Point Source Approximations in Health Physics

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Abstract

Point source approximations are often used to represent physical situations in a variety of health physics areas. However, these approximations must be applied in a judicious manner that considers both the source configuration and distance from that source. An extended source may be represented by a point source with an accuracy of about 1% whenever the distance from the source reaches about three times the maximum source dimension.

Keywords

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Introduction

Health physics students, including individuals preparing for both Parts I and II of the American Board of Health Physics (ABHP) Certification Examination, often are uncertain when to apply the point source approximation when solving problems in a variety of health physics areas. This uncertainty results from a number of factors, including the structure of introductory textbooks [1-3] and a student's natural tendency to simplify a problem in order to facilitate its solution.

Point source approximations are often utilized in health physics applications. For example, the radiation emitted from an accelerator target, a criticality event, activated fragments, hot particles, or an x-ray tube are commonly represented by a point source. However, a number of students preparing for the ABHP Certification Examination do not clearly understand when this approximation is applicable. Some students tend to focus on adopting a specific paradigm (e.g., an accelerator target can be represented as a point source), and do not consider the point source approximation as a general principle or consider the accuracy of this approximation. In this article, the applicability and accuracy of point source approximations will be reviewed.

Theory

Although we illustrate the applicability of the point source approximation by considering a source that emits photons, the conclusions are applicable to other radiation types. For a point photon source of isotope i, the exposure rate ($\dot{X}_i$) may be written in terms of the source activity (A_i), the distance from the source (r), and a gamma constant (Γ_i) for the i-th radionuclide comprising the source:

$$\dot{X}_i = \frac{A_i \Gamma_i}{r^2} \qquad \text{(Eq. 1)}$$

One of the most common questions that a student asks is, "When is a point source applicable?" This question is typically asked when extended source geometries, such as the line source and thin disk source, are introduced. The question that *should* be asked is: "Given a desired accuracy, at what distance will an extended source be represented by a point source?"

In order to answer this question, we consider line and thin-disk sources as examples of extended sources. Examples of line sources in health physics applications include: a pipe carrying a radioactive fluid, an activated rod, a resin column, and an irradiated fuel pin. Thin disks may be used to represent a variety of configurations, including a spill of a radioactive liquid and activity deposited on a surface. Specific examples of recent ABHP Part II Examination questions requiring the student to exercise judgment regarding the applicability of the point source approximation are contained in Reference 4.

Line Source

The exposure rate ($\dot{X}_i$) from a line source composed of a photon-emitting isotope i is given by:

$$\dot{X}_i = \frac{C^i{}_l \Gamma_i \Theta}{w} \qquad \text{(Eq. 2)}$$

where

$C^i{}_l$ = concentration of activity per unit length or the total source activity of isotope i divided by the length of the line source (L);

Θ = included angle or the angle the point of interest makes with the ends of the line source. The angle must be expressed in radians; and

w = perpendicular distance from the point of interest to the line source.

Disk Source

The exposure rate ($\dot{X}_i$) on the axis of a thin-disk source composed of a photon-emitting isotope i is given by:

$$\dot{X}_i = \pi \; C^i{}_a \Gamma_i \ln \frac{r^2 + h^2}{h^2} \qquad \text{(Eq. 3)}$$

where

$C^i{}_a$ = activity concentration per unit area or the total activity of isotope i divided by the area of the disk source;

r = radius of the disk source; and

h = distance above the source (on axis).

In applying these equations, a number of assumptions are made. For the purpose of this article, the assumptions outlined in Table 1 are required. These assumptions will facilitate the comparison of point, line, and disk sources.

***Table 1.** Assumptions Associated with the Application of Various Source Geometries*	
Source Geometry	**Assumptions**
Point	1. No attenuation within the source 2. No attenuation by intervening media (e.g., air)
Line	1. No attenuation within the source (e.g., fluid containing the radioactive material in a pipe) 2. No attenuation by intervening media (e.g., pipe wall and air) 3. Uniform distribution of activity or constant activity per unit length within the source.
Disk	1. No attenuation within the source (e.g., fluid containing the radioactive material in a spill) 2. No attenuation by intervening media (e.g., air) 3. Uniform distribution of activity or constant activity per unit area within the source.

Results

In order to compare the point, line, and disk sources, it is necessary to define specific attributes of these sources. These attributes are identified in terms of a specific configuration as follows:

1. The source is ^{60}Co and is defined by a gamma constant of 1.3 $\frac{R-m^2}{h-Ci}$. Reference 5 provides a discussion of the accuracy of the gamma constant for external dosimetry applications.
2. The maximum source dimension (e.g., length of the line source and diameter of the disk source) is 20 m.
3. The source activity is 1000 Ci and it is uniformly distributed over the assumed geometry.
4. The point of interest resides on the axis of the disk.
5. The perpendicular distance w from the line source to the point of interest bisects the line source (e.g., $\tan(\Theta/2) = \frac{L}{2w}$).

Using Equations 1 – 3 and the attributes noted above leads to the results shown in Table 2. Table 2 compares the exposure rates calculated for three specific source geometries (i.e., point, line, and disk) each containing 1000 Ci of ^{60}Co.

Table 2 indicates that a point source is not a credible approximation near an extended source, but the approximation improves as the point of interest moves away from the extended source. Significant errors are encountered near the source. When the distance from the source reaches a value equal to the maximum source dimension (20 m), errors of about 8% and 12% result for a line and disk source, respectively. At two times the maximum source dimensions, the errors

Table 2. Exposure Rates from Point, Line, and Disk Sources [a,b]					
	Exposure Rate (R/h)			**Error (%)**	
Distance from the source (m)	**Point**	**Line**	**Disk**	**Line**[c]	**Disk**[d]
0.5	5,200.000	395.418	77.921	1,215	6,573
1	1,300.000	191.247	59.997	580	2,067
2.5	208.000	68.943	36.832	202	465
5	52.000	28.786	20.923	81	149
10	13.000	10.210	9.011	27	44
15	5.778	5.096	4.780	13	21
20	3.250	3.014	2.901	8	12
25	2.080	1.979	1.929	5	8
30	1.444	1.394	1.370	4	5
40	0.813	0.796	0.788	2	3
50	0.520	0.513	0.510	1	2
60	0.361	0.358	0.356	< 1	1
70	0.265	0.264	0.263	< 1	< 1
80	0.203	0.202	0.202	< 1	< 1
90	0.160	0.160	0.160	< 1	< 1
100	0.130	0.130	0.129	< 1	< 1

[a] Each source contains 1000 Ci of ^{60}Co. The line source has a length of 20 m, and the disk source has a diameter of 20 m.

[b] The number of significant figures illustrates the numerical results and not the inherent accuracy of the input parameters (i.e., the gamma constant).

[c] $$Error = \left[1 - \frac{\dot{X}_{point}}{\dot{X}_{line}} \right] x100\%$$

[d] $$Error = \left[1 - \frac{\dot{X}_{point}}{\dot{X}_{disk}} \right] x100\%$$

decrease to about 2% and 3% for a line and disk source, respectively. The line and disk sources only differ by about 1% from the point source approximation when the distance from the source reaches three times the maximum source dimension.

Table 2 also suggests that the question regarding the applicability of point source approximations must also consider the result's accuracy. Errors can be significant near the source and differences smaller than 50% require that the point of interest lie beyond a distance equal to approximately half the maximum source dimension.

Conclusions

The point source approximation can be a useful tool to represent physical situations. However, point source approximations must be applied in a judicious fashion that considers both the source configuration and distance from that source. A point source is a credible representation of an extended source and provides an accuracy of about 1% whenever the distance from the extended source reaches about three times the maximum source dimension.

References

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