Thyroid Radiation Dose During Panoramic and Cephalometric Dental X-ray Examinations

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Radiation hazards in dentistry and medicine have been the subject of inquiry since the early 1900's. Many methods for reducing patient exposure during diagnostic procedures have been proposed.[1-6] High-speed film, intensifying screens, grids, filters, and collimators all contribute toward lower patient exposure. Among the most notable reports on this subject are those of Franklin on cephalometric exposures.[7-10]

Of particular concern is the relationship between inadvertent thyroid exposure and the induction of neoplasms in later life. Evidence of thyroid injury has been reported since 1950 by several investigators.[11-19] All of these reports concerned thyroid exposure during therapeutic X-ray treatments in which the radiation exposure to the head and neck was several orders of magnitude greater than in the diagnostic procedures to be discussed here. It is important to place these diagnostic exposures in perspective. Although the individual dose from diagnostic X-rays is considerably less than therapeutic doses, a larger number of individuals are exposed. Efforts must be made to reduce diagnostic exposures to the lowest practicable limit.

Previous studies of skin dose over the thyroid during intraoral diagnostic exposures were made by Alcox.[20] Antoku[21] suggested that higher doses can be delivered to thyroid tissue during panoramic procedures, since deep tissue near the axis of rotation of these machines is exposed to the primary beam during the entire procedure.

This study will show measurements of the thyroid dose received during both panoramic and cephalometric examinations and will present ways in which this dose may be substantially reduced by simple means without affecting the quality of the diagnostic information sought.

Methods and Materials

In this investigation thyroid dosimetry was performed with a phantom in which thermoluminescent crystals could be inserted as dosimeters. The RANDO phantom, developed by Alderson et al.[22] and used by Franklin,[10] Nelson and Rupp,[23] and by McMahon[24] for depth dose studies, is a natural skeleton devoid of extremities with the head containing teeth, the whole skeleton being embedded in a tough thermoplastic material based on synthetic isocyanate rubber which simulates human soft tissue in regard to attenuation of diagnostic and therapeutic X-rays. The phantom torso consists of transverse sections, each 2.5 cm thick, which are numbered consecutively, the top cranial slice being "zero." The sections are penetrated by holes in which thermoluminescent dosimeters can be placed and exposed to radiation. Thermoluminescent dosimetry is accomplished through energy absorption by lithium fluoride crystals.[25] The crystals used in this investigation were accu-

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rately positioned during measurements of the dose. Harshaw TLD-100 lithium fluoride crystals, 1 x 3.5 x 3.5 mm, were used to measure the radiation. This is in contrast to other methods of dosimetry in which Sievert chambers or Victoreen ionization chambers are used.

The radiation absorbed by the crystals changes the energy state of internal electrons within the crystal. The magnitude of the exposure is determined later by heating of the crystals under a photomultiplier tube. As the crystal is heated, it emits light in proportion to the number of electrons which changed their state as a result of the absorption of radiation. The amount of thermoluminescence produced is directly proportional to the radiation exposure. The induced thermoluminescence was measured in a nitrogen atmosphere in an Eberline TLR-5 reader. The crystals were calibrated against cobalt-60 sources calibrated by the National Bureau of Standards. An energy correction of twenty percent was applied to the observed exposures because of the greater crystal sensitivity at X-ray energies compared with cobalt-60.[25]

The levels in the phantom where the thyroid is located are transverse sections nine and ten. Anatomically, the thyroid is slightly below the hyoid bone and extends downward to the sternal notch and laterally to the medial borders of the sternocleidomastoid muscle, approximating the levels of the bottom of the fourth through seventh cervical vertebrae. In older individuals it can extend downward to the level of the thoracic vertebrae. The topographical anatomy of the thyroid was determined on lateral and anteroposterior head films.

Panoramic

In this study, therefore, the phantom was positioned for panoramic exposure after the crystals had been placed in the appropriate holes at the ninth, tenth, and eleventh transverse levels. Conventional exposures were made with three different types of panoramic machines. The exposure configuration is illustrated in Figure 1, and the crystal locations are shown in Figure 2.

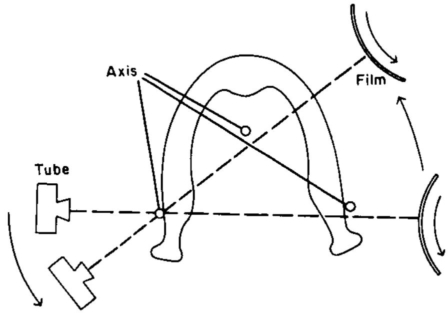

Fig. 1 Diagram illustrating the relationship of the axes of rotation, in panoramic exposures, to the mandible. The lateral axes can be located immediately outside of the mandibular ramus, as shown here; they can also be in the mandible or medial to the mandibular ramus, depending upon the kind of machine used and the anatomic size of the patient. Machines with continuously changing axes of rotation tend to produce elliptical exposure curves on the profile film, as seen in Fig. 5, with end points approximately in the locations of the axes illustrated here.

In addition to the dosimetry studies a profile of the primary beam emanating from a rotational axis was recorded on film which had been contoured to the outlines of transverse phantom sections nine and ten and was sandwiched between these sections.

Cephalometric

In cases where cephalometric equipment rather than panoramic equipment is used, the thyroid is still at risk because the circular primary beam produced in cephalometric examinations includes the thyroid within its path, as confirmed by the appearance of this area in the film (Fig. 3). The upper pole of the thyroid is usually located anterior to the fourth cervical vertebra in the lateral cephalometric view.

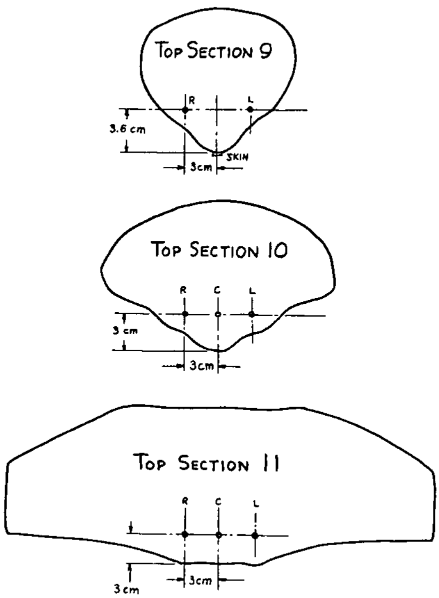

Fig. 2 Diagram of phantom slabs indicating the location of crystals used for dosimetry. The sites selected are within the expected location of the thyroid gland.

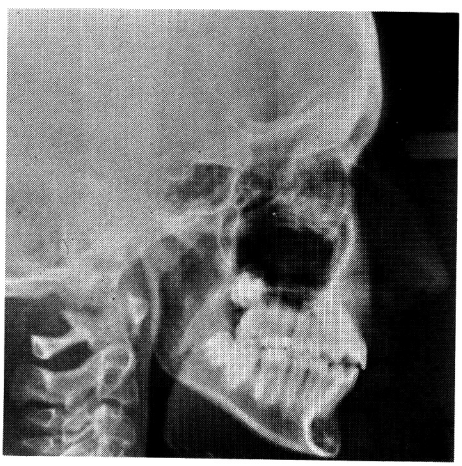

Fig. 3 Cephalometric film demonstrating inclusion of cervical vertebrae in the primary field. The upper pole of the thyroid gland is usually situated at the level of the fourth cervical vertebra. Limiting the primary beam to the region above this vertebra will usually cut off important landmarks along the inferior border of the mandible, unless the face is rotated upward; such rotation is not desirable, however, because the strained head posture distorts landmark relationships.

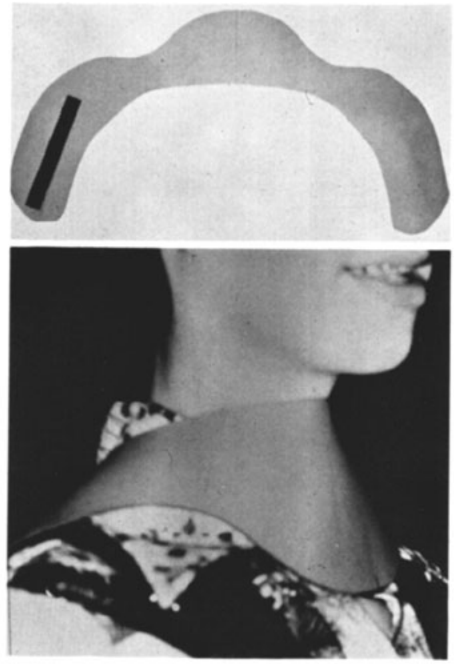

Fig. 4 Above, top view of lead-impregnated collar showing one of two fastening strips. Below, collar in place on the neck shielding the thyroid area, but not interfering with landmark registration on the film.

Dosimeter crystals were placed in the phantom as indicated in Figure 2, and conventional cephalometric exposures were made at 68 kVp, 20 MA for 4 seconds at a 60-inch source-to-skin distance. A lead-impregnated collar was designed to cover the thyroid area on the phantom during cephalometric procedures and modified for use on human subjects. This collar is shown in Figure 4.

Results

Panoramic

Dose readings obtained from the panoramic equipment with the crystals are listed in Table I. Table I shows that, for unit 1, with the tube in the "low" position, the thyroid is closer to the axis of rotation than in the standard position. Slabs 10 and 11 are farther from the axis of rotation in the

TABLE I

Thyroid doses in panoramic radiology (millirads per film)

Panoramic		Interior Top of Slabs								Skin Surface of Slab 9	
		9		10			11				
		R	L	R	C	L	R	C	L	R	L
Unit 1	Tube Std.	8.1	8.4	11.0	11.0	9.0	3.7	3.0	3.4	5.8	11.7
	Tube Low	35.0	36.0	11.0	13.0	11.0	*	*	*	35.0	31.0
Unit 2	Tube Std.	28.0	23.0	2.3	1.9	3.8	5.6	6.8	5.3	12.0	12.0
	Tube Low	84.0	120.0	16.0	19.0	19.0	8.0	8.0	7.0	187.0	287.0
Unit 3	Tube Std.	460.0	432.0	80.0	82.0	76.0	24.0	27.0	27.0	97.0	106.0
	Tube Low	673.0	858.0	145.0	139.0	138.0	34.0	30.9	29.8	555.0	812.0

*Measurement not possible (machine movement obstructed by immobility of phantom shoulder).

tube "low" position. For slab 9 the dose in the tube "low" position is 35 millirads per film compared with 8 millirads per film for the standard or ideal position. The low position gives appreciably higher readings in all cases. Panoramic unit 3 can be operated by the split technique with two centers of rotation. There is considerable variation in the location of centers of rotation of the different units, as indicated by the widely differing dose values obtained with unit 3. From slabs 9 to 11 there is an enormous decrease in absorbed dose, since the areas in slab 11 are farther away from the center of rotation of the primary beam. The dose is greatest on the axis since the axis of rotation in the tissue is always in the beam during the entire procedure. The dose decreases as a function of the depth in tissue due to absorption. It also decreases with the distance from the axis of rotation. For example, the skin dose in any one area over the thyroid is much less than the dose deep in the tissue at the axis of rotation. The lateral axes of panoramic machines are in line with the long axis of the thyroid gland; thus the gland may also be in the axis field.

This was the case, as expected, for each machine studied. The difference is even more pronounced when the teeth are positioned high on the film, the beam being low on the patient exposing the thyroid. The thyroid doses are much higher when the tube is positioned low; this is probably due to the position of the thyroid area in or very close to the axis of rotation of the primary beam. The surface dose with the tube in the standard position is usually less than the dose in deep tissue, because the skin surface is farther from the axes of rotation than the thyroid itself.

These dosimetry figures should not be considered as universal for panoramic machines; variables such as the position of the patient, the technique used, and the length of the neck can alter the measured dose values. In addition, it has been found that thyroid tissue is present at lower neck levels in older than in younger individuals. According to the measurements in the average-man phantom, the thyroid area receives appreciable doses during panoramic procedures. In the child and adolescent, in whom the neck is shorter and the thyroid lies relatively higher, one can expect doses higher than those reported here. We were unable to study

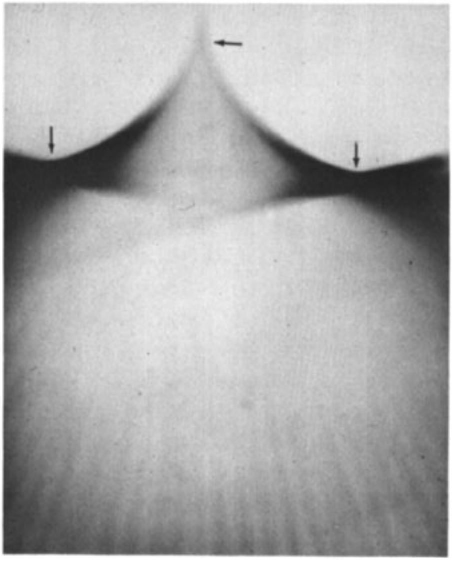

Fig. 5 Profile film showing the path of axis movement for a machine with a continuously changing center of rotation. The movement of the axis is relatively slow in the lateral segments, as evidenced by the heavier exposure, and thus higher tissue dose, near the lateral axes. The three arrows indicate the two lateral poles and one anterior pole in the path of axis movement.

thyroid doses in the child or young adult, however, because no corresponding phantoms are presently available.

A profile film is illustrated in Figure 5. This film was produced by radiation from a panoramic X-ray machine with a continuously changing axis of rotation. The film density in the path of rotation, i.e., the much greater exposure to the primary beam in the lateral segments, indicates that the axis moves very slowly per unit distance of travel as opposed to the anterior segment which shows a very light exposure indicating more rapid movement of the beam. Thus, since the beam moves very slowly in the lateral segments, it has approximately the same effect on the thyroid dose as a beam with a stationary axis.

The dosimetry findings indicate that if, in panoramic procedures, the film has an unexposed band across the top, or if the occlusal table is below the midlevel of the film, the primary beam was too low; this is demonstrated in Figure 6. Conversely, if the mandible is too low on a film, the retina and cornea are brought into the radiation field. Thus what may be considered an acceptable diagnostic film, since the den-

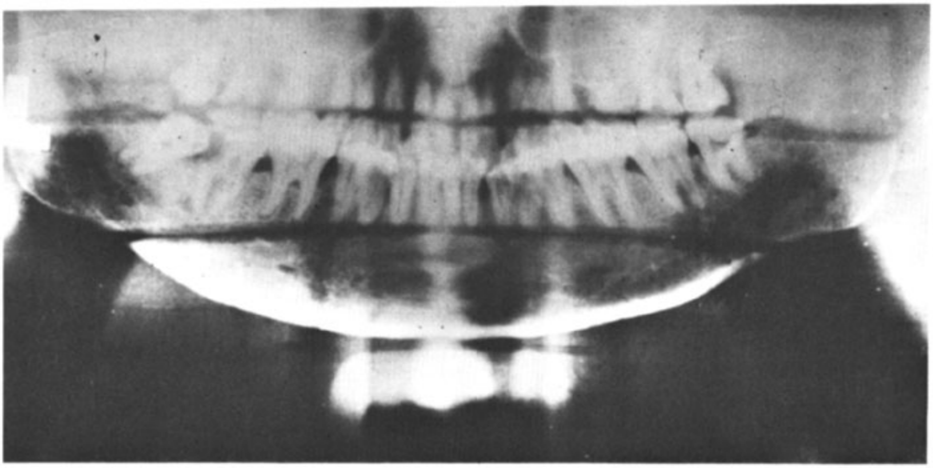

Fig. 6 Panoramic film taken with patient positioned too high resulting in exposure of the thyroid area to the primary beam.

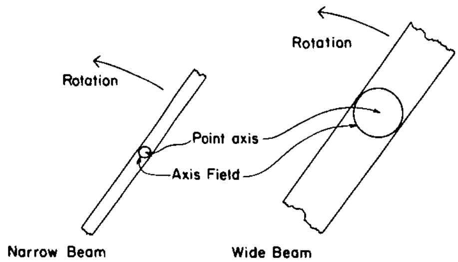

Fig. 7 Diagram illustrating the relationship between primary beam width and the diameter of the axis field, that is, the area of continuous irradiation.

tal arch is completely visible, is not acceptable because it may cause unnecessary eye exposure. If the patient or the rotating double-axis head, or both, are not properly aligned, thyroid tissue may be included in or close to the primary beam, resulting in unnecessary exposure.

Even if the patient is in an optimal position, there are inherent machine factors such as beam height and beam width which can be altered to minimize exposure. Early observation disclosed that the relatively large width (5 or 6 inches) of a typical panoramic film made it possible to position the dental area at varying heights on the film and yet completely visualize the dental arch. The width of the film used determines the height of the beam. Inspection of both types of exposed film reveals that even the five-inch width covers the profile of the jaws more than adequately. Areas above and below the jaws, such as the sinuses and orbits, are projected onto the film. Because of the relative movement of the beam which blurs these areas, the patient gains nothing from exposure to excessively tall beams; we recommend using a smaller width film and adjusting the height of the beam to the film.

Not only the beam height should be minimized, but the width as well. Antoku[21] measured a considerable reduction in thyroid dose when a narrow beam was used; he reported that a 1 cm-wide beam compared with a 0.5 cm-beam reduced thyroid exposure from 269 millirads to 38 millirads. This is because the width of the beam determines the diameter of the radiation field at the axis of rotation. The wider the beam, the larger the area of continuous irradiation of tissue, as demonstrated in Figure 7. Since the thyroid lies close to the rotational axis of panoramic machines, a larger-diameter field will increase the thyroid dose.

Cephalometric

In contrast to panoramic radiography the X-ray beam in cephalometrics is static; there is no movement of the tube head. The dose to the right side of the head was found to be higher than that to the left, as shown in Table II, because the right side, being closer to the X-ray tube, shields the left side. The attenuation of the beam is greater in slab 10 because this slab is thicker laterally than slab 9. The doses in slab 10 are less also because it lies below the lower edge of the primary beam.

In cephalometric procedures there appears to be no way of removing the thyroid from the primary beam because changes in positioning would reduce the diagnostic information obtained. Therefore, attention was directed to protecting the gland with a local radiation shield. The lead-impregnated collar previously mentioned was designed to cover the thyroid area on the phantom and was modified for use on human patients. The beam attenuation of one thickness of this material was found to be equivalent to that of 0.7 mm of lead, based on both its mass and the attenuation of 70 kVp X-rays. Measurement with lithium fluoride crystals in air, with no phantom to contribute to scatter, revealed that a dose of 72 millirads in front of the collar was reduced to 2.3 millirads after passing through the absorbing material; thus the collar ma-

TABLE II

Thyroid dosimetry in cephalometric radiography

	Interior Top of Slabs					Surface of
	9		10			Slab 9
Dosimeter position (Fig. 2)	R	L	R	C	L	Skin
Without collar (Millirads/film)	85	23	17	10	6	45
With collar (Millirads/film)	13	8	4	4	3	12
Dose reduction (percent)	85	65	76	60	50	73

terial absorbs over 97 percent of the primary radiation.

As shown in Table II, the collar applied to the phantom reduced doses ranging from 50 to 85 percent, the shielding effect being greater closer to the right side of the phantom because of increased internal scatter as the beam traverses the phantom from the right to the left side.

Conclusions

Radiation exposure from panoramic equipment can be reduced significantly by use of smaller film, adjustment of the beam height to the height of the smaller film, and careful positioning of patients. These techniques have no adverse effect on the quality of the diagnostic information needed in dentistry.

In addition to describing methods of reducing exposures from panoramic machines, this study demonstrates that the use of a barrier collar during static, cephalometric examinations can appreciably reduce thyroid exposure. Since the objective is to obtain diagnostic information from the film without irradiating the thyroid, the application of a lead-impregnated collar is a minor inconvenience, easily borne by the patient and operator. It should be noted that the use of the collar during panoramic examinations affords little or no protection since the relative motion of the panoramic machine places the axis of movement inside the head and neck of the patient.

While the evolution of diagnostic radiology may have reached a high level of technical refinement of equipment and film, the clinician still must avoid unnecessary exposure for X-ray examinations and must carefully select the best type of examination to be used for each patient. For example, a complete panoramic examination to determine the position of a known unerupted third molar tooth is probably not an exercise of good judgment since other examinations, such as periapical, could yield the same information with less exposure. Decisions must be made with good judgment, value being placed on relative risks versus the benefits of diagnostic yield.

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BIBLIOGRAPHY

1. Cohen, M.: Reduced radiation for an orthodontic survey. *Am. J. Ortho.*, 44:513-517, 1958.
2. Cohen, M. and Hammond, E.: Cephalometrics in the atomic age. *Am. J. Ortho.*, 43:592-597, 1957.
3. Graber, T. M.: Implementation of the roentgenographic cephalometric technique. *Am. J. Ortho.*, 44:906-939, 1958.
4. Paden, W. W.: A survey of radiation hazards in orthodontics. *Am. J. Ortho.*, 46:575-587, 1960.
5. Updegrave, W. J.: Simplified and standardized intraoral radiography with reduced tissue irradiation. *J. Am. Dent. Asso.*, 85:861-869, 1972.
6. Goepp, R., Strandjord, N. and Hodges, P.: The reduction of unnecessary x-ray exposure during intraoral examinations. *Oral Surg., Oral Med., Oral Pathol.*, 16:39-45, 1963.
7. Franklin, J. B.: Radiation hazards in cephalometric roentgenography. *Angle Ortho.*, 33:222-228, 1953.
8. ———: Radiographic phenomena in cephalometric roentgenology. *Angle Ortho.*, 27:162-170, 1957.
9. ———: The effect of aluminum filter disks in roentgenographic cephalometry. *Angle Ortho.*, 32:252-269, 1962.
10. ———: Newer studies of radiation exposure in cephalometric roentgenography utilizing the Rando head phantom. *Angle Ortho.*, 43:53-64, 1973.
11. Duffy, B. J. and Fitzgerald, P. J.: Cancer of the thyroid in children: A report of 28 cases. *J. Endocrinol. Metabolism*, 10:1296-1308, 1950.
12. Hemplemann, L.: Risk of thyroid neoplasms after irradiation in childhood. *Science*, 160:159-163, 1968.
13. Richards, A. G. and Webber, R. L.: Dental x-ray exposure of sites within the head and neck. *Oral Surg., Oral Med., Oral Pathol.*, 18:752-756, 1964.
14. Clark, D. E.: Association of irradiation with cancer of the thyroid in children and adolescents. *J. Am. Med. Asso.*, 159-1007-1009, 1955.
15. Pincus, R., Reichlin, S. and Hemplemann, L.: Thyroid abnormalities after radiation exposure in infancy. *Ann. Intern. Med.*, 66:1154-1163, 1967.
16. Doida, Y., Hoke, C. and Hemplemann, L. H.: Chromosome damage in thyroid cells of adults irradiated with x-rays in infancy. *Radiat. Res.*, 45:645-656, 1971.
17. DeGroot, L. and Paloyan, E.: Thyroid carcinoma and radiation—A Chicago Endemic. *J. Am. Med. Asso.*, 225:487-491, 1973.
18. Refetoff, S., Harrison, J., Karanfilski, B., Kaplan, E., DeGroot, L. and Bekerman, C.: Continuing occurrence of thyroid carcinoma after irradiation to the neck in infancy and childhood. *N. Engl. J. Med.*, 292:171-175, 1975.
19. Modan, B., Mart, H., Baidatz, D., Stemitz, R. and Levin, S.: Radiation induced head and neck tumors. *Lancet*, Feb. 23, 1974, pp. 277-279.
20. Alcox, R. W. and Jameson, W. R.: Patient exposure from intraoral radiographic examinations. *J. Am. Dent. Asso.*, 88:568-579, 1974.
21. Antoku, S., Kihara, T., Russell, W. J. and Beach, D. R.: Doses to critical organs from dental radiography. *Oral Surg., Oral Med., Oral Pathol.*, 41:251-260, 1976.
22. Alderson, S. W., Lanzl, L. H., Rollins, M. and Spira, J.: An instrumented phantom system for analog computation of treatment plans. *Am. J. Roentgenol. Radium Ther. Nucl. Med.*, 87:185-195, 1962.
23. Nelson, R. and Rupp, T.: Phantom depth dose distributions from Panorex dental x-rays. *Oral Surg.*, 32:982-989, 1971.
24. McMahon, J. J.: Head and neck exposures from panoramix roentgenography. *Oral Surg., Oral Med., Oral Pathol.*, 31:122-132, 1971.
25. Cameron, J. R., Zimmerman, D., Kenney, G., Buch, R., Bland, R. and Grant, R.: Thermoluminescent radiation dosimetry utilizing LiF. *Health Physics*, 10:25-29, 1964.