ML-TDR-64-277

RESEARCH ON RADIOGRAPHIC TECHNIQUES OF GRAPHITE EVALUATION

TECHNICAL DOCUMENTARY REPORT No. ML-TDR-64-277

NOVEMBER 1964

AF MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 7350, Task No. 735003

(Prepared under Contract No. AF 33(657)-11245 by the
Ohio State University Research Foundation, Columbus, Ohio 43212;
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NOTICES

700 - December 1964 - 448-20-500

FOREWORD

This report was prepared by The Ohio State University, Research Foundation under USAF Contract AF 33(657)-11245. The contract was initiated under Project No. 7350, "Refractory Inorganic Nonmetallic Materials", Task No. 735003, "Theory and Mechanical Phenomena". The work was administered under the direction of the Air Force Materials Laboratory, Research and Technology Division, with Mr. W. L. Shelton acting as Project Engineer.

This report covers work conducted from 1 June 1963 to 31 May 1964.

ABSTRACT

This is the Summary Technical Report prepared on Contract No. AF 33(657)-11245 for Research on Radiographic Techniques of Graphite Evaluation.

Technique charts are presented for the radiography of graphite in the medium thickness range 2 to 14 inches using typical industrial X-ray equipments. Results of experimental data presented in this report demonstrating the problems in the radiography of graphite are due to scatter radiations and economics of inspection. The thicknesses of graphite billets (now ranging up to 103 inches) present geometrical unsharpness problems as related to economy of inspection. When the X-ray source is removed from the film sufficient distances to obtain a reasonable D/T ratio, exposure times become uneconomical.

Techniques reported also demonstrate that better than 1 per cent radiography can readily be obtained using typical industrial techniques and lead filtering, for the ranges of thicknesses from 1/2 to 40 inches.

This technical documentary report has been reviewed and is approved.

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INTRODUCTION

The uses of graphite and graphitic materials are expanding at a very rapid rate in the missile and aerospace industry. The unique physical properties of graphite and its resistance to high temperatures make this a useful material for missile and high-speed aircraft components. The unique physical and chemical properties of the family of carbonaceous materials may be listed as follows:

a. Good electrical conductivity
b. High thermal conductivity
c. Excellent high temperature strength
d. Superior refractory material
e. High thermal shock resistance
f. High sublimation temperature
g. Low modulus of elasticity
h. Good machinability.

The technology of graphite manufacture has expanded since first described by Acheson in 1896, to produce hundreds of grades with various mechanical properties. The manufacture of graphite was considered an art, until very recently, and the various processes were kept as closely guarded secrets. The scientific approach to the manufacture of graphite has occurred only within the past few years due to applications for critical components. For critical components in aerospace vehicles, where failure may cause the loss of lives or failure of mission, quality control becomes an important factor. Knowledge of quality control factors, inspection and nondestructive testing techniques are very limited. It is the purpose of this project to evaluate radiography as a nondestructive testing technique for the inspection of graphite billets. Although other nondestructive tests might be developed, radiography offers the most promise for a quick solution to the problem of inspecting graphite in the billet form.

Radiography has been used for many years as an inspection method for other structural materials used in critical applications. The knowledge and experience gained from the extensive use of this inspection method have been used to prepare specifications that are accepted as standards for the inspection of such materials as steel, aluminum, and other materials. Limited experience and knowledge have been obtained on the radiography of

Manuscript released by authors May 1964 for publication as an RTD Technical Documentary Report.

graphitic materials.

Variables That Affect Radiographic Image Quality

A brief discussion of the parameters that must be considered in the production of radiographs are presented for those who may not be familiar with the X-ray inspection process.

Radiographic Sensitivity. For the radiographic inspection of structural materials, a method has been established to reveal the image quality of the radiography in terms of per cent sensitivity. The film image sensitivity is assumed to be related to the sensitivity revealed by radiographic penetrameters placed on the part being inspected. The penetrameter sensitivity is the penetrameter thickness, expressed in percentage of the total specimen thickness, that produces visible radiographic images of the holes, slots, or other cavities included in the penetrameter to resemble discontinuities. The design and use of such penetrameters are outlined in Specifications MIL-I-6865.

Two factors contribute to the film image quality or the radiographic sensitivity. These are: (a) contrast, or density differences in the film image, and (b) sharpness, or the suddenness with which the density differences occur. Many parameters can affect these two major factors which combine to determine the image quality.

Image Contrast. First, consideration will be given to radiographic contrast as one of the two factors that combine to determine radiographic sensitivity. The contrast exhibited in the image in the processed film is the sum of the subject contrast and the film contrast.

Some of the parameters that affect the inherent contrast of the film are:

a. The Film Contrast Characteristic. Different films have different contrast characteristics affecting the image contrast. The film characteristic curve, sometimes referred to as the "sensitometric curve", or H and D curve, expresses the relationship between the exposure applied to the photographic material and the resulting photographic density. The slope or steepness of the H and D curve is the film contrast.

b. Film Density. The film density affects the contrast or gradient; the greater the density, the greater is the film contrast. The film density is affected by the amount of exposure and processing.

c. Processing. The film processing, particularly development, can affect the film contrast. The time of development, the particular developer being used, and fog caused in the developer all affect the film contrast.

d. Screens. Various screens are used in industrial radiography, either to enhance film speeds; that is, to provide an intensifying action, or to act as a filter to the X-ray beam. The screen and the screen-film combination can affect film contrast.

e. Film Fog. Film fog can be caused by age or by any source of exposure, such as darkroom lights, stray radiation, or heat. This fogging produces an even exposure and reduces the image contrast.

Other parameters affecting the film contrast may affect the image contrast, but those mentioned above are considered the most important.

Test-Object Contrast. The test-object contrast is the contrast due to the test object reaction with the X-ray beam and is the actual contrast in the transmitted image.

a. Geometry of Test Object. The geometry of the test object greatly affects the contrast. This is usually referred to as the "test-object contrast". For instance, a test object of uniform thickness presents very small differences in radiation intensities, resulting in a low-contrast radiograph.

b. Test-Object Material. The material of the test object affects contrast due to the transmission characteristic of the particular material. Dense materials offer greater contrast than low-density materials. Large variations in material thicknesses, or material densities produce high-contrast images.

c. Kilovoltage. The kilovoltage, or energy, of the X-rays determines the penetrating ability of the radiation and affects the radiographic contrast. The mass absorption coefficient, μ, is related to the atomic number and density of the material, and specific values are applicable only to a specific energy of radiation.

d. Scatter Radiations. Scattered radiation adds exposure to the radiograph, but this scatter radiation does not have image-carrying qualities. Scatter reduces image contrast in approximately the same manner as film fogging. In radiography, the amount of scatter can be very detrimental to image visualization. This scatter is affected by the wavelength of the radiation, the atomic number of the test material, and the thickness of the test object. Scattering can occur from objects surrounding the test object, from the material supporting the film and test object (commonly called "back-scatter"), or from any objects in the path of the radiation beam.

Image Unsharpness. The unsharpness of an image affects the visualization of radiographic detail of the test object. Several factors affect the image sharpness. Some of these factors are:

a. The Film. Grain size of the silver halide crystals affects the image sharpness. Therefore, the finer the grain size, the better is the detail in the resulting image if all other parameters are constant. However, finer-grained films are usually slower in response to X-ray exposure.

b. Distortion. The shadow image of a test object can be affected by the angle of the central ray as related to the film plane. Normally, the more nearly the film is placed perpendicular to the radiation beam, the less distortion occurs. This distortion can obliterate fine detail of the test object.

c. Geometrical Unsharpness. The geometrical unsharpness is the penumbral shadow caused by the focal-spot size and distance relationships. Since the geometrical unsharpness is so important in the radiography of thick sections of graphite, more details of this problem will be considered later in this report.

d. Undercutting. Undercutting is usually referred to as the "high density" of the radiograph at the edges of the material, especially where great thickness differences occur. This is mostly due to scatter radiation that originates in the surfaces of the test object or surrounding materials and tends to obliterate the detail of the edges.

It is evident from the brief description of some of the parameters that affect the radiographic image quality that a great number of variables must be considered to determine optimum techniques.

Results of Literature Survey

Attempts were made to gather up-to-date information on the state-of-the-art in the radiography of graphite. It appears that very little literature exists on this subject. Available literature was procured and studied to gain information on past work in this field. (See References.)

A form letter was prepared and sent to 15 manufacturers and users of graphite and graphitic materials. This letter requested information on the quality-control procedures and nondestructive tests conducted on graphite in each particular facility. Answers to this request indicate that little nondestructive testing is done on graphite. Only two companies indicated that any nondestructive tests are conducted. Most of the companies indicated that quality control is a matter of determination of the carbon content and a microscopic determination of crystalline structure. Very little useful information was received from these graphite users or manufacturers. The manufacturers were very generous in answering the request for information and their cooperation is greatly appreciated.

Procurement of Graphite Material for Test Purposes

Various graphite materials were procured for test purposes. Some of this material is identified as to grade, but volume-weight measurements were made to determine the material density. A billet of CFW grade of graphite was received from National Carbon Company through the courtesy of the sponsor, Wright-Patterson Air Force Base. This billet was originally 30 inches in diameter and 40 inches in length. For ease of handling, the billet was cut across the longitudinal dimension to form 3 pieces; 20, 13, and 7 inches in thickness. The 7-inch piece was broken and damaged. Sections were used to fabricate penetrameters for radiographic tests.

A 14-inch diameter billet was cut to form test pieces 4 inches thick by 14 inches in diameter. This material has a density of approximately 1.7 gm/cc, and can be stacked to provide a range of thicknesses for radiographic test purposes.

Radiation Absorption by Graphite

The available literature and past experience in radiography indicate that the greatest problem in the radiography of graphite is the production of scatter radiation by the test material. The absorption characteristics of graphite are graphically presented as Fig. 1. It is interesting to note that practically all of the radiation absorption between 70 kvp and 30 Mev is due to scattering of the primary radiation beam. This scattering is mostly Compton scattering, and tends to produce other scattered rays producing degenerated radiation commonly called "scatter build-up".

Comparison of Graphite to Aluminum

A theoretical comparison was made between aluminum with graphite absorption characteristics. The knowledge and experience gained in the radiographic inspection of aluminum should be applied to the radiography of graphite, if at all possible. The possibility of making such a comparison for use in the radiography of graphite was considered justification of a theoretical comparison. Table I shows the comparative absorption coefficients for aluminum and graphite. This table also shows linear absorption per centimeter and per inch for graphite with a density of 1.8 gm/cm^2.

Fig. 2 is a graphical comparison of the linear absorption coefficients per inch for aluminum and for graphite with a density of 1.8.

Table II shows the per cent radiation transmitted through various thicknesses of graphite (D = 1.8) and aluminum for 50 and 100 kilovolt monochromatic radiation.

Tables I and II and Fig. 2 illustrate the theoretical comparison of aluminum and graphite. In actual practice, the build-up of scatter radiation causes the graphite to give readings in excess of the theoretical values.

Fig. 3 is a graph that illustrates the theoretical absorption values for graphite (D = 1.8) and aluminum, for monochromatic radiation with an energy of 100 kv. It is interesting to note that the ratio is approximately 1 to 2.7, therefore, from the theoretical calculations, 1-inch aluminum techniques should be applicable for the radiography of 2.7 inches of graphite. Due to the

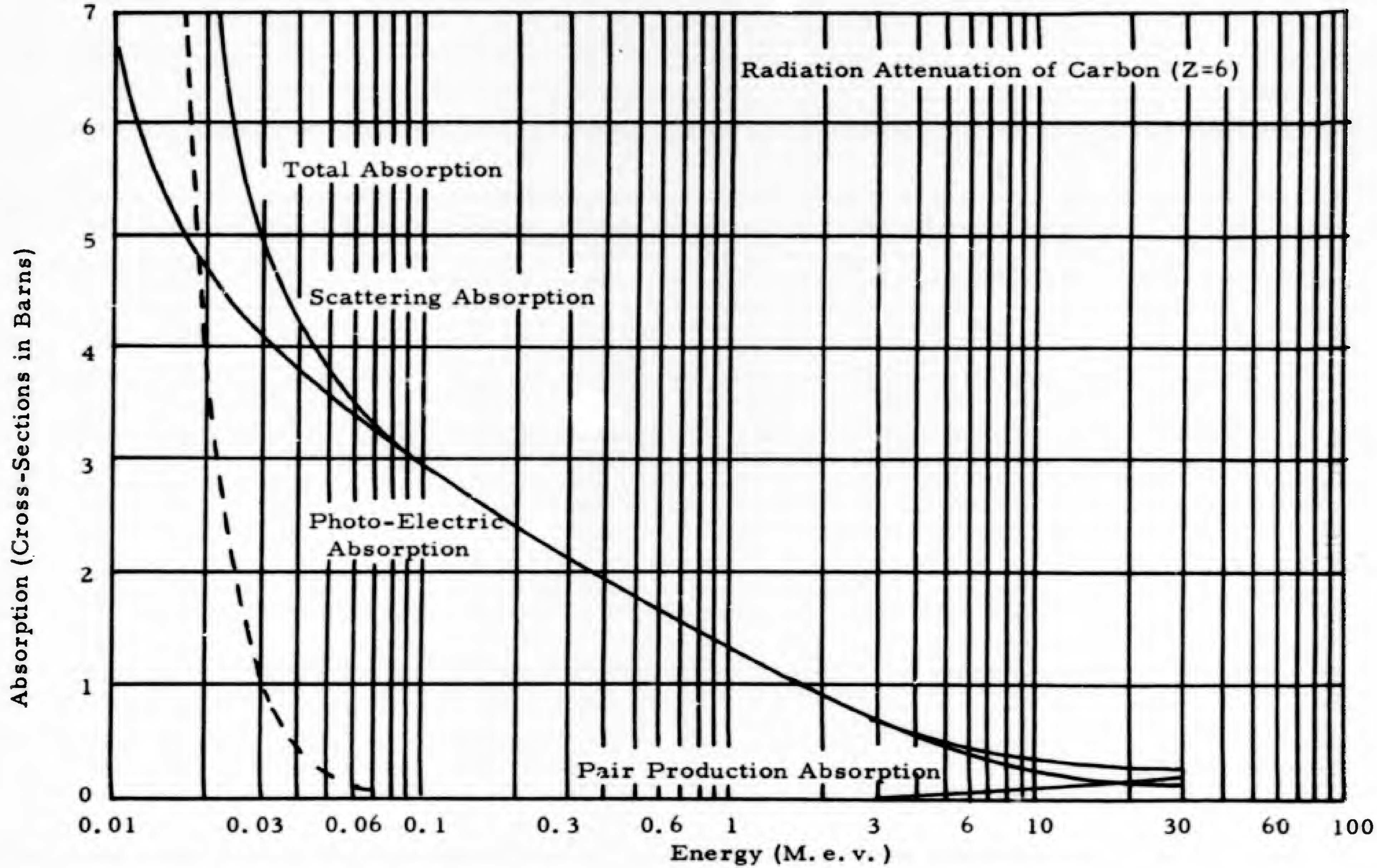

Fig. 1. Absorption characteristics of carbon (Z=6) as a function of energy.

TABLE I.
COMPARATIVE ABSORPTION COEFFICIENTS
FOR GRAPHITE AND ALUMINUM

Monochromatic Radiation Energy Mev.	Graphite Mass Absorption Coefficient ρ	Graphite Density 1.8 Linear μ/cm.	Graphite Density 1.8 Linear μ/cm.	Aluminum Linear μ/in.
0.010	2.280	4.100	10.410	183.800
0.015	.778	1.400	3.550	55.300
0.020	.429	.770	1.950	23.870
0.030	.252	.453	1.150	7.740
0.040	.205	.369	.937	3.810
0.050	.186	.335	.850	2.440
0.060	.175	.315	.806	1.850
0.080	.162	.291	.739	1.371
0.100	.153	.275	.698	1.165
0.15	.135	.243	.617	.947
0.2	.123	.221	.561	.835
0.3	.107	.192	.487	.713
0.4	.0953	.171	.434	.636
0.5	.0873	.157	.398	.579
0.6	.0808	.145	.368	.533
0.8	.0707	.127	.322	.467
1.0	.0637	.114	.289	.421
1.5	.0517	.093	.236	.342
2.0	.0444	.080	.203	.294
3.0	.0356	.064	.162	.243
4.0	.0305	.055	.139	.212
5.0	.0270	.0486	.123	.194
6.0	.0246	.0440	.117	.182
8.0	.0214	.0385	.0976	.166
10.0	.0195	.0350	.0889	.157
15.	.0169	.0304	.0772	.148
20.	.0156	.0280	.0711	.147
30.	.0146	.0262	.0667	.149

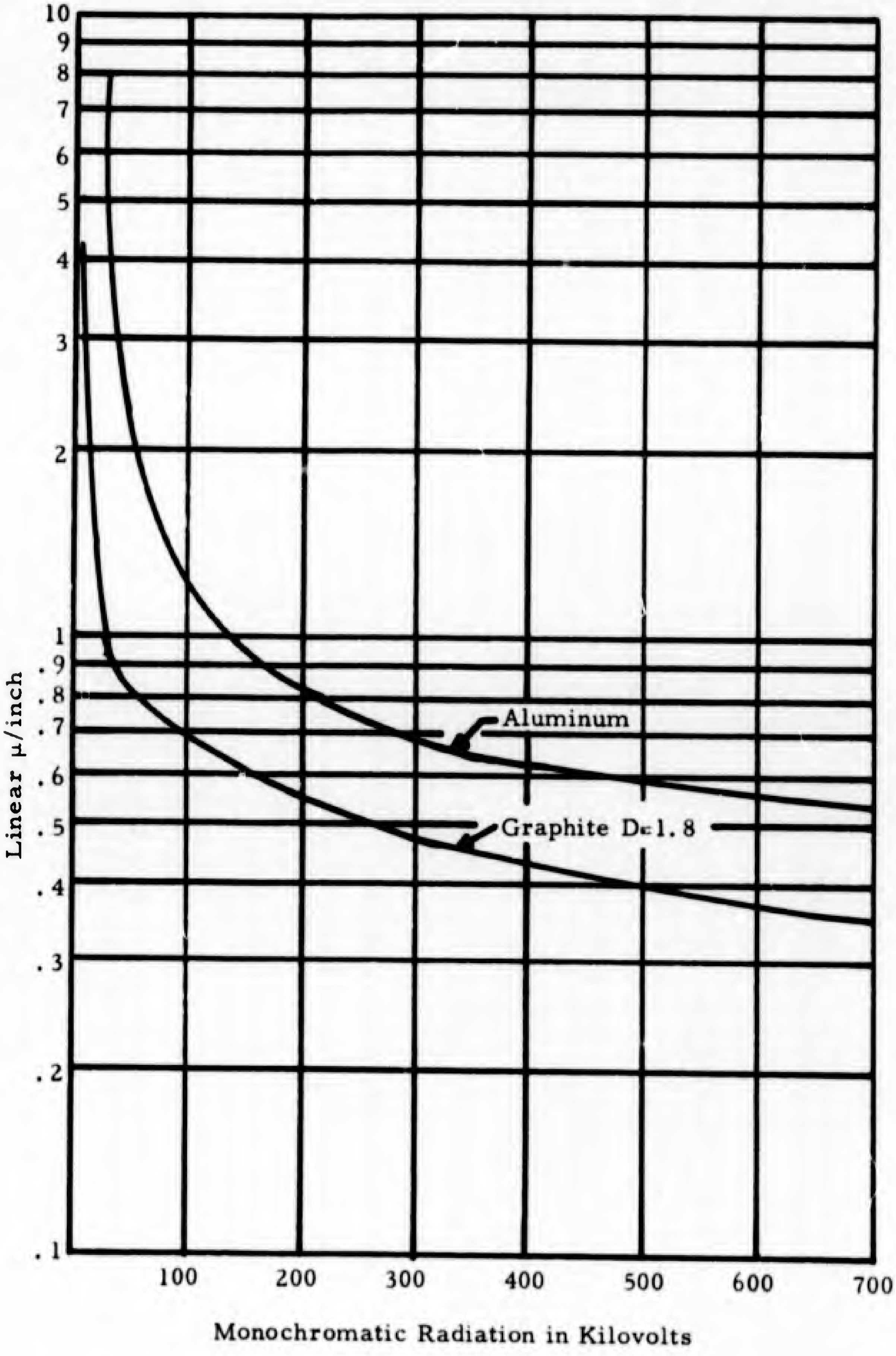

Fig. 2. Graph showing the comparison of the linear absorption per inch of graphite (D = 1.8) and aluminum for various radiation energies.

TABLE II.
COMPARATIVE ABSORPTION FOR GRAPHITE AND ALUMINUM

Thick-ness inches	50 KV μx Graphite	Radiation Transmission Percent (%)	50 KV μx Alum.	% Trans.	Thick-ness inches	100 KV μx Graphite	% Trans.	100 KV μx Alum.	% Trans.
.25	.212	80.9	.610	54.2	.25	.174	84.	.291	74.8
.50	.425	66.2	1.22	29.5	.50	.349	78.	.582	56.
.75	.637	53.	1.83	16.1	.75	.523	59.5	.873	42.
1.0	.850	43.1	2.44	8.8	1.0	.698	50.	1.165	31.2
1.25	1.062	34.8	3.05	4.7	1.25	.872	42.	1.456	23.4
1.5	1.275	28.	3.66	3.2	1.5	1.047	35.1	1.74	17.8
2.	1.70	18.4	4.88	.68	2.	1.396	25.	2.33	9.8
3.	2.55	7.8	7.32	.066	3.	2.094	12.4	3.49	3.1
4.	3.40	3.35	9.76		4.	2.79	6.2	4.66	.98
5.	4.25	1.45	12.20		5.	3.49	1.3	5.82	.3
8.	6.80	.12			8.	5.58	.4	9.32	.0098
10.	8.50	.021			10.	6.98	.1		
12.	10.20				12.	8.37			
14.					14.	9.77			

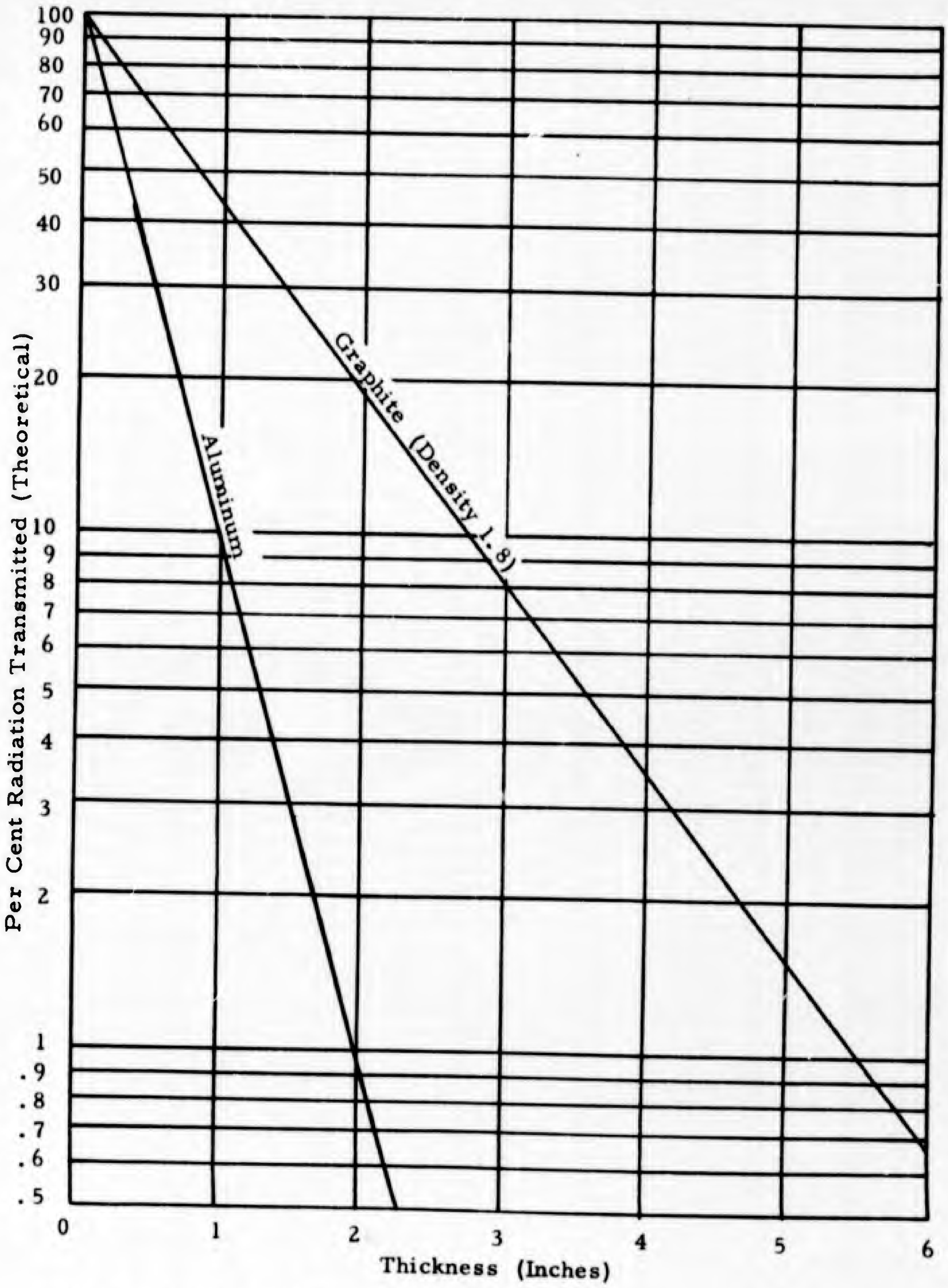

Fig. 3. Theoretical comparison of radiation transmission of aluminum and graphite for 100 kv. monochromatic radiation.

build-up scatter radiation emitted by the graphite, actual absorption does not coincide with the theoretical calculations. To reveal the magnitude of the build-up scatter, a radiograph was made using 1 inch of aluminum on one half of the film holder and 2.7 inches of graphite adjacent to the aluminum. Actual film density of the aluminum was 1 H and D Unit and the graphite was 2.5. This test indicates the actual relationship of aluminum to graphite under typical industrial radiographic practice. It is expected that industrial X-ray laboratories are using an X-ray exposure much less than should be used and the build-up scatter radiation is producing the film density.

Radiation Transmission Measurements for Graphite

The scatter radiation appears to be the problem in radiography of graphite. Several techniques were used to obtain actual measurements to evaluate the magnitude of the scatter radiation.

A Victoreen 510 Rate Meter was used for making the radiation transmission measurements. A lead protective housing was made to fit over the ion chamber. This lead shield has a front thickness of 1.18 inches and the side walls are 1/4-inch, to prevent radiation transmission. When placed in the direct radiation beam this shielding was sufficient to eliminate any radiation reading. A hole with a diameter of 0.114 inch was made in the front of the shield to permit entrance of the radiation to the ion chamber. A sketch of this test arrangement is shown as Fig. 4. This test arrangement permitted the central rays of the primary beam to strike the ion chamber and also includes scatter radiations with an angle of 5-1/2 degrees or less with respect to the primary beam axis. This small-angle forward scatter can be considered as containing the small-angle forward scatter and would contribute to the radiographic image. Radiation transmission measurements were made through various thicknesses of graphite at different radiation energy levels using the shielded ion probe. These measurements are considered to eliminate the undesirable scatter radiations. Fig. 5 shows the per cent of radiation transmitted through graphite with the elimination of the undesirable scatter. It is interesting to note that these form straight lines on semi-log graph paper and approach theoretical values.

This information was replotted on log-log graph paper as shown in Fig. 6 to provide contrast or gamma curves. The gamma or contrast values are shown on this graph for the material thickness and kilovoltage combinations.

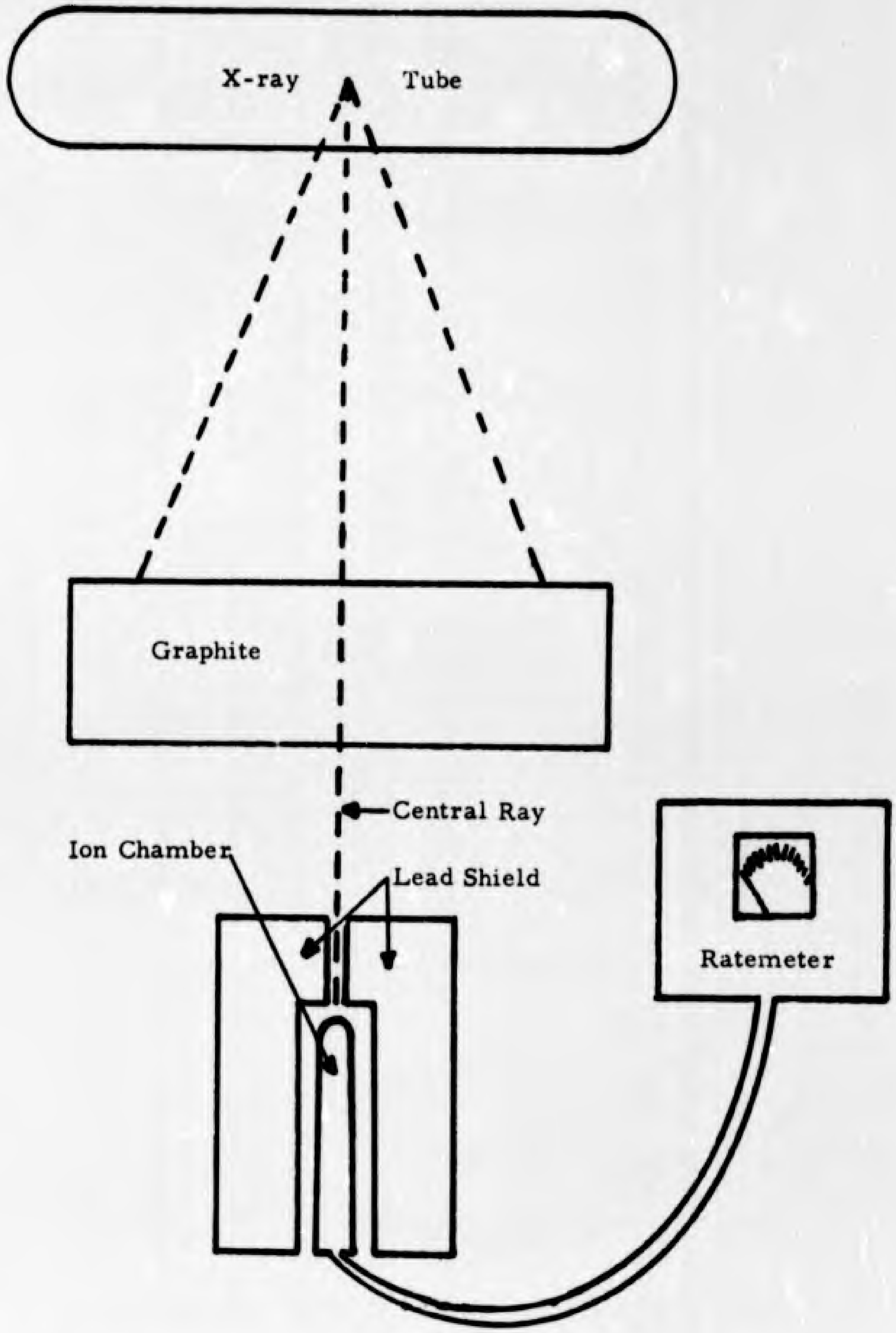

Fig. 4. Sketch of test arrangement for radiation transmission measurements eliminating most of the scatter.

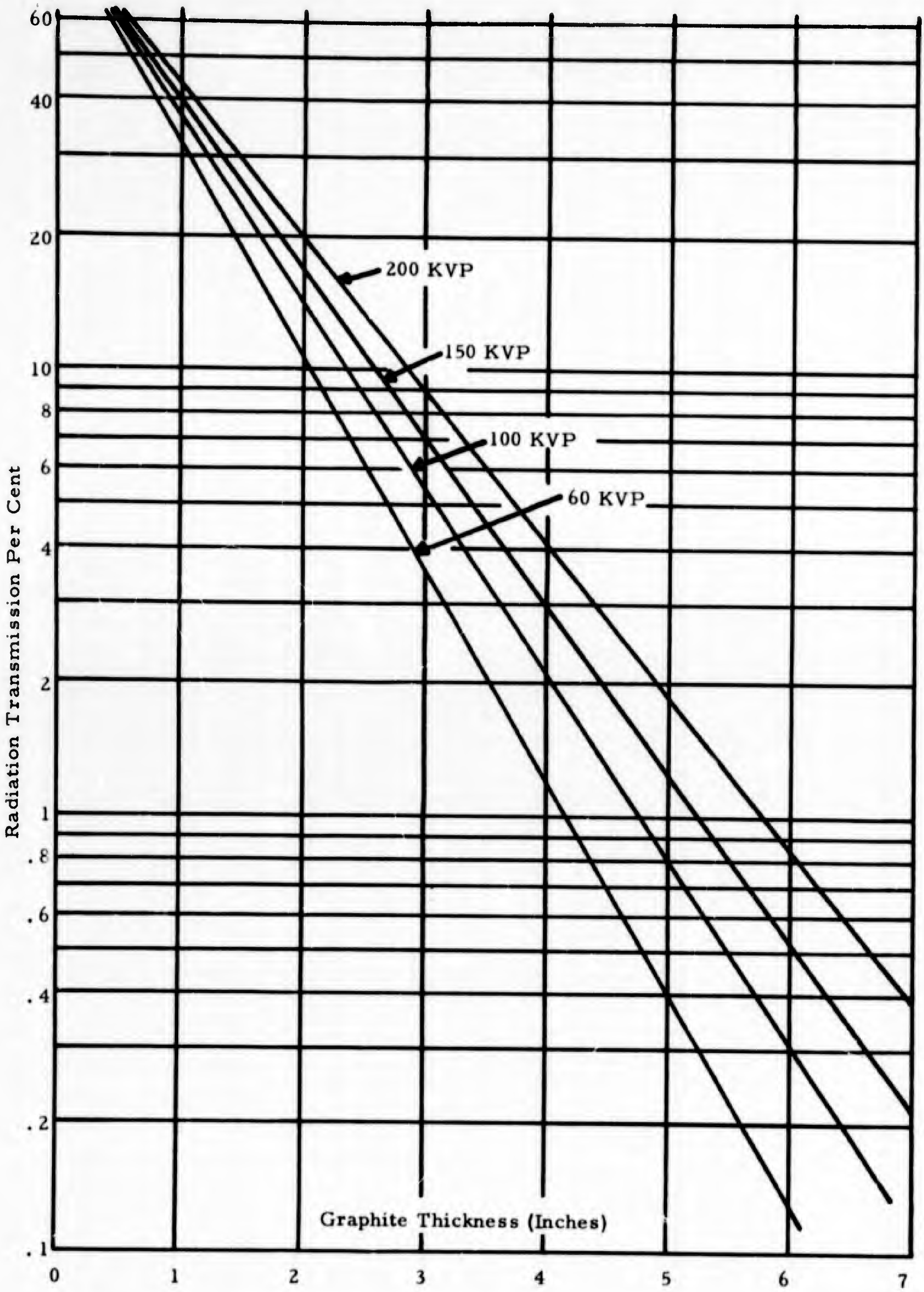

Fig. 5. Per cent radiation transmitted through various thicknesses of graphite at different energy levels. Scatter reduced to 5.5 degree angle and less.

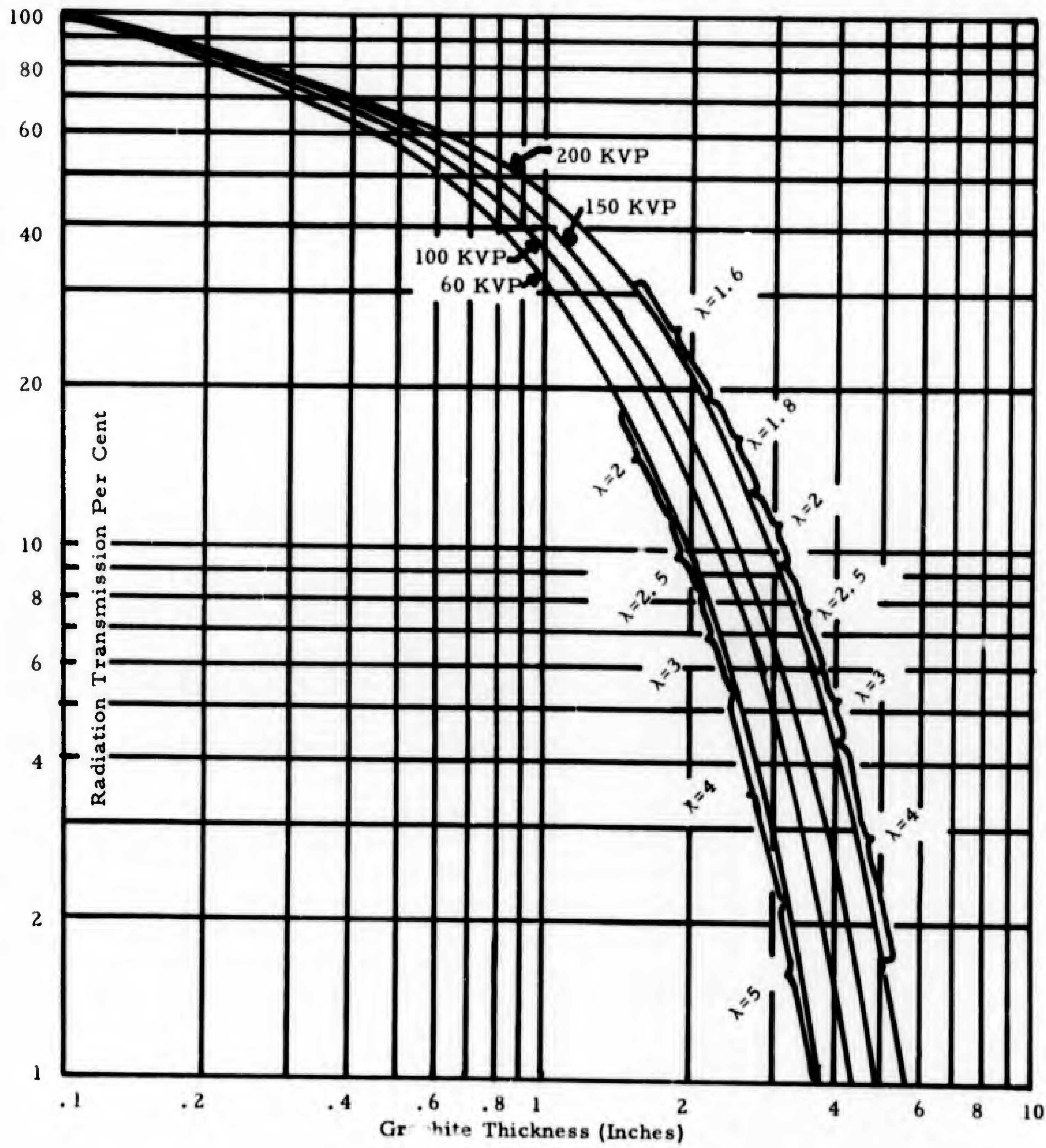

Fig. 6. Material contrast (or gamma) curves for graphite with only small angle scatter included. Approximate gamma values of 60 and 200 kvp curves are shown.

Radiation transmission measurements were made through the same material and using the same conditions, but with the lead shield removed from the ion chamber. These readings are considered to include the build-up scatter radiation emitted from the back of the graphite material. The results of these measurements were plotted on log-log graph paper and shown in Fig. 7. This provided a means of comparing the material contrast values for conditions with and without the undesirable scatter radiation.

The comparison of contrast values are shown in Fig. 8 for the conditions with scatter radiation (no filtration), the effect of a 0.005-inch lead filter and 5.5 degree forward scatter only. The difference between the 5.5 degree scatter radiation readings and the readings that include the entire scatter was plotted and shown in Fig. 9 to demonstrate the magnitude of the scatter problem in the radiography of graphite. This can be compared to what might be called a "signal-to-noise ratio" and illustrates that for 5 inches of graphite, the scatter is equal to about 10 times the image-carrying radiation beam. These data have been presented to illustrate the magnitude of the scatter radiation problem in the radiography of graphite materials.

Results of Experiments in the Reduction of Scatter Radiation

Various techniques are commonly used to reduce scatter radiation in the transmitted beam. These include the use of filters, grids, and movable grids (or Potter-Bucky Diaphragms). High-energy radiations produce less scatter than low energies, but image contrast is reduced due to the lower absorption of the radiation.

Various methods and combinations of methods have been studied in an effort to determine optimum techniques for the reduction of scatter radiation.

Use of Filters for Reduction of Scatter Radiation. Filters can be inserted between the film (or recording medium) and the back of the graphite to remove some of the scattered radiation from the image-carrying beam. This filter technique is applicable due to the loss of energy of the primary beam when collisions occur with electrons in the absorbing material. This loss of energy changes the wavelength of the radiation, but a single collision changes the wavelength very slightly. From Reference 5, the change in wavelength can be stated

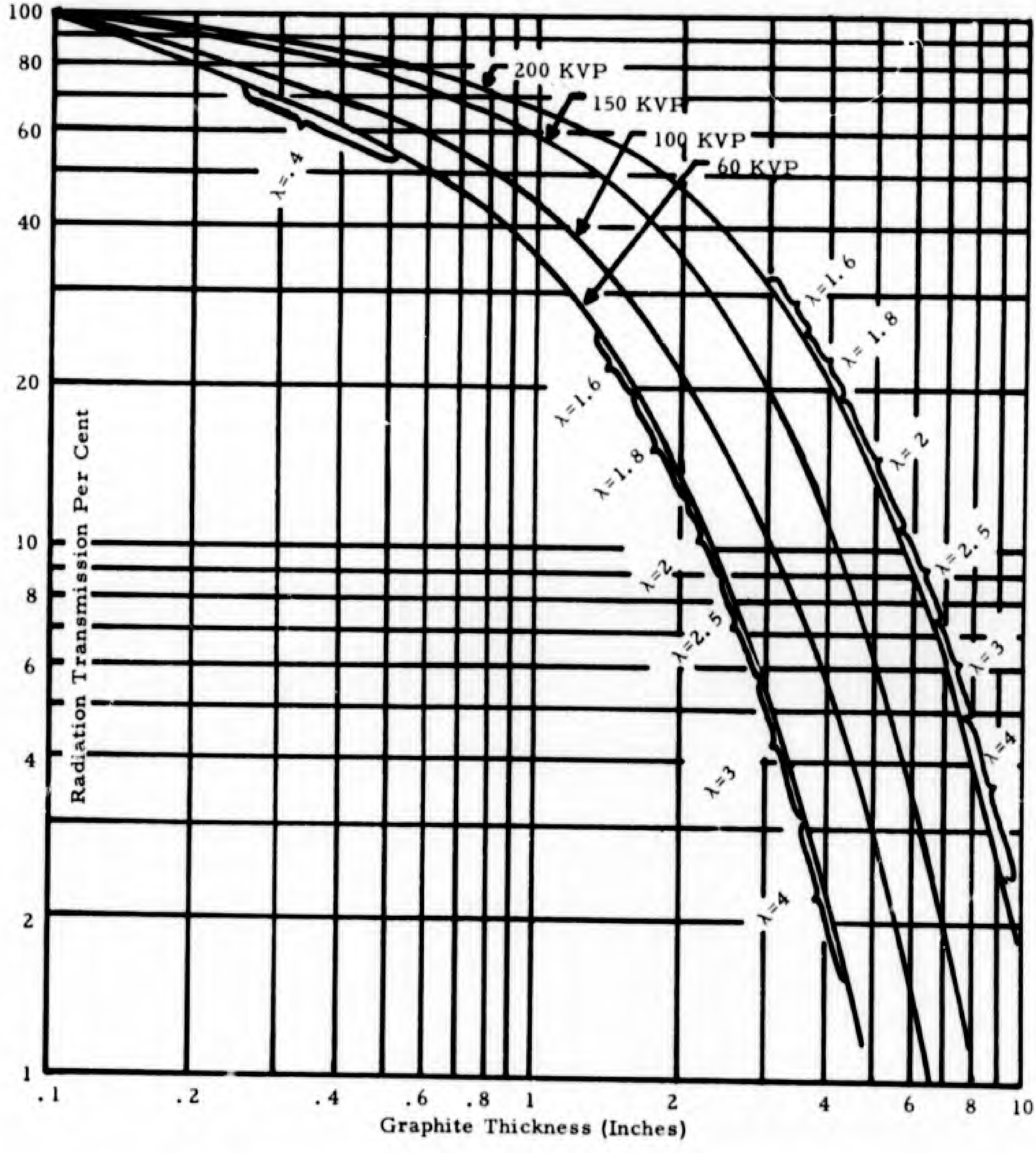

Fig. 7. Material contrast or gamma curves for graphite with the scatter radiation included. Gamma values are shown at various points on the curves.

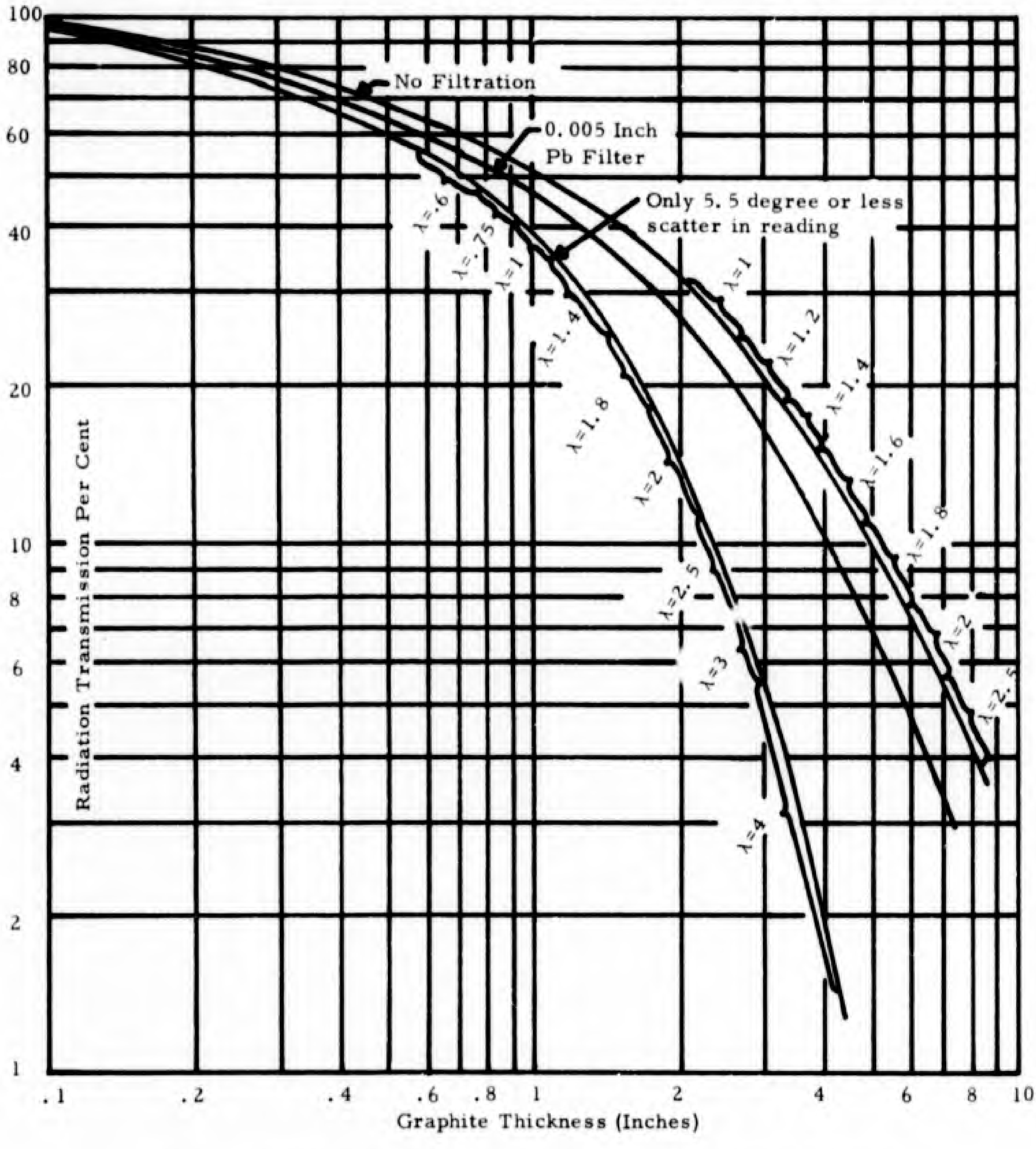

Fig. 8. Contrast or gamma curves illustrating the effect of scattered radiation on gamma values with 200 kvp X-radiation.

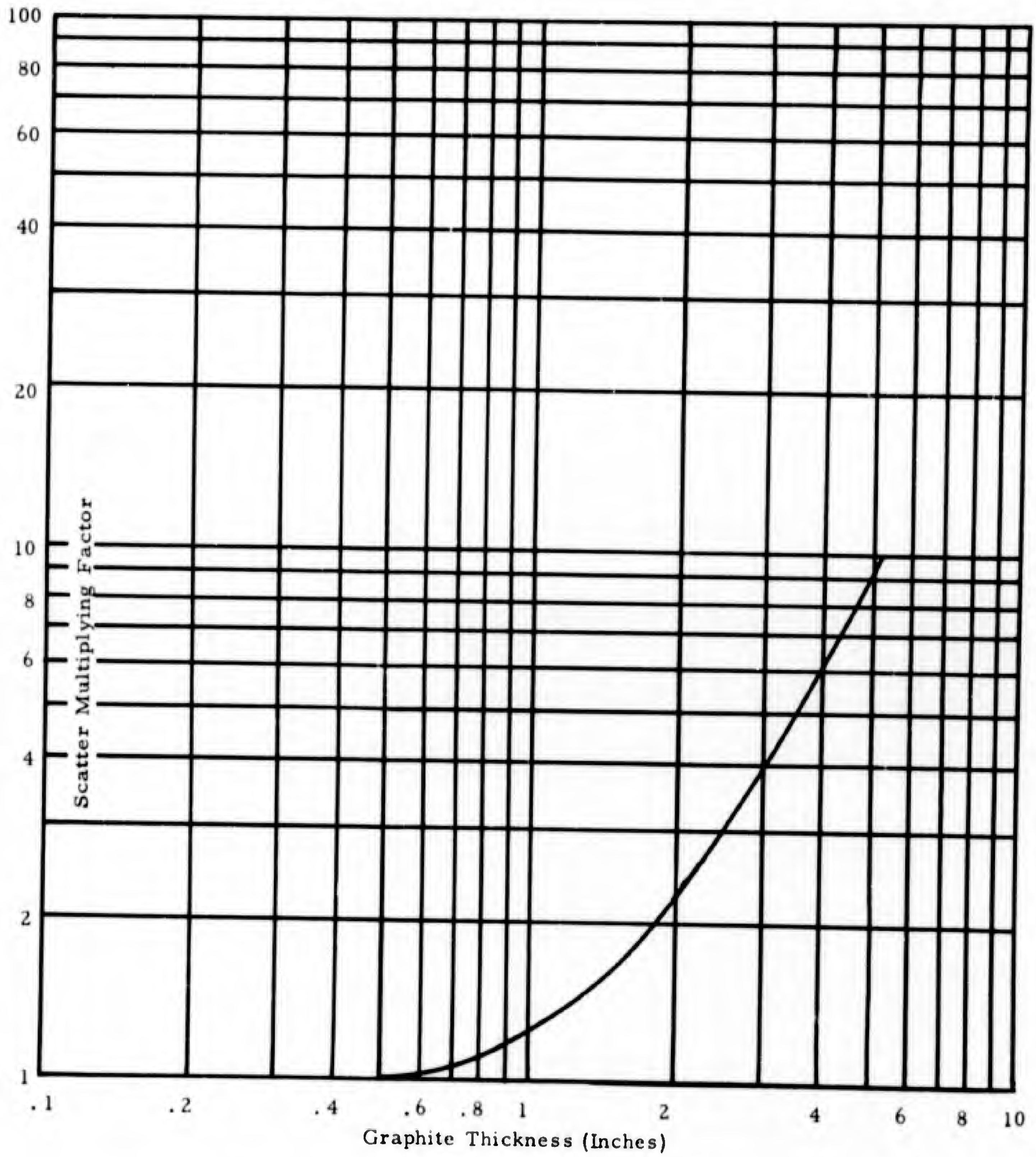

Fig. 9. Scatter radiation multiplying factor as related to graphite thickness for 200 kvp X-radiation.

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}(1 - \text{Cos}\,\phi) \qquad (1)$$

Thus, the change in wavelength equals the wavelength of the scattered photon, minus the wavelength of the original photon

$$\lambda' = \frac{h}{mc}(1 - \text{Cos}\,\phi) + \lambda \qquad (2)$$

where:

h = Planck's Constant (6.624×10^{-27} erg. sec.)
m = Mass of the electron (9.1×10^{-28} gms)
c = Velocity of light (3×10^{10} cm/sec)

Thus,

$$\frac{h}{mc} = \frac{6.62377 \times 10^{-27}}{(9.10721 \times 10^{-28})(2.99790 \times 10^{10})} = 0.0243\ \text{Å} \qquad (3)$$

Therefore, as an example:

$$\lambda' = 0.0243\,(1 - \text{Cos}\,\phi) + \lambda$$

If $\lambda = 0.2$ Å and the angle of scatter $\phi = 15^{o}$, Cos $15^{o} = 0.96593$ and $1 - 0.966 = 0.044$, $\lambda' = (0.0243 \times 0.044) + 0.2 = 0.201069$ Å.

The above equation reveals that the original photon transmits a very small amount of energy to the electron in a single collision, and therefore changes only slightly in wavelength ($\lambda' - \lambda \simeq 0.001069$ Å). As an example, a photon with a wavelength of 0.2 Å (energy level of 61.975 kv), when colliding with an electron and being deviated from its original path by 15^{o}, changes wavelength to 0.201069 Å (61.650 kv).

Apparently the scattered radiation generated in a graphite material is a result of many collisions, forming degenerate heterogenous scattered radiations, commonly called "build-up scatter".

Although various filter materials and thicknesses have been used, an example of the filtering effect of 0.005-inch of lead is shown in Fig. 10. This graph shows the scatter-multiplying factor for: (a) 100 kvp radiation; (b) 200 kvp radiation; and (c) 100 kvp radiation with 0.005-inch lead filtration. This shows how the

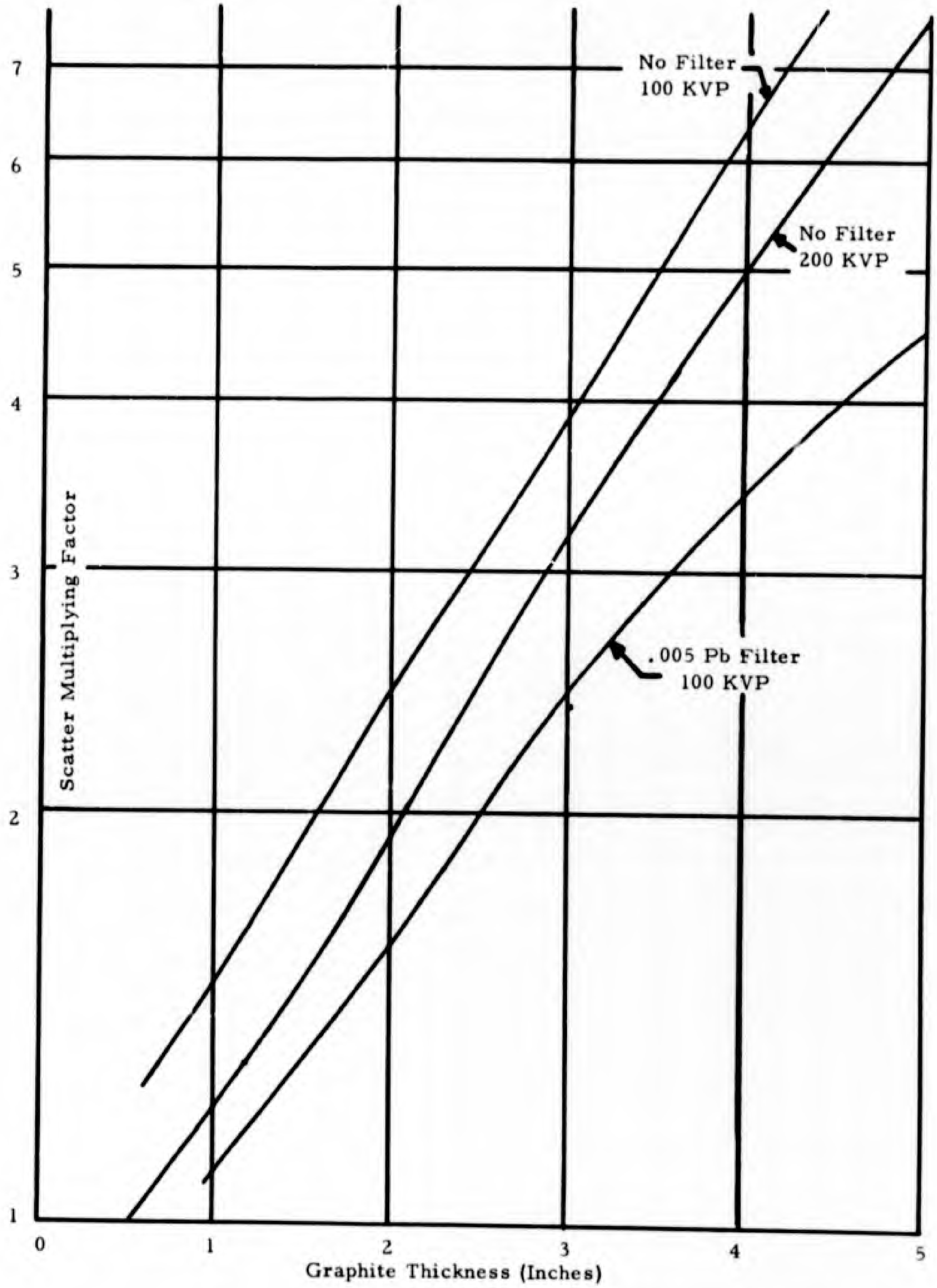

Fig. 10. Scatter radiation multiplying factor for various thicknesses of graphite as a result of 0.005-inches of lead filtration.

lead filter reduces the scattered radiation, but increases exposure times considerably.

Test radiographs were made to illustrate the effect of filtration on image quality. Exposures were made through 4, 5, and 6 inches of graphite with all parameters identical with the exception of added filtration and increased exposure time (10 times) to compensate for the absorbed radiation. The film density was read on a McBeth Densitometer and the results are shown in Fig. 11. The radiograph with the 0.005-inch Pb plus 0.005 Cu filtration revealed better than 1.4 per cent radiographic sensitivity. It is evident that filtration can be used to remove the scatter radiation to produce high-quality radiographs.

Use of Grids for Removal of Scatter Radiation.

Aligned grids have been used for many years by the medical profession for removal of scatter radiation. These grids are assembled by using laminates of lead (as a radiation absorber) and a material relatively transparent to radiation, usually wood. These are often used stationary in front of the film to absorb the large-angle scatter. When used stationary the lead laminations show in the radiograph and are considered objectionable by most film readers.

A mechanism designed to move the grid is called a "Bucky" and moves the grid during the X-ray exposure, thus eliminating the grid lines on the radiograph.

Liebel-Flarsheim Company loaned two grids for evaluation studies. One of these was a "Superfine" 133-line-per-inch, 10:1 ratio, aligned for 72 inches. The other grid was an 80-line-per-inch, 16:1 ratio aligned for 40 inches.

Fig. 12 is a photographic 1:1 reproduction of an X-ray image made of the 133-line grid and Fig. 13 is an image of the 80-line grid. The X-ray exposures were made at the focal-film distances for which the grids were manufactured. Figs. 12 and 13 show the anomalies in the grids themselves that produce variations in density on the radiographs.

Absorption of the grids is shown in Fig. 14 as compared to the absorption of lead foils of various thicknesses. Exposure techniques for the use of grids are presented in this report.

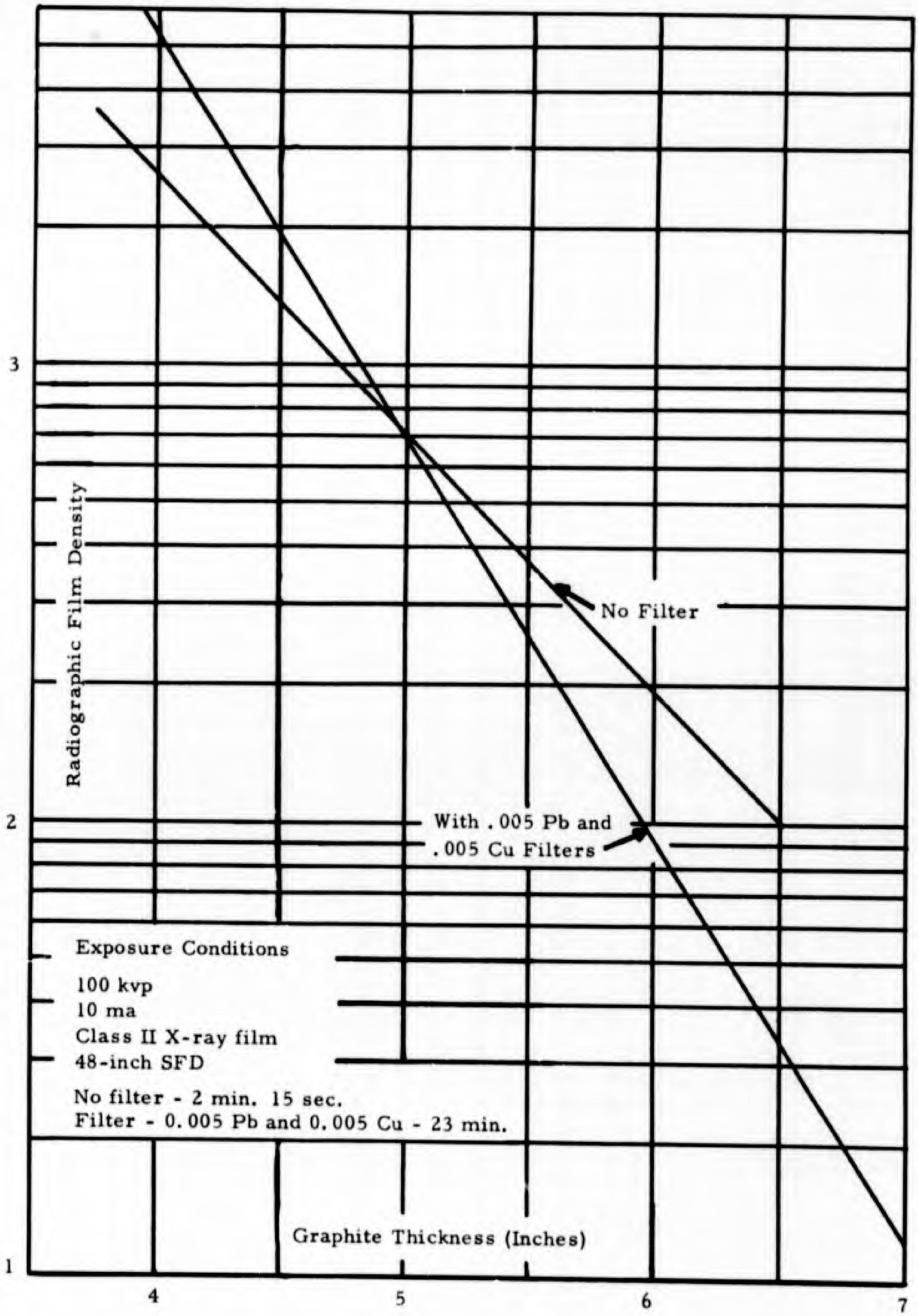

Fig. 11. Comparison of film densities for radiographs made with and without filtration. Filtration revealed 1.4 per cent radiographic sensitivity.

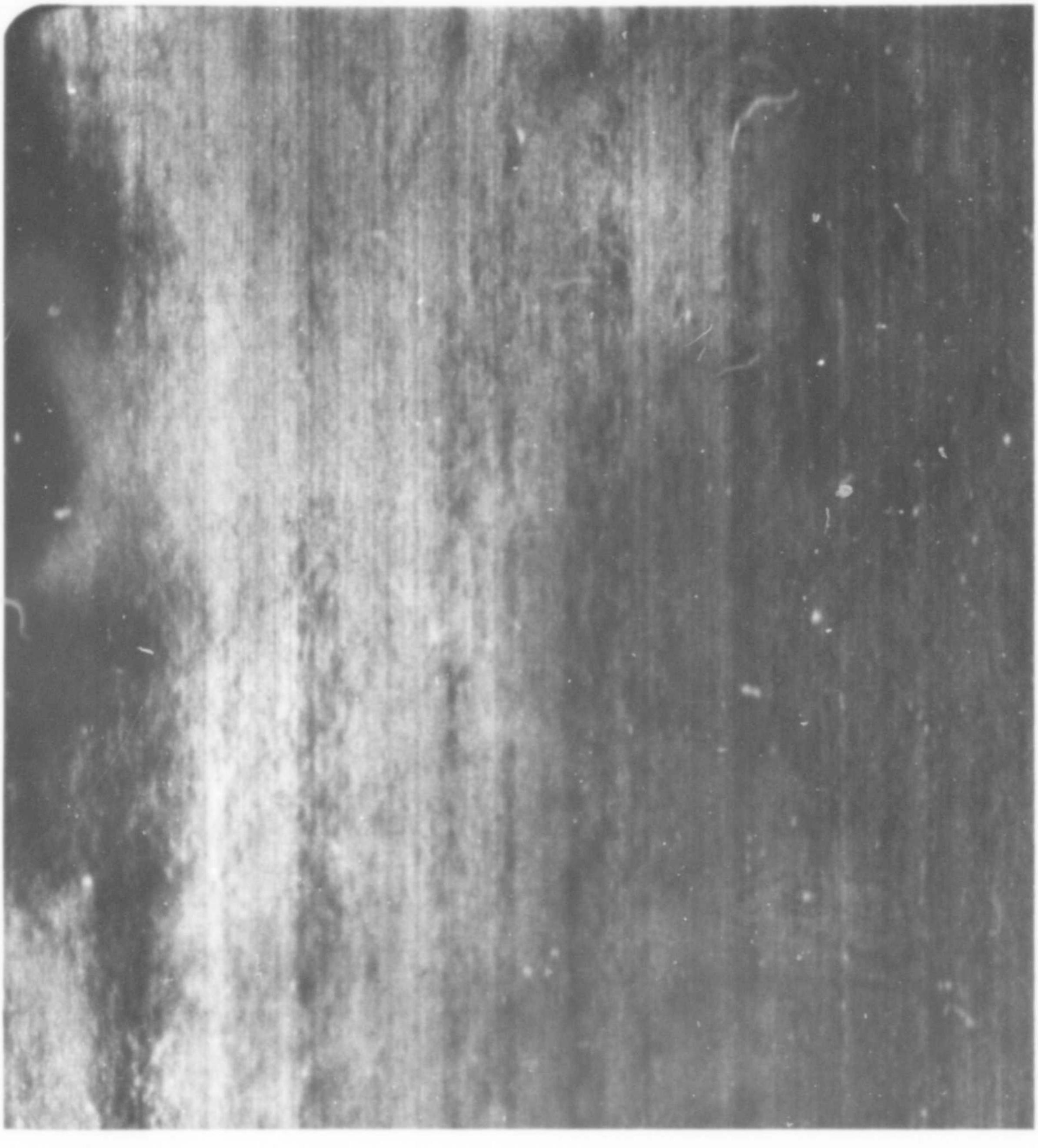

Fig. 12. Photographic 1:1 reproduction of an X-ray image made of the 133-line grid showing anomalies within the grid itself.

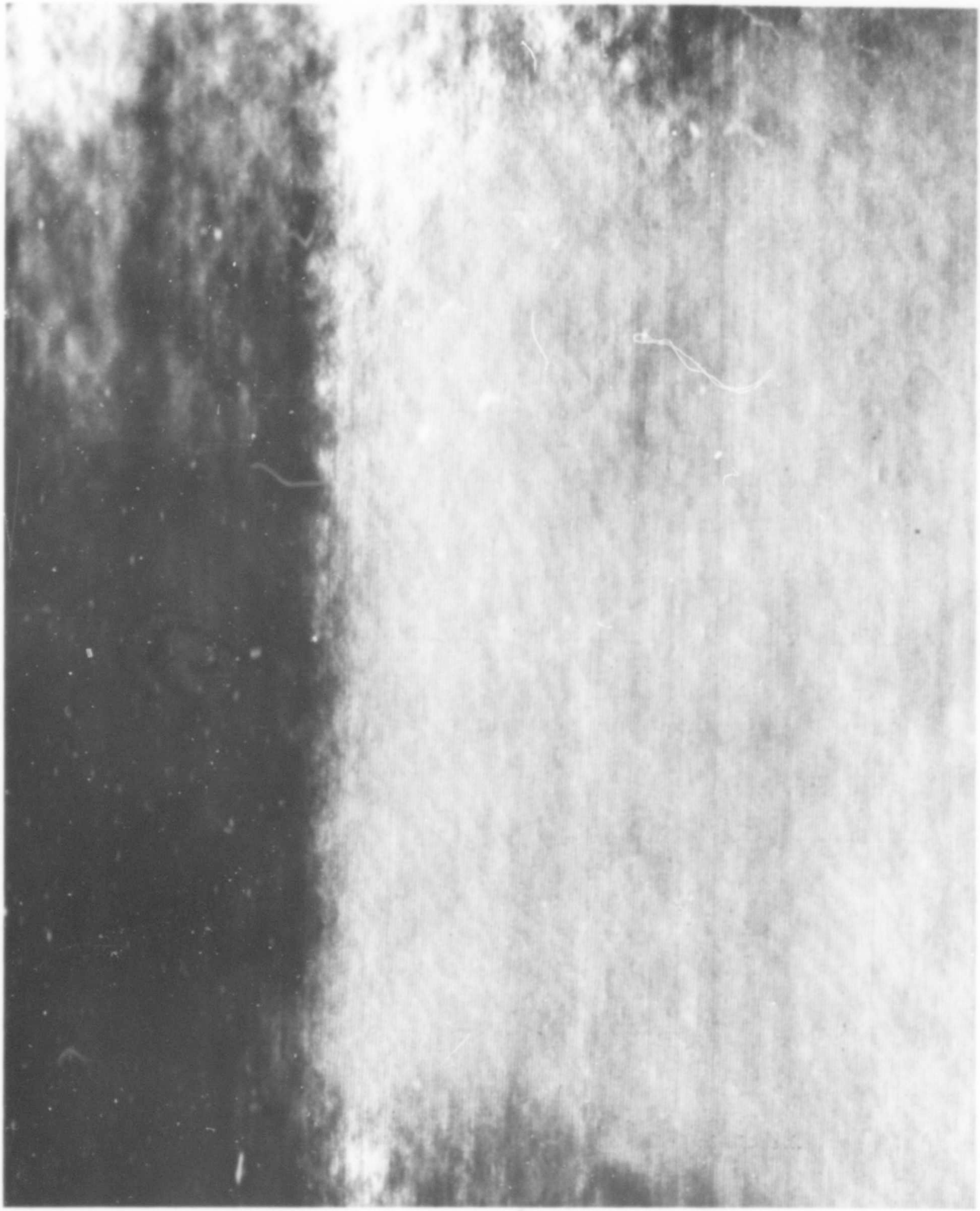

Fig. 13. Photographic 1:1 reproduction of an X-ray image made of the 80-line grid showing anomalies within the grid itself.

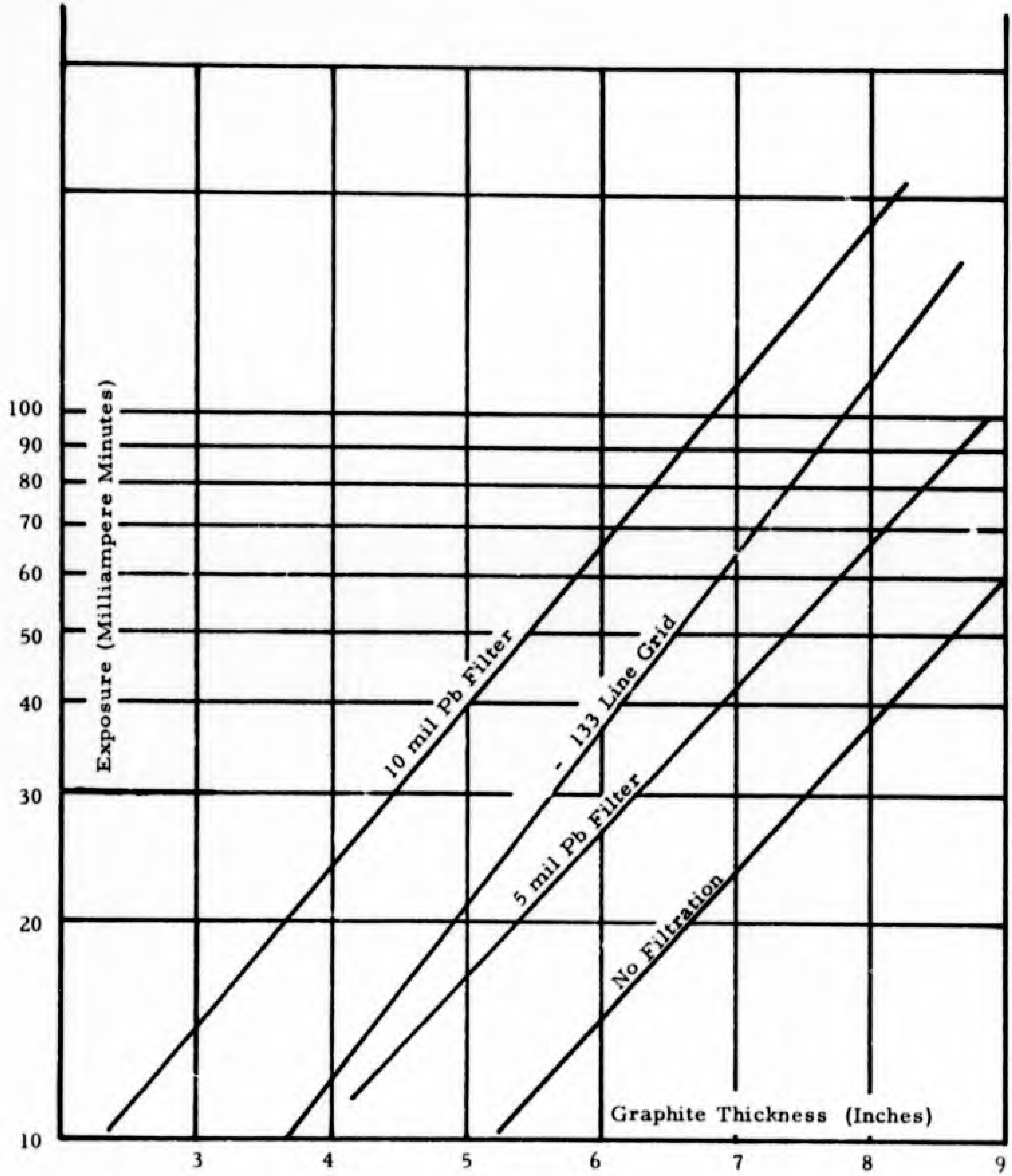

Fig. 14. Graph showing absorption of 0.005-inch, 0.010-inch lead, and 133 line grid for various thicknesses of graphite at 150 kvp.

Chemical Reduction of Radiographs to Remove Film Density

The build-up scatter radiation emitted from the graphite material being radiographically inspected produces film density, but does not have imaging qualities. This can be compared to film fog, and reduces image contrast. It was conceived that by the use of chemical reduction of the film to remove the fog level, the radiographic image could be improved.

A survey of various methods of chemical reduction was made and a reducer commonly known as "Haddon's Reducer" was chosen. This reducer affects low density areas to a greater extent than the more dense areas, therefore, increasing the image contrast. This reducing agent is easily made, easy to use, and has stable keeping qualities. The chemical formula for Haddon's Reducer is:

Potassium Ferricyanide	5 gms.
Ammonium Thiocyanate	10 gms.
Water to make one liter.	

Radiographs were prepared and cut into four sections, to determine the effect of reduction time on film densities. The results of this experiment were plotted and are shown as Fig. 15. This graph indicates the percentage of reduction of the various film densities as related to time of reduction. This reduction increased image contrast and produces radiographs with increased sensitivity.

Time has not permitted more extensive work with reducing agents as a method of removing the film fog due to scattering. This technique shows considerable promise and future work should be conducted to determine the optimum reduction time and the sensitivity increase obtainable.

Radiographic Techniques

Radiographic techniques for the radiography of graphite have been established for the X-ray equipment available. This equipment ranges from 25 kvp to 400 kvp inclusive and X-ray technique charts have been prepared and are included as Appendix I to this report.

Preparation of Penetrameters

To reveal the radiographic sensitivities obtained by

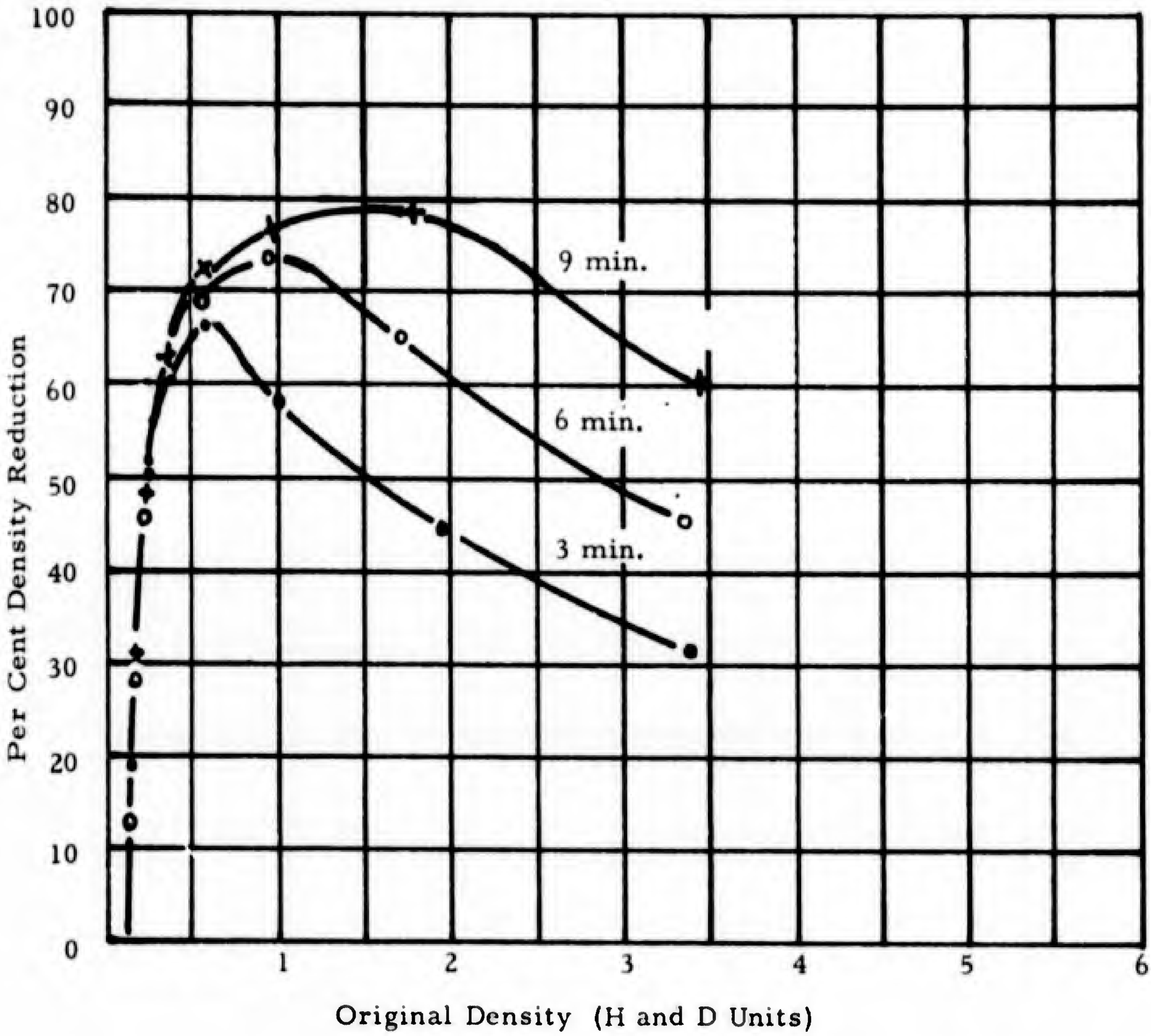

Fig. 15. Per cent of reduction of film density as related to original density for various times of immersion in Haddon's Reducer.

various radiographic techniques, graphite penetrameters were fabricated. These penetrameters were made from CFW grade of graphite in accordance to MIL-I-6865-271 Specification. This Specification states that the penetrameter shall be made of the same material as the test material, 2 per cent of the thickness being radiographed, and containing holes with a diameter of 1T, 2T, and 4T of the penetrameter.

These penetrameters were made for various thicknesses of graphite and were used to demonstrate radiographic quality obtained at various techniques.

Determination of Optimum Radiographic Techniques

Radiographic techniques were established for various conditions. In order to compare the results of techniques, standardization of some parameters was considered valuable.

CFZ graphite was used for technique development. This is a grade being used in large billet form by the aerospace industry. The normal density is in the order of 1.85 - 1.9 gms/cm^2 and radiographically compares to other grades being used at this time. For practical applications, any graphite in the 1.8 - 1.9 density range could be radiographically inspected by the given techniques. A source-to-film distance of 48 inches was used to establish the technique charts attached.

The X-ray effective focal-spot sizes were 1.5 to 5.5 mm. on the equipments used to determine techniques. The combined parameters were chosen to produce film densities of 2 H and D Units within experimental limitations. Technique charts presented as Appendix I include:

a. Techniques for the use of 0.005 front lead screen with a 0.010-inch back lead screen. These lead intensifying screens used in conjunction with Class II X-ray film represent typical industrial radiographic practices for the radiography of aluminum and steel structures whose thickness requires kilovoltages above the 125 kvp level.

b. Techniques for use of 0.010 lead front and back screens. The 10 mil lead front screen absorbs some of the scatter radiation producing radiographs with better contrast and detail resolution. Necessarily, exposure times must be increased to compensate for the radiation absorption.

c. Techniques for use of 0.005 and 0.010 lead screens with an additional 0.010-inch lead screen positioned between the graphite test material and the film to act as an absorbing medium to the scattered radiation.

d. Techniques for use of 0.005 and 0.010-inch lead screens with a 133-line, 10:1 grid between the graphite test material and the film to absorb scatter radiation.

e. Techniques for use of 0.005 and 0.010-inch lead screens with an 80-line, 16:1 ratio grid positioned between the graphite material and the film to absorb scattered radiations.

These technique charts demonstrate the differences in exposure required to produce a radiographic film density of 2 H and D Units on a Class II X-ray film due to different filters.

Techniques for various focal-film-distances can easily be calculated by using the inverse square law and the technique charts provided.

Personal preferences may require radiographs with a density different than 2 H and D Units. By using the log-relative exposure curves provided by the various film manufacturers calculations can be made using the attached technique charts to provide the desired film density using various films.

Radiography of Graphite Mechanical Test Specimens

The Sponsor, Wright-Patterson Air Force Base, requested that this research program be coordinated with a research program being conducted by Southern Research Institute, Birmingham, Alabama. Research on "The Determination of Design Criteria for Grade CFZ Graphite", Contract No. AF-33-(657)-11298, is being conducted by Southern Research Institute. This program requires that the mechanical properties of CFZ graphite be determined. The opportunity to correlate radiographic testing with actual mechanical properties was considered to be of great value.

An experimental CFZ graphite billet (A-26) was cut into slabs and submitted for radiographic inspection. These slabs were 31-11/16 inches in diameter and cut into various thicknesses. The slabs were identified as follows:

No. 1 - 7-1/4 inches thick
No. 2 - 6-3/8 inches thick
No. 3 - 3-1/2 inches thick
No. 4 - 20 inches thick

The results of the radiographic examinations are attached as Appendix II, with the report submitted to Southern Research Institute.

Radiography of Prepared Test Specimens

Mechanical test specimens were prepared from the slabs in accordance to the cutting plan outlined in the Second Progress Report prepared by Southern Research Institute on Contract AF-33-(657)-11298, January 22, 1964.

The test specimens were submitted for radiographic inspection and interpretation.

Radiographic Interpretation of Graphite Mechanical Test Specimens

Radiographic techniques were established that produced radiographs with excellent sensitivity, in the order of 0.7 per cent or better. To date, 1267 test specimens have been radiographically inspected. Two sets of radiographs were made of the specimens, one set being submitted to Southern Research Institute and one set being retained for correlation with mechanical test data.

Interpretation of the radiographs of these mechanical test specimens presented a problem due to the lack of background knowledge and experience in viewing radiographs of graphite material.

Radiographs were interpreted based on knowledge and experience gained in other materials such as aluminum and steel. Attempts were made to grade the test specimens into five grades, dependent upon the discontinuities visualized, their position and direction. The validity of this interpretation will be correlated with mechanical test results as soon as they are made available.

Copies of the radiographic test reports submitted to Southern Research Institute are attached as Appendix III. The original set of radiographs are being retained for comparison to mechanical test results.

Small white spots appear in the radiographs of the CFW mechanical specimens, indicating the inclusion of some dense material.

Fig. 16 is a positive enlarged view of these spots and their typical distribution. Variations in size and distribution were noticed throughout the specimens. An analysis report submitted by Union Carbide Corporation, 12900 Snow Road, Parma, Ohio states that these dense spots are concentrations of calcium sulphate.

A variation of these dense inclusions is shown in the enlarged positive view in Fig. 17. It is expected that these discontinuities will reduce mechanical strength by a considerable amount. It is assumed that the dense material as visualized in Figs. Nos. 16 and 17 are of the same chemical content and differ only in quantity and type of distribution.

Radiography of Graphite

The technique charts presented as Appendix I were used to expose a series of radiographs in an effort to report the image quality obtainable by various filtering techniques. To compare image quality a series of radiographs were made using a Class II X-ray film, a fixed source-film-distance of 48 inches, and the same X-ray unit as a radiation source. These radiographs show various graphite penetrameters (MIL-I-6865-271), and bronze wire mesh screens to reveal image quality.

A film quality indicator was prepared by using small areas of ASA bronze mesh screens. The screen dimensions were 30, 50, 100, 140, 200, and 270-mesh-per-inch, with wire sizes corresponding to mesh dimensions. It was found that the 30-mesh screen was invisible through 10 inches of graphite when the less-sensitive techniques were used. A cross-hatch was made of 0.035-inch wire and another of 0.045-inch wire to assure some measure of sensitivity on the 10-inch sections.

Three typical techniques were used to demonstrate the effect of scatter-absorbers on image visualization. Technique A is a typical industrial radiographic technique using Class II X-ray film with a 0.005-inch lead front screen and a 0.010-inch lead back screen. This combination is normally used for the radiography of such structural materials as aluminum and steel when the kilovoltage ranges from 100-125 up to about 400 kvp.

Technique B is the same as Technique A except that 0.010-inch lead screens were used for both front and back, and exposure time was increased to produce a film density of 2 H and D Units.

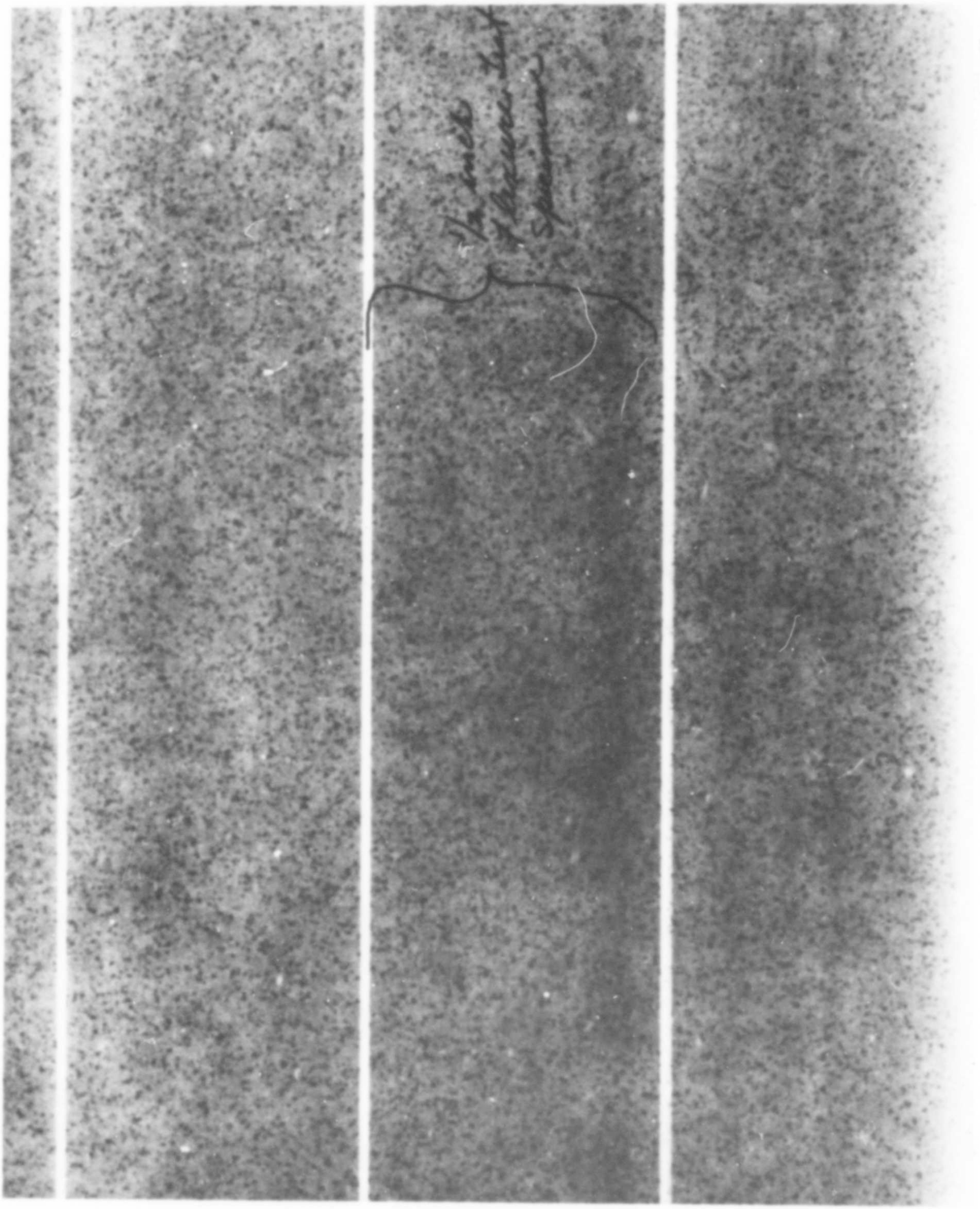

Fig. 16. Enlarged positive print of X-ray image showing size and distribution of dense specks visualized in CFZ graphite specimens.

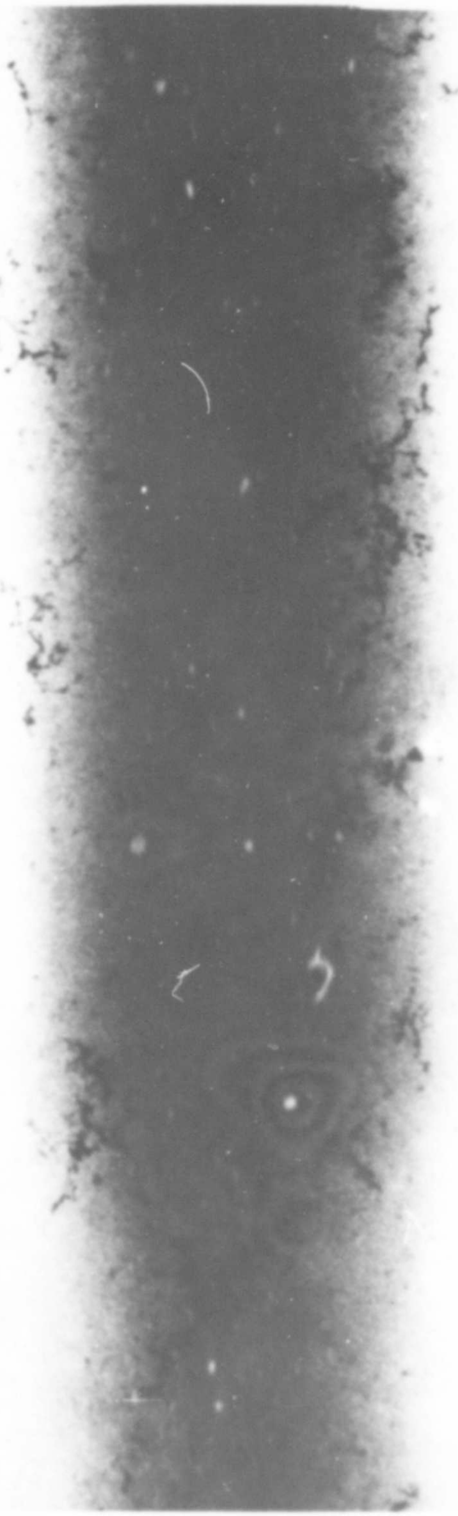

Fig. 17. Enlarged positive print of X-ray image showing shape and distribution of dense inclusions in 0.250 tensile specimen of CFW graphite.

Technique C is also the same as Technique A (0.005-inch lead screen front and 0.010-inch lead screen back), but with an additional 0.010-inch lead screen placed between the film and the graphite. Effectively, these three techniques reveal the results of the use of 0.005, 0.010, and 0.015-inch of lead to absorb corresponding amounts of the scatter radiation.

Visualization of the mesh screen was used to show the comparative image qualities obtained by the different techniques. The results of this comparison is presented as Fig. 18, which indicates that the 0.015-inch lead produces images with the greatest detail. It is possible that increased filtration would improve images, but exposure times become ridiculous and would be of little value as an industrial inspection method. The actual radiographs used for this comparison study are enclosed with the report to the Sponsor.

Penetrameter sensitivities obtained with the various techniques are also indicated in Fig. 18.

Betatron Radiography of Graphite

It is well known and quite evident that high-energy radiation is required for the penetration of very thick sections of graphite material. Thicknesses of 12 to 15 inches are near the maximum thickness for high quality radiography with conventional industrial X-ray equipment operating at 400 kvp.

For graphite thicknesses of 20, 30, and 40 inches, a 24 Mev. betatron generator was used for radiographic inspection. A focal-film-distance of 19-feet was used to minimize geometrical unsharpness. A Class II X-ray film was used in cardboard holders with 0.040-inch lead front screens and 0.010-inch lead back screens.

Thirty inches of graphite were exposed with 500 R (5 min.). The film density was 2.8 and considered slightly more dense than the usual 2.0 to 2.5 radiographs. The 1T hole in a 10-inch graphite penetrameter is visualized.

Forty inches of graphite were exposed using the Class II film with the same screen combination with 600 R (6 min.). The resulting radiograph was of a density of approximately 2.0, and revealed the 1T hole in a 10-inch graphite penetrameter indicating a radiographic sensitivity of approximately 0.35 per cent.

It is evident from these limited tests that betatron radiography will produce sensitivities better than 0.5 per cent of graphite thicknesses ranging from 20 to 40 inches. These radiographs were reviewed by the sponsor's representative

Geometrical Unsharpness

In order to demonstrate the effect of scatter radiation on image quality due to thickness of graphite only, a series of radiographs were made as follows:

Graphite Thickness	KVP	MAM	SFD
3 inches	96	20	24 inches
4 inches	100	23	32 inches
5 inches	114	35	40 inches
6 inches	136	50	48 inches
7 inches	166	68	56 inches

Class II X-ray film was used in conjunction with 0.005-inch lead front and 0.010-inch lead back screens which corresponds to Technique B. Exposures were calculated to produce the same geometrical unsharpness in each instance, and kilovoltage was adjusted in relation to graphite thickness. These radiographs all demonstrate better than 0.7 per cent sensitivity. The mesh screens used as a guide to visualization of image quality are more readily visible on the thinner sections of graphite. The 50-mesh screen is just discernible on the 7-inch thickness. Fig. 18 demonstrates that the loss of visualization of the various meshed screens is due mostly to geometrical unsharpness. The radiographs used for this test are enclosed with the report to the Sponsor.

Film No.	% Pene. Sensitivity	Meshed Screens 140	100	50	30	Wire 35 mil	45 mil
3-100-15-A	.93	x	X	X	X	X	X
4-100-38-A	.70		x	X	X	X	X
5-100-51-A	1.12			X	X	X	X
6-150-15-A	.93			X	X	X	X
7-150-24-A	.80			X	X	X	X
8-150-37-A	1.4				X	X	X
9-150-60-A	1.24				X	X	X
8-200-13-A	1.05				X	X	X
9-200-23-A	1.78				x	X	X
10-200-34-A	1.12					X	X
2-100-21-B	1.4	X	X	X	X	X	X
3-100-36-B	.94	x	X	X	X	X	X
4-100-66-B	.70		X	X	X	X	X
4-150-13-B	.70		x	X	X	X	X
5-150-23-B	.56			X	X	X	X
6-150-38-B	.94			X	X	X	X
7-150-65-B	.80			X	X	X	X
7-200-20-B	.80			X	X	X	X
8-200-32-B	1.05			x	X	X	X
9-200-55-B	.88				X		
2-100-50-C	1.4	X	X	X	X	X	X
3-100-85-C	.93	X	X	X	X	X	X
3-150-15-C	.93	x	X	X	X	X	X
4-150-24-C	.70		X	X	X	X	X
5-150-38-C	.56		X	X	X		
6-150-65-C	.93		x	X	X		
6-200-21-C	.93		x	X	X		
7-200-35-C	.80			X	X		
8-200-58-C	1.05			x	X		

Fig. 18. Penetrameter sensitivity and visualization of mesh screens for various X-ray techniques using 0.005, 0.010, and 0.015-inch of lead.

SUMMARY

Technique charts are presented for the radiography of graphite in the medium thickness range 2 to 14 inches using typical industrial X-ray equipments. Results of experimental data presented in this report demonstrate the problems in the radiography of graphite are due to scatter radiations and economics of inspection. The thicknesses of graphite billets (now ranging up to 103 inches) present geometrical unsharpness problems as related to economy of inspection. When the X-ray source is removed from the film sufficient distances to obtain a reasonable D/T ratio, exposure times become uneconomical.

Techniques reported also demonstrate that better than 1 per cent radiography can readily be obtained using typical industrial techniques and lead filtering, for the ranges of thicknesses from 1/2 to 40 inches.

LIST OF REFERENCES

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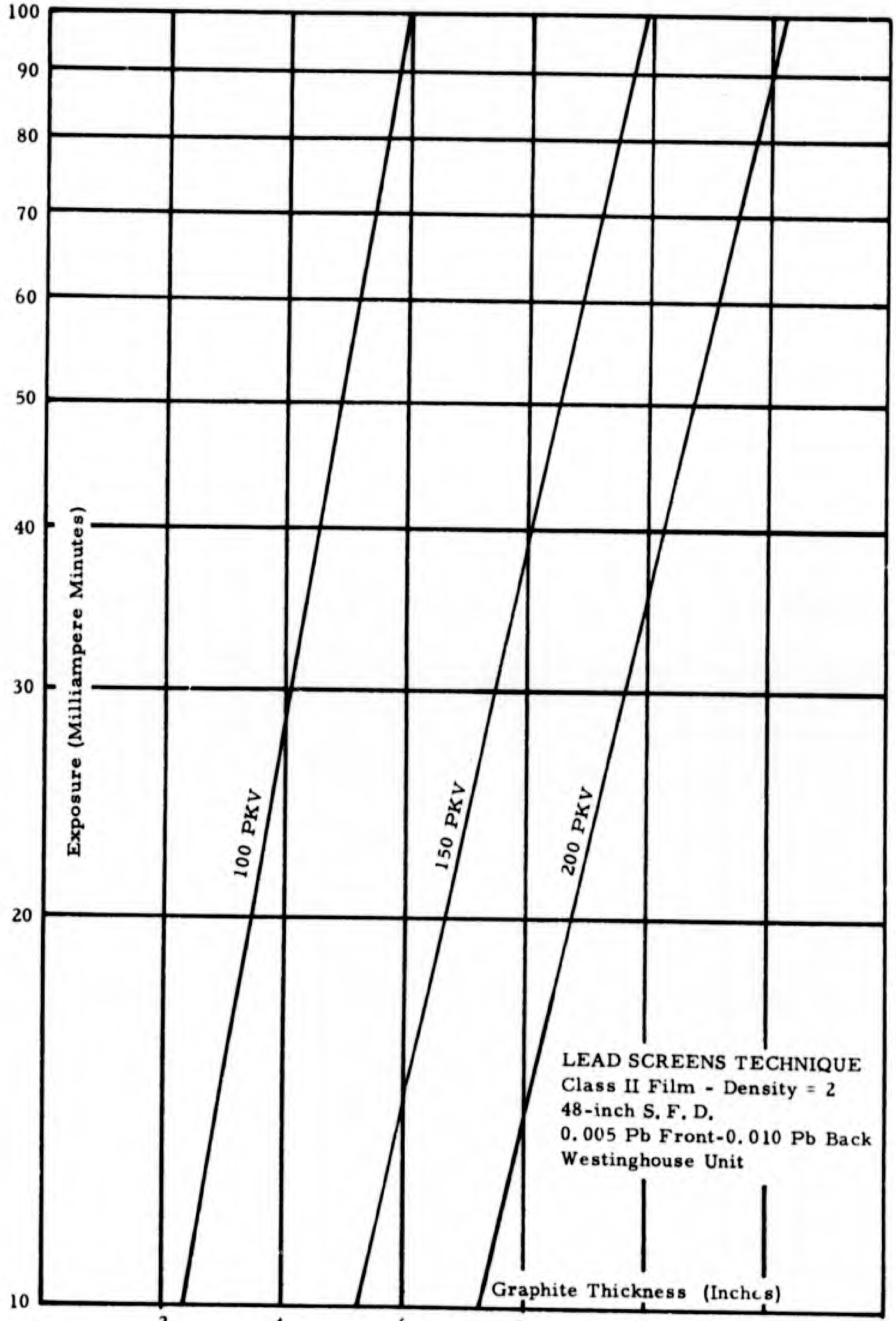
2. Nightingale, R. E., Nuclear Graphite, Academic Press, 1962.

3. Walbouch, R. W.,"Research and Development on Advanced Graphite Material", WADD Technical Report, Vol. IV, pp. 61-72.

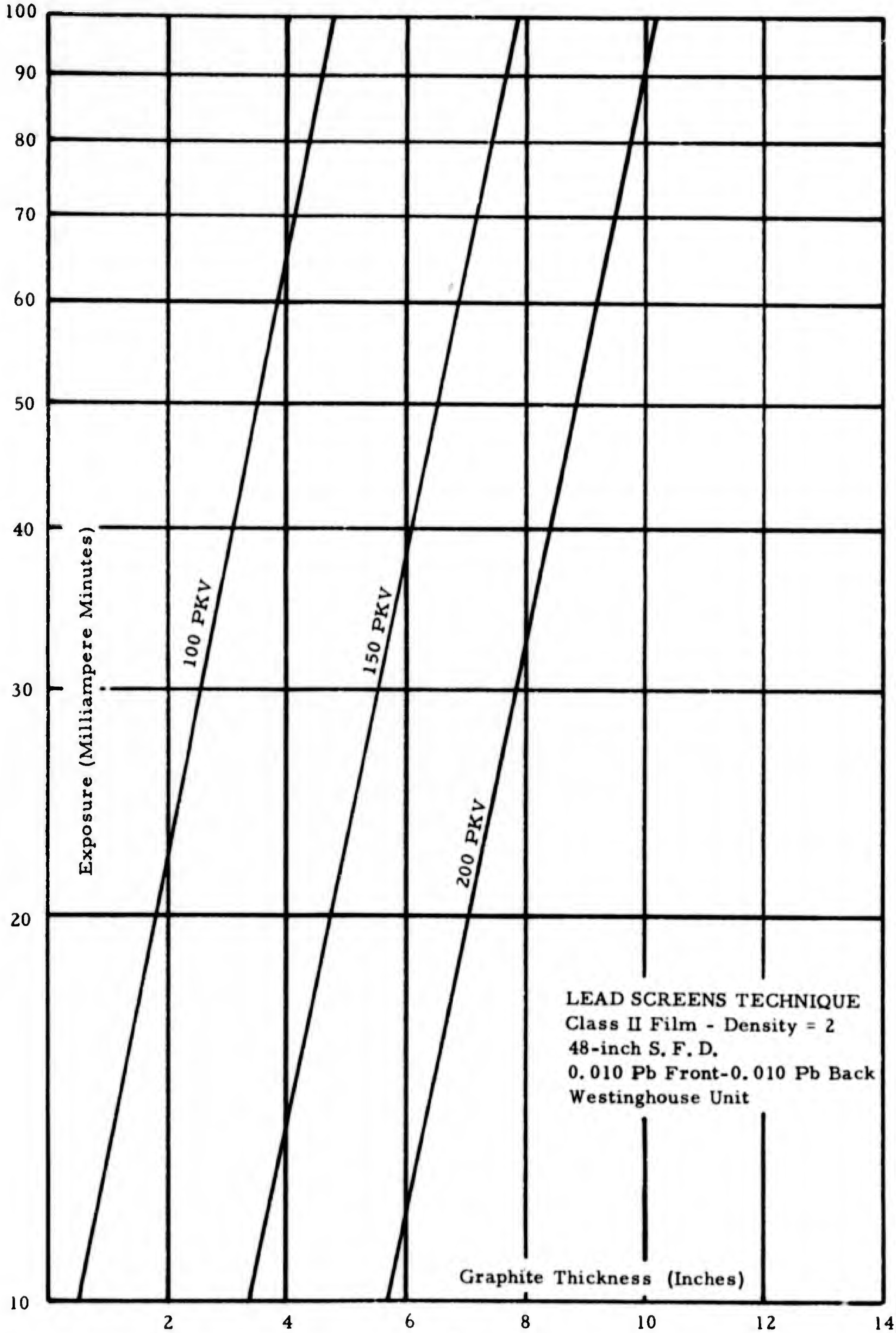
4. Ubbelohde, A. R. and F. A. Lewis, Graphite and Its Crystal Compounds, Oxford at the Clarendon Press, 1960.

APPENDIX I

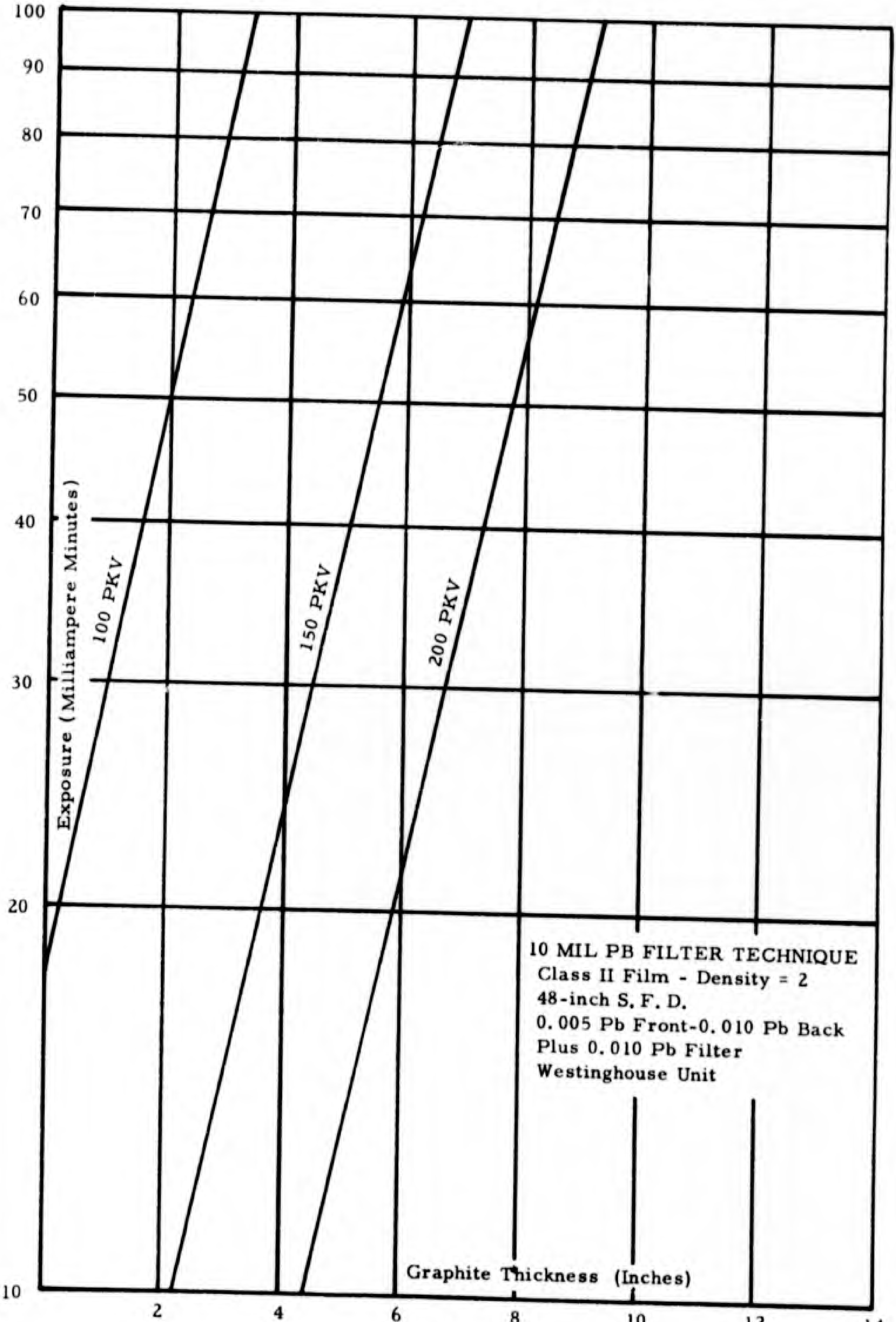
RADIOGRAPHIC TECHNIQUE CHARTS FOR GRAPHITE

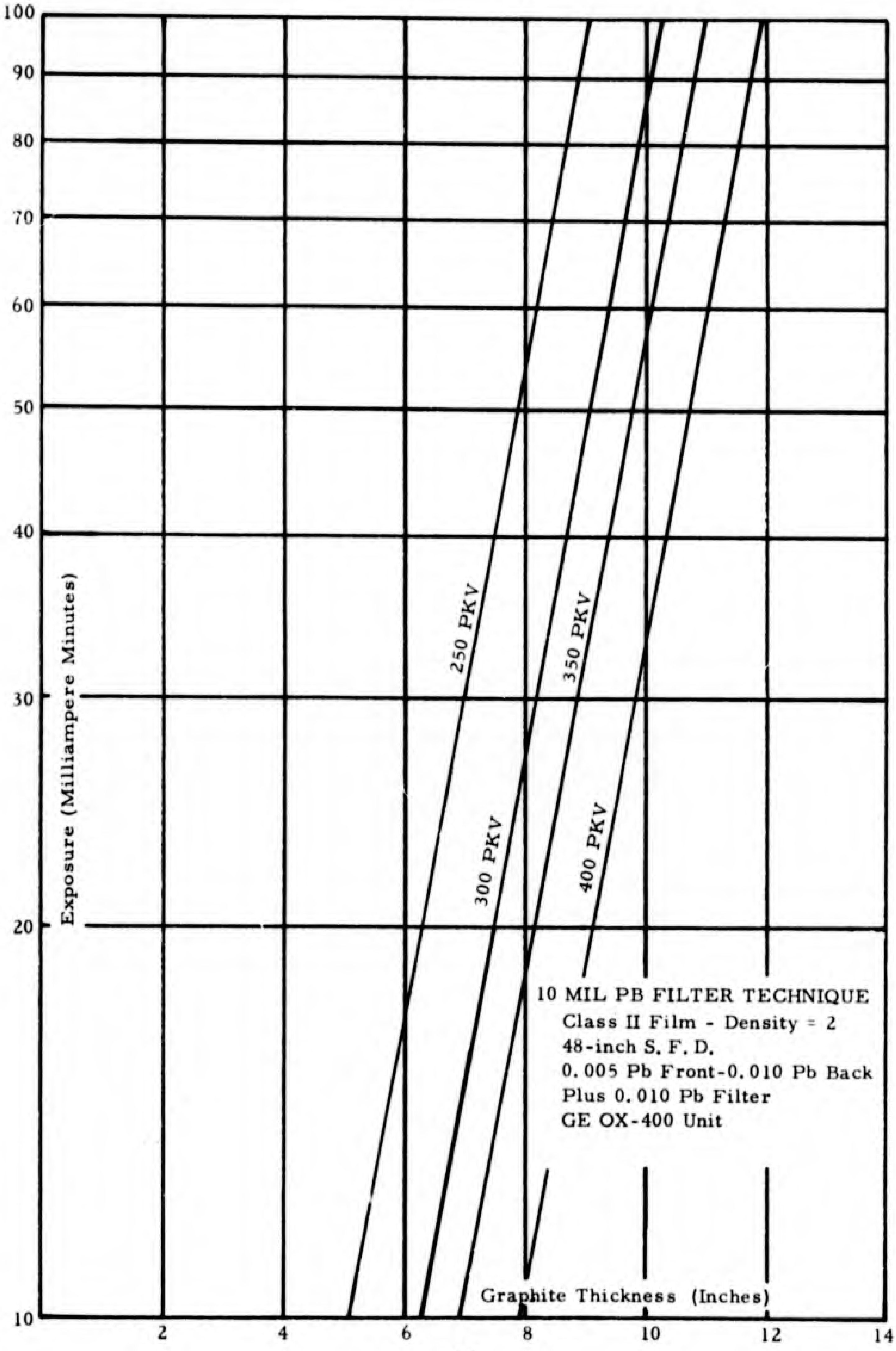


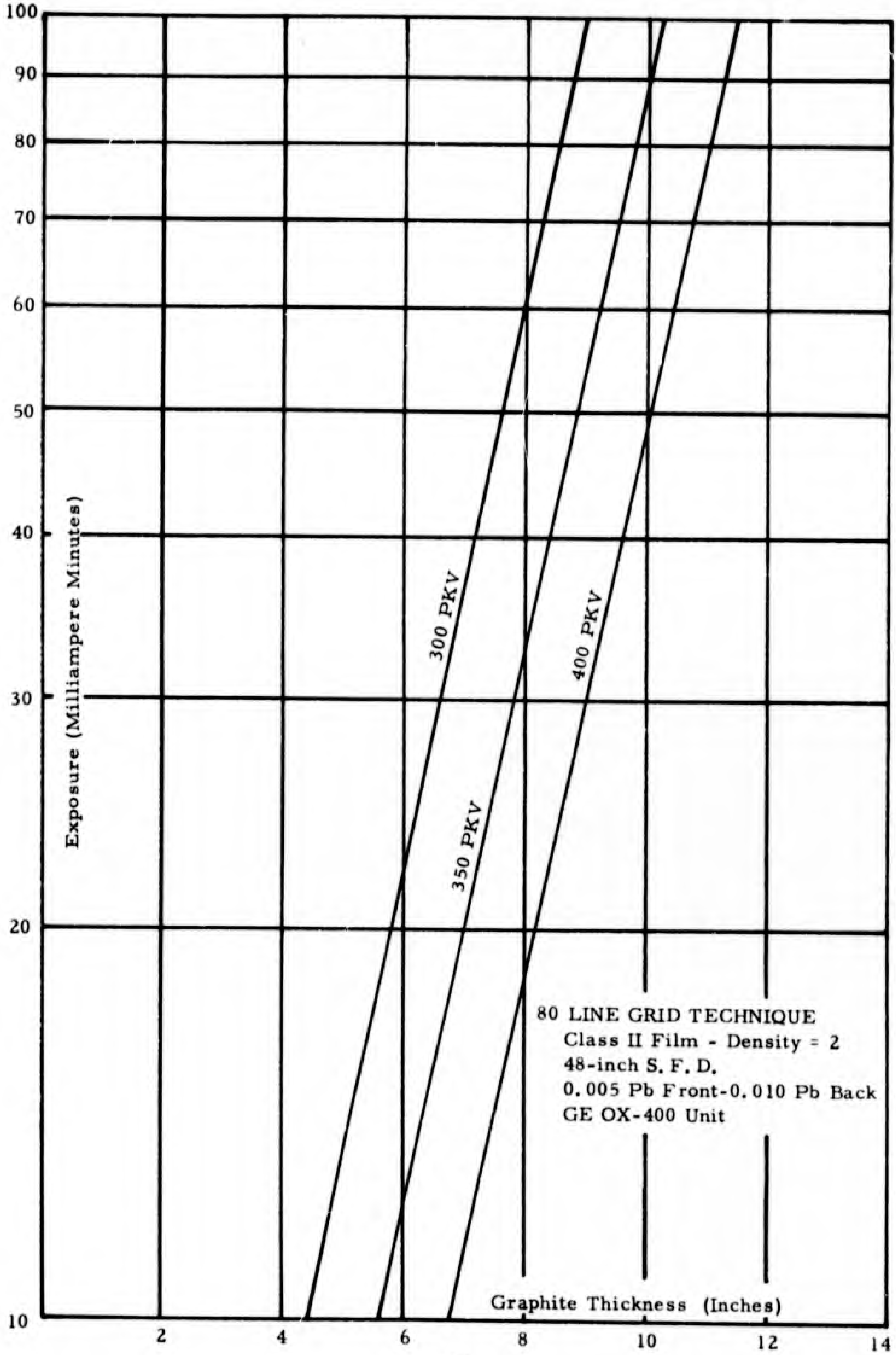
Exposure (Milliampere Minutes)
10
20
30
40
50
60
70
80
90
100
100 PKV
150 PKV
200 PKV
LEAD SCREENS TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0.005 Pb Front-0.010 Pb Back
Westinghouse Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14

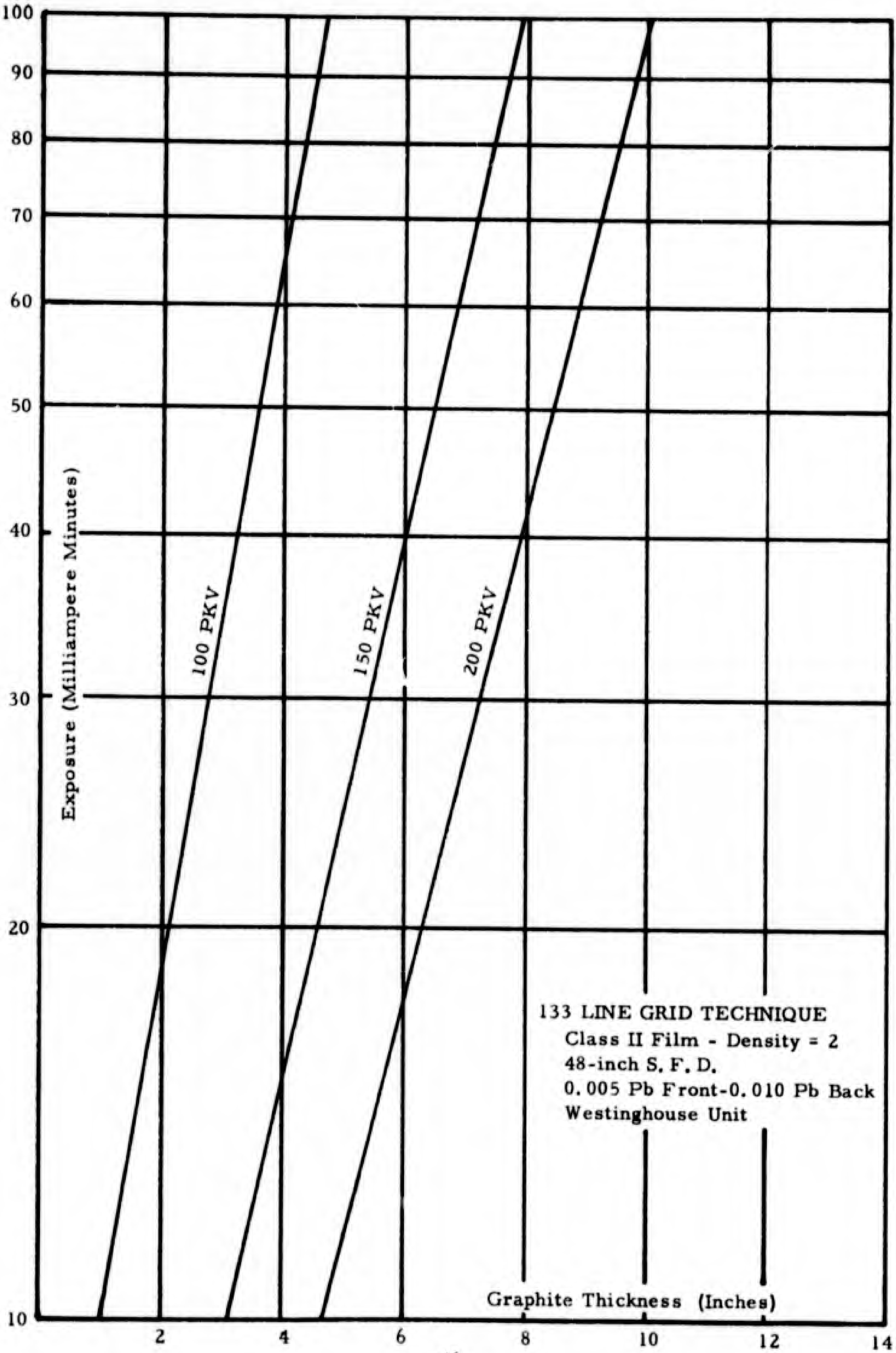


100
90
80
70
60
50
40
30
20
10
Exposure (Milliampere Minutes)
100 PKV
150 PKV
200 PKV
LEAD SCREENS TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0.010 Pb Front-0.010 Pb Back
Westinghouse Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14


100
90
80
70
60
50
40
30
20
10
Exposure (Milliampere Minutes)
100 PKV
150 PKV
200 PKV
10 MIL PB FILTER TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0.005 Pb Front-0.010 Pb Back
Plus 0.010 Pb Filter
Westinghouse Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14


100
90
80
70
60
50
40
30
20
10
Exposure (Milliampere Minutes)
250 PKV
300 PKV
350 PKV
400 PKV
10 MIL PB FILTER TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0. 005 Pb Front-0. 010 Pb Back
Plus 0. 010 Pb Filter
GE OX-400 Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14


100
90
80
70
60
50
40
30
20
10
Exposure (Milliampere Minutes)
300 PKV
350 PKV
400 PKV
80 LINE GRID TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0.005 Pb Front-0.010 Pb Back
GE OX-400 Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14


100
90
80
70
60
50
40
30
20
10
Exposure (Milliampere Minutes)
100 PKV
150 PKV
200 PKV
133 LINE GRID TECHNIQUE
Class II Film - Density = 2
48-inch S. F. D.
0.005 Pb Front-0.010 Pb Back
Westinghouse Unit
Graphite Thickness (Inches)
2
4
6
8
10
12
14

APPENDIX II

RADIOGRAPHIC TEST REPORTS FOR GRAPHITE BILLETS

December 18, 1963

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John D. Woodward

Dear Sir:

Radiographic inspection has been completed on graphite billets Nos. 1, 2, and 3. These billets were submitted to our shipping department for return. Billet No. 4 offers a different problem and may require the use of one of our isotopes. I hope that I may have this billet for a few more days without causing you delay with your program.

The radiographs of billets Nos. 1, 2, and 3 are considered to be good images with penetrameter sensitivities between 0.5 and 1.4 per cent. Although the penetrameter sensitivity is in the order of 1 per cent, discontinuities of any magnitude were not visualized. Some areas of the billets showed low-density striations in varying dimensions. These areas were marked on the billets with a white grease pencil to simulate the indications revealed by the X-ray inspection.

BILLET NO. 1 - 7-1/2-inches thick

In the film area of A-1, low-density spots were visualized. The density change appeared to be in the order of 2 per cent of the total thickness, or about 0.150-inch difference in graphite. These do not appear as round in shape, but quite misshapen as if striations or shrinkage lines may lay horizontal to the radiation beam.

The marks indicate areas that contain low-density shrinkage-like lines. These are not sharp in detail, but compare

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to shrinkage commonly found in castings. The lines attempt to simulate the length and frequency in the appropriate areas, as well as the direction in which they lay.

A very unusual low-density area was visualized in area C-1 at the edge of the billet at 180° from the 0° axis. The size and shape of this area is demonstrated on the sketch.

BILLET NO. 2 - 6-3/4-inches thick

This billet shows a greater number of low-density striations than No. 1 or No. 3. The direction of the striations are nearly at 90° to the indications visualized in No. 1 and No. 3. Low-density spots, or areas, are visualized in film area B. These indications appear to be of a density change equivalent to 0.10 to 0.20-inch of graphite.

BILLET NO. 3 - 3-inches thick

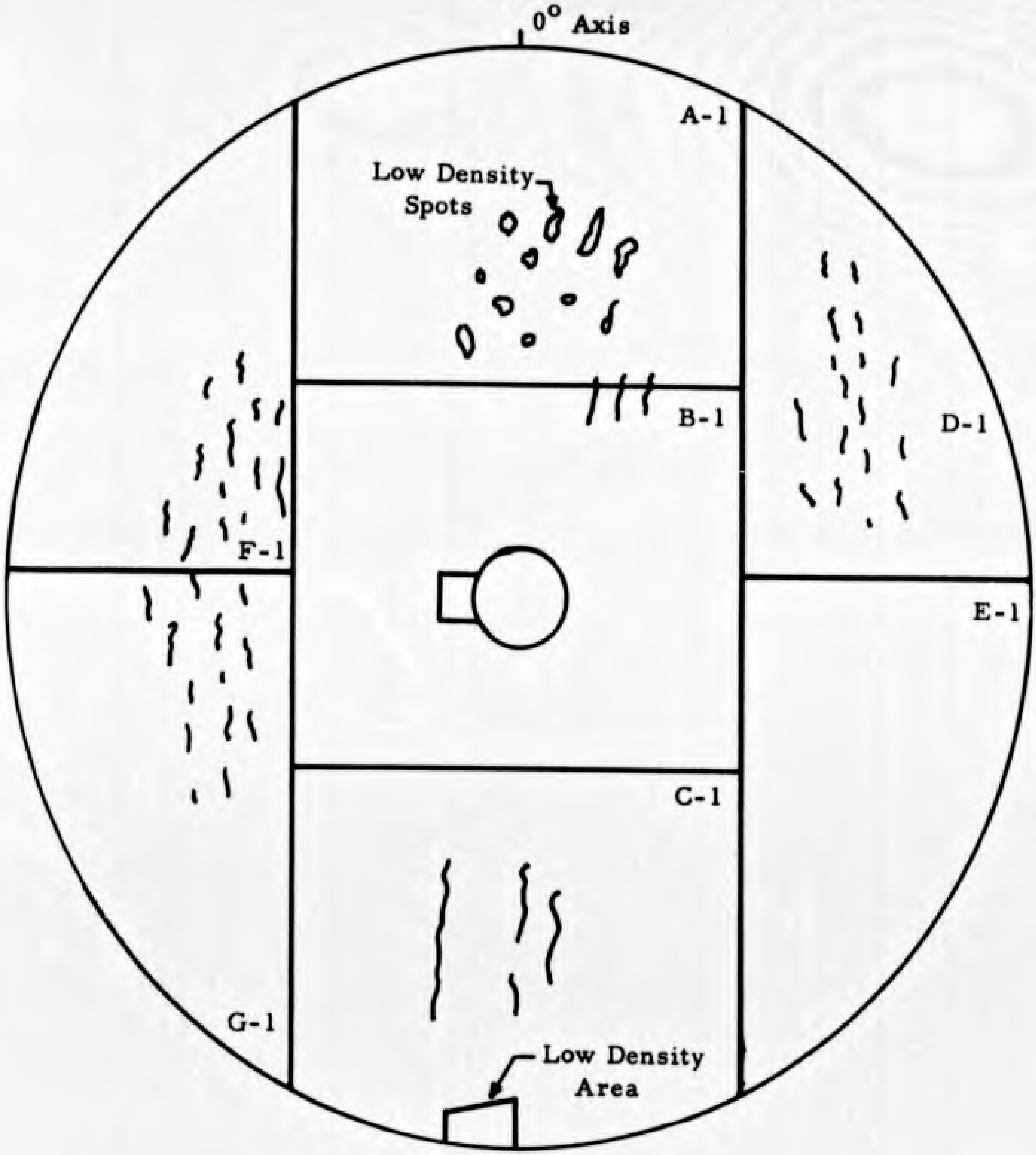
The striations visualized in this billet generally lay parallel to the 0° axis. Correlation of these indications with the actual conditions revealed by cutting the billets are of great interest. I would like very much to be there when the billets are being cut to see if any of these indications are revealed and their correlation with the X-ray indications.

Yours truly,

Merle Rhoten
Research Associate

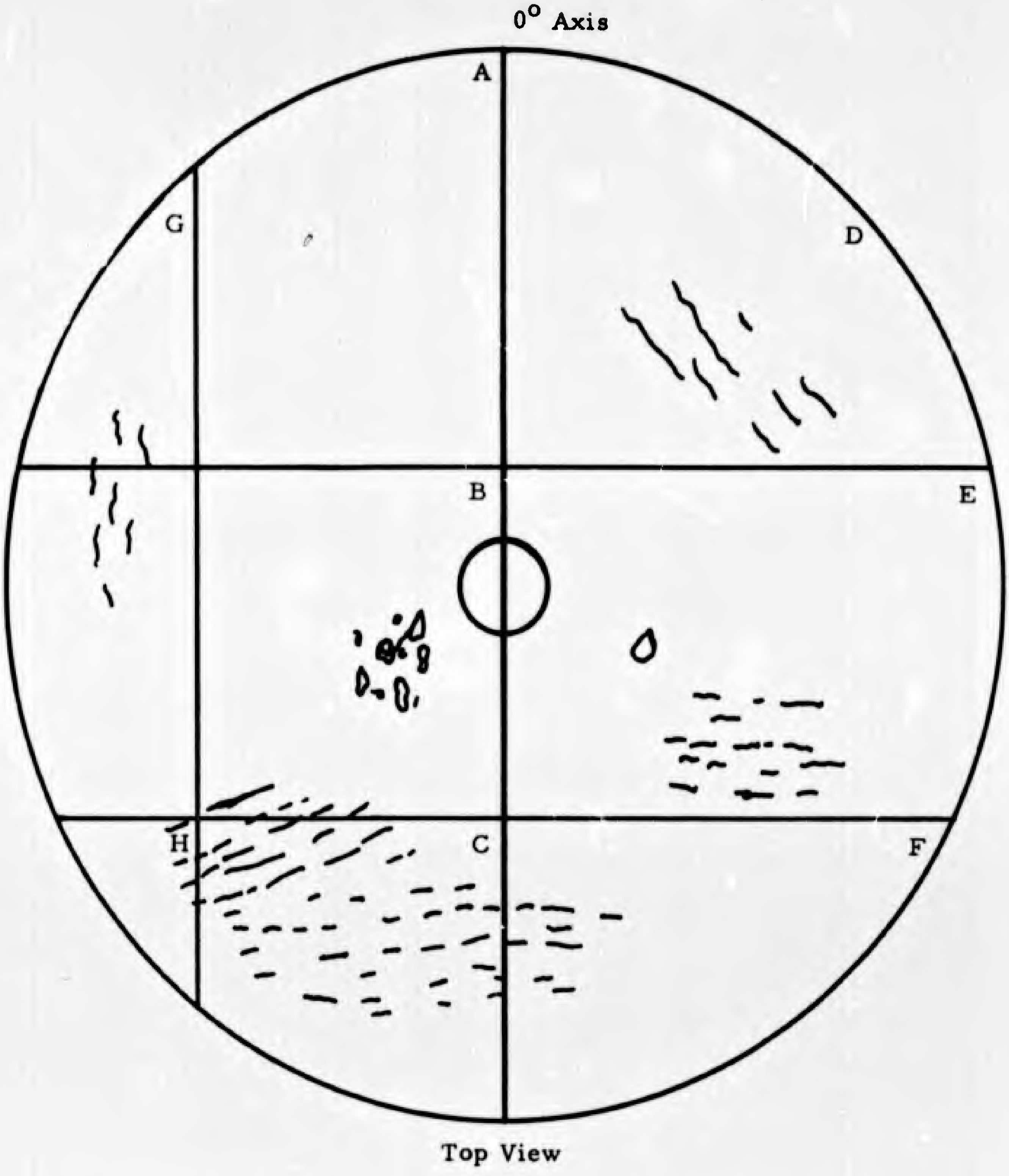
MR/bf

Encls: (3) sketches

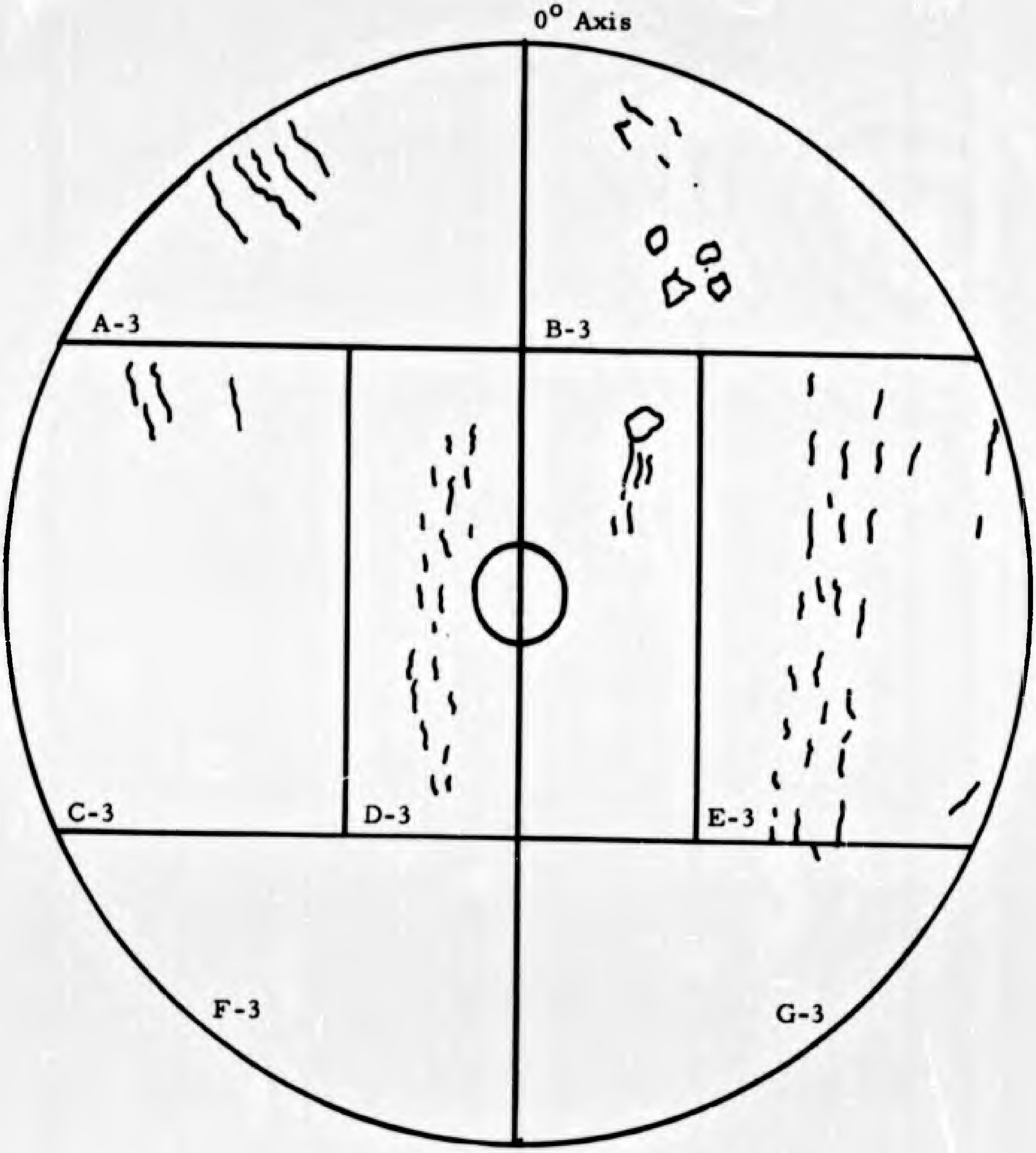


Top View

BILLET NO. 1 - CFZ GRAPHITE 7-1/2 INCHES THICK. Norelco 300 - 235 kvcp - 10 ma - 5 min. - 72 in. S. D. D. - AA Film - Pb Screens (0.005 front 0.010 back) superfine grid. Between 0.7 and 1.4 per cent sensitivity.



BILLET NO. 2 - CFZ GRAPHITE 6-3/4 INCHES THICK. Norelco 300 - 220 kvcp - 10 ma - 5 min. - 72 in. S. D. D. - AA Film - Pb Screens (0.005 front 0.010 back) superfine grid. Approximately 1 per cent sensitivity.



Top View

BILLET NO. 3 - CFZ GRAPHITE 3 INCHES THICK. Norelco-140 kvcp - 10 ma - 5 min. - 72 in. S. D. D. - AA Film - Pb Screens (0.005 front 0.010 back) superfine grid. Better than 1.4 per cent sensitivity.

APPENDIX III

RADIOGRAPHIC TEST REPORTS FOR GRAPHITE MECHANICAL TEST SPECIMENS

February 12, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear Sir:

The 94 flexure specimens have been radiographed and test reports prepared for each specimen. Copies of the test reports are being sent to Mr. William Shelton, Wright-Patterson Air Force Base.

Procedure for Radiography of Flexure Test Specimens

The 1/2 x 1/2 x 5-inch flexure specimens were placed on the X-ray exposure holders by identification numbers. A Class I X-ray film was used to produce fine-grain, high-contrast X-ray images. An industrial X-ray unit was used as a source of X-radiation. This unit is equipped with a beryllium-window X-ray tube which permits utilization of the long-wavelength radiation for the radiography of the low-density graphite materials.

The exposure conditions were: Class I X-ray film in a cardboard holder, 20 KVP, 15 MA, 5 MIN, 34-inch source-film-distance, 1.5 mm effective focal-spot size. This exposure produces a film density of approximately 3.0 when developed 5 minutes at 68 degrees F. Film density in the order of 3.0 was considered desirable to the production of high-contrast images. This density takes advantage of the contrast characteristics of the film as shown by the Hurter and Driffield Curves, and is easily interpreted by use of a high-intensity industrial illuminator.

Penetrameters

Industrial penetrameters described in Specification MIL-6865-271 are not readily available for graphite material. Since the CFZ grade of graphite was not readily available, penetrameters were made (to the best of our ability) from CFW grade of graphite. These penetrameters were made to cover a large range of thicknesses (from 1/4 to 40 inches) in various increments.

Graphite penetrameters for material thicknesses of 1/4 and 1/2-inch were very difficult to make. Especially, the 1/4-inch penetrameter where the thickness is 0.005-inch with hole diameters of 0.005, 0.010, and 0.020-inch. By hand-polishing techniques this penetrameter was made to within 0.0005-inch of the 0.005-inch dimension. The 0.005 and 0.010-inch holes were made with success, but the 0.020-inch hole chipped out and is in excess of dimension.

The penetrameter made for 1/2-inch of graphite is 0.010-inch, plus or minus, 10 per cent. The holes were drilled in accordance to the MIL-6865-271 Specification with considerable success, and are very near the specified dimensions. These penetrameters are very fragile, and lead identifying numbers were omitted. The 1/4-inch penetrameter was broken by handling in the radiography of the flexure specimens, but it was used in this condition and appears on the radiographs.

Radiographic Sensitivity

The actual radiographic sensitivity obtained is difficult to determine due to the granular structure of the test specimens. In some views, it is possible to see the 2T hole in the 0.005 (1/4-inch) penetrameter through the 1/2-inch specimens. This would indicate radiographic sensitivities in excess of 1 per cent. In other radiographs it is not possible to see the 1T hole in the 2 per cent (0.010) penetrameter. Since the image contrast clearly reveals the outline of the 0.005 penetrameter, it is thought that the detail of the penetrameter hole is obscured by the granular pattern of the graphite. The radiographs are considered to have better than 1 per cent sensitivity.

Test Reports

Two complete sets of radiographs are being made. One set is to be furnished to Southern Research and the other set to Wright-Patterson Air Force Base upon completion of the study. X-ray interpretation reports are being prepared in an effort to demonstrate the results of the radiographic inspection. The original X-ray is placed in an 8 x 10 contact printing frame, and typical photographic contact prints are made on a glossy No. 2 contrast print paper. These prints are a positive print of the original X-ray negative. The images of each specimen are then cut out and attached to the X-Ray Test Report Data Sheet; both the 0^o and 90^o views are shown. Interpretation is made from the original X-ray film and information transferred to the print images. The positive print images are not considered reliable for interpretation purposes, but simply provide a means of reporting information revealed by the original X-ray film.

Radiographic Interpretation

Interpretation of the X-ray images is considered very difficult due to the lack of experience in the radiography of graphite materials and the correlation of discontinuities with mechanical tests. Therefore, these reports are not considered as an interpretation, but simply statements of variables visualized in the X-ray film. Some of these variables include the following:

1. Dense specks throughout the material. These appear as white specks in the originals and as black specks in the positive prints. An enlarged view of specimens 2A4A-AF3 and AF4 is included to demonstrate the density differences of these specks, their size and distribution in the material.

2. Low-density striations in some of the specimens. These appear in the radiographs as shrinkage which might appear in castings. They are often crack-like in appearance, but are not in straight lines. These may appear in one view on a radiograph but not be seen in a 90 degree view of the specimen.

3. Low-density spots, variable in dimension, in some of the specimens.

Radiographic interpretation was made from the radiographic film and the positive prints were used to indicate areas and discontinuities for reporting position in the specimen. By evaluating the most prominent low-density striation, the magnitude and direction of its position, attempts were made to predict where failure of the specimen would occur. In some instances, where numerous low-density striations were visualized, it was considered impossible to determine which of these would be the most detrimental to the strength of the specimen.

Future Plans

Experience gained from the radiography of these specimens indicates that better information could be obtained from the positive prints if they were made darker. Normally, the discontinuities of low-density would appear as light areas on the positive prints. It is believed that the light areas would be more prominent on a darker background.

Yours truly,

Merle Rhoten

MR/bf

cc: Mr. William Shelton
Wright-Patterson Air Force Base
Dr. Robert McMaster

Encls: Test Data Sheets
X-Ray Films (8 x 10) (14)
Positive Prints (8 x 10)
Enlarge print from X-ray to illustrate random scattered dense specks. (8 x 10)

February 18, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Radiography of the second box of mechanical test specimens has been completed and the specimens are being returned with radiographs and reports. This shipment consisted of 101 tensile specimens of the 2A2 series.

Positioning for Radiography

The specimens were placed on 8 x 10 Class I X-ray film and grouped according to numerical designation. Each specimen was marked with a white line in order to position for the 0 and 90-degree views. The specimens were always placed on the film with the identification tape on the right side of the film. Due to the difference in marking some of the necked-down areas appear to the right and some appear to the left of the center of the specimens.

Penetrameters

The 0.005-inch and the 0.010-inch penetrameters were placed on the tensile specimens and can often be seen through the specimen. Occasionally they are seen where the penetrameter edge appears longitudinally with the specimens. Care should be used so that the penetrameter edge is not interpreted as a discontinuity.

Radiographic Technique

These tensile specimens were radiographed with the industrial X-ray unit equipped with a beryllium-window tube with a 1.5 mm effective focal-spot size. Exposures were 14 KVP, 15 MA, 5 MIN, 34-inch focal-film-distance. This technique produces a film density of about 1.7 through the center section of the circular test specimens. It was considered necessary to use this comparatively low density through the center of the specimens in order to provide an interpretable image over a large cross section of the specimens. The radiographs reveal very good sensitivity as the 0.005-inch penetrameter is visualized indicating 2 per cent sensitivity.

Radiographic Interpretation

In the interpretation of the images, an attempt has been made to grade these specimens. Although the cause of failure in graphite material is not known by the film reader, the interpretation has been made based on the past experience in reading radiographs of other structural material. In general, the most consistent discontinuity visualized was low density, crack-like lines traversing across the specimen. Judgement was made on the density, position, and length of these markings as related to the expected strength of the specimen. In general, the grading was somewhat as follows:

Grade No. 1. Either no low-density markings were visualized in the necked-down area, or very small marks in the thicker portions of the necked-down area. These specimens were considered to be the best from the radiographic images.

Grade No. 2. Some small low-density lines were visualized in the necked-down area, usually extending only a small portion of the total dimension. These occasionally appeared in only one view.

Grade No. 3. This grade consisted of low-density markings that extended possibly 30 to 50 per cent of the necked-down area. In some instances, 2 or 3 such markings appear in the same specimen. Some specimens were graded as No. 3 specimens when small low-density lines appeared on both edges of the necked-down area.

Grade No. 4. This grade consists of specimens where the low-density lines were quite prominent and were visible for a considerable portion of the cross section of the necked-down area.

Grade No. 5. This grade was considered to be very low in strength due to the low-density mark which extends entirely across the necked-down area.

It is considered that there is insufficient background knowledge for this grading system to be highly accurate. Often, these were graded by guesswork and considerable error may be revealed. This grading system was attempted in an effort to establish the degree of ability to read these images at the present time and to use the results for future evaluation.

It would be appreciated if the results of the mechanical tests be submitted as soon as possible for correlation so that this information can be utilized in future interpretation. Enclosed you will find a test data sheet for ease of correlation of the estimated grade with the actual tensile strength of the specimen. It would be greatly appreciated if this sheet were completed and returned as soon as possible.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Mr. William Shelton
Wright-Patterson Air Force Base
Dr. Robert C. McMaster

Encls: X-Ray Films (8 x 10) (14)
Positive Prints (8 x 10) (14)
Test Data Sheet (2)

RADIOGRAPHIC TEST DATA SHEET

For: Second shipment of mechanical test specimens from Southern Research Institute, consisting of 101 CFZ graphite tensile test specimens.

Specimen No.		Interpreted Grade	Tensile Strength PSI
2A2a-at-	1	2	
	2	2	
	3	3	
	4	1	
2A2b-at-	1	4	
	2	4	
	3	2	
	4	1	
	5	2	
	6	3	
2A2c-at-	1	2	
	2	2	
	3	2	
	4	3	
	5	2	
	6	3	
	7	3	
2A2d-at-	1	4	
	2	4	
	4	2	
	5	2	
	6	3	
	7	4	
	8	4	
	9	3	
2A2e-at-	1	4	
	2	3	
	3	4	
	4	4	
	5	2	
	6	3	
	7	2	
	8	3	
	9	2	
	10	2	
2A2f-at-	1	1	
	2	2	
	3	3-4	
	4	2	
	5	2	
	6	2	
	7	2	
	8	3	
	9	2	
	10	3	
2A2f-at-	11	3	
	12	4	
2A2g-at-	1	1	
	2	3	
	3	4	
	4	3	
	5	2	
	6	1	
	7	2	
	8	4	
	9	1	
	10	3	
	11	4	
	12	4	
	13	4	
	14	2	
	15	4	
	16	2	
	17	5	
	18	2	
2A2h-at-	1	2	
	2	3	
	3	2	
	4	4	
	5	3	
	6	2	
	7	3	
	8	4	
	9	3	
	10	2	
	11	4	
	12	not machined	
	13	2	
	14	3	
	15	2	
	16	4	
	17	4	
	18	4	
2A2i-at-	1	2	
	2	4	
	3	3	
	4	5	
	5	3	
	6	3	
	7	3	

contd.

Radiographic Test Data Sheet Contd. -

Specimen No.		Interpreted Grade	Tensile Strength PSI
2A2i-at-	8	4	
	9	4	
	10	4	
	11	4-5	
	12	4-5	
	13	4	
	14	5	
	15	4	
	16	3-4	
	17	3	
	18	2	

February 24, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Your Shipment No. 3 of mechanical test specimens has been radiographed and are being returned. This shipment consisted of the 2A1 series of both flexure and tensile specimens.

Flexure specimens included were:

2A1 - AF -

a	b	c	d	e	f	g	h	i
1	1	1	1*					1
2	2	2	2					2
3	3	3						3
4	4	4						4
	5*	5						5
	6	6						6
		7						7
								8
								9
								10
								11
								12
								13
								14
								15
							16	16
							17	17
							18	18

Tensile specimens included were:

2A1 - AT -

a	b	c	d	e	f	g	h	i
				1	1	1	1	
				2	2	2	2	
			3	3	3	3	3	
			4	4	4	4	4	
			5	5	5	5		
			6	6	6	6	6	
			7	7	7	7	7	
			8	8	8	8	8	
			9	9	9	9	9	
				10	10	10	10	
					11	11	11	
					12	12	12	
						13	13	
						14	14	
						15	15	
						16		
						17		
						18		

Test data sheets were prepared for the flexure specimens and discontinuities visualized were identified and marked accordingly. It was considered impossible to grade the flexure specimens since the direction of flexing will have considerable influence on the effect of discontinuities. In general, it was noticed that the dense spots in some of the specimens were not evenly disbursed, but appear as clumps. This condition is quite evident in 2A1i-AF specimens. It may be noted that the dense specks are relatively evenly distributed in Specimens Nos. 1, 2, and 3, but start appearing in clumps that progressively increase through Specimen No. 18. It would be of considerable interest to know what these indications are, and their effect (if any) upon the mechanical properties of the material.

The tensile specimens were graded as to their estimated quality and these are shown in the attached table. Results of the mechanical tests will be correlated with this report as soon as the mechanical test data are received.

cc: Mr. Wm. Shelton, WPAFB
Dr. R. C. McMaster
Encls: 8x10 X-Ray Films (18)
8x10 Positive Prints (18)
Test Data Sheets (21)

Yours truly,

Merle Rhoten
Research Associate

MR/bf

RADIOGRAPHIC TEST DATA SHEET

For: Third shipment of mechanical test specimens from Southern Research Institute, consisting of CFZ Graphite flexure and tensile specimens.

Specimen No.		Interpreted Grade	Tensile Strength PSI	Specimen No.		Interpreted Grade	Tensile Strength PSI
2A1D-at-	3	2		2A1G-at-	9	2	
	4	2			10	3	
	5	1			11	1	
	6	3			12	1	
	7	4			13	1	
	8	2			14	1	
	9	3			15	3	
2A1E-at-	1	2			16	2-3	
	2	3			17	2	
	3	1			18	2	
	4	2		2A1H-at-	1	3	
	5	2			2	2	
	6	1			3	1	
	7	2			4	3	
	8	1			6	3	
	9	3			7	2	
	10	1			8	2	
2A1F-at-	1	2			9	3	
	2	3			10	3	
	3	3			11	2	
	4	3			12	3	
	5	2			13	2	
	6	2			14	3	
	7	5 very poor			15	3	
	8	1					
	9	1					
	10	2					
	11	4					
	12	2					
2A1G-at-	1	2					
	2	3					
	3	2					
	4	3					
	5	1					
	6	1					
	7	2					
	8	2-3					

February 28, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Your Shipment No. 4 has been radiographed and the specimens are being returned. This shipment consisted of 165 flexure specimens as follow:

1A12a-WF	1A34a-WF	1A34b-WF	1B12a-WF
1	1	1	1
2	2	2	2
		3	
		4	
		5	
6	6	6	6
		7	
		8	
9	9	9	9
		10	
		11	
		c12	
13	13	13	13
14	14		14

cont'd.

1B34a-WF	1B34b-WF	1C12a-WF	1C34a-WF
1	1	1	1
2	2	2	2
	3		
	4		
	5		
6	6	6	6
	7		
	8		
9	9	9	9
	10		
	11		
	12		
13	13	13	13
14		14	14

1C34b-WF	1E12a-WF	1E34a-WF	1E34b-WF
1	1	1	1
2	2	2	2
3			3
4			4
5			5
6	6	6	6
7			7
8			8
9	9	9	9
10			10
11			11
12			12
13	13	13	13
	14	14	

1D12a-WF	1D34a-WF	1D34b-WF	1F12a-WF
1	1	1	1
2	2	2	2
		3	
		4	
		5	
6	6	6	6
		7	
		8	
9	9	9	9
		10	
		11	
		12	
13	13	13	13
14	14		14

1F34a-WF	1F34b-WF	1G12a-WF	1G12b-WF
1	1		1
2	2		2
	3		3
	4		4
	5		5
6	6	6	
	7		
	8		
9	9	9	
	10		
	11		
	12		
13	13		
14			

1G34a-WF	1G34b-WF
3	
4	
5	
6	
7	
	15
	16
	17

Radiographic Technique

The technique for the radiography of these specimens was identical to the exposure technique used on the flexure specimens in Shipment No. 1. The industrial 50 KVP X-ray unit was used at 20 KVP, 15 MA, 5 MIN., with Class I X-ray film, and at a 34-inch source-film-distance.

Penetrameters

The 1 per cent (0.005-inch) and the 2 per cent (0.010-inch) penetrameters were placed on the specimens when being radiographed. The 1 per cent penetrameter (0.005-inch) is very fragile and is being broken by the repeated handling. Although the dimensions are reduced, it still is being used to demonstrate the image sensitivity.

Radiographic Interpretation

Test data sheets have been prepared for these flexure specimens. Low-density indications were marked on the photographic reproductions of the X-ray film to indicate position. Comments were made regarding the general condition of the specimens.

A general condition was noticed in these flexure specimens that was not visible in the No. 1 shipment. There appear to be dense spots, in varying concentrations, in these specimens. Very small, randomly-scattered dense specks have been reported previously. These dense spots appear to be a concentration of the specks. Very high concentrations of these dense markings were noted in Specimens Nos. 1A34b-WF-3, 4, and 8. The effects of these indications upon the mechanical properties are not known, and interpretation from the radiographs cannot be made at this time. It will be of great interest to learn if these dense spots increase or decrease the mechanical properties of the graphite material.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Mr. William Shelton, WPAFB
Dr. Robert C. McMaster

Encls: 8 x 10 X-Ray Films (28)
8 x 10 Positive Prints (28)
Test Data Sheets

March 3, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

The No. 3 shipment of mechanical test specimens has been radiographically inspected and are being returned. This shipment consisted of 23 resistivity specimens, 22 sonic, 34 expansion and 22 flexure for a total of 101 specimens.

Radiographic Technique

A different X-ray exposure technique was used for the round specimens with 1/2-inch diameter. Exposure conditions were 20 KVP, 15 MA, 3-1/2 MIN, Class I film, and a 34-inch S. F. D. This produces radiographs with sensitivity in the order of 1 per cent as revealed by the penetrameters. This also permits interpretation of the image through most of the circular specimens.

The 1/2-inch-square flexure specimens were exposed using the same technique previously reported.

Radiographic Interpretation

Representatives of Southern Research requested that the specimens be graded as to the material quality from the radiographic images. This is considered very difficult with the present knowledge of the effects of discontinuities upon the material properties. It is also difficult to grade the different specimens due to the unknown effects of a discontinuity on different mechanical properties. An identical discontinuity may have considerable effect upon tensile strength, but very little effect upon compression or sonic properties. The interpretation of these specimens are considered to be a classification, based upon experience gained from the interpretation of other materials. Experience may alter interpretation considerably from those classifications given these particular specimens.

It is considered somewhat premature to attempt this grading of graphite, but will probably accelerate the education in interpreting X-ray images. Correlation of the mechanical test data with the X-ray interpretation can be used to illustrate errors in judgement.

The Test Data Sheet for this set of specimens is attached.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Mr. William Shelton, WPAFB
Dr. Robert C. McMaster

Encls: 8x10 X-Ray Films (16)
8x10 Positive Prints (16)
Test Data Sheet

RADIOGRAPHIC TEST DATA SHEET

Southern Research personnel requested that an attempt be made to grade the Shipment No. 5 specimens from the radiographic images. This interpretation is as follows:

Specimen No.		Interpreted Grade	Remarks
2A3d-AE-	6	2	Some small low-density striations.
	7	2	Some small low-density striations.
2A3e-AE-	5	2	Some small low-density striations.
	6	3	Some low-density spots.
	7	4	A very sharp hair-line crack near left end of specimen.
	8	4	Low-density line and crack-like indication near left end of specimen.
	9	4	Sharp hair-line crack near left end of specimen.
	10	3	Low-density striation about 3/4-inch from left end of specimen.
2A3f-AE	1	3	Low-density line across specimen about 1-1/4-inches from right end.
	2	2	Some indication, but not as prominent as seen in No. 1.
2A3g-AM-	2	2	
	3	2	
	4	3	Low-density line about 1 inch from left end.
	5	3	Low-density lines about 1-1/2-inches from right end.
	6	4	Sharp low-density line 1-inch from right end of specimen.
2A3i-AM-	1	2	
	2	1	
	3	2	
	4	4	Sharp crack-line 2-7/16-inches from right end.
	5	3	
	6	3	

Specimen No.	Interpreted Grade	Remarks
2A3A-AM- 1	2	
2	3	Sharp line 1/2-inch from left end.
3	2	
4	3	Sharp line 1/2-inch from left.
2A3B-AM- 1	2	1/8-inch diameter circular spot 1-1/2-inches from right end.
2	2	
3	3	Also, indication at tape edge that appears as a crack, but may be tape.
4	3	Sharp lines 2 inches from right end.
5	2	
6	2	
2A3C-AM- 1	2	
2A3H-AE- 1	2	
2	2	
3	1	
4	2	
5	2	
6	2	
7	3	
8	3	
9	2	
10	3	
11	2	
12	2	
13	2	
14	3	
15	2	
16	2	
17	2	
18	2	
2A3G-AR- 7	1	
8	2	
9	1	
10	2	
11	1	Better than average set.
12	2	
13	2	
14	3	
15	3	
16	2	
17	2	
18	1	

Specimen No.	Interpreted Grade	Remarks
2A3C-AR- 2	3	
3	3	
4	2	
5	2	
6	3	
7	2	
2A3D-AR- 1	3	
2	3	
3	2	
4	2	
5	1	
2A3D-AE- 8	2	
9	2	
2A3E-AE- 1	3	
2	3	
3	2	
4	2	
2A3F-AF- 3	1	
4	2	
5	2	
6	2	
7	2	
8	2	
9	1	
10	2	
11	3	
12	3	
2A3I-AF- 7	1	
8	1	
9	2	
10	1	
11	2	In general, a good set of specimens.
12	1	
13	1	
14	1	
15	2	
16	2	
17	1	
18	2	

March 6, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Your No. 6 shipment of 163 CFZ graphite tensile specimens have been radiographically inspected and are being returned. Radiographs and interpretation report are included. You will notice that indications have been marked with a white grease pencil on your radiographs. Only the most-evident indications were marked.

The condition of the 1A12b-WT set of specimens is very interesting. An enlargement from the original X-ray film of Specimen No. 8 of this series is included for your study. I would like to know: (a). what it is and, (b). what is the effect on material strength. In attempting to interpret the radiographic images, it is not known if this condition is advantageous or detrimental to the material strength.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Mr. William Shelton, WPAFB
Dr. Robert C. McMaster

Encls: 8x10 X-Ray Films (26)
8x10 Positive Prints (26)
Test Data Sheet
8x10 Enlarged Print

RADIOGRAPHIC TEST DATA SHEET

For: Sixth shipment of 163 CFZ graphite tensile specimens.

Specimen No.		Interpreted Grade	Remarks
1A12a-WT-	3	2	
	5	3	
	8	3	
	10	3	
	11	3	
	12	2	
1A34a-WT-	3	4	
	4	2	
	5	2	
	10	1	
	11	2	
	12	2	
1A12b-WT-	2	2	
	3	3	This set of specimens has some relatively-large dense spots. These gradually increase in number and size from Specimen No. 2 through No. 8, which contains the maximum. Then, there is a gradual decrease through Samples Nos. 13 and 14, which contain very few of the dense patterns. Considered below average group of specimens.
	4	3	
	5	2	
	6	3	
	7	3	
	8	4	
	9	2	
	10	2	
	11	3	
	12	4	
	13	3	
	14	2	
1B12a-WT-	3	2	
	5	2	
	8	2	
	10	2	
	11	1	
	12	2	
1B34a-WT-	3	2	
	4	1	These specimens considered above average in quality.
	5	1	
	10	1	
	11	1	
	12	2	

Specimen No.		Interpreted Grade	Remarks
1B12b-WT-	2	2	This set of specimens show the same general characteristics as set 1A12b-WT, as if they were cut from adjacent areas of the billet. The dense indications are less numerous than in set 1A12b, but again Specimen 1B12b-WT-8 has the maximum in this set. In general, these are considered superior to set 1A12b-WT.
	3	1	
	5	2	
	6	2	
	7	3	
	8	2	
	9	1	
	10	2	
	11	2	
	12	2	
	13	2	
	14	1	
1C12a-WT-	3	2	
	5	2	
	8	1	
	11	1	
	12	2	
1C34a-WT-	3	3	
	4	1	
	5	2	
	10	1	
	11	2	
	12	3	
1C12b-WT-	2	2	
	3	2	
	4	2	
	5	2	Two specimens were identified as ten (10). These were marked as "10a" and "10b". In general, these were above average specimens.
	6	1	
	7	2	
	8	2	
	9	1	
	10a	1	
	10b	2	
	11	1	
	12	2	
	13	2	
	14	1	

Specimen No.	Interpreted Grade	Remarks
1D12a-WT- 3	2	
5	2	
8	2	
10	3	
11	2	
12	2	
1D34a-WT- 3	3	
4	2	
5	1	
10	1	
11	1	
12	1	
1D12b-WT- 2	2	
3	2	
4	2	
5	2	
6	2	
7	1	
8	3	
9	3	
10	2	
11	3	
12	2	
13	1	
14	1	
1E12a-WT- 3	2	
5	1	
8	1	
10	1	
11	2	
12	2	
1E34a-WT- 3	1	
4	2	
5	1	
10	2	
11	2	
12	2	

Specimen No.		Interpreted Grade	Remarks
1E12b-WT-	2	1	
	3	2	
	4	2	These specimens appear granular and contain evenly-dispersed dense spots.
	5	2	
	6	2	
	7	1	
	8	2	
	9	2	
	10	2	
	11	1	
	12	2	
	13	2	
	14	2	
1F12a-WT-	3	1	
	5	1	
	8	2	
	10	2	
	11	2	
	12	(2)	Expected to break at mark outside necked-down area.
1F34a-WT-	3	1	
	4	2	
	5	2	
	10	1	
	11	2	
	12	2	
1F12b-WT-	2	2	
	3	2	
	4	2	
	5	1	
	6	1	
	7	2	
	8	1	
	9	2	
	10	1	
	11	2	
	12	2	
	13	2	
	14	2	

Specimen No.		Interpreted Grade	Remarks
1G12a-WT-	3	2	
	4	2	
	5	2	
	7	1	
	8	2	
	10	1	
	11	2	
1G34b-WT-	7	2	
	8	2	
	9	1	
	11	2	
	12	2	
	13	1	
	14	2	

March 13, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Your Shipment No. 7 of mechanical test specimens have been radiographically inspected and are being returned. This shipment consists of 78 specimens.

Radiographic interpretation was made to the best of our ability. The effect of various discontinuities are not known on the parameters to be measured in these specimens. Therefore, the grades assigned to these specimens are simply an estimate of the material quality.

It may be of particular interest to notice the effects of the granular conditions, observed in specimens 1A12b-WR-1 and 1B12a-WR-1, as compared to the more homogeneous specimens in this lot. The results of the tests would be of great value in future interpretation of radiographs.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Mr. William Shelton, WPAFB
Dr. Robert C. McMaster

Encls: 8x10 X-Ray Films (20)
8x10 Positive Prints (20)
Test Data Sheet

RADIOGRAPHIC TEST DATA SHEET

For: Shipment No. 7; 78 mechanical test specimens of CFZ graphite.

Specimen No.		Interpreted Grade	Remarks
1A34a-WE-	7	3	
	8	4	
1A34b-WE-	15	3	
	16	4	
1B34a-WE-	7	2	
	8	1	
1B34b-WE-	15	2	
	16	3	
1C34a-WE-	7	1	
	8	1	
1C34b-WE-	15	1	
	16	1	
1D34a-WE-	7	2	
	8	2	
1D34b-WE-	15	3	
	16	2	
1E34a-WE-	7	2	
	8	2	
1E34b-WE-	15	2	
	16	3	
1F34a-WE-	7	2	
	8	3	
1F34b-WE-	15	1	
	16	3	
1G12a-WE-	1	1	
	2	2	
1G12b-WE-	12	1	
	13	2	
	14	1	
	15	1	
	16	4	
1G34a-WE-	13	4	
	14	3	
1A12a-WM-	7	3	
1A34b-WM-	14	3	
1B12a-WM-	7	4	
1B34a-WM-	14	4	

Specimen No.	Interpreted Grade	Remarks
1C12a-WM- 7	4	
1C34b-WM- 14	4	
1D12a-WM- 7	3	
1D34b-WM- 14	4	
1E12a-WM- 7	3	
1E34b-WM- 14	3	
1F12a-WM- 7	4	
1F34b-WM- 14	3	
1G12b-WM- 6	1	
7	2	
8	3	
9	2	
10	2	
11	1	
1A12a-WR- 4	2	
1A12b-WR- 1	3	Specimen appears granular in structure.
1B12a-WR- 4	1	
1B12b-WR- 1	3	Specimen granular in structure.
1C12a-WR- 4	1	Specimen appears normal - even distribution of small, dense particles.
1D12a-WR- 4	3	
1D12b-WR- 1	2	
1E12a-WR- 4	3	
1E12b-WR- 1	3	
1F12a-WR- 4	2	
1F12b-WR- 1	2	
1G12a-WR- 4	1	
5	2	
6	2	
12	2	
13	1	
14	3	
1G34a-WR- 1	2	
2	2	
1G34b-WR- 1	1	
2	2	
3	2	

Specimen No.		Interpreted Grade	Remarks
1C12b-WT-	1	2	Specimen appears somewhat granular, but not to the extent of 1A12b-WR-1.
1G34a-WT-	8	2	
	10	3	
	11	2	
	12	2	

March 31, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Shipment No. 8 of graphite mechanical test specimens have been radiographically inspected. No interpretation of the specific heat specimens was made.

The other specimens in this shipment were graded in a relation to the discontinuities visualized. In general, these specimens appear to be above average in homogenuity.

The interpretation report is included with a complete set of radiographs for your information.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

cc: Dr. Robert C. McMaster
Mr. William Shelton, WPAFB

Encls: 8x10 X-Ray Films (26)
8x10 Positive Prints (24)
Test Data Sheet

RADIOGRAPHIC TEST DATA SHEET

Radiographic interpretation for Southern Research graphite mechanical test specimens Shipment No. 8.

Specimen No.		Interpreted Grade
5a1b-AK	1	2 (Very small crack-like lines)
	2	1
	3	1
	4	2
5a2b-AK	1	2
	2	1
	3	1
	4	1
5a3b-AK	1	1
	2	1
	3	1
	4	1
5a4b-AK	1	2
	2	5 (Crack)
	3	4
	4	4 (Crack)
5a1f-AK	4	1
	5	1
	6	1
	7	1
	8	2
	9	1
5a2f-AK	1	1
	2	1
	3	2
	4	1
	5	2
	6	1

Specimen No.		Interpreted Grade
5a1e-AP	1	1
	2	1
	3	2
	4	2
	5	1
	6	1
	7	1
	8	1
	9	1
5a3d-AP	1	1
	2	2
	3	1
	4	1
	5	2
	6	1
	7	1
5a1f-AP	1	1
	2	1
	3	1
5a1d-WK	1	2
	2	1
	3	2
	4	2
	5	2
	6	1
	7	2
5a2d-WK	1	2
	2	1 (This group
	3	1 contains
	4	1 larger dense
	5	1 inclusions)
	6	1
	7	1

contd.

Continuation of radiographic interpretation for Southern Research graphite mechanical test specimens Shipment No. 8:

Specimen No.		Interpreted Grade
5a3e-WK	1	1
	2	1
	3	1
	4	1
	5	2
	6	1
	7	1
	8	1
	9	2
5a3f-WK	1	1
	2	2
	3	1
5a1a-WP	1	1
	2	1
	3	1
5a2a-WP	1	1
	2	1
	3	1
5a3a-WP	1	1
	2	1
	3	2
5a4d-AP	1	1
	2	1
	3	1
	4	1
	5	1
	6	1
	7	1

Specimen No.		Interpreted Grade
5a2e-WP	1	1
	2	1 (Very good
	3	1 set of
	4	1 specimens)
	5	1
	6	1
	7	1
	8	1
	9	1
5a4a-WP	1	1
	2	2
	3	1
5a2f-WP	7	1
	8	1
	9	2

May 27, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Shipment No. 9 of mechanical test specimens have been received and radiographed. This shipment consisted of 153 WC specimens.

Interpretations of the radiographs were attempted and the results are attached. These were graded numerically in a relation to the homogenuity of the specimen. In general, these were considered to be good specimens.

Enclosed you will find an original radiograph of each specimen in both a 0^{o} and 90^{o} views. The white center lube used in the machining process offered some handling problems. This material is evidently high in lead content and shows a very dense indication in radiographs. In spite of very careful handling, it was smeared on the specimens in a few instances.

Very truly yours,

Merle Rhoten
Research Associate

MR/bf

Encls: Radiographs (24)
Report

RADIOGRAPHIC TEST DATA SHEET

For: Shipment No. 9 of 153 WC mechanical test specimens.

Specimen No.		Interpreted Grade
4A12a	1	2
	2	1
	3	1
	4	2
	5	3
	6	3
4A34a	1	1
	2	3
	3	2
	5	1
	6	2
4A12b	1	1
	2	3
	3	3
	4	3
	6	3
	7	2
	8	2
4A34b	1	1
	2	1
	3	1
	5	3
	6	2
	7	2
4A12c	1	1
	2	1
	3	3
	4	2
	5	3
	6	3
	7	3
	8	4
	10	2
	11	2
	12	3
	13	1

Specimen No.		Interpreted Grade
4A34c	1	1
	2	1
	3	2
	4	1
	5	1
	6	2
	7	2
	8	3
	9	3
	10	1
	11	2
	12	2
	13	3
	14	2
4B12a	1	3
	2	2
	4	2
	5	2
	6	2
4B34a	1	1
	2	2
	3	1
	4	2
	5	2
	6	2
4B12b	1	2
	2	3
	3	2
	4	2
	5	3
	6	2
	8	2

Specimen No.		Interpreted Grade
4B34b	1	1
	2	2
	3	2
	4	3
	5	2
	6	2
	7	2
	8	3
4B12c	1	2
	2	2
	3	2
	4	1
	5	2
	6	1
	7	2
	8	2
	9	1
	10	1
	13	1
	14	1
4B34c	1	2
	2	1
	3	1
	4	1
	5	2
	6	1
	7	3
	8	2
	9	2
	10	1
	11	3
	12	3
	13	2
	14	3

Continued . . . . . .

Radiographic Test Data Sheet for Shipment No. 9 continued ......

Specimen No.		Interpreted Grade	Specimen No.		Interpreted Grade
4C12a	1	2	4C12c	1	1
	2	2		2	1
	3	3		3	2
	4	2		4	2
	5	3		6	2
	6	2		7	3
				8	2
4C34a	2	3		9	3
	3	4		10	2
	4	4		11	2
	5	3		12	1
	6	2		13	2
				14	1
4C12b	1	2			
	2	3	4C34c	1	3
	3	3		4	1
	4	2		5	1
	5	2		6	3
	6	2		7	1
	7	2		8	3
	8	1		9	2
				10	2
4C34b	1	2		11	2
	2	1		12	2
	3	2		13	2
	4	3			
	5	2			
	6	3			
	7	2			
	8	3			

May 27, 1964

Southern Research Institute
2000 Ninth Avenue South
Birmingham 5, Alabama

Attention: Mr. John Woodward

Dear John:

Your Shipment No. 10 has been received and radiographed. This shipment consists of 159 AC specimens.

Radiographic interpretation was made from the radiographic images and the specimens were graded in a relation to the homogenuity. Enclosed you will find the original radiographs and the test report on the results. Correlation of this interpretation with actual mechanical properties should be very interesting.

Yours truly,

Merle Rhoten
Research Associate

MR/bf

Encls: Radiographs (32)
Report

RADIOGRAPHIC TEST DATA SHEET

For: Shipment No. 10 of 159 AC mechanical test specimens.

Specimen No.		Interpreted Grade	Specimen No.		Interpreted Grade	Specimen No.		Interpreted Grade
3A1a	1	1	3A1f	1	2	3A2e	1	2
	2	1		2	2		2	2
	3	2		3	1		3	2
				4	3		4	1
3A1b	1	2		5	3		5	2
	2	1		6	4		6a	3
	3	1		7	2		7	1
	4	1		8	3		8	2
				9	2		9b	2
3A1c	1	1		10	3		10	1
	2	2						
	3	3	3A2a	1	3	3A2f	1	1
	4	1		2	3		2	2
	5	3		3	2		3	3
	6	3					4	1
			3A2b	1	1		5	1
3A1d	1	2		2	2		6	2
	2	2		3	2		7	2
	3	1					8	1
	4	1	3A2c	1	2		9	1
	5	2		2	2		10	2
	6	2		3	2			
	7	2		4	2	3A3a	1	2
				5	2		2	1
3A1e	1	1		7	3		3	3
	2	2						
	3	2	3A2d	1	3	3A3b	1	2
	4	2		2	1		2	3
	5	1		3	2		3	2
	6	1		4	3		4	3
	7	2		5	2			
	8	1		6	3			
	9	3		7	2			
	10	2						

Continued . . . .

Radiographic Test Data Sheet for Shipment No. 10 continued . . . .

Specimen No.	Interpreted Grade
3A3c 1	2
2	1
3	1
4	3
5	3
6	1
3A3d 1	2
2	2
3	3
4	2
5	3
6	2
7	1
3A3e 1	1
2	3
3	2
4	2
5	2
6	2
7	1
8	3
9	2
10	2
3A3f 1	1
2	1
3	2
4	1
5	2
6	1
7	1
8	2
9	3
10	2

Specimen No.	Interpreted Grade
3A4a 1	2
2	2
3	1
3A4b 1	3
2	3
3	3
4	3
3A4c 1	2
2	1
3	2
4	1
5	1
6	3
3A4d 1	2
2	3
3	3
4	2
5	3
6	2
7	3
3A4e 1	2
2	2
3	1
4	2
5	2
6	1
7	1
8	2
9	2
10	2

Sepcimen No.	Interpreted Grade
3A4f 1	2
2	2
3	1
4	1
5	1
6	2
7	2
8	3
9	3
10	2