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HANDBOOK of

Selected Tissue Doses for the Upper Gastrointestinal Fluoroscopic Examination

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HANDBOOK of
SELECTED TISSUE DOSES for the UPPER GASTROINTESTINAL FLUOROSCOPIC EXAMINATION

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DESCRIPTION OF THE HANDBOOK

Purpose and Introduction

This handbook contains data from which absorbed dose to selected tissues can be estimated for upper gastrointestinal (GI) tract fluoroscopy conducted with $BaSO_4$ contrast media. The handbook permits the user to evaluate tissue doses for the range of technical parameters used in facilities. The tissue doses are for two reference patients, an adult male and an adult female. Variations due to anthropometric characteristics of individuals are not considered. Therefore, **assignment of tissue doses to individual patients is not recommended**.

The dynamic upper GI fluoroscopic examination was approximated with a set of discrete x-ray fields (**1,2**). This procedure involved videotaping the examination while fluoroscopic technique factors (i.e., tube current and tube potential) were simultaneously recorded on the audio track of the videotape. Subsequent analysis allowed the dynamic examination to be segmented into a series of discrete x-ray fields uniquely defined by field size, anatomical projection, and view. The anatomical projections associated with the upper GI examination were observed to be the upper, middle, and lower esophagus, the gastroesophageal junction, the stomach, and the duodenum.

Once the discrete x-ray fields were identified, the technical specifications for each field were used with mathematical anthropomorphic phantoms and a Monte Carlo radiation transport code to obtain tables of conversion factors (i.e., tissue dose per unit of entrance exposure, free-in-air). These phantoms and codes have evolved for use in medical x-ray dosimetry over a number of years (**3,4,5**); the most recent version was applied to this work (**5**). The conversion factors are tabulated in the Handbook and can be used to estimate tissue doses for upper GI fluoroscopy.

The mathematical phantom used to represent the reference male patient was the ADAM phantom, developed at the Gesellschaft für Strahlen- und Umwelt-forschung (GSF) (**5**) by modification of the original MIRD-5 phantom of the Medical Internal Radiation Dose Committee (**3**). The reference female patient was represented by GSF's EVA phantom. The EVA phantom is the ADAM phantom reduced uniformly to 83 percent of its original size, with the testes excluded and the ovaries, uterus and female breasts included (**5**). Anthropometric characteristics of the ADAM and EVA phantoms are listed in Appendix A.

Index of Tables

An index of the tables of conversion factors for upper GI fluoroscopy is given below. The tables present data for the left posterior oblique (LPO) and right anterior oblique (RAO) views for each of six anatomical projections—upper, middle, and lower esophagus, gastroesophageal junction, stomach and

duodenum. The data are for x-ray field sizes and the patient exposure geometry typically used in upper GI fluoroscopy. A depiction of the locations of the six anatomical projections and a table of the field centers used to locate each projection on the ADAM and EVA phantoms are presented in Appendix B. A drawing illustrating the LPO and RAO views that are common to all projections is also provided in Appendix B. Each table includes a brief description of the anatomical projection and the associated view.

Index of Tables 1 to 12

Table Number	Anatomical Projection and View	Page Number
1	Upper Esophagus (LPO)	1
2	Middle Esophagus (LPO)	2
3	Lower Esophagus (LPO)	3
4	Gastroesophageal Junction (LPO)	4
5	Stomach (LPO)	5
6	Duodenum (LPO)	6
7	Upper Esophagus (RAO)	7
8	Middle Esophagus (RAO)	8
9	Lower Esophagus (RAO)	9
10	Gastroesophageal Junction (RAO)	10
11	Stomach (RAO)	11
12	Duodenum (RAO)	12

Radiation Units

Each table contains data entries for a male and female reference patient, giving selected tissue doses (in mrad) for 1-roentgen entrance skin exposure, free-in-air. To convert from these units to Systeme Internationale (SI) units, divide the table entries by 25.8 to obtain the values in mGy per mC/kg. The values tabulated are the average absorbed dose in the tissue (weighted over its entire mass). The user must determine the actual entrance exposures associated with each of the projections and views of the examination to estimate the absorbed dose for the examination.

Tissues

For both the male and female reference patients, the tissues for which data are tabulated are the thyroid, esophagus, lung, active bone marrow, stomach, colon, bladder, liver and total trunk. The average absorbed dose in the total trunk tissue is used as an indicator for the other tissues in the trunk of the body not specifically named. Total trunk tissue excludes the lung and skeletal tissues, which have much different densities and elemental compositions than the remaining tissues (**4**). In addition, testis tissue is given for the male patient,

and breast, uterus and ovary tissues are given for the female patient. The average absorbed dose in the uterus is used to approximate the absorbed dose in the embryo, and this approximation is strictly applicable only in the first two months of pregnancy. The International Commission on Radiological Protection (ICRP) has provided risk coefficients for cancer mortality, genetic effects and in utero effects associated with absorbed doses in these tissues (**6**).

Beam Quality

Data are given for three beam qualities, namely, 4.0, 5.0 and 5.5 mm Al half-value-layer (HVL). These beam qualities span the range of fluoroscopic x-ray tube potentials and aluminum filtrations used in clinical practice (**7**). The values cited approximate those measured above a tabletop present in the beam path of undertable x-ray tubes.

The beam qualities (HVL, mm Al) listed can be produced in common practice with a variety of kVp, total filtration and waveform combinations. For the usual range of kVp and aluminum filtration combinations used in upper GI fluoroscopy, the data in Tables 1 to 12 should have uncertainties of less than 10 percent when HVL alone is used to describe beam quality. In the Monte Carlo calculation of the tissue doses tabulated, diagnostic x-ray spectra with the following kVp and HVL were simulated: 80 kVp, 4.0 mm Al; 100 kVp, 5.0 mm Al; 120 kVp, 5.5 mm Al.

Exposure Geometry

For the tabulated data, the source-to-image receptor distance (SID) is 80 cm and the source-to-skin distance (SSD) is 50 cm. In practice, the SSD is usually in the range of 40 to 55 cm. For patients of similar thickness to the male (ADAM) and female (EVA) reference phantoms, the SID would be 25 to 30 cm greater than the SSD. For the small x-ray field sizes used in upper GI fluoroscopy, the volumes of the various tissues intercepted by the x-ray field, and therefore the tissue doses, will increase or decrease somewhat depending on the actual SSD and SID values. For the preceding ranges of SSD and SID values common in upper GI fluoroscopy, differences from the tabulated entries will be less than ± 20 percent for entries greater than 100 mrad per R and less than ± 35 percent for entries less than 100 mrad per R.

$BaSO_4$ Contrast

The entries apply to both single and double $BaSO_4$ contrast procedures. An explanation of the terms "single" and "double" $BaSO_4$ contrast, a description of the manner in which the $BaSO_4$ contrast material was simulated in the phantom, and a discussion of the general effect that contrast material has on tissue doses are presented in Appendix C.

Coefficients of Variation

The last column in the tables gives maximum values of the coefficients of variation (in percent) for the entries tabulated for each tissue. The coefficient of variation is a measure of the reproducibility of the tissue dose calculation using the Monte Carlo technique (**4**).

$$\text{Coefficient of variation (in percent)} = \frac{100 \times \text{one standard deviation}}{\text{tissue dose}}$$

Significant Figures for Table Entries (Tables 1 through 12 and Table C-1)

The following convention has been used for the number of significant figures given for the Table entries for tissue dose (mrad) per 1 R entrance exposure (free-in-air):

Values	Number of Significant Figures
0.1 to 0.9, 1 to 5	one (e.g., 0.5, 4)
5.1 to 9.9, 10 to 99, greater than 100	two (e.g., 6.7, 77, 120)

Occasionally, for a particular projection and view of a reference patient, a tabulated tissue dose for a lower beam quality (HVL, mm Al) is larger than the dose to that same tissue tabulated for a higher beam quality. Such a difference is not statistically significant and can be accounted for by the magnitudes of the coefficients of variation for the particular data.

INSTRUCTIONS FOR USE OF HANDBOOK

1. Select the anatomical projection and view (e.g., stomach, RAO). Defining information for the anatomical projection and view is given in the corresponding table and in Appendix B. [A recommended approach to simulate the upper GI fluoroscopic examination with the 12 x-ray fields in the Handbook is presented in Appendix D. Note that there are two components in the examination, fluoroscopic scans and radiographic spot films.]

2. Determine the cumulative entrance exposures, free-in-air, and the representative beam qualities (HVL, mm Al) relevant to the fluoroscopic and radiographic portions of the upper GI examination that involved the selected anatomical projection and view. [A recommended approach to determine cumulative entrance exposures (free-in-air) and representative beam qualities is presented in Appendix E. It is essential that the user develop estimates specific to the facility and the conditions of interest.]

3. Use the representative beam qualities (HVL, mm Al) for the fluoroscopic and radiographic portions to look up in Tables 1 through 12 the respective tissue doses for 1-roentgen entrance exposure associated with the selected anatomical projection and view. Selection of the tissue doses for a beam quality closest to a representative beam quality is recommended.

4. Multiply the tissue doses for 1-roentgen entrance exposure obtained in instruction 3 by the corresponding cumulative entrance exposures, free-in-air, for the fluoroscopic and radiographic portions, and sum the tissue doses to obtain the total for the selected anatomical projection and view. These tissue doses are for the reference patients represented by the male (ADAM) and female (EVA) phantoms.

5. To obtain tissue doses for an upper GI fluoroscopic examination consisting of multiple anatomical projections and views, repeat instructions 1 through 4 for each anatomical projection and view and sum the resultant tissue doses for each tissue of interest. A sample computation is presented in Appendix F.

REFERENCES

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TABLES AND APPENDICES

Table 1. **Upper Esophagus, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the upper esophagus projection is that it includes the thyroid. Inclusion of the thyroid is assumed if the lower jaw, thyroid cartilage or bolus-distended pharynx is observed.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max.
Tissue	Male	Female	Male	Female	Male	Female	CV (%)[b]
Thyroid	52	95	68	120	75	120	5.6
Esophagus	69	96	84	110	92	120	1.8
Breast		2		2		3	6.3
Lung	20	18	24	21	26	22	1.4
Active Bone Marrow	12	9.8	15	12	17	13	0.7
Stomach	0.5	0.3	0.6	0.4	0.8	0.4	27
Colon	+	+	+	+	+	+	
Bladder	+	+	+	+	+	+	
Liver	0.2	0.2	0.3	0.3	0.5	0.4	11
Testis	+		+		+		
Uterus		+		+		+	
Ovary		+		+		+	
Trunk	16	17	18	19	20	20	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

Table 2. **Middle Esophagus, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. The projection is displaced slightly inferior to the upper esophagus projection and toward the patient's left. The middle esophagus projection excludes the thyroid from within the primary x-ray field and lacks the anatomical landmarks associated with the upper and lower esophageal fields.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	4	5.6	6.2	8.0	7.5	8.2	16
Esophagus	60	83	73	97	78	100	1.8
Breast		8.8		12		13	2.8
Lung	71	72	82	80	87	81	0.8
Active Bone Marrow	14	11	17	14	18	15	0.6
Stomach	2	2	3	2	3	2	11
Colon	+	+	0.1	+	0.1	0.1	38
Bladder	+	+	+	+	+	+	
Liver	1	1	2	2	2	2	4.4
Testis	+		+		+		
Uterus		+		+		+	
Ovary		+		+		+	
Trunk	19	20	22	23	24	24	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

Table 3. **Lower Esophagus, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the lower esophagus projection is that it includes the gastroesophageal junction and the upper border of the stomach along the lower perimeter of the x-ray field.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max.
Tissue	Male	Female	Male	Female	Male	Female	CV (%)[b]
Thyroid	1	0.8	2	1	2	1	33
Esophagus	66	74	80	85	88	88	1.9
Breast		14		17		19	2.3
Lung	110	110	120	120	120	120	0.6
Active Bone Marrow	11	10	14	12	15	13	0.7
Stomach	8.6	8.8	12	11	13	12	4.5
Colon	0.1	0.1	0.3	0.2	0.4	0.2	39
Bladder	+	+	+	+	+	+	
Liver	5.4	7.9	7.6	10	9.0	12	2.3
Testis	+		+		+		
Uterus		+		+		0.1	*
Ovary		+		+		+	
Trunk	17	18	20	20	21	21	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

* Greater than 50 percent.

Table 4. **Gastroesophageal Junction, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of this projection is that it is centered on the gastroesophageal junction.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	0.1	0.2	0.2	0.3	0.3	0.6	*
Esophagus	38	36	45	42	48	46	2.6
Breast		8.8		11		12	2.8
Lung	49	57	55	61	58	62	1.0
Active Bone Marrow	9.0	8.6	11	11	12	11	0.7
Stomach	33	45	43	54	47	56	2.4
Colon	2	2	3	2	3	2	17
Bladder	0.1	+	0.3	0.2	0.2	+	43
Liver	7.5	13	11	17	12	18	1.9
Testis	+		+		+		
Uterus		0.2		0.2		0.3	37
Ovary		+		+		0.4	*
Trunk	19	20	22	22	24	24	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

* Greater than 50 percent.

Table 5. **Stomach, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the projection is that it is centered on the stomach, and the entire stomach is usually included.

Field size (width x height) at image receptor: 22.9 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	0.3	0.2	0.3	+	0.6	0.4	*
Esophagus	24	29	33	34	35	33	4.2
Breast		5.1		7.4		8.3	5.1
Lung	15	18	19	21	21	23	2.0
Active Bone Marrow	15	12	20	15	21	17	0.9
Stomach	79	130	100	150	110	170	2.2
Colon	13	20	18	25	20	26	8.1
Bladder	0.6	0.4	0.9	0.9	0.9	0.7	41
Liver	10	16	15	22	17	24	2.4
Testis	+		+		0.4		*
Uterus		2		2		3	21
Ovary		0.9		5		4	42
Trunk	43	44	44	50	52	52	0.2

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

+ Less than 0.1 mrad per R.

* Greater than 50 percent.

Table 6. **Duodenum, LPO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is oriented with the left posterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the projection is that it is centered on the duodenum.

Field size (width x height) at image receptor. 11.4 cm x 11.4 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	+	+	+	+	+	+	
Esophagus	0.6	0.6	0.9	0.7	1	0.8	11
Breast		0.2		0.3		0.4	12
Lung	0.6	0.4	0.8	0.7	1	0.8	5.3
Active Bone Marrow	16	21	21	25	23	28	0.5
Stomach	3	4	5	5.3	5.5	6.0	4.7
Colon	6.1	7.9	8.1	11	9.6	12	7.8
Bladder	0.3	0.2	0.4	0.3	0.5	0.3	28
Liver	5	6.9	6.4	9.7	7.6	11	1.8
Testis	+		+		+		
Uterus		1		0.9		2	13
Ovary		1		1		2	29
Trunk	9.0	8.7	10	10	11	11	0.4

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

+ Less than 0.1 mrad per R.

Table 7. **Upper Esophagus, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the upper esophagus projection is that it includes the thyroid. Inclusion of the thyroid is assumed if the lower jaw, thyroid cartilage or bolus-distended pharynx is observed. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image, and the vertebrae are viewed on the right side of the esophagus rather than the left.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max.
Tissue	Male	Female	Male	Female	Male	Female	CV (%)[b]
Thyroid	670	750	740	800	760	780	1.8
Esophagus	36	58	46	67	52	75	2.3
Breast		3		3		4	4.8
Lung	14	14	18	17	20	18	1.5
Active Bone Marrow	7.9	7.8	9.8	9.7	10	11	0.7
Stomach	0.2	0.1	0.3	0.3	0.5	0.2	32
Colon	+	+	+	+	+	+	
Bladder	+	+	+	+	+	+	
Liver	0.5	0.3	0.9	0.5	1	0.7	8.2
Testis	+		+		+		
Uterus		+		+		+	
Ovary		+		+		+	
Trunk	18	18	21	21	22	22	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

Table 8. **Middle Esophagus, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. This projection is displaced slightly inferior to the upper esophagus projection and toward the patient's left. The middle esophagus projection excludes the thyroid and lacks the anatomical landmarks associated with the upper and lower esophageal projections. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image, and the vertebrae are viewed on the right side of the esophagus rather than the left.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	10	12	16	15	19	16	11
Esophagus	28	43	37	54	44	59	2.6
Breast		44		50		50	1.4
Lung	30	40	38	47	41	50	1.0
Active Bone Marrow	10	9.5	12	12	13	12	0.7
Stomach	1	1	2	2	2	2	12
Colon	+	+	0.1	+	0.1	0.1	36
Bladder	+	+	+	+	+	+	
Liver	3	2	4	2	5	3	3.8
Testis	+		+		+		
Uterus		+		+		+	
Ovary		+		+		+	
Trunk	21	22	25	25	26	27	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

Table 9. **Lower Esophagus, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the lower esophagus projection is that it includes the gastroesophageal junction and the upper border of the stomach along the lower perimeter of the x-ray field. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image, and the vertebrae are viewed on the right side of the esophagus rather than the left.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm

SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	0.7	0.9	2	2	1	2	36
Esophagus	28	37	35	45	41	52	2.6
Breast		73		79		80	1.1
Lung	33	41	42	50	45	52	1.0
Active Bone Marrow	9.8	9.1	12	11	13	12	0.7
Stomach	10	9.4	14	11	15	12	4.5
Colon	0.2	0.1	0.4	0.3	0.4	0.3	*
Bladder	+	+	+	+	+	+	
Liver	27	26	33	30	35	32	1.1
Testis	+		+		+		
Uterus		+		+		0.1	*
Ovary		+		+		+	
Trunk	17	17	20	20	21	21	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

\+ Less than 0.1 mrad per R.

* Greater than 50 percent.

Table 10. **Gastroesophageal Junction, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of this projection is that it is centered on the gastroesophageal junction. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image.

Field size (width x height) at image receptor: 11.4 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	0.2	+	0.1	+	0.8	0.2	*
Esophagus	15	19	20	24	22	26	3.5
Breast		14		16		16	2.3
Lung	17	23	21	26	24	28	1.4
Active Bone Marrow	8.6	8.5	10	10	11	11	0.7
Stomach	64	72	74	83	82	92	1.8
Colon	2	2	3	2	3	2	23
Bladder	0.2	+	0.1	0.1	0.3	0.2	*
Liver	65	58	75	66	79	68	0.7
Testis	+		+		+		
Uterus		0.3		0.4		0.6	35
Ovary		+		0.8		0.7	47
Trunk	18	19	21	22	22	23	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).
[b] Maximum coefficient of variation in percent.
+ Less than 0.1 mrad per R.
* Greater than 50 percent.

Table 11. **Stomach, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of this projection is that it is centered on the stomach. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image.

Field size (width x height) at image receptor: 22.9 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	+	0.2	0.3	+	0.2	0.1	*
Esophagus	10	14	15	18	16	20	5.6
Breast		7.3		8.9		10	4.1
Lung	10	14	13	17	15	18	2.4
Active Bone Marrow	12	11	15	13	16	14	0.9
Stomach	260	310	300	350	310	370	1.3
Colon	14	18	18	21	21	24	9.4
Bladder	0.9	0.4	1	0.9	0.9	0.7	46
Liver	80	62	92	70	96	74	1.0
Testis	+		+		+		*
Uterus		1		2		2	21
Ovary		2		3		2	40
Trunk	35	35	40	40	42	42	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).
[b] Maximum coefficient of variation in percent.
+ Less than 0.1 mrad per R.
* Greater than 50 percent.

Table 12. **Duodenum, RAO** - tissue dose (mrad) per 1 R entrance exposure (free-in-air)[a]

Description: The patient is usually prone with the right anterior side against the table. The patient's sagittal planes are angled at a nominal 30 degrees from the central ray of the x-ray beam. A distinguishing characteristic of the projection is that it is centered on the duodenum. Since the RAO view is reversed from the LPO view, the image is reversed from the LPO image.

Field size (width x height) at image receptor: 11.4 cm x 11.4 cm
SID = 80 cm; SSD = 50 cm.

Note: Entries apply to both single and double barium contrast procedures.

HVL (mm Al)	4.0		5.0		5.5		Max. CV (%)[b]
Tissue	Male	Female	Male	Female	Male	Female	
Thyroid	+	+	+	+	+	0.1	*
Esophagus	0.5	0.5	0.9	0.7	0.8	1	13
Breast		0.5		0.6		0.7	8.0
Lung	0.7	0.6	1	0.9	1	1	4.7
Active Bone Marrow	2	4	3	5	3	5.8	1.4
Stomach	4	5	5	5.8	5	6.2	4.6
Colon	19	23	24	26	25	27	9.6
Bladder	0.5	0.2	0.8	0.5	0.9	0.5	29
Liver	46	48	53	52	56	55	0.6
Testis	+		+		+		
Uterus		1		1		2	13
Ovary		2		2		2	22
Trunk	9.4	9.6	11	11	11	11	0.3

[a] Divide table entries (mrad per R) by 25.8 to obtain SI units (mGy per mC/kg).

[b] Maximum coefficient of variation in percent.

+ Less than 0.1 mrad per R.

* Greater than 50 percent.

APPENDIX A. Anthropometric Characteristics of Reference Male (ADAM) and Female (EVA) Adult Phantoms (5)

	Male (ADAM)	Female (EVA)
Height	170 cm	160 cm
Weight	70.5 kg	59.2 kg
Head, Thickness	20 cm	18.8 cm
Width	16 cm	15 cm
Thorax, Thickness	20 cm	18.8 cm, 23.9 cm[a]
Width	40 cm	37.6 cm
Abdomen, Thickness	20 cm	18.8 cm
Width	40 cm	37.6 cm

[a] 18.8 cm from back to chest wall;
23.9 cm from back to nipple of breast.

APPENDIX B. Information on Anatomical Projections and Views for Upper Gastrointestinal Fluoroscopic Examination

Figure B-1. Depiction of anatomical projections superimposed on the midfrontal plane of the male (ADAM) phantom.

Figure B-2. Drawing of LPO and RAO views (shown for under-table x-ray source).

Table B-1. Field-center locations of anatomical projections on reference phantoms.

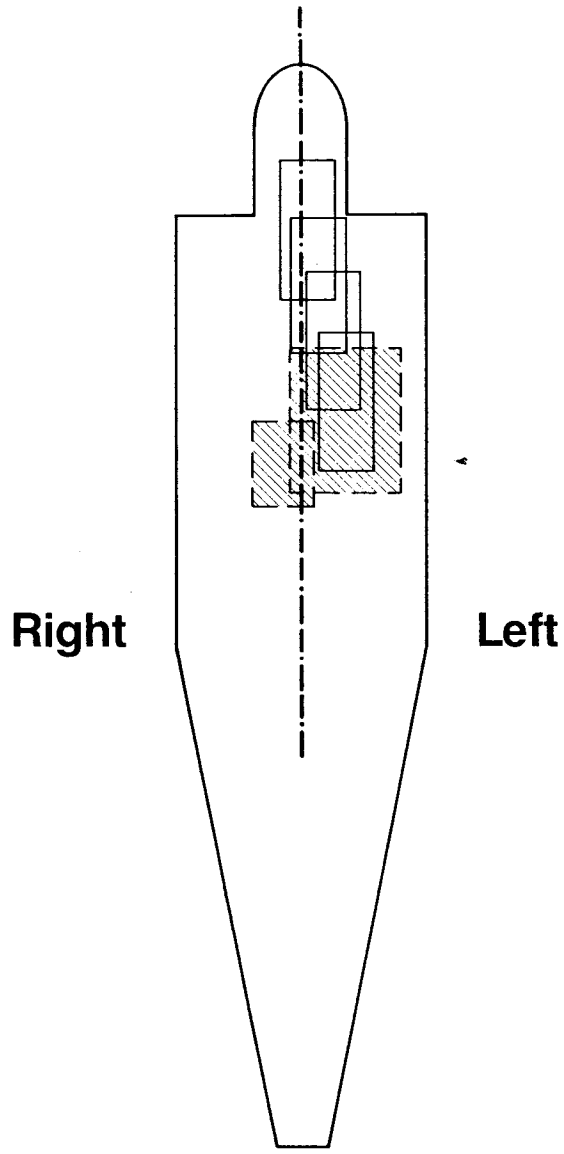
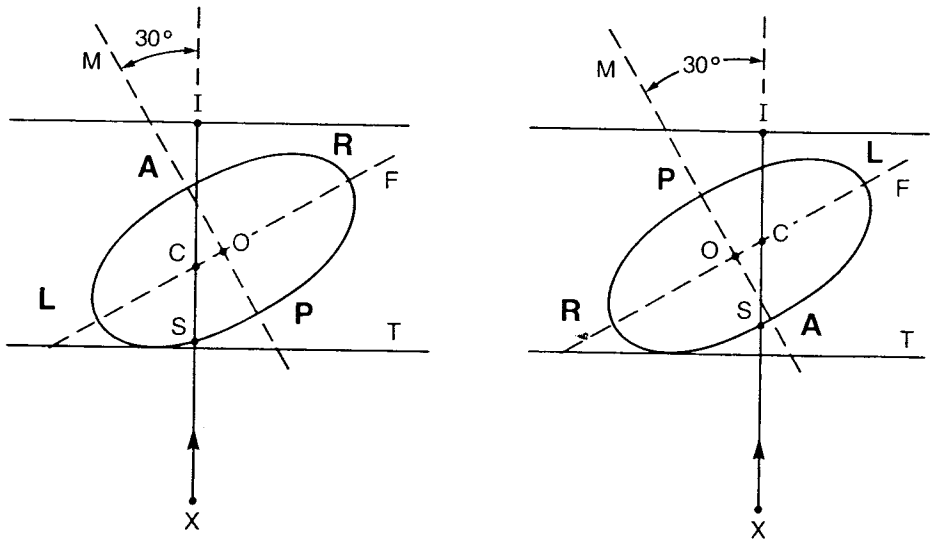


Figure B-1. Depiction of anatomical projections superimposed on the midfrontal-plane of the male (ADAM) phantom. The upper gastrointestinal fluoroscopic examination is simulated with six anatomical projections: esophagus (four projections), stomach (one projection), and duodenum (one projection). Open boxes, esophageal projections; shaded boxes, stomach and duodenal projections.

Left Posterior Oblique

Right Anterior Oblique



A	Anterior
C	Center of X-Ray Field on Midfrontal Plane
F	Midfrontal Plane
I	Point of Intersection of Central Ray of X-Ray Beam with Image-Receptor Plane
L	Left
M	Midsagittal Plane
O	Intersection of Midsagittal and Midfrontal Planes
P	Posterior
R	Right
S	Point of Entrance of Central Ray at Patient Surface
T	Tabletop Plane
X	X-Ray Source
$\overline{CO}$	Displacement of X-Ray Field Center from Midsagittal Plane
$\overline{XI}$	Source-to-Image Receptor Distance (SID)
$\overline{XS}$	Source-to-Skin Distance (SSD)

Figure B-2. Drawing of LPO and RAO views (shown for under-table x-ray source).

Table B-1. Field-Center Locations of Anatomical Projections on Reference Phantoms

Anatomical Projection	Distance from Vertex (cm)	Displacement from Midsagittal Plane along the Midfrontal Plane (cm)[a]
Male (ADAM)		
Upper Esophagus	27.5	2
Middle Esophagus	36.5	3
Lower Esophagus	45	4
Gastroesophageal Junction	54	5
Stomach	59	8
Duodenum	64	- 2
Female (EVA)		
Upper Esophagus	26	2
Middle Esophagus	34.6	3
Lower Esophagus	42.6	4
Gastroesophageal Junction	51.1	5
Stomach	55.9	8
Duodenum	60.6	- 2

[a] See Figure B-2. Positive values are to the phantom's left; negative values are to the phantom's right. The displacement values are the same for LPO and RAO views.

APPENDIX C. Simulation of $BaSO_4$ Contrast Material in Reference Phantom and Effect on Absorbed Dose to Tissues

Single and Double Contrast Techniques (2)

The upper gastrointestinal (GI) examination is conducted with either a single contrast or a double contrast technique, where $BaSO_4$ is the contrast agent used to better visualize the GI tract. The single contrast examination uses a low-density $BaSO_4$ (i.e., approximately 1.5 g/cm^3) without any additional or extraneously introduced air. The mucosal lining is imaged directly through the $BaSO_4$ pool under physical compression of the patient's abdomen, or the mucosal lining is viewed in profile along the periphery of the $BaSO_4$ pool.

The double contrast examination uses air (or a mixture of air and CO_2) and a high-density $BaSO_4$ (approximately 3.0 g/cm^3) to coat the mucosal surface of the GI tract. The double contrast technique permits complete coating and visualization, and it yields superior image quality of the mucosal lining.

Which of the two techniques is selected depends on the experience and preference of the physician conducting the examination, clinical questions associated with the patient being examined, and patient cooperativeness. The single contrast examination has less discomfort for the patient because of the use of lower density $BaSO_4$, the lack of discomfort associated with the CO_2 essential for the double contrast technique, and the absence of the rolling actions for the patient that are necessary to uniformly coat the stomach lining with the high density $BaSO_4$.

Simulation of the $BaSO_4$ Contrast Material in the Reference Phantoms

A preliminary evaluation was conducted to determine the effect on tissue doses of various thicknesses of $BaSO_4$ contrast material in the GI tract. It was concluded that simulation of the double contrast technique would be a sufficiently accurate approximation, from the standpoint of radiation transport through the $BaSO_4$ contrast layer, for both the single and double contrast techniques. Once the $BaSO_4$ contrast layer is about 1-mm thick, increasing its thickness does not further reduce photon transport to a significant degree, at the x-ray energies involved (see Table C-1).

Therefore, for the data provided in Tables 1 through 12 in the Handbook, the $BaSO_4$ contrast material was simulated as a 1-mm thick lining against the tissue walls of the esophagus, stomach and duodenum at a density of 3.0 g/cm^3. The remaining volumes within these organs were filled with air (density 0.0013 g/cm^3) to simulate the double contrast examination.

Effect on Tissue Doses of Various Thicknesses of $BaSO_4$ Contrast Materials

Table C-1 presents absorbed dose (in mrad) per 1-roentgen entrance exposure, free-in-air, for simulations of various thicknesses of $BaSO_4$ contrast material in the esophagus, stomach and duodenum, holding all other conditions constant, for the male phantom, stomach projection, RAO view.

Table C-1. Tissue Doses as a Function of $BaSO_4$ Contrast Material Thickness in GI Tract

Stomach Projection, RAO View, Male (ADAM) Phantom: tissue doses (mrad) per 1 R entrance exposure, free-in-air.
Field size at image receptor: 22.9 cm x 22.9 cm
SID = 80 cm; SSD = 50 cm; 5.0 mm Al HVL

Tissue	No $BaSO_4$[a]	Double Contrast (lining)[b] 0.25 mm	1 mm	Full $BaSO_4$[c]	Max. CV (%)[d]
Thyroid	0.2	+	0.3	0.1	*
Esophagus	26	16	15	13	3.9
Lung	19	15	13	13	1.6
Active Bone Marrow	18	15	15	14	0.6
Stomach	500	350	300	280	0.9
Colon	31	19	18	17	7.4
Bladder	2	2	1	1	21
Liver	96	93	92	92	0.6
Testis	0.2	0.2	+	+	*
Trunk	50	43	40	40	0.2

+ Less than 0.1 mrad per R.

[a] Esophagus and stomach walls are tissue equivalent; linings and contents are air equivalent.

[b] Esophagus and stomach walls are tissue equivalent; linings are either 0.25-mm or 1-mm thickness of $BaSO_4$ (density 3.0 g/cm^3); remainder of contents is air equivalent.

[c] Esophagus and stomach walls are tissue equivalent; lining and remainder of stomach contents is $BaSO_4$ (density 3.0 g/cm^3); lining of esophagus is 1-mm $BaSO_4$ (3.0 g/cm^3); remaining contents of esophagus is air equivalent.

[d] Maximum coefficient of variation in percent.

* Means CV greater than 50 percent.

The tissue doses (per 1 R entrance exposure) for the full $BaSO_4$ contrast simulation and for the double contrast simulation with 1-mm lining (i.e., the simulation used to produce the data in the Handbook) are comparable. The tissue doses (per 1 R entrance exposure) for the double contrast simulation

with 1-mm lining are lower than for a simulation with no $BaSO_4$ contrast, the largest decrease being a factor of 0.6 for those organs containing the 1-mm lining of $BaSO_4$ (i.e., esophagus and stomach).

Although the absorbed dose per 1-roentgen entrance exposure, free-in-air, is lower when $BaSO_4$ contrast material is present, the entrance exposure required to achieve the desired fluoroscopic image is higher when $BaSO_4$ is present. The entrance exposures actually observed for the clinically representative upper GI examination must be used in determining tisue doses.

APPENDIX D. Recommended Approach to Simulate the Upper GI Fluoroscopic Examination with the 12 X-ray Fields in the Handbook

The upper GI fluoroscopic examination should be analyzed and simulated with the 12 specific x-ray fields provided in the Handbook.

A practical method of accomplishing this task is to videotape a clinically representative upper GI examination and dub in a permanent visual timecode, which displays the time in hours, minutes, and seconds, and also displays the sequence of frames. The videotape can then be analyzed by using the slow playback mode of the videorecorder. The clinically representative examination can then be subdivided into the fluoroscopy scan segments and associated radiographic spot films corresponding to the anatomical projections and views provided in the Handbook (i.e., the 12 specific x-ray fields in Tables 1 through 12.) The exposure time associated with the fluoroscopy scan segments for each anatomical projection and view provided in the Handbook (e.g., stomach, RAO) can be evaluated from the timecode. An illustrative example of this segmentation by anatomical projection and view for an upper GI fluoroscopic examination is given in Table D-1.

Table D-1. Illustrative Example of Segmentation by Anatomical Projection and View of an Upper GI Fluoroscopic Examination (The patient is a male.)

Examination[a] Segment	Time per Segment (seconds)	Anatomical Projection[b] and View [c]
1	2.2	UE,LPO
2	1.2	UE,LPO
3	1.1	UE,LPO
3spot		UE,LPO
4	0.5	ME,LPO
4spot		ME,LPO
5a	1.6	LE,LPO
5b	3.6	GE,LPO
5spot		GE,LPO
6	1.9	GE,LPO
6spot		GE,LPO
7	3.0	ST,RAO
7spot		ST,RAO
8	6.1	ST,RAO
8spot		ST,RAO
9	4.3	DU,LPO
9spot		DU,LPO
10	1.6	DU,LPO
10spot		DU,LPO
11	12.2	ST,LPO
11spot		ST,LPO
12	1.2	ST,LPO
13	5.9	ST,LPO
13spot		ST,LPO
14a	0.7	ST,LPO
14b	2.7	DU,LPO
14spot		DU,LPO
15	4.6	DU,LPO
15spot		DU,LPO
16	4.5	ST,RAO
16spot		ST,RAO

Table D-1. Illustrative Example of Segmentation by Anatomical Projection and View of an Upper GI Fluoroscopic Examination (The patient is a male.) (Continued)

Examination[a] Segment	Time per Segment (seconds)	Anatomical Projection[b] and View[c]
17	2.2	ST,RAO
17spot		ST,RAO
18	3.8	ST,RAO
18spot		ST,RAO
19a	6.5	UE,RAO
19b	3.3	ME,RAO
19c	3.7	GE,RAO
19d	14.0	ME,RAO
19e	2.4	LE,RAO
19 f	3.1	GE,RAO
19g	0.2	LE,RAO
19h	0.6	ME,RAO
19 i	1.5	UE,RAO
20	3.4	UE,RAO
20spot		UE,RAO
21a	0.5	LE,RAO
21b	2.0	GE,RAO
21spot		GE,RAO
22a	0.8	ST,LPO
22b	3.1	ST,LPO
22spot		ST,LPO
23	16.9	DU,LPO
23spot		DU,LPO
24	1.9	DU,LPO
25	7.8	DU,LPO
25spot		DU,LPO
26	3.7	DU,LPO
26spot		DU,LPO
27	2.3	DU,LPO
27spot		DU,LPO

[a] "3spot" means spot film associated with fluoroscopic scan segment 3; "5a, 5b" means a continuous segment divided between anatomical projections and views.

[b] Symbols for anatomical projections are: UE, upper esophagus; ME, middle esophagus; LE, lower esophagus; GE, gastroesophageal junction; ST, stomach; DU, duodenum.

[c] Symbols for views are: LPO, left posterior oblique; RAO, right anterior oblique.

APPENDIX E. Recommended Approach to Determine Entrance Exposure (free-in-air) and Beam Quality for the X-ray Fields Provided in Tables 1 through 12

Entrance Exposure (free-in-air)

1. Calibration of fluoroscopic and radiographic output in milliroentgen per milliampere second (mR/mAs).

   An output curve relating the fluoroscopic entrance exposure rate (free-in-air) (mR/s) at the tabletop (for an undertable x-ray tube) or patient entrance plane (for an overtable x-ray tube) per unit of tube current (mA) should be derived from local measurements performed at clinically used x-ray tube potentials (kVp). A similar output curve should be obtained for the radiographic mode of operation relating the radiographic entrance exposure (free-in-air) (mR) per unit of tube current and time product (mAs) as a function of x-ray tube potential (kVp). The output curves enable determination of actual entrance exposures from the record of x-ray tube currents, scan times, and x-ray tube potentials used in the fluoroscopic segments and from the mAs and x-ray tube potentials associated with the radiographic films of the upper GI examination.

2. Collection of information on mA and kVp (fluoroscopic scans) and mAs and kVp (radiographic films) for the upper GI examination.

   The data for mA and kVp for the fluoroscopic segments are orally recorded on the videorecorder via microphone by a qualified observer during the examination. The audio recording of these data is unnecessary when using fluoroscopy systems where the mA and kVp are simultaneously displayed along with the image on the monitor. The data for mAs and kVp for the radiographic films are also recorded during the examination. These data are displayed on the x-ray tube console immediately after the radiographic exposure. Newer x-ray systems may provide printouts of the radiographic data.

3. Determination of entrance exposure (free-in-air) for the discrete x-ray fields.

   The average mA and kVp are determined for each of the fluoroscopic scan segments, and the mAs and kVp are determined for each of the radiographic spot films that are associated with each of the 12 x-ray fields provided in the Handbook tables.

   The entrance exposure (free-in-air) (mR) is determined from the relevant fluoroscopic or radiographic output curves:

   mR/mAs (for average kVp) x mA x s = mR (for fluoroscopic segments)

   mR/mAs (for specific kVp) x mAs = mR (for radiographic spot films)

   For a particular x-ray field, the total entrance exposure (free-in-air) is the sum of the entrance exposures for each of the contributing fluoroscopic

scan segments and radiographic spot films. The total entrance exposure, free-in-air (R) times the table entries (mrad per 1 R entrance exposure, free-in-air) for the corresponding x-ray field yields the tissue doses (mrad) for that portion of the upper GI examination.

Beam Quality (HVL, mm Al)

The beam quality expressed as half-value-layer (HVL, mm Al) should be measured locally for each of the clinically used x-ray tube potentials.

The following procedure applies to each of the 12 x-ray fields. From the average x-ray tube potentials (kVp) determined earlier for each of the fluoroscopic scan segments and radiographic spot films, the overall average value of kVp for all fluoroscopic scan segments and the overall average value of kVp for all radiographic spot films should be determined. From these overall average values of kVp, a representative beam quality (HVL, mm Al) should be assigned to all the fluoroscopic scan segments and a second representative beam quality should be assigned to all the radiographic spot films. These representative beam qualities are used to select the appropriate table entries for the fluoroscopic and radiographic portions of the specific x-ray field.

Illustrative Example

Table E-1 presents an illustrative example of the determination of cumulative entrance exposures (free-in-air) and representative beam qualities for the stomach projection, RAO view, portion of the upper GI fluoroscopic examination given in Table D-1.

Table E-1. Illustrative Example (Stomach, RAO, Male Patient) of the Determination of Cumulative Entrance Exposure (free-in-air) and Representative Beam Quality

Examination Segment[a]	Time[a] (s)	Avg. mA	Avg. kVp	mAs	Output (mR/mAs)	Entrance Exposure (mR)
Fluoroscopic scan number						
7	3.0	0.60[b]	120[b]	1.8	33[b]	59
8	6.1	0.85	120	5.2	33	172
16	4.5	0.80	120	3.6	33	119
17	2.2	0.80	120	1.8	33	59
18	3.8	0.80	120	3.0	33	99
Radiographic spot-film number						
7spot	--	--	110[c]	15.7[c]	30[b]	470
8spot	--	--	110	15.7	30	470
16spot	--	--	110	15.7	30	470
17spot	--	--	110	9.0	30	270
18spot	--	--	110	9.0	30	270

	Fluoroscopic Scans	Radiographic Spot Films
Cumulative Entrance Exposure, free-in-air (mR)	508 (0.51 R)	1,950 (1.95 R)
Overall Average X-Ray Tube (Potential kVp)	120	110
Representative Beam Quality[d] (HVL, mm Al)	5.5	5.0

[a] From Table D-1.

[b] Data are derived locally by recording of mA and kVp for fluoroscopic scans, and by calibration of fluoroscopic and radiographic outputs (mR/mAs) at the tabletop (or patient entrance plane) as a function of kVp.

[c] Data are derived from the technique factors displayed (i.e., mAs and kVp) for each radiographic spot film.

[d] Data are derived from local measurements relating beam quality to x-ray tube potentials.

Appendix F. Computation of Stomach and Thyroid Doses for Upper GI Fluoroscopic Examination (Stomach, RAO, Male Patient) Presented in Appendix D

Anatomical Projection and View[d]		Cumulative Entrance Exposure (free-in-air)[a] (R)	Representative Beam Quality[a] (mm Al)	Tissue Dose (mrad) per 1 R Entrance Exposure[b]		Tissue Dose (mrad)	
				Stomach	Thyroid	Stomach	Thyroid
UE,LPO :	Scans	0.04	5.5	0.8	75	[c]	3.0
	Films	0.21	5.0	0.6	68	0.1	14
UE,RAO:	Scans	0.10	5.5	0.5	760	[c]	76
	Films	0.16	5.0	0.3	740	[c]	118
ME,LPO :	Scans	0.01	5.5	3	7.5	[c]	[c]
	Films	0.21	5.0	3	6.2	0.6	1.3
ME,RAO :	Scans	0.20	5.5	2	19	0.4	3.8
	Films	--	--	--	--	--	--
LE,LPO :	Scans	0.03	5.5	13	2	0.4	[c]
	Films	--	--	--	--	--	--
LE,RAO :	Scans	0.05	5.5	15	1	0.8	[c]
	Films	--	--	--	--	--	--
GE,LPO :	Scans	0.14	5.5	47	0.3	6.6	[c]
	Films	0.84	5.0	43	0.2	36	0.2
GE,RAO :	Scans	0.23	5.5	82	0.8	19	0.2
	Films	0.42	5.0	74	0.1	31	[c]
ST,LPO :	Scans	0.65	5.5	110	0.6	72	0.4
	Films	1.21	5.0	100	0.3	121	0.4
ST,RAO :	Scans	0.51	5.5	310	0.2	153	0.1
	Films	1.95	5.0	300	0.3	585	0.6
DU,LPO :	Scans	3.0	5.5	5.5	<0.1	17	<0.3
	Films	7.1	5.0	5	<0.1	36	<0.7
DU,RAO :	Scans	--	--	--	--	--	--
	Films	--	--	--	--	--	--

	Stomach	Thyroid
Total Doses (mrad)	1,079	219

[a] Developed following example for stomach, RAO, male patient in Table E-1.

[b] From Tables 1 through 12.

[c] Less than 0.1 mrad.

[d] See Table D-1 (footnotes [b] and [c]) for explanation of symbols for anatomical projections and views (i.e., UE,LPO); the terms "scans" and "films" mean fluoroscopic scans and radiographic spot films, respectively.

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