NATIONAL BUREAU OF STANDARDS REPORT

7443

Progress Report

on

DENTAL RADIOGRAPHIC FILM:
STANDARDS AND SPECIFICATION

by

A. F. Forziati

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT | **NBS REPORT**

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Progress Report

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Dental Radiographic Film:
Standards and Specification

by

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This work is a part of the dental research program conducted at the National Bureau of Standards in cooperation with the Council on Dental Research of the American Dental Association; the Army Dental Corps; the Dental Sciences Division of the School of Aviation Medicine, USAF; the Navy Dental Corps, and the Veterans Administration.

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U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

DENTAL RADIOGRAPHIC FILM: STANDARDS AND SPECIFICATION

Abstract

Characteristics of dental radiographic film were determined. Speeds and contrast values of available films were determined and a standard for the classification of film in six speed groups was established. A method for determining the moisture resistivity of dental radiographic film was developed and data on the water penetration of 24 types of film packets were obtained. A standard for film sizes based on five preferred sizes and a standard decimal exposure system extending from 0.02 to 16 seconds in 11 steps are proposed.

1. INTRODUCTION

During the period 1952 to 1955, the Dental Research Section at the National Bureau of Standards conducted a survey of methods used by dentists for exposing and processing dental radiographic films and of labeling and packaging practices of manufacturers. This was followed by a laboratory study of properties such as sensitometric characteristics of the film, thickness of film backing and water penetration of the individual wrapper.

2. PROPERTIES OF DENTAL X-RAY FILM

2.1 Sensitometric Properties

The three most important properties of a film for dental radiographic purposes are its speed, contrast, and resolving power. As the latter is subject to psycho-physical interpretation, it will not be discussed in the present report.

The speed and contrast of a film may be computed from its characteristic curve. This curve is obtained by plotting the photographic density* of a film against the logarithm of the exposure required to produce that density. In ordinary photography this curve is obtained by plotting the density of the film against the logarithm of the time of exposure; the intensity of the light is assumed to be constant. In radiography, the density of the film is plotted against the logarithm of the exposure in roentgens. Of course, if the dose rate in roentgens per second is maintained at a fixed value, then the logarithm of the exposure time may be used as in ordinary photography.

2.1.1 Film Speed

The photographic density of dental radiographs ranges from 0.4 for areas corresponding to metallic fillings to 2.0 for the background. Areas of diagnostic interest vary in density from 0.5 to 1.5. Accordingly, the speed of a film, intended for dental radiography, is defined as the reciprocal of the exposure in roentgens necessary to produce a density of 1.0, above the opacity due to the film base and to the fog of the emulsion, when the film is processed in accordance with a carefully outlined procedure [1]. This exposure is determined from the characteristic curve of the film under consideration. Typical curves are shown in Figures 1, 2, and 3.

* Photographic density is a specialized use of the term "optical density".

In Figure 1, the average opacity due to the film base of these three films and the unavoidable fogging (blackening) caused by the developer in processing, is equal to a density of 0.10. Therefore, the speeds of these films are computed from the exposure required to produce a density of 1.10. This is done by drawing a straight line, from the point on the ordinate corresponding to a photographic density of 1.10, parallel to the abscissa axis of the plot. Another straight line is then drawn parallel to the ordinate axis, from the point of intersection of the first straight line and each curve, as shown in the figure. The corresponding exposure, in roentgens is either estimated from the top abscissa or calculated from the logarithm of the exposure on the bottom scale. The exposures are found to be 0.063, 0.275, and 0.531 roentgens for the three films represented in the plot. The film speeds corresponding to these exposures are 15.8, 3.6, and 1.9 reciprocal roentgens, respectively. Thus film A is about eight times as fast as film C.

The difference in photographic density of areas of a film which have received different amounts of radiation is referred to as contrast. The change in exposure required to produce areas of a definite low and high density is a quantitative measure of film contrast. The contrast of dental radiographic film is defined as the ratio of the change in density to the difference in the logarithm of the exposure required to produce a density of 0.25 and of 2 [2]. This relation may be expressed by the equation:

$$\text{Film Contrast} = \frac{D_{2.0} - D_{0.25}}{\log\,(\text{exposure for } D_{2.0}) - \log\,(\text{exposure for } D_{0.25})}$$

$$\text{Film Contrast} = \frac{1.75}{\log \text{ exposure } D_{2.0} - \log \text{ exposure } D_{0.25}}$$

This quantity represents an average value for the film over the range of densities specified. The contrast of the film at any point on its characteristic curve is given by the relation $C = \frac{\Delta D}{\Delta \log \text{ exposure}}$ where C is the contrast, ΔD the change in density, and Δ log exposure the change in the logarithm of the exposure associated with the change in density.

Since the densities of dental radiographs ordinarily range from 0.25 to 2.0, the average contrast of film is considered in this report. Figures 4, 5, and 6 show the contrast values for several commercial films. Note that, as in computing film speeds, the exposures used to calculate contrast must be those required to produce densities of 2.0 and 0.25, <u>above the den-</u>

sity due to opacity of the film base and chemical fog of the emulsion.

3. PROPERTIES OF THE FILM PACKET

3.1 Film Backing

The primary objective of dental roentgenography is the production of a roentgenogram suitable for the diagnostic evaluation of a particular tooth, several teeth, or the dental arch. Any radiation not directly contributing to the formation of the radiographic image is undesirable from the standpoint of exposure to the patient to radiation and should be eliminated. As the film absorbs only a small fraction of the radiation incident upon it, radio-opague film backing of some sort is essential. Otherwise, the unabsorbed radiation would continue on through the opposite cheek. When the conventional 8" cone is used, the area of the opposite cheek exposed to radiation would be about twice* that of the cheek nearest the tooth being radiographed. This backing must not be so stiff as to prevent flexing of the film packet nor must it be so thick as to prevent proper positioning of the packet. Although zinc and aluminum have been used, a layer of lead 0.0025 inch thick has been found to be most satisfactory.

3.2 Moisture Resistivity

The penetration of saliva into a dental radiographic film packet is undersirable for several reasons. Bacterial growths supported by the saliva cause fogged areas on the developed film whereas acid salivas produce areas of under-development. These effects are particularly troublesome if the film packets are stored for a week or more, as is the custom in portable clinics and by survey groups. Packets swollen by saliva stick together, are a nuisance to processing technicians and may be a source of infection.

A test to determine the resistivity of film packets to mositure (liquid) penetration was developed in this laboratory. Although empirical, it was based on clinical usage of the packets.

3.2.1 Moisture Penetration Test

All procedures shall be carried out at 73.5 ± 2°F and 50 ± 4 percent relative humidity.

* The ratio of the two areas will depend on the location of the tooth being radiographed.

3.2.1.1 Ten film packets shall be stored until a constant weight is obtained, that is, when the daily weighings shall be within ± 0.002 gram of each other. (Usually about one week is required to obtain this condition of equilibrium).

3.2.1.2 The films shall be removed from five of these film packets and shall be weighed individually to the nearest 0.001 gram. The average weight of the five films shall be designated as Weight A. If the average deviation of the individual film-weights from the average exceeds 0.005 gm the film will not qualify for further testing.

3.2.1.3 Five additional film packets conditioned as described above shall be deformed as follows:

The tube side of the film packet shall be placed face down on the template shown in Figure 7, (A) with the tab as close as possible to the line of bending. A metal block at least 3 inches long and one inch square in cross section (with edges rounded to 0.10 inch radius) shall be placed on top of the film packet on line L of Figure 7 (A). The corner of the film packet that projects beyond the block shall be bent up at an angle of 90° with the finger and shall be held in this position for 10 seconds, Figure 7, (B). The film packet shall then be bent over a cylindrical metal rod or tube of circular cross section, one inch in diameter, with the long dimension of the film along the circumference of the rod, Figure 7 (C), and with the tab side in contact with the rod. The film packet shall be held in this position for 10 seconds.

3.2.1.4 The film packets deformed as in 3.2.1.3 shall be immersed in distilled water at 73.5 ± 2°F for 30 seconds and then shall be placed on a cloth towel. The excess water shall be blotted from the film packets with another towel. The film packets shall then be wiped individually with a dry towel and allowed to stand at 73.5 ± 2°F and 50 ± 4% relative humidity for 30 minutes.

3.2.1.5 The first film shall then be removed from its packet and weighed to the nearest 0.001 gram. (Due care shall be exercised to avoid the transfer of moisture from the operator's hand to the film). The weighings shall be repeated at one minute intervals until the weight remains constant to ± 0.001 gram. The average weight of the five films, shall be designated Weight B. The weighing and recording of the values of the five films shall not take less than 10 nor more than 20 minutes.

3.2.1.6 The moisture absorbed by the film samples shall be determined to the nearest 0.1 percent as follows:

$$\frac{\text{Weight B} - \text{Weight A}}{\text{Weight A}} \times 100 = \text{Percentage of moisture absorption}$$

3.3.3 Results of Mositure Penetration Test

Twenty-four different types and makes of radiographic film packets were purchased in the commercial market and tested as described above. The results are given in Table I. The identification of the various samples is given in Table II.

4. STANDARDS AND SPECIFICATIONS

4.1 Need for Standardization

An analysis of the results of the survey of film and film packets showed that there was little or no relation between film designation in the trade and film characteristics determined in the laboratory.

For example, the "intermediate" speed film of one manufacturer was slower than any other film surveyed. In some instances, practitioners were not obtaining optimum performance from the film being used because they were unaware of its correct characteristics.

In the belief that the interest of the patient, dentist, and film manufacturer would be furthered by well formulated standards of performance, markings, and size, the Council on Dental Research sponsored a project, through the American Standards Association, on the "nomenclature, standards, and specifications for dental radiographic film including sizes and methods of designation".

One of the requirements of ASA procedure is that all interests be represented on the specifications committee. The present committee consists of 11 consumers, 7 producers, and 6 members who have a general interest in dental radiographic film. To expedite the work, it was decided to formulate four separate standards; the first standard would deal with film speeds only; the second, with film sizes; the third, with film packets (moisture penetration, film backing, etc.); and the fourth, with exposure systems (fractional decimal, or impulse).

4.1 Standard Speed Classes

The standard on film speed has been completed by the committee and has been approved by the American Standards Association. It is designated as "American Standard Speed Classification for Intraoral Dental Radiographic Film: Diagnostic Grade, PH6.1 - 1961. A copy is included in this report, Appendix 1.

This standard establishes six speed groups. The fastest film in each group has twice the speed of the slowest film in the same group and there is a two-fold increase in speed between groups. This means that a dentist using film in one speed group may use film in the next higher group by simply halving the previously used exposure times. Furthermore, by asking for film in a definite speed group, the dentist is assured of obtaining film of the desired speed.

The speed and speed-group rating of dental radiographic film available during 1960 are given in Table III

4.2 Standard Sizes

At present, 14 different film sizes of dental radiographic film are marketed by American distributors. Several film mount and dispenser sizes are required to accommodate these films.

Measurements showed that many of the films differ by only 1/16 of an inch, in one or both dimensions. A survey of 184 members of the American Academy of Oral Roentgenology showed that 80% were using only 5 of the 14 sizes marketed. Accordingly, a standard based on these 5 preferred sizes was developed in cooperation with the American Standards Association.

A final draft of the proposed American Standard Sizes for Intraoral Dental Radiographic Film, Diagnostic Grade, will be submitted to ASA Sectional Committee Ph6 for letter ballot in the near future. A copy is included in this report, Appendix 2.

As this standard is subject to editorial modification by the American Standards Association, the final form may be slightly different from that shown here.

4.3 Specifications for Film Packets

The data in Table I show that 50% of the packets will pass the moisture penetration test if the permissible gain in weight is set at 5%. This suggests that it should not be difficult to improve manufacturing techniques so that all packets would pass. Several manufacturers have indicated that they have adopted improvements in sealing techniques. A survey is in progress to determine the performance of present film packets, including the presumably new packets.

4.4 Standard Exposure Systems

The committee is considering an exposure system in which exposure times are expressed in decimals, to the nearest 0.02 second, rather than the conventional fractions. Furthermore, each exposure step is twice as long as the preceding step, eliminating intermediate steps which do not produce significant differences in density of the resultant radiograph. The exposures in this system are 0.02, 0.04, 0.06, 0.12, 0.24, 0.50, 1.00 2.00, 4.00, 8.00, and 16.00 seconds and are intended for marking X-ray machine timer dials and for expressing times in exposure tables furnished with film.

5. SUMMARY

A method of calculating the speed and contrast of dental radiographic film is described. Film speeds of 13 dental radiographic films marketed, during 1960, are listed. The lack of correlation between actual speeds and the speed implied by the brand names illustrates the need for standardization. Accordingly, six speed groups for the classification of dental radiographic film are established.

The many film sizes presently marketed necessitate an array of film mounts and dispensers. A standard based on five preferred sizes is proposed.

The status of the work on the standard on film packets and on exposure markings for dental X-ray machine timer dials and exposure charts is reported. A method of testing the moisture resistivity of dental X-ray film packets is described. Data on the water penetration of 24 different types of packets is presented. A decimal exposure system extending from 0.02 to 16 seconds, in 11 steps is proposed.

REFERENCES

1. American Standard Method for the Sensitometry of Medical X-ray Films, PH2.9-1956, Section 3., Standard Testing Conditions.

2. Ibid., Section 5., Determination of Contrast.

TABLE I Moisture Penetration of Film Packets

Sample		1	2	3	4	5	6	7	8	9	10	11	12
Weight A in grams	1	0.296	0.211	0.313	0.667	0.327	0.661	0.146	0.200	0.303	0.168	0.237	0.347
	2	0.296	0.206	0.318	0.658	0.336	0.665	0.146	0.198	0.303	0.170	0.238	0.347
	3	0.299	0.206	0.311	0.672	0.328	0.665	0.144	0.196	0.302	0.171	0.237	0.351
	4	0.296	0.209	0.318	0.658	0.326	0.654	0.146	0.194	0.302	0.170	0.236	0.353
	5	0.296	0.211	0.315	0.659	0.326	0.667	0.146	0.195	0.303	0.170	0.237	0.350
	Avg.	0.297	0.209	0.315	0.663	0.329	0.662	0.146	0.197	0.303	0.170	0.237	0.350
Weight B in grams	1	0.451	0.208	0.323	0.665	0.352	0.706	0.147	0.233	0.360	0.173	0.250	0.363
	2	0.360	0.215	0.325	0.682	0.360	0.696	0.145	0.218	0.338	0.172	0.261	0.375
	3	0.451	0.206	0.321	0.672	0.331	0.718	0.168	0.209	0.342	0.175	0.264	0.380
	4	0.454	0.209	0.319	0.664	0.330	0.665	0.158	0.210	0.341	0.173	0.257	0.367
	5	0.448	0.206	0.318	0.667	0.331	0.659	0.164	0.215	0.327	0.171	0.257	0.366
	Avg.	0.433	0.209	0.321	0.670	0.341	0.689	0.156	0.217	0.342	0.173	0.258	0.370
Percentage of moisture absorption		45.8	0.0	1.9	1.0	3.6	4.1	6.8	10.2	12.9	1.8	8.9	5.7

Sample		13	14	15	16	17	18	19	20	21	22	23	24
Weight A in grams	1	0.154	0.251	0.340	0.180	0.210	0.299	0.358	0.274	0.409	0.830	0.283	0.326
	2	0.156	0.250	0.338	0.180	0.211	0.300	0.349	0.273	0.410	0.831	0.284	0.326
	3	0.162	0.247	0.336	0.184	0.209	0.305	0.335	0.273	0.408	0.830	0.284	0.327
	4	0.155	0.243	0.336	0.186	0.212	0.309	0.337	0.273	0.410	0.828	0.284	0.327
	5	0.150	0.249	0.336	0.188	0.212	0.304	0.354	0.272	0.409	0.828	0.284	0.327
	Avg.	0.155	0.248	0.337	0.184	0.211	0.303	0.347	0.273	0.409	0.829	0.284	0.327
Weight B in grams	1	0.162	0.278	0.375	0.211	0.239	0.345	0.349	0.286	0.445	0.867	0.284	0.327
	2	0.168	0.257	0.364	0.188	0.212	0.315	0.351	0.295	0.438	0.919	0.284	0.327
	3	0.169	0.255	0.358	0.194	0.226	0.310	0.357	0.282	0.411	0.874	0.285	0.327
	4	0.178	0.259	0.365	0.188	0.227	0.301	0.349	0.308	0.427	0.935	0.285	0.327
	5	0.175	0.246	0.356	0.186	0.228	0.316	0.360	0.295	0.460	0.862	0.284	0.328
	Avg.	0.170	0.259	0.364	0.193	0.226	0.317	0.353	0.293	0.436	0.891	0.284	0.327
Percentage of moisture absorption		9.7	4.4	8.0	4.9	7.1	4.6	1.7	7.3	6.6	7.5	0.0	0.0

TABLE II

Sample Identification

Sample No.	Manufacturer	Code
1	Buck X-Ograph Company	SDC-1
2	International Film Industries	Child size
3	" " "	BH-1
4	" " "	BH-2
5	" " "	SBH-1
6	" " "	SBH-2
7	Rinn Corporation	DC-O-1
8	" "	DC-N-1
9	" "	DC-1
10	" "	EF-O-1
11	" "	EF-N-1
12	" "	EF-1
13	" "	MF-O-1
14	" "	MF-N-1
15	" "	MF-1
16	The Minimax Company	OB x 3
17	" " "	OBF x 3
18	" " "	BS
19	" " "	EFS
20	E.I. duPont deNemours and Co., Inc.	150D-1
21	" " " " "	150 LF-1
22	" " " " "	150 LF-2
23	Eastman Kodak Company	DF-7
24	" " "	DF-58

TABLE III

Dental Radiographic Film Speeds

Film	Speed (reciprocal roentgens)	Speed Group Rating
Eastman Kodak Ultraspeed	18.5	D
DuPont Lightning Fast	15.8	D
Eastman Kodak Super	15.4	D
Minimax Extra Fast	11.0	C
International Film Industries Super	9.1	C
Rinn Extra Fast	8.7	C
DuPont "D"	3.6	B
Eastman Radiatized	3.6	B
International Film Industries Intermediate	3.6	B
Rinn DC	2.6	A
Eastman Kodak Regular	2.3	A
DuPont "S"	1.9	A
Minimax Intermediate	1.8	A

American Standard

Speed Classifications for Intraoral Dental Radiographic Film: Diagnostic Grade

ASA
Reg. U. S. Pat. Off.
PH6.1-1961

*UDC 778.33:616.314

APPENDIX 1

1. Scope

This standard provides a method of classifying films used with direct x-ray or gamma-ray exposure, or both, for intraoral dental radiography according to speed and specifies limits for each speed group.

2. Speed Groups

Diagnostic-grade intraoral dental radiographic film shall be classified for speed according to the following speed groups:

Speed Group *	Speed Range (In Reciprocal Roentgens)
A	1.5— 3.0
B	3.0— 6.0
C	6.0—12.0
D	12.0—24.0
E	24.0—48.0
F	48.0—96.0

The upper limit of each speed range shall be excluded from that range.

3. Speed Determination

The speed of a film shall be determined as described in 4.1, Films Exposed Directly to X-rays, of American Standard Method for the Sensitometry of Medical X-ray Films, PH2.9-1956.

4. Revision of American Standard Referred to in This Document

When the following American Standard referred to in this document is superseded by a revision approved by the American Standards Association, Incorporated, the revision shall apply:

American Standard Method for the Sensitometry of Medical X-ray Films, PH2.9-1956

* Film speeds increase from A to F; that is, A is the slowest speed class and F is the fastest.

Approved May 16, 1961, by the American Standards Association, Incorporated

Sponsor: American Dental Association

* Universal Decimal Classification

Printed in U.S.A.
ASA12½C861/40

Appendix 2

Proposed American Standard Sizes for Intraoral Dental Radiographic Film Diagnostic Grade, PH6.2____, Twelfth Draft, Dated January, 1962

Foreward

(This Foreword is not a part of American Standard Sizes for Intraoral Dental Radiographic Film, Diagnostic Grade, PH6.2____.)

This American Standard Sizes for Intraoral Dental Radiographic Film, Diagnostic Grade, was developed to promote the achievement of an optimum number of standard sizes.

The Standard incorporated two innovations:

1. In the past, film sizes commonly have been expressed in terms of nominal dimensions, but in some cases these differed from actual dimensions. Instead of nominal values, mean film dimensions and tolerances as presently manufactured have been stated in this standard. In addition, the dimensions are given in terms of decimal inches rather than the older convention of fractional inches.

2. To encourage adoption of a uniform and simple key to sizes of dental films, a system of film type-size numbers has been devised. The following relation exists between these numbers and the old reference system of nominal sizes expressed in fractions:

<u>Periapical</u>

Size 1.00	13/16 x 1 1/4 inches
Size 1.0	7/8 x 1 3/8 inches
Size 1.1	15/16 x 1 9/16 inches
Size 1.2	1 1/4 x 1 5/8 inches

<u>Bite-Wing</u>

Size 2.00	(posterior)	1 1/4 x 13/16 inch
Size 2.0	(posterior)	1 3/8 x 7/8 inch
Size 2.1	(anterior)	15/16 x 1 9/16 inches
Size 2.1	(posterior)	1 9/16 x 15/16 inch
Size 2.2	(posterior)	1 5/8 x 1 1/4 inches
Size 2.3	(posterior)	2 1/8 x 1 1/16 inches

Proposed American Standard Sizes for Intraoral Dental Radiographic Film, Diagnostic Grade, PH6.2-____, Twelfth Draft, Dated January, 1962

2. Sizes

2.1 Film. The sizes of intraoral dental radiographic film shall be as follows:

Type of Dental Film	Inches	Tolerance (Inches)	Millimeters	Tolerance (Millimeters)
Periapical (shorter dimension first)				
Size 1.00	0.812 x 1.250	± 0.020	20.6 x 31.8	± 0.5
Size 1.0	0.875 x 1.375	± 0.060*	22.2 x 34.9	± 1.5
Size 1.1	0.938 x 1.562	± 0.020	23.8 x 39.7	± 0.5
Size 1.2	1.219 x 1.609	± 0.020	31.0 x 40.9	± 0.5
Bite-Wing (horizontal dimension first)				
Size 2.00 (posterior)	1.250 x 0.812	± 0.020	31.8 x 20.6	± 0.5
Size 2.0 (posterior)	1.375 x 0.875	± 0.020	34.9 x 22.2	± 0.5
Size 2.1 (anterior)	0.938 x 1.562	± 0.020	23.8 x 39.7	± 0.5
Size 2.1 (posterior)	1.562 x 0.938	± 0.020	39.7 x 23.8	± 0.5
Size 2.2 (posterior)	1.609 x 1.219	± 0.020	40.9 x 31.0	± 0.5
Size 2.3 (posterior)	2.109 x 1.047	± 0.020	53.6 x 26.6	± 0.5
Occlusal (shorter dimension first)				
Size 3.4	2.250 x 3.000	± 0.020	57.2 x 76.2	± 0.5

*New cutting dies and new equipment for the 1.0 size should be designed to produce the film within a tolerance of ± 0.020 inch (0.5mm) instead of ± 0.060 (1.5mm).

Note: The digit at the left of the decimal point in the size number indicates the usage of the film (i.e., periapical, bite-wing, or occlusal). The digit (or digits) at the right of the decimal point denotes the film size (i.e., Size 00, 0, 1, 2, 3, or 4).

Occlusal

Size 3.4 2 1/4 x 3 inches

The aim of this standard is to reduce the cutting tolerances for all sized to 0.020 inch (0.5mm) as soon as practicable.

Suggestions for improvement gained from experience with this standard will be welcome. They should be sent to the American Standards Association, Inc., 10 East 40th Street, New York 16, New York.

1. Scope

This standard established the sizes for film used in intraoral dental radiography.

USCOMM-NBS-DC

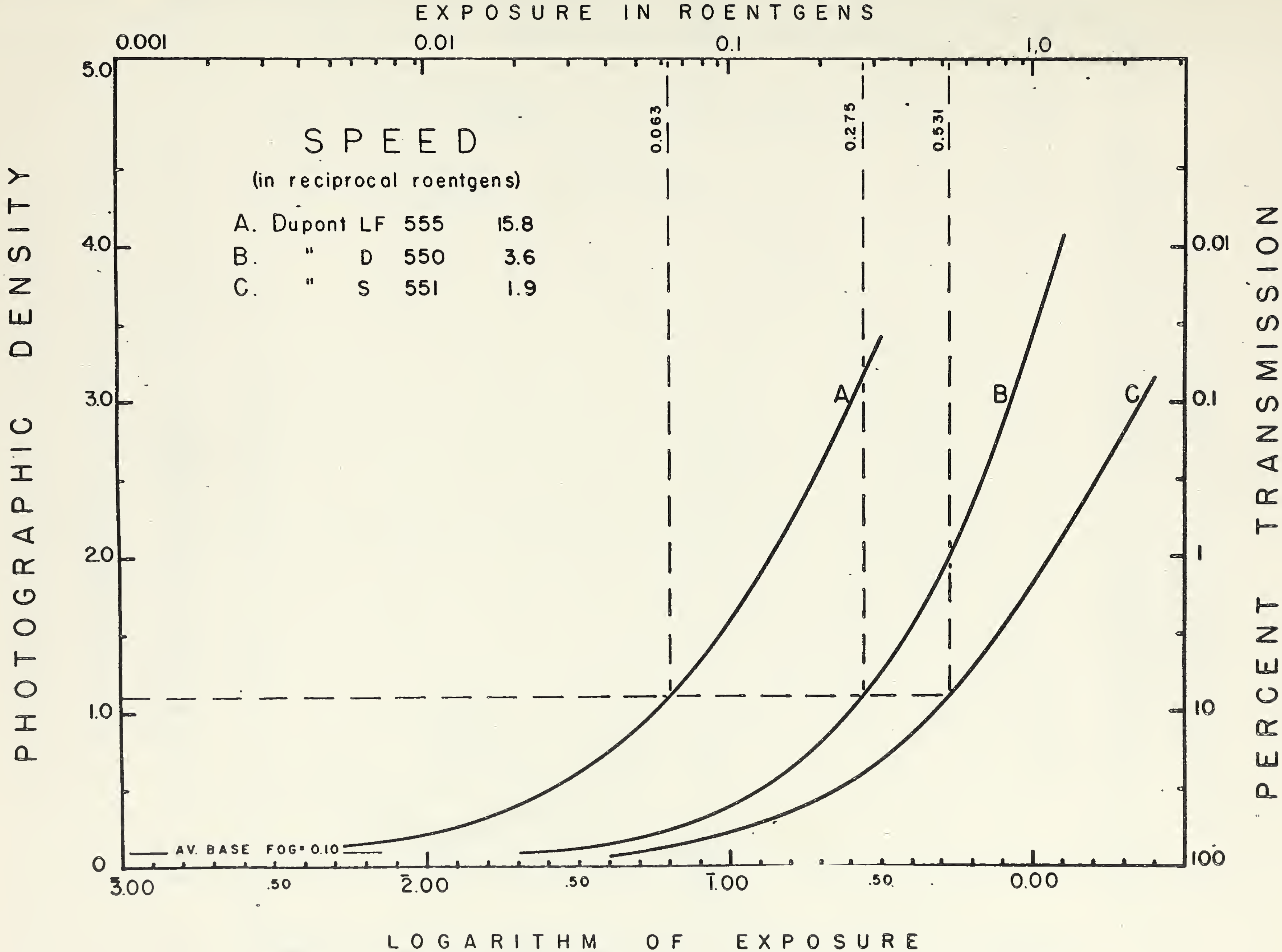

Figure 1. Characteristic curves and speeds of three dental X-ray films.

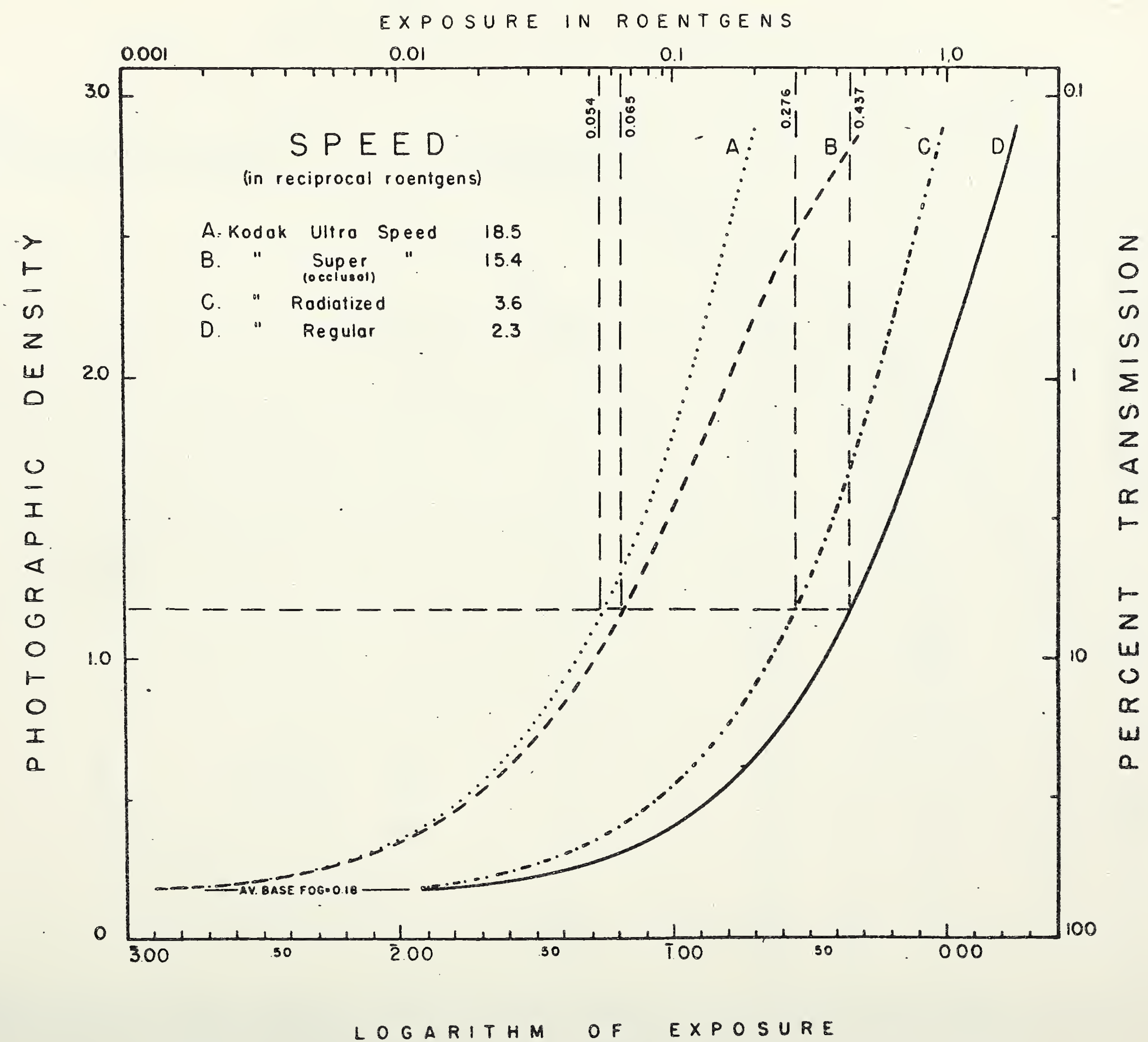

Figure 2. Characteristic curves and speeds of four dental X-ray films.

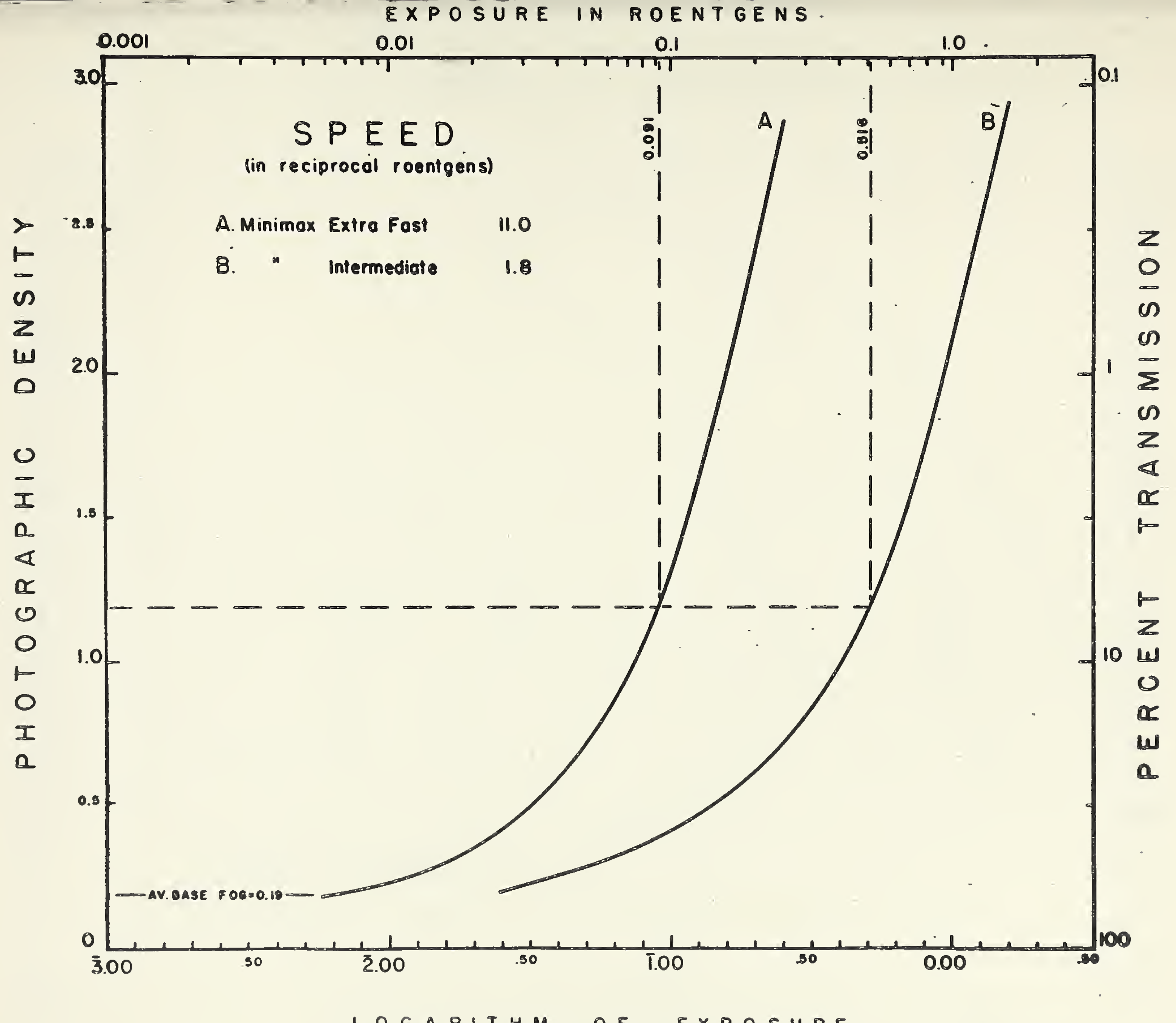

Figure 3. Characteristic curves and speeds of two dental X-ray films.

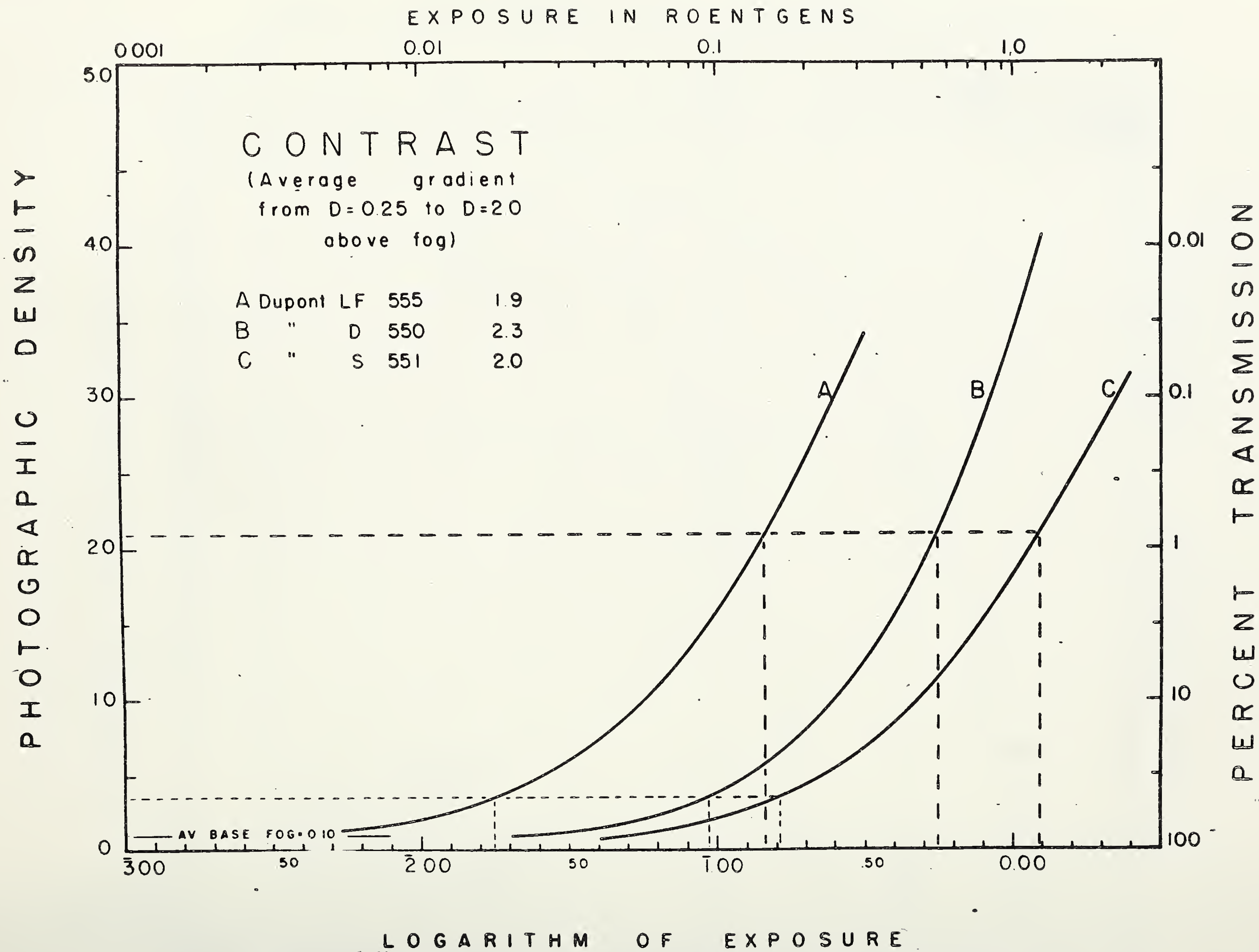

Figure 4. Characteristic curves and contrasts of three dental X-ray films.

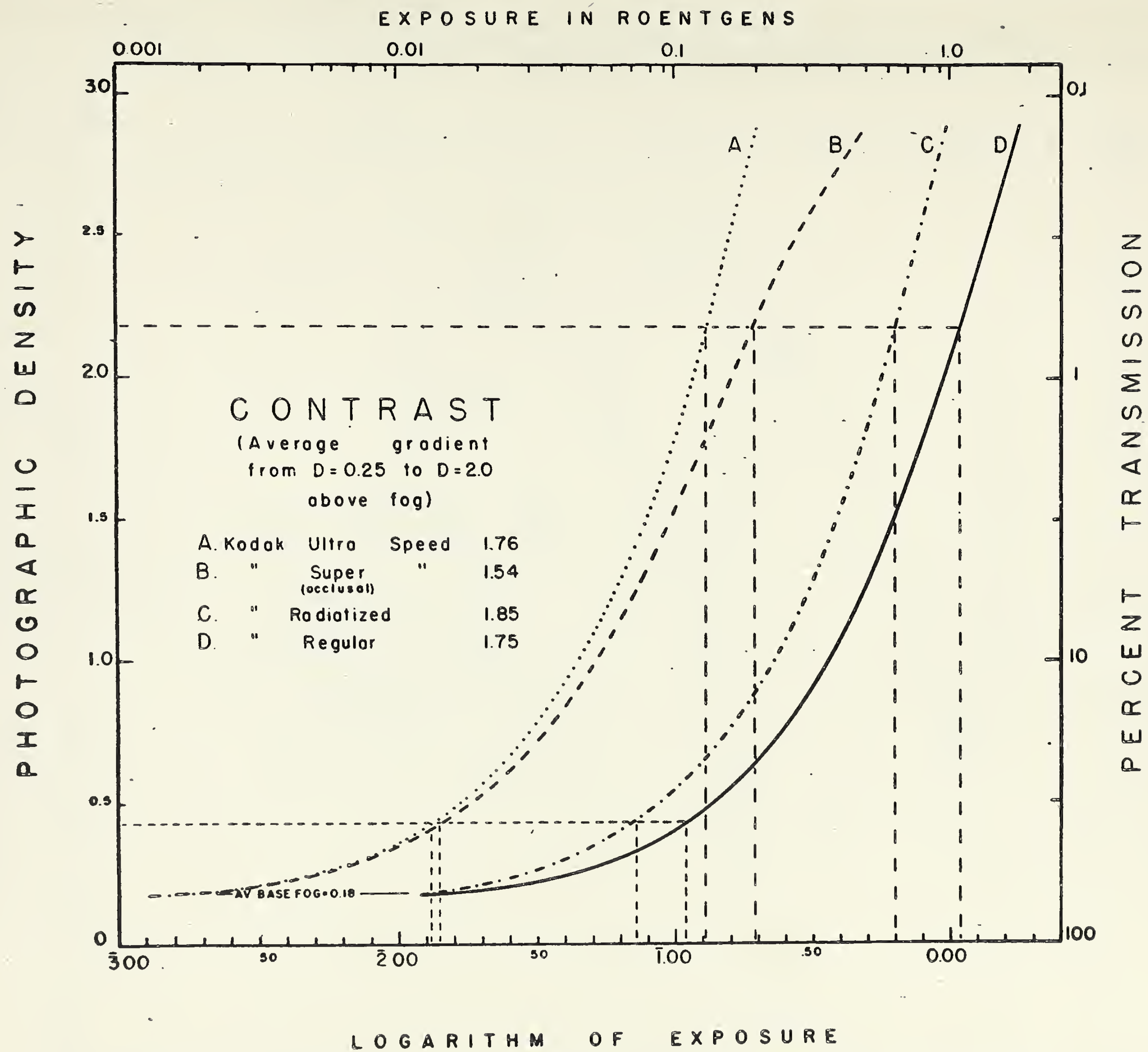

Figure 5. Characteristic curves and contrasts of four dental X-ray films.

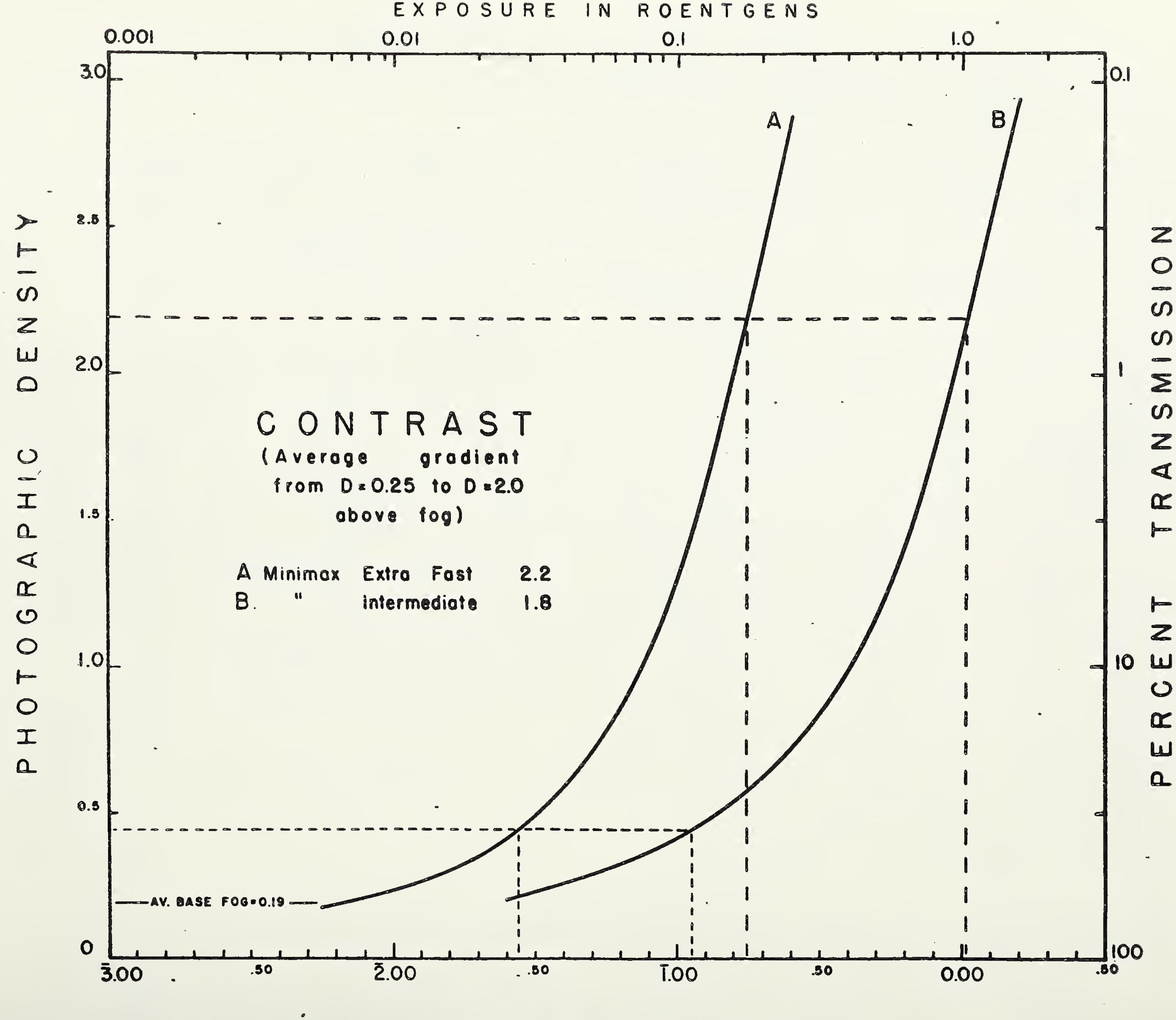

Figure 6. Characteristic curves and contrasts of two dental X-ray films.

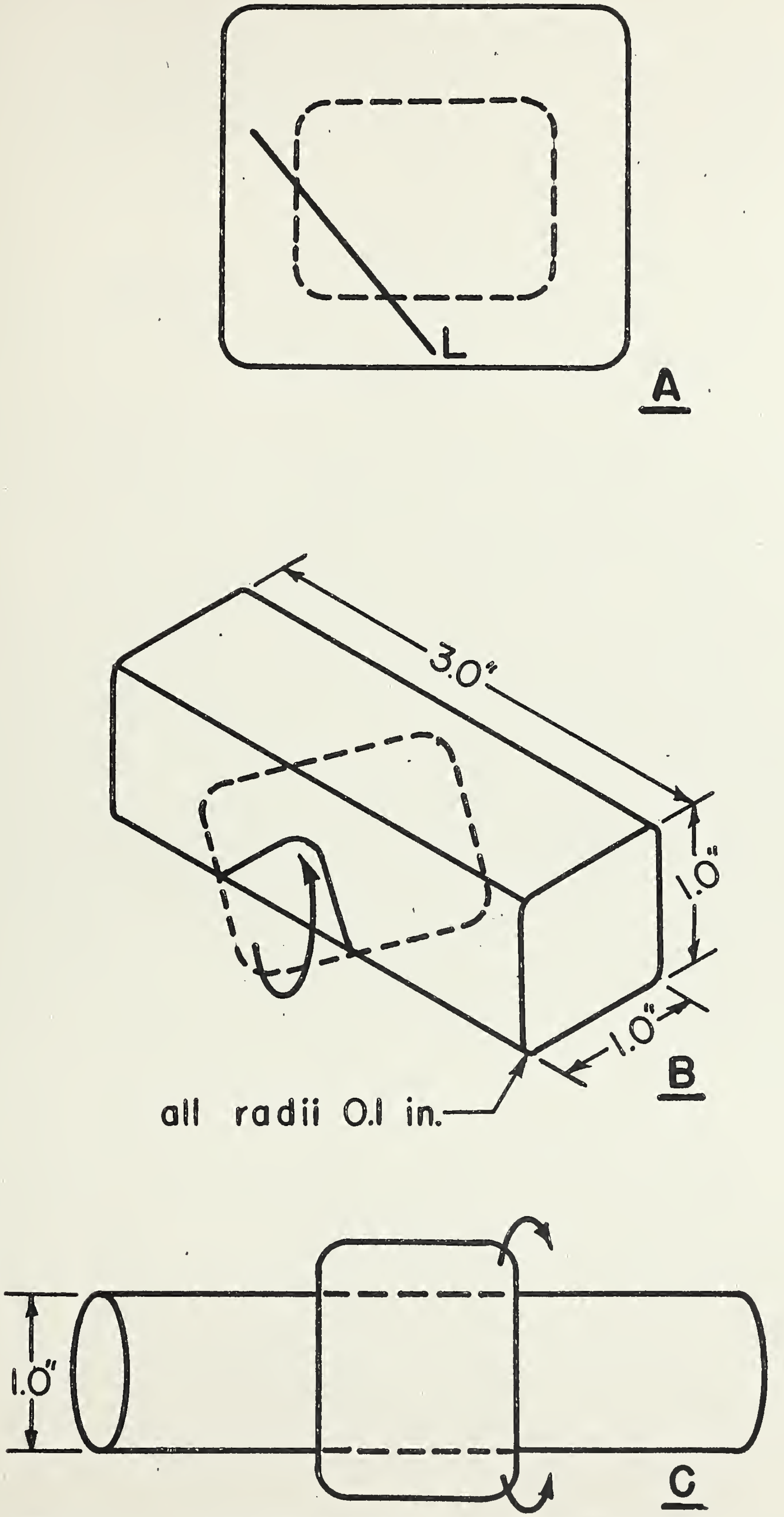

Figure 7. Apparatus used for film deformation for mositure penetration test.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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