40 (includes daughter contributions)

Note: Multiply mSv/hr/MBq by 3.7 to get R/hr/mCi

Table data compiled by Steve Sugarman

Table 2: Skin Injury Thresholds vs. Acute Doses

Dose	Effect	Timing* (time post exposure)
300 rads, 3 Gy	Epilation	14-21 days
600 rads, 6 Gy	Erythema	Early, then 14-21 days later
1000-1500 rads, 10-15 Gy	Dry Desquamation	2-3 Weeks
1500-2500 rads, 15-25 Gy	Wet Desquamation	2-3 Weeks
> 2500 (> 25 Gy)	Deep Ulceration/Necrosis	Dependent upon dose

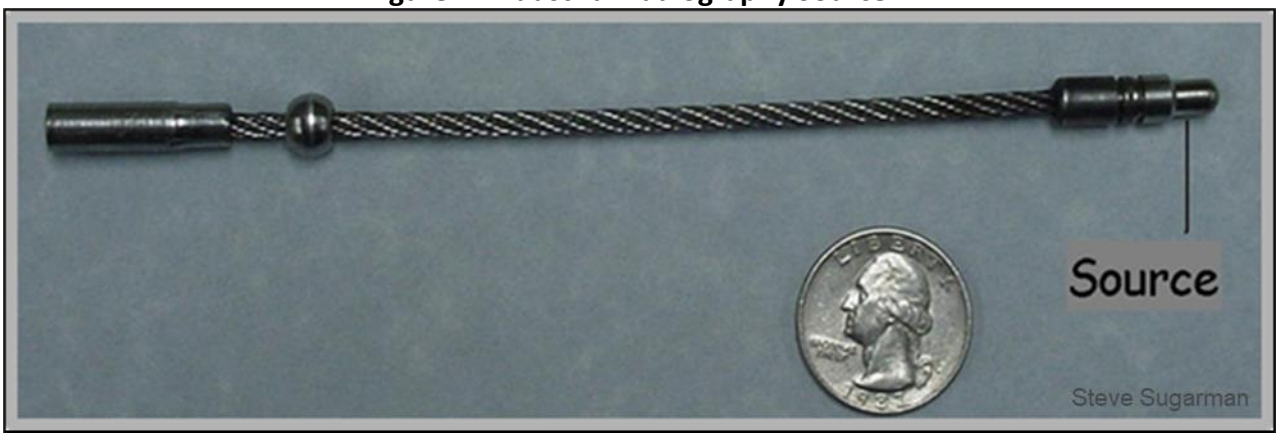
* At higher doses the time to onset of signs/symptoms may be compressed.

Table 3: Thresholds for Acute Radiation Syndromes

Dose	Syndrome	Signs/Symptoms*
0-100 rads, 0-1 Gy	NA	Generally asymptomatic, potential slight drop in lymphocytes later (near 1 Gy)
> 100 rads, > 1Gy	Hematopoietic	Anorexia, nausea, vomiting, initial granulocytosis and lymphocytopenia
> 6-800 rads, > 6-8 Gy	Gastrointestinal	Early severe nausea, vomiting, watery diarrhea, pancytopenia
> 2000 rads, > 20 Gy	Cardiovascular/ CNS	Nausea/vomiting within first hour, prostration, ataxia, confusion

* At higher doses the time to onset of signs/symptoms may be compressed.

Figure 1: Industrial Radiography Source



Example Problem

An individual enters an area where industrial radiography was previously performed. The radiographer left for another job where he noticed that the source wasn't in the camera. He returns to retrieve the source and finds it lying underneath the boiler where he was taking pictures. Your investigation into the incident reveals that there was only one person in the area where the source was left, a maintenance worker working on the piece of equipment adjacent to where the source was found. The worker was only 3 feet away from the source. He was in the area for a total of 1 hour. The source strength was reported to be 1.85 TBq (~50 Ci); the isotope being Ir-192. What is his potential whole-body dose? About 3 weeks later the maintenance worker complains of tenderness and reddening of his index finger and thumb on his right hand. He states he picked up something he didn't recognize under the boiler and examined it – holding it about an inch from the end for approximately a minute – but seeing no use for it, he threw it back in the floor where he found it. Could this be radiation related?

Question 1: Whole body dose

1.85 TBq of Ir-192 at a distance of 3 feet for 1 hour
Gamma constant (Γ) = 1.24 mSv-cm^2/hr-MBq
Activity (A) = 1.85 TBq x 1E6 MBq/TBq = 1.85E6 MBq (1.85 million MBq)
Time (t) = 1 hours
Distance (d) = 3 feet X 0.3048 meters/foot = 0.9144 meters = 91.4 cm
Using Equation 2:

$$\textit{Equation 2: } D = \frac{\Gamma A t}{d^2}$$

(1.24)(1.85E6)(1) / (91.4)^2 = approximately 275 mGy

Assume 18" from body while the worker examined the source for 1 minute:

(1.24)(1.85E6)(1 minute X 1 hour/60 minutes) / (18 inches X 2.54 cm/inch)^2 = about 18 mGy

Total whole-body dose is estimated to be approximately 300 mGy (assumes 1 Sv = 1 Gy)

Question 2: Dose to fingers

1.85 TBq of Ir-192 at a distance of 1 inch for 1 minute
Gamma constant (Γ) = 1.24 mSv-cm^2/hr-MBq
Activity (A) = 1.85 TBq X 1E6 MBq/TBq = 1.85E6 MBq
Time (t) = 1 minute X 1 hour/60 minutes = 0.017 hours
Distance (d) = 1 inch X 2.54 cm/inch = 2.54 cm
Using Equation 2:

$$\textit{Equation 2: } D = \frac{\Gamma A t}{d^2}$$

(1.24)(1.85E6)(0.017) / (2.54)^2 = approximately 6 Gy, so it's possible that this is radiation related (erythema threshold is approximately 6 Gy)

Note that the time to onset of signs/symptoms and the estimated dose seem to align with what is described in Table 2. Should the onset of signs/symptoms not occur as expected, it's likely that there's an error in estimated time of exposure or in the distance estimate. Healthcare personnel should "treat the patient, not the dose." It's not uncommon for dose estimates to be revised multiple times throughout an incident investigation.

Other useful rules of thumb:

Alpha (α)

- Alpha particle of at least 7.5 MeV is needed to penetrate the protective layer of skin.
- Range of common alpha emitters (4.5 MeV to 5.5 MeV) is 3 to 4 cm in air.

Beta (β)

- Average β energy is approximately 1/3 its maximum energy.
- Range of beta particles (g/cm^2) is approximately equal to E_{max} /2. [Density thickness = g/cm^2 = Thickness (cm) X density (g/cm^3)]
- 70 keV is required to penetrate the protective layer of skin
- Dose rate (rads/hr) at 1 cm (point source) is approximately 200 X mCi.
- Skin dose (through outer protective layer) is approximately 9 rads/hr from a uniformly thin deposit of $1\mu Ci/cm^2$.

Gamma (γ)

- Exposure rate (R/hr) = $6CEN/r^2$ (feet) or $0.5CEN/r^2$ (meters)

  where: C = activity in curies
  E = photon energy in MeV
  N = fractional yield of photon emission
  r = distance in feet or meters (as applicable)

Useful References for Early External Dose Estimation

Encapsulated Gamma Source Contact Dose Conversion Factors: Updating NCRP-40 Guidance. Health Physics. Volume 120, Number 2. Waller, Heritage (2021)

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Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides. Health Physics. Volume 102, Number 3. Smith, Stabin (2012)

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Basic Radiation Protection Technology – 5th Edition, Gollnick, Pacific Radiation Corporation, (2006)

The Medical Basis for Radiation-Accident Preparedness, The Clinical Care of Victims, Eds: Ricks, Berger, O'Hara (2002)

Protection Against Radiation from Brachytherapy Sources, NCRP Report No. 40, National Council on Radiation Protection and Measurement (1972)

Early Magnitude Assessment of Internal Contamination

After the normal questions asked by many medical care providers when treating a radioactively contaminated patient, such as “Is it safe for me to treat this patient?” (The answer to which is nearly always, “Yes,” with regard to radiological concerns.), the questions often turn to how to treat for intakes of radioactive materials should the realistic potential for internalization exist. There’s quite a bit of published guidance regarding how to treat (for instance, NCRP Report No. 161), but not much regarding how to rapidly estimate the intake of radioactive materials in a non-occupational setting where there are no routine air samplers, survey histories, or other normally accessible tools to help guide decisions.

The key to early management of internalized radioactive materials isn’t necessarily radiation dose calculation and assignment, but radiation dose *magnitude* estimation. An early estimate of the magnitude of the intake and resulting dose can be used to predict potential biological consequences and the corresponding need for medical intervention. All radiation doses should be assigned using proper dosimetry techniques. However, waiting for the results of the formal internal dosimetry process to make treatment decisions often takes time that may delay treatment. For some radioisotopes, including ^{241}Am and $^{238/239}$Pu, it’s especially important to be able to make early assessments of potential intakes so that a rapid decision whether or not medical countermeasures are needed can be made. For instance, DTPA is most effective when given within a few hours of the intake of Am or Pu; therefore, a delay in treatment while waiting on urinalysis/fecal analysis results may lead to decreased dose reduction.

Radiation doses from internally deposited radioactive materials are calculated based on the intake. The intake is the amount of radioactive material taken into the body by inhalation, absorption through the skin, injection, ingestion, or through wounds (*NCRP Report No. 87, Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition* -1987). Unfortunately, there isn’t a good way to rapidly assess how much radioactive material is absorbed through the skin other than *in vivo*/*in vitro* counting. It’s easy to swab the mouth for potential ingestion intakes or mouth-breathing, but the mouth clears so quickly that one can’t rely upon negative results. This leaves us with two of the most common routes for significant intake: inhalation and via contaminated wounds.

It’s important for responders to be able to quickly gauge potential intakes that may have occurred in the field, both for the responders, themselves, as well as other people potentially affected. Magnitudes of inhalation intakes can be estimated by applying simple rules of thumb to sample results or direct measurements and comparing your answers to known limits – in the case of inhalation, the inhalation ALI.

A nasal swab is a quick and simple sampling method for suspected inhalation intakes. A nasal swab is obtained by lightly rubbing a cotton swab along the anterior nasal passages in order to collect the sample. A separate swab should be used for each nostril. The individual performing the swabs should take care not to go too deeply into the nose or to abrade the lining of the nasal cavity.

According to the Nuclear Emergency and Radiological Decision Handbook (Mansfield, 1997), intakes due to particle sizes in the 1-5 micron (μm) AMAD (activity median aerodynamic diameter) range can be estimated by assuming that the nasal swab results are about 5%-10%, respectively, of the intake. This is provided they are taken within the first hour since the nose clears itself relatively quickly. (1 μm is the particle size used in *Interpretation of Bioassay Measurements NUREG/CR-4884* which uses ICRP 26 and 30 modeling. Newer ICRP models use 5 μm as the default particle size.) Using the ICRP 66 model (ICRP 1994a) and its values for regional depositions of 5 μm AMAD particles, one finds the ratio of deposition between the external nasal passages and the other respiratory tract compartments is 1 to 4.1 (or about 25% deposition in the external nasal passages). This backs up the numbers found by Mansfield: If 25% is deposited in the external nasal passages, and a sample is taken from that area, some fraction of that 25% will be on the swab. Additionally, ICRP 66, reports nose-blow values ranging from 1% to 17% in 10 observed individuals.

Since we are interested in early dose magnitude estimation – again, not a definitive method for dose assignment – a workable rule-of-thumb is that nasal swab results (separate swabs for each nostril, summed) taken from the involved individual(s) represent approximately 10% of the potential intake, provided the swabs are taken early (~1 hr post-intake or earlier). Additionally – and importantly – it's easy to work with powers of ten, making this rule of thumb easily applied by people of different experience levels and backgrounds (responder vs. health physics, for instance). According to Yoon, et.al., wetting the swab has an effect on the collection efficiency.

Once the intake is determined, the committed internal doses can then be estimated. Annual Limits on Intake (ALIs) are regulatory limits on how much radioactive material can be taken into the body by radiation workers each working year. U.S. guidance regarding ALIs can be found in *EPA Federal Guidance Report No. 11, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. ALIs are are based on "whole body" doses (CEDE – committed effective dose equivalent – stochastic risk based) or doses to individual organs (CDE – committed dose equivalent – deterministic risk based), whichever is most restrictive. (The ALIs are listed in uCi or MBq. 1 uCi is 2.22×10^6 disintegrations per minute, or dpm, and 1 MBq is 27 uCi.)

Example:

Nasal swabs are taken from an individual that was in the vicinity of a release of an unknown radioactive material. However, it has been determined that the primary emission of concern is gamma radiation. The swabs are taken from the person 15 minutes after the release. Individual swabs are taken from each nostril. They are counted separately using a pancake GM detector, and the numbers from each swab are then added together for a total of 40,000 counts per minute (cpm). If we then assume a 10% detector efficiency 40,000 cpm will equal 400,000 dpm (1 cpm = 10 dpm). Using the above referenced rule of thumb, we can assume that about 10% of the intake was found on the swabs, so the intake was about 10 times the total swab activity resulting in a potential intake of around 4,000,000 dpm. Since we don't know what the radionuclide is, we use Table 4 (unknown gamma-emitter assumes Cs-137) and compare the

estimated intake activity to the inhalation ALI. In this case we have a magnitude estimate of 4,000,000 (4E6) dpm/440,000,000 (4.4E*) dpm, or about 1% of one ALI. This initially indicates that the intake isn't likely of immediate concern.

Table 5 provided ALI information for commonly encountered radioactive materials not listed in Table 4. A complete list of ALIs can be found in US EPA Federal Guidance Report No. 11.).

Note: *In vivo* and/or *in vitro* bioassays should be performed, and stricter internal dosimetry protocols should be followed to verify the intake.

One of the keys to proper assessment is to apply common sense to your investigation. Some things to consider are 1) Is the contamination bilateral? Most of us breathe through each nostril fairly uniformly. If elevated contamination levels are found in one nostril, but not the other, it may be because of cross contamination – check for a contaminated finger! Of course, it may be due to a deviated septum or other reasons. 2) Will the estimate need to be adjusted to take mouth breathing into account? 3) Was there significant facial contamination? It seems reasonable that in most cases where there's enough airborne contamination for a medically significant inhalation intake there would be the presence of facial contamination. However, keep in mind that when people sweat, they may decontaminate their faces. Contamination of the clothing near the breathing zone or neck may be an appropriate indicator. 4) Particle size will affect how far down the respiratory tract the material deposits and will likely be unknown at the time of an incident. 5) The ALI is an annual regulatory limit. An intake exceeding an ALI does not necessarily mean that the individual is at excessive risk, but that a regulatory limit will have been surpassed.

Obviously, there are other things to consider, but one needs to remember to maintain awareness of what would seem to make sense when assessing potential internal contamination for dose magnitude purposes. It's worth stating that the absence of positive results does not necessarily mean that an intake has not occurred, but that the presence of positive results may be used for dose magnitude assessment. Any time an intake is suspected, bioassays should be performed for verification purposes. This is especially true for alpha-emitting radioisotopes since alphas are 1) so easily shielded, and 2) the dose conversion factors of alpha emitters typically have a much higher dose-to-activity ratio than those radioisotopes that are primarily beta/gamma emitters.

Although still in regulatory use in the United States, the International Commission on Radiological Protection (ICRP) Publication 103: *The 2007 Recommendations of the ICRP* recommends that the ALI concept no longer be used and that doses should be calculated for each organ with consideration given to external doses, as well. However, ICRP 103 states on page 309 that the ALI concept can be useful in some practical situations such as characterizing relative hazards. By providing the basis for a quick and simple method for determining the magnitude of the potential dose, the ALI provides us with a comparison point that can be easily obtained and compared to the estimate of the intake, thus allowing early magnitude estimations to be made.

The ALI is likely familiar to health physicists and other people who routinely deal with occupational exposures to radioactive materials, but many radiation protection professionals may not be aware of the Clinical Decision Guides (CDGs) introduced in *NCRP Report No. 161, Management of Persons Contaminated with Radionuclides* (2009). The CDG can be used as an alternative to the ALI as a comparison point when assessing internal dose magnitude. It's intended to provide a measurement to be used to help guide medical decisions regarding recommendations of the use of medical countermeasures after an intake of radioactive materials. The CDG considers the stochastic (statistical) risk based on effective dose over 50 years for adults or until age 70 for children. The stochastic risks considered are in the range of risks associated with the dose recommendations for emergency responders found in the 2017 EPA PAG Manual (Protective Action Guides and Planning Guidance for Radiological Incidents). The avoidance of deterministic effects is also considered in the formulation of the CDG where appropriate.

The CDG for radioiodine is defined somewhat differently because the organ at primary risk is the thyroid gland. The Food and Drug Administration (FDA) has provided specific guidance for projected thyroid doses. CDGs are provided for inhalation in ingestion intakes. Obviously, nasal swab results should only be compared to inhalation CDGs. For a more detailed definition of the CDG and its associated dose parameters, NCRP-161 should be consulted. Table 6 provides an example of the information provided in the CDG tables found in Part C, Section 11 of NCRP Report No. 161.

Because of the time constraints associated with nasal swabs (need to be taken with the first hour), other tools need to be considered when the concern is monitoring/assessing larger groups of people. The number of people that one may find at a large public gathering like a football game that need to be screened for internal contamination may affect the ability to do timely nasal swabs for all who need it. It would be very difficult to perform nasal swabs on significant numbers of people within one hour. The Centers for Disease Control and Prevention (CDC) recognized this need and developed ICAT (Internal Contamination Assessment Tool - https://www.cdc.gov/nceh/radiation/emergencies/clinicians/evaluation/index.htm) which allows for the use of portable survey meters and portal monitors for initial screening and triage of internally contaminated people. This is useful because it allows for data to be gathered up to 30 days post-intake by using information from specified radiation detection instrumentation in combination with information from the affected individual (age, sex, weight, etc.).

Open wounds present another route of intake that needs to be considered. NCRP Report No. 156, Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for their Assessment, Dosimetry, and Treatment (2006) was consulted to calculate dose conversion factors for various radioisotopes and contaminant/wound types using the Activity and Internal Dose Estimates (AIDE, Bertelli) internal dosimetry software. Dividing the applicable regulatory dose limit by the corresponding dose conversion factor (DCF) results in what can be termed a derived reference level (DRL) – similar to an ALI. The ALI isn't defined for intakes of radioactive materials through contaminated wounds, but the DRL is similar in its philosophy (Toohey, 2011). *Note: This is referred to as a derived regulatory guide (DRG) in the*

Toohey reference, however, DRL is used to minimize potential confusion with regulatory applicability.

Because of their similar philosophies (regulatory limit divided by a dose conversion factor), DRLs (Table 7) can be used as a reference point in much the same way as the ALI is used above. To apply this concept simply obtain an early wound count, convert the count rate to an activity (dpm), and compare it to the appropriate DRL. Remember that just because the contamination levels may be higher than the DRL does not necessarily mean there's a significant issue, but that the contamination levels may result in an internal dose over to the regulatory limit if decontamination isn't performed.

As is usual with rapid field assessments common sense must be used. Confounding factors may include contamination of intact skin immediately surrounding the wound site, the fact that alpha particles being so easily shielded may not be readily detected due to blood or other bodily fluids, or an injection may have occurred at a depth (or of a size) that precludes the contamination from being readily measured by simple handheld instrumentation.

Following is an example of rapidly field assessing a contaminated wound:

An individual was using a reciprocating electrical saw in a contaminated environment. He sustained a wound to the arm when the broke after becoming stuck in the material he was cutting. A direct count of the wound with a pancake GM reveals a total count rate of 400,000 cpm. The radionuclide of concern is Cs-137. If we assume a 10% instrument efficiency the activity level is 4,000,000 (4E6) dpm (or about 2 µCi or 74 kBq). Consulting the table of DRLs (Table 7) one finds that approximately 200,000,000 (2E8) dpm in the wound would result in an expected committed effective dose equivalent (CEDE) of 5 rem. The contamination found in the wound is significantly below the most restrictive numbers found in Table 7 for Cs-137. Therefore, initial magnitude estimates indicate that medical intervention isn't immediately necessary.

Note: Bioassays that follow established laboratory and internal dosimetry protocols should be performed to verify the magnitude estimation and intake amount.

There's some data related to aerosolization of actinides (Am and Pu) that suggests nasal swabs are a poor indicator of dose when radioisotopes of those elements are involved (Klumpp, 2017). It bears repeating that the internal dose magnitude estimation methods discussed in this document are not intended to specifically quantify the radiation doses associated with potential intakes associated with inhalation or contaminated wounds, but to provide a tool the radiation protection professional may find useful to help guide the path forward. Other tools for initial dose assessment are also available such as those described by Geoffrey Korir and Andy Karam (Health Physics, 2018).

Table 4 – U.S. ALIs for Assumed Radionuclides

Emission	Assumed Nuclide	Inh. ALI (µCi)	dpm
alpha	Am-241	0.006 - W	1.3×10^4
beta	Sr-90	4 - Y	8.9×10^6
gamma	Cs-137	200 - D	4.4×10^8

Most restrictive ALI values in FGR-11 are listed (solubility class also listed).

Table 5 – U.S. ALIs for Specific Radionuclides

Nuclide	Inh. ALI (µCi)	dpm
H-3	80,000 (H_20 Vapor)	1.8×10^{11}
Co-60	30 - Y	6.7×10^7
U-235, 238	0.04 - Y	8.9×10^4
Pu-238	0.007 - W	1.6×10^4
Pu-239	0.006 - W	1.3×10^4
Cf-252	0.02 - W	4.4×10^4

Most restrictive ALI values in FGR-11 are listed (solubility class also listed).

Table 6 - Selected CDG Information from NCRP-161

Radioisotope	Method of Intake	Form	Activity in urine (0-24 hr) indicative of 1 CDG (dpm)	Activity on nasal swabs soon after inhalation indicative of 1 CDG (dpm)*
Co-60	Inhalation	Type M	4.2E+7	1.1E+8
Co-60	Inhalation	Type S	Not recommended	4.4E+7
Sr-90	Inhalation	Type F	3.4E+7	2.5E+7
Sr-90	Ingestion	Soluble	3.0E+7	NA
Cs-137	Inhalation	Type F	7.7E+7	1.7E+8
Cs-137	Ingestion	Soluble	7.6E+7	NA
Pu-239	Inhalation	Type M	9.6E+1	2.3E+4
Pu-239	Inhalation	Type S	3.8E0 (supplement with fecal)	8.9E+4
Am-241	Inhalation	Type M	1.0E+3	2.8E+4

* Assumes 5% of the intake is found on the swabs. Sampling time post-intake is only defined as “early hours”

Table 7 - Selected DRLs for Defined Solubility Class (dpm)

Isotope	Based on*	Weak	Moderate	Strong	Avid
Co-60	ED	1.54E+08	1.54E+08	1.65E+08	2.01E+08
Sr-90	BS	2.20E+07	2.20E+07	2.25E+07	2.38E+07
Tc-99m	ED	2.00E+11	2.56E+11	9.33E+11	8.78E+11
I-131	Thy	7.06E+07	8.01E+07	1.26E+08	3.46E+08
Cs-137	ED	2.20E+08	2.20E+08	2.23E+08	2.34E+08
Ir-192	ED	4.49E+08	4.66E+08	6.21E+08	1.69E+09
U-235	BS	8.23E+05	8.23E+05	8.29E+05	8.46E+05
U-238	BS	8.55E+05	8.55E+05	8.63E+05	8.78E+05
Pu-239	BS	1.81E+03	1.81E+03	1.85E+03	1.92E+03
Am-241	BS	1.65E+03	1.65E+03	1.68E+03	1.74E+03
Cf-252	BS	5.14E+03	5.15E+03	5.75E+03	7.96E+03

* ED = Effective Dose, BS = Bone Surface, Thy = Thyroid
ED reference point = 5 rem (committed)
Organ dose reference point = 50 rem (committed)

Useful References for Early Internal Dose Estimation

Centers for Disease Control and Prevention – Radiation Studies Branch: Radiation and Your Health | Radiation | NCEH | CDC

Klumpp, J; Bertelli, L; Waters, J. *Interpretation of Nasal Swab Measurements Following Suspected Releases of Actinide Aerosols*. Health Physics, 112.5 (May, 2017)

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S. Sugarman. *Early Internal and External Dose Magnitude Estimation*. REAC/TS. 2008, last updated 2017 (internet-based document).

Sugarman, S; Toohey, R; Goans, R; Christensen, D; Wiley, A. *Rapid Internal Dose Magnitude Estimation in Emergency Situations Using Annual Limits on Intake (ALI) Comparisons.* Health Physics, 96.6 (June, 2010): 815-818.

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Toohey, R; Bertelli, L; Sugarman, S; Wiley, A; Christensen, D. Dose *Coefficients for Intakes of Radionuclides Via Contaminated Wounds*. Health Physics, 100.5 (May, 2011): 508-514.

Yoon, S; Ha, W; Park, S; Lee, S; Jin, Y. *Rapid Analysis of ^{239,238}Pu, ^{241}Am, and ^{90}Sr for Nasal Smear Samples in Radiation Emergency and Evaluation of Intake Retention Fraction*. Health Physics, 112.5 (May, 2017).

The information provided throughout the text pertaining to the various NCRP, ICRP, CDC, and EPA documents used as references should provide sufficient information to access those documents for verification and/or further research into the topic.

The tools/methods described in *Initial Dose Magnitude Estimation for Individuals Involved in a Radiological Incident/Accident* are in no way intended to take the place of established/validated internal dose assessment (urinalysis, whole body counting, etc.) or external dose assessment (selection of proper dosimetry, in-depth reconstructions, etc.) techniques, nor are they to be used for regulatory and/or occupational dose assignment. Each situation should be evaluated for the applicability of the described tools with an understanding of the strengths and weaknesses that are inherent in each of them.

Note: *Initial Dose Magnitude Estimation for Individuals Involved in a Radiological Incident/Accident* updates *Early Internal and External Dose Magnitude Estimation*, an internet-based document funded by the US Department of Energy and originally authored by Steve Sugarman in August, 2008 (last updated in July, 2017) that was previously posted on the website of the Radiation Emergency Assistance Center and Training Site, a response asset of the US Department of Energy.