Intercomparison of Visual Diffuse Transmission Density Measurements

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An intercomparison of visual diffuse transmission density measurements of photographic and x-ray film step tablets was completed by two national metrology institutes, the National Institute of Standards and Technology, USA, and the Physikalisch-Technische Bundesanstalt, Germany. The samples were measured by three reference densitometers according to procedures described in international documentary standards. The instruments are well characterized with estimates of their measurement uncertainties. The systematic differences between the density measurements were less than 0.010 for the photographic films and 0.015 for the x-ray films for densities as great as 3.3.

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Introduction

Visual diffuse transmission density is the base ten logarithm of the luminous transmittance of an object under either diffuse illumination or collection conditions. Accurate values of visual diffuse transmission densities of scattering samples are needed for many purposes—quality assurance in medical X-ray diagnostics, industrial nondestructive X-ray testing, quality control in graphic arts, and, of course, for characterizing photographic materials. Calibration and testing of densitometers used for these purposes requires suitable test objects, usually film step tablets with known densities.

Such film step tablets are calibrated by services that need reference standards for this task. For reasons of traceability, these reference standards are calibrated with very low uncertainty by national metrology institutes such as the National Institute of Standards and Technology (NIST) and the Physikalisch-Technische Bundesanstalt (PTB). These institutes have developed dedicated instruments that are capable of measuring visual diffuse transmission densities directly, without any film step tablets being needed for calibration. PTB has set up two, and NIST one, densitometer for measuring these densities. The instruments comply with the conditions described in international standards ISO 5-1, 5-2 and 5-3.[1–3]

A direct comparison of measured densities obtained by the two national metrology institutes is important to maintain traceability at the highest level, and is the key method to assure equivalence of measurement standards. The first intercomparison of measurements of visual diffuse transmission density between the two national metrology institutes is reported here.

Instrumentation

This section gives a brief overview of the instrumentation used in this intercomparison; detailed descriptions of the densitometers have been published elsewhere.[4,5]

PTB Inverse Square Law Densitometer

The PTB inverse square law densitometer is the German national standard reference densitometer capable of measuring visual diffuse transmission densities of spectrally neutral and non-neutral film samples. It uses the "diffuse efflux mode" measuring configuration,[2] where the film sample is illuminated directionally and the transmitted flux is measured by a diffuse receiver. The densitometer is a dual beam device using the same light source and the same photodetector for both the reference and the sample beam. The luminous flux is time-shared by the reference and sample path, and is detected by applying phase-sensitive lock-in techniques. This arrangement is chosen to avoid deviations of the measurement results caused by possible long-term drifts or instabilities of the luminous intensity of the light source or the photodetector sensitivity. Furthermore, it helps to reduce the influence of low-frequency noise contributions. The densitometer uses a null-balance measuring configuration based on the fundamental photometric inverse square law.

PTB Fiber Densitometer

The fiber densitometer is specially designed to measure high densities of neutral samples, and it thus complements the range of application of the inverse square law densitometer. It is a single-beam densitom-

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TABLE I. Details of Step Tablet Films Used in the Intercomparison

Owner	Type	Manu.	No. of Tablets	Serial Nos.	No. of Steps	Max.D_T	Properties
PTB	Photo.	Agfa	2	N-2001, N-2002	20	3	Neutral, single-sided emulsion
PTB	Industrial X-Ray	Agfa	2	D7-2002, D7-2003	20	3	Blue, double-sided emulsion
PTB	Medical X-Ray	Kodak	2	S3-8, S3-11	10	3	Blue, double-sided emulsion
NIST	Photo.	Agfa	4	970003 to 970006	21	4	Neutral, single-sided emulsion
NIST	Medical X-Ray	Agfa	4	291401 to 291404	17	4	Blue, double-sided emulsion

eter that uses the "diffuse influx mode" configuration[2] with an opal glass as a diffuser. In this measuring mode, the sample is illuminated by diffuse light, and the transmitted luminous flux is detected with a directional receiver. In the case of spectrally non-neutral samples the densities measured with the fiber densitometer may differ significantly from that measured with the inverse square law densitometer as a consequence of a worse spectral product; therefore, this densitometer is applied only for measurements of the photographic film step tablets.

NIST Densitometer

The NIST densitometer is the national standard reference instrument of the United States for measuring visual diffuse transmission density.[5] The densitometer was designed to automatically measure many film step tablets in a single batch run using computerized data acquisition and control. Its primary function is to calibrate both x-ray and photographic films, sold as Standard Reference Materials, whose steps have transmission densities from approximately 0.1 to 4.0.

The densitometer uses the diffuse influx mode. Diffuse illumination is achieved with a flash opal glass, which transmits the radiant flux from a quartz-tungsten-halogen lamp—infrared filter combination. Directional detection is accomplished with a lens system. The radiant flux transmitted by the film passes through a photopic filter and is detected by a temperature-controlled silicon photodiode with amplifier electronics capable of measuring signals spanning seven orders of magnitude. Accurate measurements of transmission density therefore rely upon the linearity of the photodiode-amplifier combination over the range of signals for the aperture and transmitted fluxes. The film transport system uses a vacuum system to center each step of a film on the opal for measurements.

For simplicity and consistency in the following sections, the PTB inverse square law densitometer and fiber densitometer will be referred to as the PTB diffuse efflux and diffuse influx instruments, respectively, while the NIST densitometer will be referred to as the NIST diffuse influx instrument. Also, the measurement uncertainties of the instruments were analyzed according to the ISO Guidelines for the Expression of Uncertainty in Measurement.[6]

Experimental Procedure

The intercomparison was performed by exchanging film step tablets, three types from PTB and two types from NIST, between the two institutes. Specific details about the step tablet films are given in Table I. Each institute measured their films several times using their standard procedures prior to sending them to the other institute, and again when they returned. Likewise, each institute measured the films from the other institute several times with appropriate modifications for the other institute's films. Specifically, PTB attached a narrow piece of tape marking the positions of the steps to the NIST films, while NIST measured the PTB samples manually rather than automatically. For no films did the measured densities vary by more than the assigned uncertainties after being measured by the other institute. Therefore, all the densities measured by each institute were averaged for the results presented in the **Results and Discussion** section.

Results and Discussion

The purpose of the work presented here was to compare the visual transmission densities of different types of film step tablets measured by the instruments at both PTB and NIST. Because three instruments were involved in this intercomparison, the results are best understood by comparing the densities measured by two of the instruments to the third. The one chosen as the basis for the intercomparison is the PTB diffuse efflux instrument because it can measure both photographic and x-ray film types, it has been in operation for the longest period of time of any of the instruments, and it is well-characterized. Therefore, the results presented here will first detail the agreement between the two PTB instruments, followed by a comparison between the PTB diffuse efflux instrument and the NIST diffuse influx instrument.

The comparison between the two PTB instruments is limited to the neutral photographic films because the diffuse influx instrument is not used to measure other types of films. The difference in measured visual transmission density between the two instruments is shown in Fig. 1 as a function of step density for the (a) PTB and (b) NIST photographic film step tablets. The different symbols are for the different films of each type. The expanded uncertainties (k = 2) arising from systematic effects are shown in Fig. 1 as dashed lines. The differences shown in Fig. 1 are within the expanded uncertainty arising from systematic effects for all steps except those of the PTB films at the lowest density, and the differences are all less than 0.005. There is an increase of about 0.002 in the difference at densities of approximately 1.6, where the auxiliary sample is used on the diffuse efflux instrument for larger densities. This is likely due to systematic effects with the diffuse efflux instrument, which are taken into account by a density-dependent component of uncertainty.

Because the differences for a given film type have nearly the same values at each density and the same trend with density, as shown in Fig. 1, random effects are not a significant cause of uncertainty when comparing between instruments. Therefore, uncertainties arising only from systematic effects will be considered when using the density differences to compare between instruments. This applies not only to the comparison between the two PTB instruments but also to the comparison between the PTB and NIST instruments. The uncertainties arising from systematic effects[4] for the comparison between the two PTB instruments is given in Table II. Note that these uncertainties include the uniformity of the step for the films because the aperture flux may not pass through the same area of the step on each instrument.

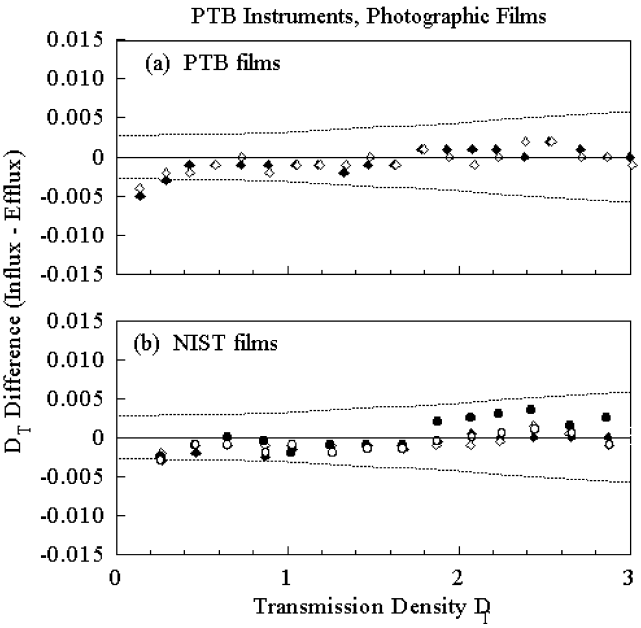

Figure 1. Difference in transmission density D_T between the PTB diffuse influx and efflux instruments as a function of step density for photographic films supplied by (a) PTB and (b) NIST. The symbols are for the different films of each type, and the dashed lines are the expanded uncertainties from systematic effects.

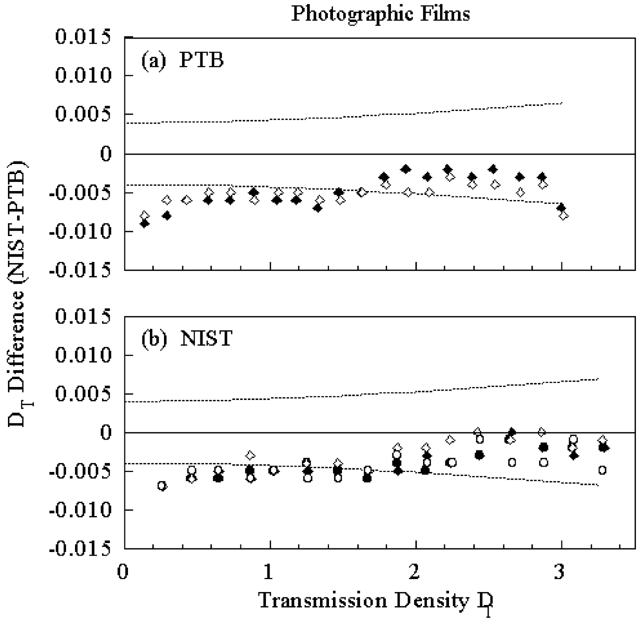

Figure 2. Difference in transmission density D_T between the NIST diffuse influx and the PTB diffuse efflux instruments as a function of step density for the photographic films listed in the panels. The symbols are for the different films of each type, and the dashed lines are the expanded uncertainties from systematic effects.

TABLE II. Expanded Uncertainties (k = 2) Arising from Systematic Effects for the Comparison Between the Two PTB Instruments

Component of Uncertainty	Expanded Uncertainty $U(D_T)$
Diffuse efflux length measurement	0.0016 D_T
Diffuse efflux inverse-square-law	0.0007 D_T
Diffuse efflux, other	0.002
Diffuse influx linearity	0.001
Diffuse influx filter calibration	0.002
Step uniformity	0.002

The comparison between the PTB diffuse efflux instrument and the NIST diffuse influx instrument includes both photographic and x-ray films. The difference in measured visual transmission density between the two instruments as a function of density is shown in Fig. 2 for the photographic films and in Fig. 3 for the x-ray films, with the film owner indicated in the panels. As with Fig. 1, the different symbols are for the different films of each type and the expanded uncertainties (k = 2) arising from systematic effects are shown as dashed lines. The uncertainties arising from systematic effects[4,5] are given in Table III.

The differences shown in Figs. 2 and 3 are generally larger than the expanded uncertainty, indicating that there is a systematic difference between the PTB and NIST instruments. In some cases, particularly that shown in Fig. 3(a), there is a systematic difference between films of the same type, possibly resulting from film nonuniformity. For the photographic films, the difference decreases with increasing density so that it is less than the expanded uncertainty for densities greater than approximately 1.6. This is partially due to the use of an auxiliary sample for the PTB diffuse efflux instrument starting at this density. For all samples, the difference is always less than 0.010, with a mean difference of –0.004. A comparison of non-scattering Wratten filters with transmission densities from 0.1 to 1.0 found that measurements made with the NIST diffuse influx instrument were systematically lower by 0.003 from those made with the PTB diffuse instrument, independent of density.

For the x-ray films, the difference is nearly always greater than the expanded uncertainty, but always less than 0.015, with a mean difference of –0.008. The difference for the PTB industrial x-ray films has the same dependence on density as for the photographic films, but with an approximately constant offset. This dependence is not present for the PTB medical x-ray films, while the NIST photographic and x-ray films have opposite dependencies with density—the difference decreases for the photographic films and increases for the x-ray films. Drawing firm conclusions from the differences for the x-ray films is complicated by the observation by both institutes that the density depends on humidity. Generally, the density decreases with increasing humidity, and this effect is more pronounced for the steps with greater densities. Because the humidity was not carefully monitored at either institute during this intercomparison, it is not possible to correlate the differences shown in Figs. 2 and 3 with humidity.

Overall, the results from this intercomparison are very encouraging, particularly for the first such intercomparison between national metrology institutes. The differences shown in Figs. 2 and 3 indicate that there is a systematic difference, greater than that expected based upon the uncertainties assigned to the individual instruments, between the measurements made by PTB and NIST, with the NIST values generally lower than those of PTB. However, the difference is relatively small and is less than the uncertainties of many commercial instruments,[7] being less than 0.010 and 0.015 for the photographic and x-ray films, respectively, In contrast,

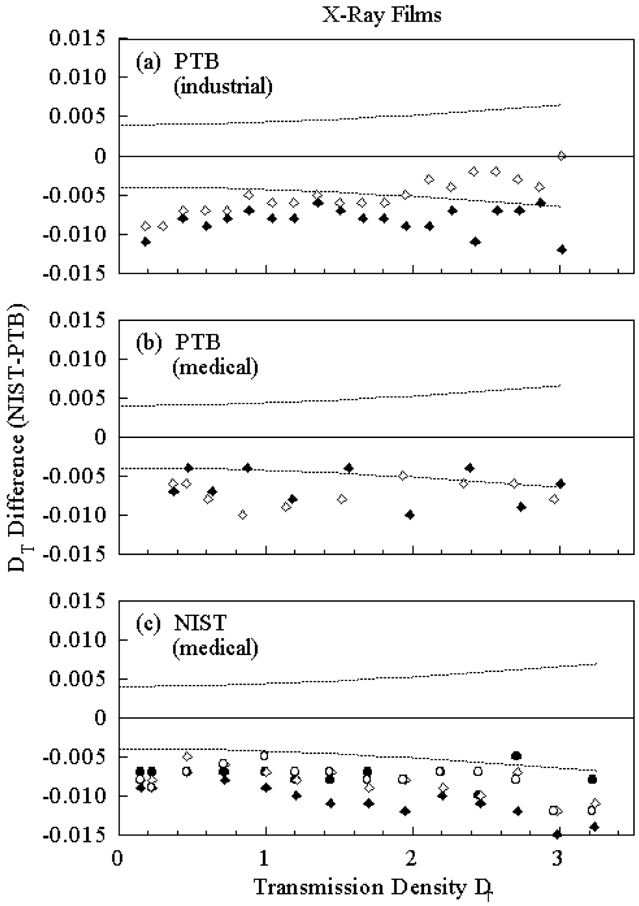

Figure 3. Difference in transmission density D_T between the NIST diffuse influx and the PTB diffuse efflux instruments as a function of step density for the x-ray films listed in the panels. The symbols are for the different films of each type, and the dashed lines are the expanded uncertainties from systematic effects.

differences as large as 0.03 for photographic films and 0.04 for x-ray films were obtained in a recent comparison between NIST and two other laboratories in the United States.[8] Reduction of the differences from this intercomparison will require detailed analyses and experiments, which may be performed in the future but are outside the scope of this work.

TABLE III. Expanded Uncertainties (k = 2) Arising from Systematic Effects for the Comparison Between the PTB Diffuse Efflux and the NIST Diffuse Influx Instruments

Component of Uncertainty	Expanded Uncertainty $U(D_T)$
Diffuse efflux length measurement	0.0016 D_T
Diffuse efflux inverse-square-law	0.0007 D_T
Diffuse efflux, other	0.002
Diffuse influx linearity	0.002
Diffuse influx opal reflectance	0.002
Step uniformity	0.002

Conclusions

An intercomparison of visual diffuse transmission density measurements was successfully conducted between PTB and NIST. Both photographic and x-ray film step tablets were used in this intercomparison, which involved diffuse influx and efflux instruments at PTB and a diffuse influx instrument at NIST. The differences in density between the two PTB instruments using photographic films were within the expanded uncertainties arising from systematic effects, indicating that the measurements made by the two instruments agree with each other. The densities measured by the NIST instrument were systematically lower, by an amount greater than the expanded uncertainties, than those measured by the PTB diffuse efflux instrument for all types of films. However, the differences in density of less than 0.010 for the photographic films and 0.015 for the x-ray films are very encouraging for the first intercomparison of this type between two national metrology institutes, as they are comparable to the uncertainties of many commercial instruments.

References

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