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IODINE 125 AS A RADIATION SOURCE WITH SPECIAL EMPHASIS ON ITS APPLICATIONS IN MEDICAL RADIOLOGY

I. Theoretical considerations

by

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Radioactive nuclides have been used for many years as radiation sources in equipment for industrial purposes. Attempts have also been made to use roentgen and gamma radiations from various nuclides in medical roentgenography. Among the disadvantages of some of the radioactive nuclides, used for roentgen diagnostics in the medical field, have been the presence of gamma-rays of undesirably high energy and hard beta radiation, in addition to the electromagnetic radiation of suitable energy. The high energy radiation requires heavy shielding and results in lower film contrast. The beta radiation requires a primary filter. Another disadvantage in medical roentgenography has been the difficulty of obtaining a radiation source of sufficiently small dimensions. Because of these and certain other disadvantages, the roentgen units constructed have not been widely used.

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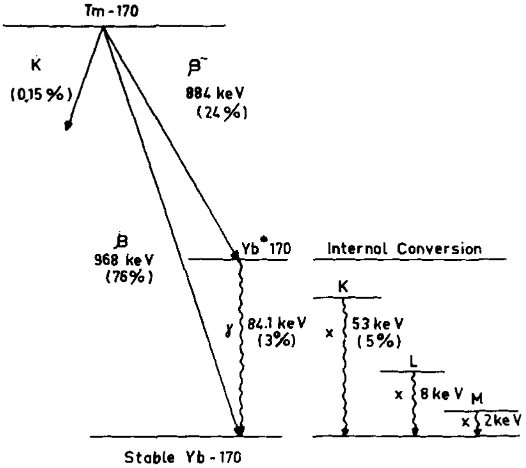

Fig. 1. The disintegration scheme of ^{170}Tm (from STEIGER & WESTERMARK 1957).

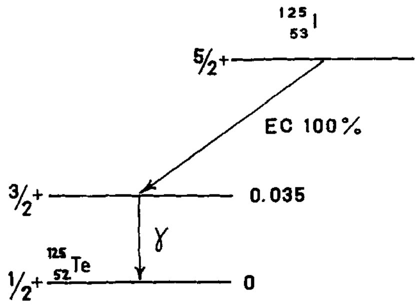

Fig. 2. The disintegration scheme of ^{125}I (from KUNZ & SCHINTLMEISTER 1958).

The studies reported in this paper deal with the theoretical background of ^{125}I as a roentgen source, and represent continuation of earlier investigations on ^{125}I (BERONIUS et coll. 1962, and HENRIKSON et coll. 1962).

The gamma radiations from some radioactive nuclides, e. g. ^{60}Co, ^{192}Ir, ^{144}Ce, and ^{170}Tm, ranging in energy between 1.33 MeV (million electron volts) and 53 keV (kilo electron volts), have, as mentioned, been used as radiation sources for industrial radiography (BROWNELL 1961). However, of the nuclides used for industrial applications, only those that seem to have influenced the field of medical roentgenography will now be mentioned.

SPANGENBERG (1948) produced a roentgenogram of three teeth by means of radiocesium, ^{131}Cs. The radiation source was placed inside the oral cavity. No information was given concerning the size or activity of the source, nor of exposure times. MAYNEORD (1952) suggested the use of a radioactive source placed inside the body in order to obtain a clearer view of structures which become superimposed when conventional roentgenographic techniques are used. He discussed the possible application of radiothulium, ^{170}Tm, in medicine and produced roentgenograms of a dried skull by means of this nuclide. The radiation source was about 3 mm in diameter. Though certain localized areas of a living subject could be radiographed with an exposure time of only 5 minutes, at a source-film distance of 6 cm, the exposure times for other areas were often long, i. e. 10 to 11 hours, at 12 cm. Screens, under the same conditions, reduced these exposure times to one hour. WEST (1953) demonstrated the possibility of using ^{170}Tm for the non-destructive inspection of light alloys and other materials within the thickness range of about 1 to 10 g/cm^2. He also used radioactive americium, ^{241}Am, for producing a roentgenogram of a femur.

Spangenberg & Pool (1953) published a roentgenogram, obtained with ^{131}Cs as the source, of the lower jaw of a dried skull. They concluded that the low intensities of roentgen rays did not permit clinical use of this material at that time and they continued: 'It is a distinct probability, however, that further investigation will lead to the discovery of other radioactive X-ray emitters which will produce an X-ray beam of sufficient intensity and of proper wave length and one which will have a long enough half-life to make possible its clinical use as a source of X-ray radiations'.

Untermyer (1954) described a portable roentgen unit for ^{170}Tm. It weighed 3.1 kg and the dimensions were 4.5″ × 2″ (114 × 51 mm). In spite of the heavy shieldings, the dose rate at the surface of the unit was about 75 mr/hr. Hasterlik (1954) by means of this unit produced roentgenograms of a hand, an ankle, and three teeth from a skeleton. Dennis & DeLuca (1954) used ^{170}Tm (5 C) and ^{144}Ce (15 C) for roentgenography of the hands and elbows of cadavers and living subjects. The source-film distances were between 21 and 22 inches (53 and 56 cm) and the exposure times with no-screen film were 0.5 hours or longer. Burke (1956) demonstrated a technique for the localization of renal calculi during surgical operations by means of a new ^{170}Tm unit. Steiger & Westermark (1957) studied in some detail the radiation of ^{170}Tm (Fig. 1) and its absorption properties and discussed the possibilities of using the gamma and roentgen rays of ^{170}Tm for industrial thickness measurements of various materials.

Spangenberg & Pool (1958) studied the possibilities of producing roentgenograms with ^{144}Ce, ^{155}Eu, ^{145}Sm, ^{137}La, ^{157}Dy, ^{159}Dy, ^{169}Yb, ^{153}Gd, ^{193}Pt, ^{199}Au, and ^{175}W.

Kellershohn (1963) investigated the applications of ^{197}Hg.

As a radiation source in roentgen diagnostics, ^{125}I was introduced by Beronius et coll. (1962), and Myers (1962), and for forensic roentgenography by Henrikson et coll. (1962).

The use of beta emitters in combination with absorber material to produce roentgen radiation (Bremsstrahlung) suitable for medical and industrial roentgenography has been suggested by Lidén & Starfelt (1953), Kereiakes & Krebs (1954 and 1955), Kereiakes & Kraft (1956), and others.

Most investigators have used ^{170}Tm in medical roentgenography. About 76 % of the ^{170}Tm nuclei disintegrate through 968 keV betas to the ground state of ytterbium 170; the smaller fraction, 24 %, disintegrates via 884 keV

Table 1

Calculated approximate disintegration table of ^{125}I

Main processes Data utilized for the calculations	Number of vacancies (in ^{125}Te) per 100 disintegrating nuclei		Intensity (number of emissions per 100 disintegrating nuclei)	Energy (or energy limits of resp. radiation group) keV	Type of radiation
	K-shell	L-shell			
Electron capture (EC):					
$EC_L/EC_K = 0.23 \pm 0.03$, neglecting EC_M,	81	19			
Isomeric transition (IT):					
Internal conversion (IC)					
$\alpha_K = 11.7$; $\alpha_K/\alpha_L = 7.3$,					
assuming $\alpha_L/\alpha_M = 3$					
unconverted gammas:					
$1/(\Sigma\alpha + 1) \cdot 100$			7	35	γ
$IC_K : \alpha_K/(\Sigma\alpha + 1) \cdot 100$	79		79	3	e_{IC}
IC_L:		11	11	30	e_{IC}
IC_M:			3	34	e_{IC}
L vacancies induced by K vacancies		150			
Total vacancies in K and L	160	180			
Fluorescence:					
K fluorescence total			139		
K_α roentgen rays			106—139	27.20—27.47	X_K
K_β » »			33—0	30.99—31.70	X_K
L » » total			24	3.76—4.57	X_L
Other roentgen-rays				< 1.0	X
Auger electrons:					
From K vacancies			22	21.9—31.8	e_A
From L vacancies			155	2.3—4.9	e_A
From other vacancies				< 1.0	e_A

betas to an excited state of ytterbium 170. The excitation energy, 84.1 keV, is partly dissipated as gamma radiation, and partly by internal conversion, IC. The latter process results in the emission of characteristic roentgen radiation, mainly with an energy of 53 keV, but also with low intensity rays of 8 and 2 keV. The two beta rays produce Bremsstrahlung from any material surrounding the thulium nuclei. The disintegration scheme of ^{170}Tm, as it was presented by STEIGER & WESTERMARK (1957), is shown in Fig. 1.

Another nuclide, ^{144}Ce, which has been suggested as a radiation source by

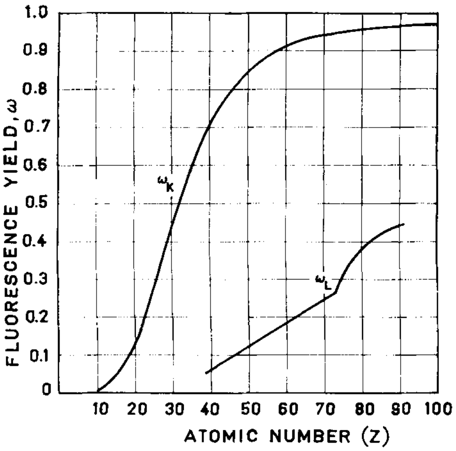

Fig. 3. Fluorescence yield versus atomic number (from SLACK & WAY 1959).

some authors, emits electromagnetic radiation having energies of approximately 33, 54, 80, and 134 keV. The contrast of films obtained with radiation from ^{144}Ce was considerably less than that obtained with radiation from a conventional dental roentgen machine (SPANGENBERG & POOL 1958).

Physical properties of iodine 125

The decay scheme of ^{125}I, presented in Fig. 2, has been taken from the nuclear data compilation of KUNZ & SCHINTLMEISTER (1958). The half-life is 60.0 ± 0.5 days, and the nuclide decays to 100 % by electron capture (EC) to excited ^{125}Te, followed by an isomeric transition (IT) of 35 keV to the stable ground level; about 93 % of this transition is however internally converted. The intensities and energies of the various radiations of ^{125}I have been calculated and are tabulated in Table 1.

The energies of the roentgen rays were taken from FINE & HENDEE (1955), and the Auger electron energies have been calculated from the electron binding energies of tellurium as given in the nuclear data tables of STROMINGER et coll. (1958). The intensities of the various radiations of ^{125}I, as calculated in Table 1, have been based on the conversion coefficients and EC ratios given in the two nuclear data compilations mentioned, and on the fluorescence yield given by SLACK & WAY (1959) (see Fig. 3; cf. MYERS & VANDERLEEDEN 1960).

As regards roentgen diagnostics, the most important radiation emitted during the decay of ^{125}I is the intense roentgen rays of about 27.4 keV. Due to low intensities and/or low energies, the unconverted gamma rays, the L, M and N roentgen rays, as well as the conversion and Auger electrons, are all of minor importance. These roentgen rays and electrons can easily be absorbed without any appreciable attenuation of the K-roentgen rays. The gamma rays have an intensity of about 5 % of the intensity of the K-roentgen rays, and an energy of only 8 keV more than the K-roentgen energy. The presence of the gamma rays therefore produces no complications in most roentgenologic applications. In cases of high absorption, however, the transmitted gamma rays may be more intense than the roentgen rays because the higher energy is usually less attenuated.

Strength of radioactive radiation sources

For many applications of radioactive sources, especially in medical radiology, there is a need for high intensity from a source of small dimensions in order to enable the combination of short exposure times and high resolution in the films. The intensity obtainable from a source of given cross-section is however limited by the physical properties of the radiation and of the elements constituting the source. These principal limitations are generally not mentioned in current literature on radiation sources, wherefore a short presentation may be of value to readers who are not familiar with such calculations.

For purposes where isotropic intensity and a large solid angle are required, a spherically-shaped source appears to offer the best choice, but when the only requirement is a narrow beam, a cylindrical source would seem to be just as satisfactory. As the latter design involves simpler mathematical formulas and constitutes an integral part in the calculations for a spherical source, it will be dealt with first.

I. Cylindrical radiation source

Let the radioactive nuclide be characterized by the following parameters:

$T_{\frac{1}{2}}$	half-life in sec
$\eta_{q\mathrm{E}}$	yield of radiation = number of emitted quanta per nuclear disintegration
f_{a}	specific activity expressed as the fraction of radioactive nuclides of the element in question

Further:

$\mathcal{N}_{\mathrm{A}}$	Avogadro number ($6.02 \cdot 10^{23}$)
ϱ	density of the source matter in g cm^{-3}
l	length of the source cylinder in cm
r_{c}	radius (in the case of a circular cylinder) in cm
n_{Z}	average number of atoms of element number Z per atom of the active element in the source

A_Z atomic weight of element number Z
μ_Z linear absorption coefficient of element Z in cm^{-1} for the energy in question
ϱ_Z density of element number Z

The resulting linear absorption coefficient, μ, of the source matter for radiation of the energy considered, can then be calculated as

$$\mu = \varrho \cdot \frac{\Sigma n_Z \mu_Z \varrho_Z^{-1} A_Z}{\Sigma n_Z A_Z} \tag{1}$$

where the summations are to be performed over all elements of the source. In the case where radioiodine has been deposited as $_{47}\mathrm{Ag}_{53}\mathrm{I}$, there is only one atom of silver ($Z = 47$) per atom of iodine ($Z = 53$), i. e. $n_{47} = 1$ and $n_{53} = 1$.

The atomic weights are $A_{47} = 107.9$, and $A_{53} = 126.9$, the densities are $\varrho = 5.67$, $\varrho_{47} = 10.5$, $\varrho_{53} = 4.93$, and the resulting linear absorption coefficient of silver iodide is

$$\mu = 5.67 \cdot \frac{\mu_{47} \cdot 10.5^{-1} \cdot 107.9 + \mu_{53} \cdot 4.93^{-1} \cdot 126.9}{107.9 + 126.9} = 0.248\mu_{47} + 0.62\mu_{53}$$

The intensity of the radiation in the direction of the axis of the cylinder can then be expressed as

$$I = \frac{\pi r_c^2 l \cdot \varrho \cdot N_A f_a \cdot \ln 2}{\Sigma(n_Z A_Z) \cdot 4\pi \cdot T_{\frac{1}{2}}} \cdot \eta_E \cdot Y_{c,a} \text{ quanta sec}^{-1} \text{ steradian}^{-1} \tag{2}$$

$Y_{c,a}$ is a factor for the average self-absorption correction which approaches unity for very thin sources (small l-values).

For a layer of infinitesimal thickness dx at the depth x, the transmission to the surface in the perpendicular direction, or the differential yield, is

$$Y_x = e^{-\mu x} \tag{3a}$$

The transmission from the bottom layer

$$Y_{c,m} = e^{-\mu l} \tag{3b}$$

is defined as the marginal yield.

Integration from the surface to the depth l over all differential yields gives the average yield for a source of length l.

$$Y_{c,a} = \frac{1 - e^{-\mu l}}{\mu l} \tag{4}$$

Both the percentage marginal and average yields from a cylindrical source are plotted against the source length in units of $1/\mu$ (and of $L_{\frac{1}{2}}$, the half-absorption thickness) in Fig. 4.

II. Spherical radiation source

For cylindrical sources with a large diameter, as compared with the $1/\mu$ or $L_{\frac{1}{2}}$ value, the intensity will be considerably lower in directions significantly deviating from the axial one. A source formed as a sphere therefore seems to have advantages for exposures over large solid angles. This form can for instance be obtained by sorption of radioactive ions in a particle of ion exchange resin.

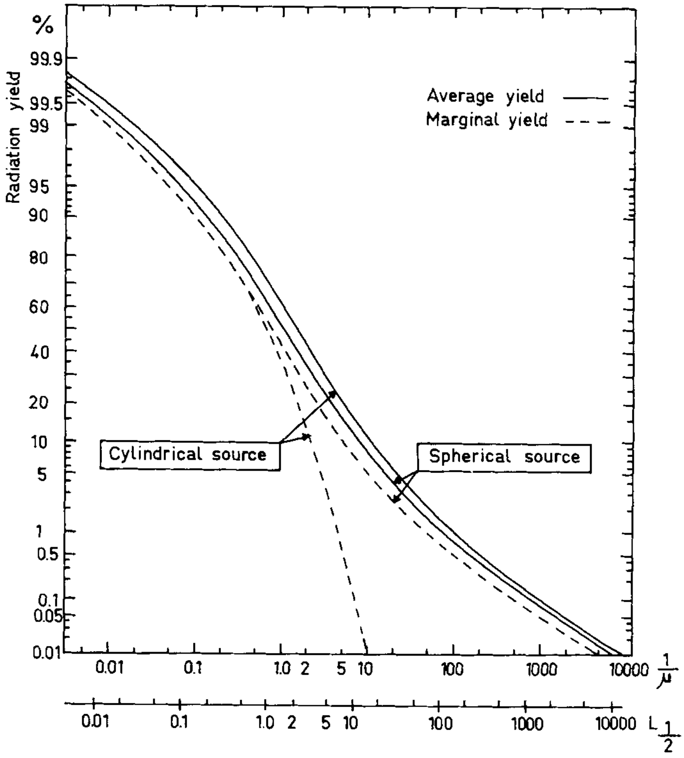

Fig. 4. Average and marginal yields in the axial direction from cylindrical and spherical radiation sources (on a normal distribution scale) versus cylinder lengths and sphere radii in units of $1/\mu$ (on a logarithmic scale). An abscissa scale is also given in units of $L_{\frac{1}{2}}$, the half-value thickness. For a certain source, its length, l, is divided by the unit length, $1/\mu$, for the particular radiation, and the curves are read for the corresponding abscissa value, i. e. the numerical value of μl.

Let r denote the radius of the sphere in cm. The radiation intensity from this is then

$$I = \frac{4}{3} \cdot \frac{\pi r^3}{4\pi} \cdot \frac{\varrho \cdot N_A \cdot f_a}{\Sigma n_Z A_Z} \cdot \eta_E \cdot \frac{\ln 2}{T_{\frac{1}{2}}} \cdot \Upsilon_{s,a} \text{ quanta} \cdot \text{steradian}^{-1} \cdot \text{sec}^{-1} \tag{5}$$

Again, $\Upsilon_{s,a}$ is evaluated by integration over all volume elements of the source, and is found to be

$$\Upsilon_{s,a} = \frac{3}{2\mu r} \left\{ \frac{1}{2} + \frac{e^{-2\mu r}}{2\mu r} - \frac{1 - e^{-2\mu r}}{(2\mu r)^2} \right\} \tag{6}$$

or, after series expansion of the exponential terms

$$\Upsilon_{s,a} = 3 \sum_{m=0}^{\infty} \left\{ (-1)^m \frac{m+2}{(m+3)!} (2\mu r)^m \right\} \tag{7}$$

where the first terms are

$$Y_{s,a} = 1 - \frac{3}{8}(2\mu r) + \frac{1}{10}(2\mu r)^2 + \cdots \tag{8}$$

Thus $Y_{s,a}$ approaches unity for small values of the product μr, and this is so in the case of negligible self-absorption.

From eq. (6) it is seen that at large values of μr, the yield $Y_{s,a}$ approaches the value $\frac{3}{4\mu r}$. This means that the intensity becomes proportional to the cross section of the sphere and corresponds to 100 % yield from a cylindrical layer of this cross section and $1/\mu$ cm thick. This might be expected for an infinitely thick source which expressed mathematically becomes:

$$\lim_{\mu r \to \infty} I = \frac{\pi r^2}{4\pi\mu} \cdot \frac{\varrho \cdot N_A \cdot f_a}{\Sigma n_Z A_Z} \cdot \eta_E \cdot \frac{\ln 2}{T_{\frac{1}{2}}} \text{ quanta steradian}^{-1} \text{ sec}^{-1} \tag{9}$$

In the case of a cylindrical source the marginal yield was defined as the transmission from its bottom layer, eq. (3b), i. e. the ratio between the increments of the intrinsic and the external radiation intensities. This formulation can also be applied to a spherical source, in which case the marginal yield is found to be

$$Y_{s,m} = \frac{1 - e^{-2\mu r}}{2\mu r} \tag{10}$$

The marginal and average yields from spherical sources are plotted against sphere radii in Fig. 4.

III. *Sources of* ^{125}I

Eqs (2), (4), (5), and (8) make it clear that in order to obtain the highest intensity from a small source the following four requirements should be fulfilled:

1. The specific activity, f_a, should be as high as possible, i. e. the actual isotope should be available as carrier-free, and this is the case with ^{125}I.
2. The intrinsic yield of usable radiation, η_E, should be as high as possible. Being considerably more than 100 per cent, the roentgen ray yield from ^{125}I is excellent.
3. The half-life should be short because it is inversely proportional to the activity/weight ratio in the case of carrier-free activities; for practical reasons, on the other hand, it should not be too short. The 60 days half-life of ^{125}I seems to offer a well balanced compromise.
4. The source should be composed of as few and as light elements as possible, in addition to the radioactive one. According to this requirement, the elemental form would be the best choice although from safety considerations the choice is limited in practice to stable compounds of very low vapour pressure. The compound should, in addition, enable a ready rendering as a small-sized source. In the case of ^{125}I, silver iodide and copper iodide seem to fulfill these requirements and will be investigated.

Table 2

Mass absorption coefficients ($\mu\varrho^{-1}$) *of Ag, Cu, and I, derived from Hogdman (1962) and Berry (1961), are tabulated for five different roentgen energies together with calculated mass absorption coefficients of AgI and CuI and linear absorption coefficients* (μ) *of AgI, CuI, and* I_2. *(For comparison, the yields of other characteristic radiations from a source of 1 C* mm^{-2} *are tabulated in Table 3)*

	Primary radiation			Secondary radiation	
Energy in keV	27.4	35	3.8	22.2	8.05
Type of radiation	K_α(Te)	$\gamma(^{125}I)$	L_α(Te)	K_α(Ag)	K_α(Cu)
$(\mu\varrho^{-1})_I$ $cm^2 \cdot g^{-1}$	12	33	~ 500	21	290
$(\mu\varrho^{-1})_{Ag}$ »	53	26	1250	13.3	
$(\mu\varrho^{-1})_{Cu}$ »	14	7	380		51
$(\mu\varrho^{-1})_{AgI}$ »	31	30	850	17.5	
$(\mu\varrho^{-1})_{CuI}$ »	13	24	460		210
μ_{I_2} cm^{-1}	59	163	~ 2500		
μ_{AgI} »	175	170	4800	99	
μ_{CuI} »	73	135	~ 2600		1200

IV. *Self-absorption of* ^{125}*I-sources*

As may be seen from Fig. 4 and eqs (3), (4), (6), and (10) the absorption coefficient must be known before the radiation yield can be calculated.

Of primary interest in the present case is, of course, the yield of the tellurium K_α roentgen rays. These have energy 27.4 keV and are so referred to below. For certain purposes the yields of the 35 keV gamma rays and the 3.8 keV tellurium L_α rays may also be of interest. Furthermore, the copper and the silver in the iodide deposits and their backings will, as secondaries, emit their own characteristic roentgen radiation upon absorption of the 27.4 and 35 keV radiations. The attenuation of K_α roentgen rays of copper and silver, 8.05 and 22.2 keV, may therefore be of interest for the respective sources.

The mass absorption coefficients of copper, silver and iodine for the five energies mentioned were obtained by graphical interpolation of the values in 'Handbook of Chemistry and Physics' (HOGDMAN 1962). Some values for iodine were derived from the diagram of BERRY (1961). These coefficients are tabulated in Table 2 together with the resulting mass ($\mu\varrho^{-1}$) and linear (μ) absorption coefficients of elementary iodine, copper iodide, and silver iodide.

One curie of the 60 days ^{125}I in carrier-free form weighs 57.3 μg and corresponds to 58.2 μg of natural iodine (^{127}I) with respect to roentgen ray attenuation. From this weight, and the absorption coefficients of Table 2, the yields of 27.4 keV roentgen rays in the axial direction of cylindrical sources were calculated and plotted against source intensity in Fig. 5.

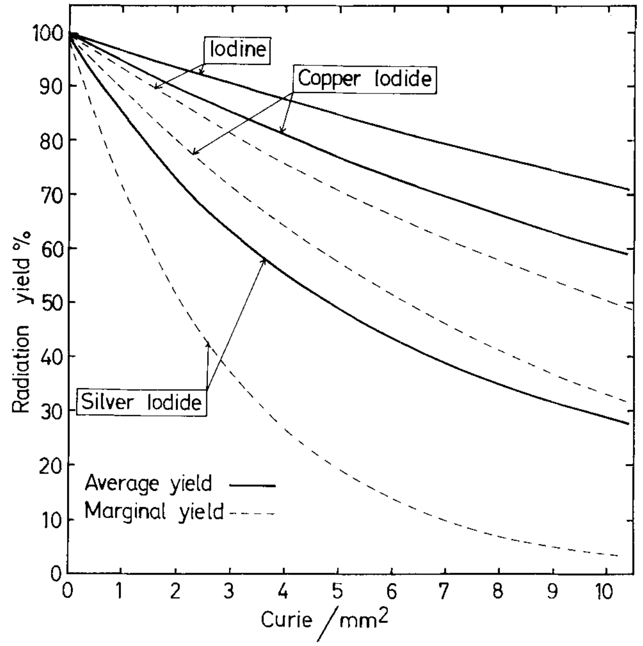

Fig. 5. Average and marginal radiation yields of 27.4 keV roentgen rays from elemental ^{125}I, ^{125}AgI and ^{125}CuI sources versus source thicknesses in units of curies mm^{-2}. The yields are calculated for the axial direction.

As may be seen from Fig. 5, the marginal yield for a silver iodide source loaded with 2 curies per mm^2 is 50 % ; a source of copper iodide must be three times stronger before the same self-absorption is attained.

V. *Fluxes from filter-equipped ^{125}I-sources*

As may be seen from Tables 1 and 3, the intensity of 3.8 keV roentgen rays is less than 5 % of the 27.4 keV intensity, both for a copper and silver iodide source of 1 C mm^{-2}. In view of its contribution to the skin dose, however, this low-energy radiation is not so negligible as might be supposed from its low intensity. It is inferred from a slight extrapolation of a dose rate versus photon energy curve (SLACK & WAY 1959) that at the same quantum flux the dose rate from 3.8 keV roentgen may be 60 times higher than from 27.4 keV roentgen radiation. In order to reduce the relative skin dose contribution from the 3.8 keV radiation to a negligible level, this radiation must be further attenuated by a factor of about 30 or more. This filtering can be accomplished by, for instance, 0.05 mm of aluminium, transmitting only 0.55 % of the 3.8

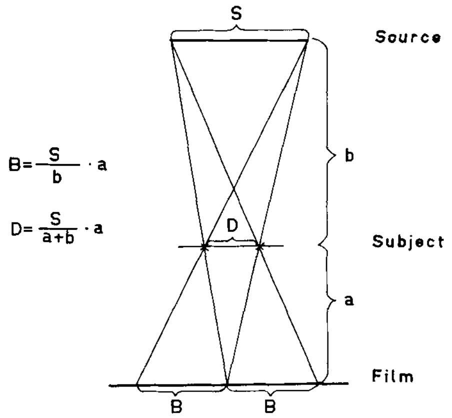

Fig. 6. Schematic illustration of blur (B) and theoretical resolving power (D) concepts.

keV radiation but 99 %, 98 %, 96 %, and 52 % of the 35, 27.4, 22.2, and 8.05 keV radiation.

If we consider a 1-curie source of ^{125}I that has been deposited as copper iodide on an area of 1 mm^2 and equipped with an aluminium absorber 0.05 mm thick, we may calculate the fluxes along the axial direction for this source. Expressed as number of quanta per sec and mm^2 10 cm from the source, these have values of $380 \cdot 10^3$, $18 \cdot 10^3$, and 110 for the radiations having energies of 27.4, 35 and 3.8 keV, respectively.

The silver K_α radiation in a silver iodide source may be expected to amount to a small percentage of the 27.4 keV roentgen rays; the exact ratio between these intensities will, however, depend both on the thickness of the silver backing, the geometric form of the deposit and on the source strength. The copper K_α intensity in a copper iodide source will for three reasons be much weaker than the corresponding one from a silver iodide source: (1) the absorption in copper is less than in silver, (2) the fluorescence yield in copper is less than in silver, and (3) the self-absorption of copper K_α is larger than of silver K_α radiation.

Table 3

Average and marginal yields at characteristic energies in the axial direction from ^{125}I-sources loaded with 1 C mm^{-2}.

Radiation energies, keV	27.4	35	3.8	22.2	8.05
AgI-source avg. yield %	87	88	13	91	
marg. yield %	73	74	0.01	83	
CuI-source avg. yield %	95	90	27		48
marg. yield %	90	81	1.8		18

The iodides of a ^{125}I-source will upon aging be converted to tellurides. Provided that the telluride does not react with the surrounding matter in any way, however, the self-absorption relations will remain mainly unchanged during this process.

Dimensions of the radioactive radiation source

I. *Blur and resolving power definitions*

When radioactive nuclides are utilized as radiation sources in roentgenography, it is evident that the dimensions of the source, like those of the focus of a conventional roentgen tube, limit the obtainable resolving power and the blur. Most roentgen units used for diagnostics have a focus diameter of 2 to 0.5 mm; for some medical applications, however, a fine focus diameter of 0.5 to 0.1 mm is used.

The geometric blur, B, varies with the distances between the object and film, a, and between the source and the object, b, according to eq. (1) (see Fig. 6)

$$B = \frac{S}{b} \cdot a \tag{11}$$

where S is the largest diameter of the radiation source.

The theoretical resolving power, D, is most simply defined as in eq. (12)

$$D = \frac{S}{a+b} \cdot a \tag{12}$$

where a, b, and S represent the same factors as in eq. (11), and D is the shortest distance between two points in the object whose penumbrae (blurring) touch one another (FRANZELL 1951) (see Fig. 6). According to this definition the points should be situated in a plane parallel to the film. Thus, regarding the blur as well as the resolving power, the film-object distance ought to be as short as possible; this distance is, however, usually limited by anatomical conditions.

II. *Relation between resolution and exposure time*

When the film-object distance for a certain application is given, $\frac{S}{a+b}$, or the ratio between the source diameter and the source-film distance, must be sufficiently small to meet the resolving power requirement. This ratio will here be called the relative source width, S_r

$$S_r = \frac{S}{a+b} \tag{13}$$

The exposure time in medical roentgenography must be kept as low as possible. It is inversely proportional to the radiation intensity, or, more directly expressed, inversely proportional to the dose rate at the film level.

In the case of radioactive sources like that of ^{125}I, the radiation intensity from a source of a given cross section is limited in practice by the self-absorption relations. The intensity obtainable under these conditions is proportional to the square of the source diameter; at the same time the dose rate at the film level is inversely proportional to the square of source-film distance. The dose rate at the film level is therefore proportional to the square of the relative source width, and the exposure time can, below a certain limit, be shortened only by increasing the relative width of the source. For the best choice between the contradictory demands on the relative source width, the resolution and exposure time requirements should be weighed against each other. It seems logical for most medical applications to satisfy the demand for resolving power at the expense of the exposure time.

The above may be summarized by stating that for sources of the same intensity per surface unit the resolution as well as the exposure time are constant for different source diameters, provided that the relative source widths are kept constant.

III. *Relation between source cost and skin dose*

The cost of a ^{125}I-source, and of other radioactive sources too, may be expected to be nearly proportional to the total activity, or to the square of the source diameter for a certain intensity per surface unit. From considerations of cost as well as for the sake of the total activity level, the smallest possible source diameter is desirable. Small sources require proportionally small source-film distances in order to maintain the minimum exposure time. There are, however, two main obstacles preventing the shortening of the source-film distance below a certain limit.

First, the geometry changes and the blur increases when the source-object distance is diminished.

Secondly, the local skin dose must be taken into consideration when using small source-object distances. Thus, when the distance between the source and the nearest part of the object is half the source-film distance, the dosage received by this part will be four times as large as for an infinite source-film distance. When the source-object skin distance is two-thirds of the source-film distance, the skin dose will be about twice that at an infinite distance. If the first condition, resulting in a four-fold increase of the local skin dose, is accepted as the worse one, the resolving power will be half the source diameter or better. Under these circumstances a source diameter of 0.5 mm will yield a resolution of 0.25 mm and better, and this diameter was chosen for the present studies of the applications of ^{125}I to dental roentgenography. Whenever possible the source should be kept at a position that is three times the greatest film-object distance, or more, from the film, in which case the corresponding resolving power will be 0.17 mm or better.

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SUMMARY

Formulae are given for the intensities obtainable from both cylindrical and spherical sources constituted of any radioactive nuclide suitable for medical radiography. The intense 27.4 keV roentgen rays emitted on the disintegration of ^{125}I are discussed. The optimum source width is shown to be limited by the resolving power and exposure time requirements as well as by the cost of the radionuclide and the increased skin dose from a proximate source.

ZUSAMMENFASSUNG

Es werden Formeln angegeben für die Strahlungsintensitäten von zylindrischen und sphärischen radioaktiven Kernstrahlern, die für die medizinische Strahlendiagnostik verwertbar sind. Die intensive 27,4 KeV Strahlung, die beim Zerfall des ^{125}I auftritt, wird besprochen. Die optimale Weite der Strahlenquelle ist einerseits durch das Auflösungvermögen bestimmt und andererseits durch die Anforderung nach kurzen Belichtungszeiten; auch die Kosten des Kernstrahlers und die erhöhte Hautbelastung bei kurzem Abstand verdienen Berücksichtigung.

RÉSUMÉ

Les auteurs indiquent des formules donnant l'intensité fournie par des sources cylindriques et sphériques constituées par l'un quelconque des corps radioactifs convenant à la radiographie médicale. Ils étudient l'intense rayonnement de 27 keV émis par la désintégration de ^{125}I. Ils montrent que le diamètre optimum de la source est limité par le pouvoir de résolution et le temps de pose, ainsi que par le prix de ce radionuclide et par l'augmentation de la dose cutanée quand la source est proche.

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