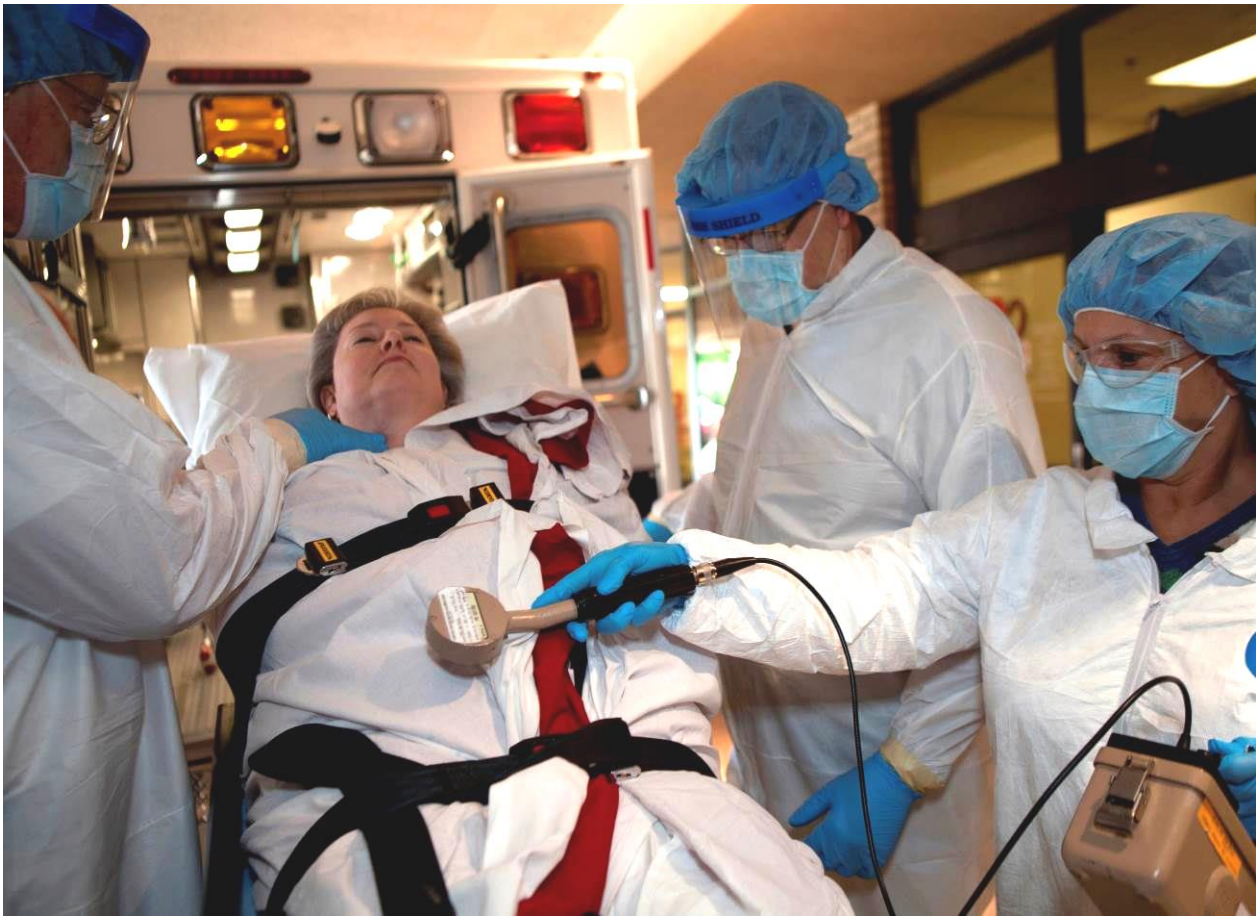
Early Internal and External Dose Magnitude Estimation



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Internal Dose Magnitude Estimation
Using Annual Limit on Intake (ALI)/Clinical Decision Guide (CDG) Comparisons and Derived Reference Levels (DRLs)

Assessing the radiological condition of injured personnel is an important part of the health physicist's job, although hopefully, one that is not done very often. 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. Also, one should not forget that in many cases medical care providers may not be accustomed to working with radioactive materials. Therefore, they may need attention from the health physicist not only for advice and assistance with radioactive material controls, but for reassurance.

When a person has sustained an injury, there is one over-riding 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. 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 is a suggested general lack of knowledge within the medical community about ionizing radiation and its effects, so it is essential to integrate the health physicist into the radiation emergency medical response team. Establishing a good working relationship between health care providers and health physics personnel in advance of an incident will help the response go much more smoothly and efficiently.

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. There is quite a bit of published guidance regarding how to treat, 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.

Just as 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 victim at the time of the accident? What was he/she doing? Aside from contamination issues, should exposure be a concern (to the victim and/or care providers)? What radioisotopes were involved? What type of protective clothing or respiratory protection was used? Where are the areas of contamination – wounds? Intact skin? Face?

The key to early medical management of internalized radioactive materials is not 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, such as many of those in the actinide series (^{241}Am, the plutonium isotopes, etc.), it is especially important to be able to make early assessments of potential intakes so that the decision whether or not to administer appropriate medical countermeasures can promptly be made. For instance, DTPA is most effective when given within a few hours of the occurrence of the intake; therefore a delay in treatment may lead to less dose aversion.

Radiation doses due to internally deposited radionuclides 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). Once the intake is determined, the CEDE and/or CDE can then be calculated. 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*. There, ALIs are provided for both inhalation and ingestion intakes and 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 x 10^6 disintegrations per minute, or dpm, and 1 MBq is 27 uCi.)

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 this case the ALI for the radioisotope of concern, for a projection of dose magnitude. For suspected inhalation intakes, the nasal swab is a quick and simple sampling method. A cotton swab is lightly rubbed along the anterior nasal passages in order to collect the sample. A separate swab should be used for each naris. 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 Mansfield (1997), intakes due to particle sizes in the 1 to 5 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. (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 anterior nares). Additionally, ICRP 66, reports nose-blow values ranging from 1% to 17% in 10 observed individuals.

Since we are interested in dose magnitude estimation to be used as an early triage tool, a workable rule-of-thumb is that nasal swab results (separate swabs for each naris, 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 is easy to work with powers of ten, making this rule of thumb easily applied by people of different experience levels and backgrounds (medical vs. health physics, for instance).

Example:

> Nasal swabs are taken on an individual that was in the vicinity of a small explosion that occurred in a laboratory fume hood. The swabs are taken from the individual 15 minutes after the explosion. It has been determined that the contamination is from an unknown beta-emitting radionuclide. Individual swabs are taken from each naris. They are counted separately using a pancake GM detector, and the numbers from each swab are then added together for a total of 10,000 counts per minute (cpm). If we then assume a 10% detector efficiency 10,000 cpm will equal 100,000 dpm (1 cpm = 10 dpm). Using the above referenced rule of thumb we know that about 10% of the intake was found on the swabs, so the intake was about 10 times the total swab activity resulting in an intake of 1,000,000 dpm. Since we don't know what the radionuclide is, we use Table 1 (unknown beta-emitter assumes Sr-90) and compare the estimated intake activity to the inhalation ALI. In this case we have 1,000,000 dpm/8,900,000 dpm, or about 11% of one ALI, call it 0.1 ALI. This indicates that the intake isn't likely of immediate medical concern.
>
> > Note: Bioassays should be performed, and stricter internal dosimetry protocols should be followed to verify the magnitude estimation and intake amount.
>
> If the radionuclide is known, we may use Table 2 (A complete list of ALIs can be found in US EPA Federal Guidance Report No. 11.).

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 naris, 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 is 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 the deposition depth 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 reach the level of acute medical concern. Obviously, there are other things to consider, but, one needs to remember to maintain awareness of what would seem to make sense when assessing contamination for the potential of medically significant internal doses. It is 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 can be used for dose magnitude assessment. Any time an intake is suspected bioassays should be performed for verification purposes.

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. It is worth noting that the ALIs currently used in the United States differ from those in many other parts of the world because of the use of different biokinetic models, tissue weighting

factors, radiation dose limits, and other reasons. Since in this case the ALI is used solely as a reference point based on an "acceptable risk" for radiation workers, it is not as important which set of ALIs (U.S. or international) one uses, but that one understands upon what their benchmark is based. 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 medical treatment decisions to be made in a timely fashion.

The ALI is likely familiar to health physicists and other personnel who routinely deal with occupational exposures, 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 is intended to provide a measurement a physician can use to help guide his/her decision regarding recommendations of the use of medical countermeasures after an intake of radioactive materials. The CDG considers the stochastic 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 EPA PAG Manual (Protective Action Guides and Planning Guidance for Radiological Incidents). The avoidance of deterministic effects based on 30-day RBE-weighted marrow and lung doses is also considered in the formulation of the CDG for a specific radioisotope. The CDG for radioiodine is defined somewhat differently because the organ at primary risk is the thyroid gland, and the 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 4 provides an example of the information provided in the CDG tables found in Part C, Section 11 of NCRP Report No. 161.

The Centers for Disease Control and Prevention (CDC) has developed tables relating an external measurement at a time post-intake at a specified distance to an estimate of the radiation dose associated with an inhalation or ingestion intake. It is intended for initial screening/triage and has information tabulated for the use of several common portable radiation detectors. In an effort to make this tool as simple as possible, the information is presented in counts per minute (cpm) – meaning the user does not have to take instrument efficiency into account – as it relates to effective doses of 50, 250, and 500 mSv (5, 25, and 50 rem, respectively). Along with other useful information, these tables (as well as a detailed explanation of their proper use) can be found at the website of the Radiation Studies Branch of the CDC.

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, which is not defined for wounds (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*.

DRLs (Table 3, below) 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 are higher than the DRL does not necessarily mean there is a significant medical issue, but simply that the contamination levels may result in an internal dose close to the regulatory limit.

Please note that Table 3 is based upon US dose limits, but the dose conversion factors were based on effective dose (international guidance). This should not affect the use of this table for dose magnitude estimation. Remember that the point is to determine a point with which comparisons can be made. These comparisons can then be used to help guide medical decisions. International guidance will use different dose limits resulting in different DRLs (20 mSv – or 2 rem – divided by the appropriate DCF). Refer to NCRP No. 156 or contact REAC/TS for further guidance.

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 disk grinder to grind welds on contaminated waste containers. He sustained a wound to the thigh when the weld seam was weakened allowing the lid to rapidly break free, bouncing the grinder against his leg. After ensuring he was medically stable, a direct count of the wound with a pancake GM reveals a total count rate of 200,000 cpm. The radionuclide of concern is Cs-137. If we assume a 10% instrument efficiency the activity level is 2,000,000 dpm (or about 1 μCi or 37 kBq). Consulting the table of DRLs above 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. Therefore, initial magnitude estimates indicate that medical intervention is not immediately necessary.
>
> > Note: Bioassays should be performed, and stricter internal dosimetry protocols should be followed to verify the magnitude estimation and intake amount.
>
> If the radionuclide is unknown, based on the emission we may use Table 1 (A complete list of ALIs can be found in US EPA Federal Guidance Report No. 11.).

It bears repeating that these methods are not intended to specifically quantify the radiation doses associated with potential intakes due to inhalation or contaminated wounds, but to provide a tool the health physicist or physician can use to help guide initial medical management. Doses should be confirmed with proper dosimetry methods (urinalysis, whole body counting, etc.).

Table 1 – 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 2 – 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 3 - 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)

Table 4 - 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"

Information for Internal Dose Magnitude Estimation Using Annual Limit on Intake (ALI)/Clinical Decision Guide (CDG) Comparisons and Derived Reference Levels (DRLs) was taken from the following sources that may not be specifically mentioned in the text:

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.

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.

Sugarman, S; Goans, R; Garrett, S; Livingston, G. *The Medical Aspects of Radiation Incidents*. REAC/TS (2010). http://orise.orau.gov/reacts/resources/radiation-accident-management.aspx

Mansfield, G. *Nuclear Emergency and Radiological Decision Handbook* (Draft). Lawrence Livermore National Laboratory (May, 1997).

The information provided in 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.

Early External Dose Estimation

Early medical care to an irradiated patient is oftentimes greatly influenced by the initial dose estimates. It is, therefore, important to be able to quickly and accurately determine the magnitude of the radiation dose. This, however, is not always an easy task. There are many variables 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 is oftentimes much more difficult to be able to pinpoint the distance the affected area was from the source or the time of exposure. Due to distance vs. dose rate relationships and the extremely high dose rates often encountered, these 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 useful rules of thumb for estimating gamma radiation doses include:

Line source: The dose rate falls off proportionally with the distance (1/R where R = distance).
Disk/cylindrical source: The dose rate falls off somewhere between 1/R and $1/R^2$.

More accurate equations 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:

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

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 is 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 .

$$\textit{Equation 3:}\quad D = SAt$$

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)

Early dose estimations should always be compared to physical dosimetry, if available, and to the onset of medical signs/symptoms (or lack thereof). In many cases, the true dose will be elusive and medical management will require ongoing teamwork between medical care personnel and health physics personnel in order to provide the proper response to the situation. Oftentimes, the best that one can hope for is determination of the magnitude of the radiation dose. Keep in mind that observable injuries/illnesses due to acute radiation exposure are related to threshold doses and usually take time to fully develop. If 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 health physicist must also be mindful of potential pitfalls associated with dose estimation in accident situations in order to provide good support to the medical staff. 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

Nuclide	Gamma Constant (mSv-cm^2/ hr-MBq)	*Dose to first 0.07mm*			*Dose to first 1mm*			Dose rate at 1cm tissue depth (mSv/h)	Dose rate at 3cm tissue depth (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 Photon Only (mSv/h)	Dose Rate due to secondary electron buildup in encapsulation (mSv/h)	Dose Rate Total (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 *Improved Contact Dose Rate Conversion Factors and Secondary Electron Correction Factors for Encapsulated Gamma Sources*: Presented by Ed Waller on 07/12/17 - Raleigh, NC - Health Physics Society Annual Meeting - Session WAM-A.10 (Primary Author: Eric Heritage, University of Ontario Institute of Technology)
- 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

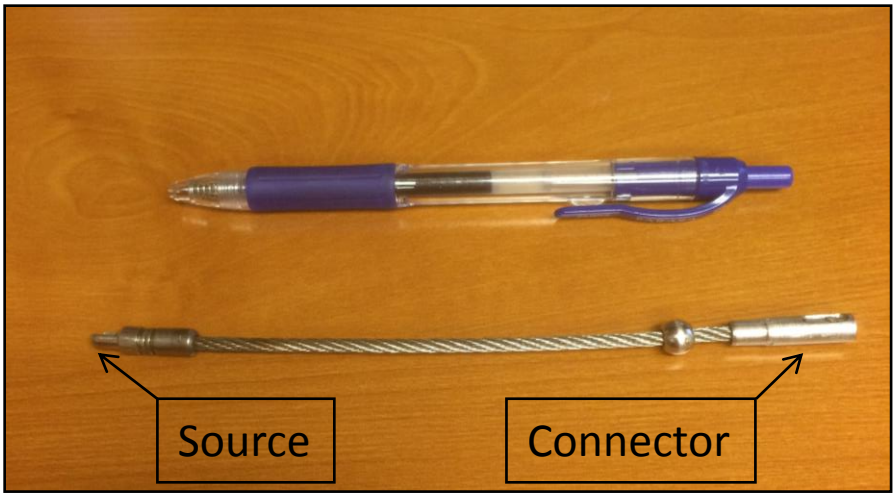
* At higher doses the time to onset of signs/symptoms may be compressed.

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:

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

(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:

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

(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 is likely that there is an error in estimated time of exposure or in the distance estimate. Healthcare personnel should "treat the patient, not the dose." It is 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)

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