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Preparation of X-radiation Characteristic Curves for Cathode Ray Tubes

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Preparation of X-radiation Characteristic Curves for Cathode Ray Tubes**CONTENTS**

	Page
Foreword	iii
1 Introduction	1
2 Adjustment of X-radiation data	1
2.1 Normalization to a different beam current	2
2.2 Calculation of X-radiation at minimum glass thickness and minimum absorption coefficient	2
2.3 Data acquisition	4
3 Construction of X-radiation characteristic curves	7
3.1 Color - entire tube	7
3.2 Color - tube anode contact	9
3.3 Monochrome - cathode ray tubes	14
4 References	16

Foreword

This standard was prepared by the Electronic Industries Association's JT-32 Electronic Tube Safety Committee Task Force on X-ray Measurements.

1 Introduction

In accordance with the Radiation Control for the Health and Safety Act of 1968, cathode ray tube (CRT) manufacturers are required to submit an initial report to the Center for Devices and Radiological Health (CDRH), an agency of the U.S. Department of Health and Human Services (DHHS). The initial report for cathode ray tubes must provide results of the testing and measuring of the X-radiation emissions from a cathode ray tube.

The initial report for a new CRT tube is submitted by a manufacturer. The parts of the initial report to be discussed by this document are the preparation of the data plots for X-radiation limit curves and 36 pA/kg isoexposure-rate limit curves. The X-radiation limit curve defines the relationship between CRT high-voltage and the X-radiation exposure rate (pA/kg) under a constant beam current. The "36 pA/kg isoexposure rate limit curve" defines the combinations of CRT anode voltages and beam currents that produce a constant rate, in this case 36 pA/kg, of X-radiation emission from the CRT. Usually, such limit curves represent the worst case conditions for X-radiation emission from the CRT. Pertinent parameters to be reported are the registration reference points and limit curve slope factors.

Throughout this document the terms "CRT high-voltage" and "anode voltage" mean the overall acceleration of the electron beam from cathode to final anode.

Two limit curves should be developed, one for the entire CRT and one for the anode contact. The following instruction for the preparation of the X-radiation characteristic curves is recommended to insure uniformity throughout the CRT industry.

NOTE—To conform with the International System of Units (SI) dimensions, the unit for radiation exposure of "pA/kg" (picoamperes per kilogram) has replaced "mR/h". The SI equivalent of 0.5 mR/h is 36 pA/kg. The relationship between the two measurements scales is:

$$1 \text{ mR/h} = 72 \text{ pA/kg}$$

2 Adjustment of X-radiation data

In the development of X-ray limit curves, five adjustments are made to the original data. All of these changes could, in principle, be accomplished "physically"; that is, by actually measuring tubes that were constructed of minimum specified glassware and tested at the standard reference beam current. However, the practicality of such testing is beyond tube manufacturing and radiation detection methods of accomplishment. Adjustment of the X-radiation data to glass of minimum thickness and minimum absorption coefficient, with additional safety margin, is a five step process.

- Step 1)** Adjust exposure rate data for background, meter calibration factor, etc. Refer to detection system operations manual.
- Step 2)** The test beam current is normalized to the standard reference current (see 2.3.5) specified for the tube being tested. See 2.1.
- Step 3)** Convert the data from step 2 to the exposure rate expected from a tube constructed with materials that are of minimum specifications for glass thickness and glass absorption. See 2.3.6.
- Step 4)** Calculate the sample average ($\bar{X}$), sample standard deviation (σ), and ($\bar{X} + 3\sigma$) for the converted data from the previous step. See 2.3.7.
- Step 5)** Establish a guardband for the results from step 4. See 3.1.5.

It may be instructional at this time to review the consequences of making the various adjustments to the measured X-ray data. To this end a hypothetical X-radiation curve was synthesized.

2.1 Normalization to a different beam current

Because the X-radiation exposure rate is linearly proportional to the beam current, shifting from one beam current level to another is done by simple proportion. The curve is simply translated up or down. In figure 1, the original curve ($I_b = 300 \mu\text{A}$) has been shifted upward by a factor of 10. In practice, a $3000 \mu\text{A}$ curve may be developed first and a $300 \mu\text{A}$ curve would then be derived by dividing by a factor of 10 (see figure 1).

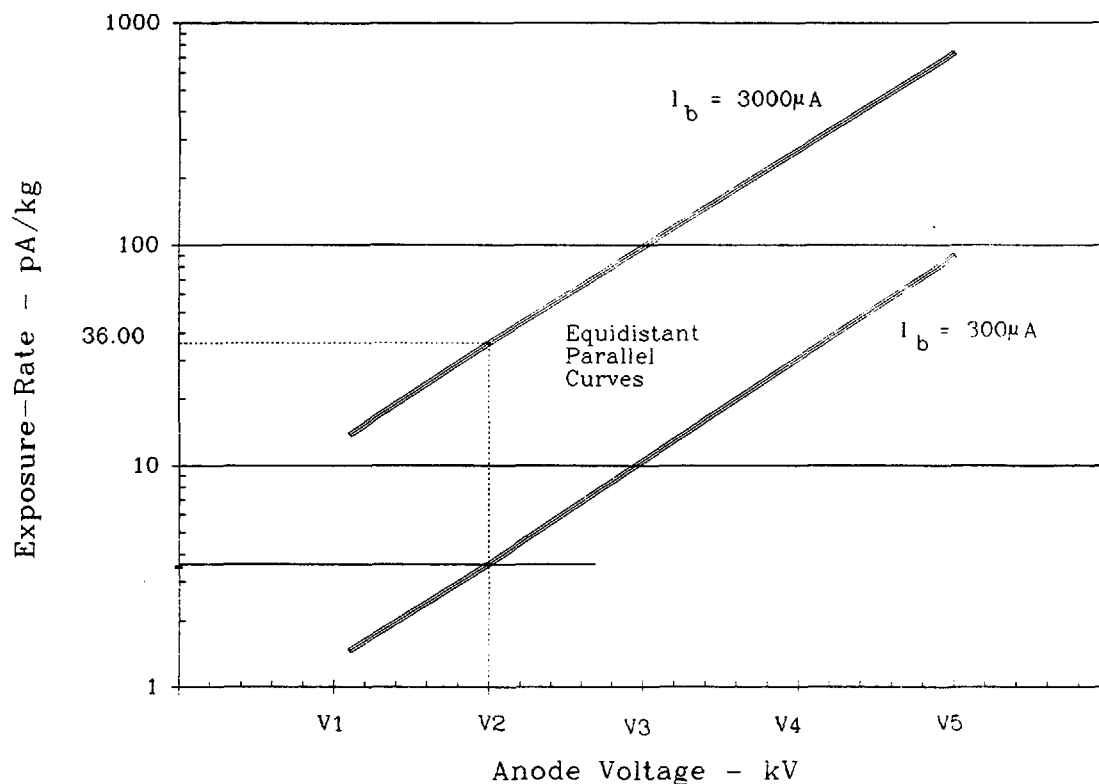


Figure 1—Adjustment due to different beam current

2.2 Calculation of X-radiation at minimum glass thickness and minimum absorption coefficient

In practice, actual glass thickness and absorption coefficient always exceed minimum. In addition, X-radiation increases with decreased thickness and/or with decreased absorption coefficient. Therefore, adjustments to the measured X-radiation values must be made to predict worst case emission for glass containing minimum thickness and minimum absorption coefficient.

In a composite material such as glass, each component element absorbs independently of the other elements. Hence, the effective mass absorption coefficient for the composite glass (ω_{glass}) is the summation of these separate elemental absorption contributions shown in equation 1.

$$\omega_{\text{glass}} = \sum_{c=1}^n f_c \omega_c \quad (1)$$

where

f_c is the mass fraction of component;

ω_c is the mass absorption coefficient of component.

The linear absorption coefficient (μ) at a specific X-ray wavelength equals the density (ρ) multiplied by the mass absorption coefficient (ω) for that wavelength shown in equation 2.

$$\mu = \rho\omega \quad (2)$$

Conventional practice is to characterize the X-ray absorption of CRT glassware by the linear absorption coefficient at the wavelength of 60 pm (20.6 keV).

CRT glass manufacturers will supply, to the tube manufacturer, linear absorption coefficient data at 60 pm. The data is representative of the glass produced during the reporting period. The date code applied to the CRT glass components identifies the date of glass manufacture.

Because the glass absorption and therefore the half-value layer are voltage dependent, an adjustment must be made to the absorption data supplied to the tube manufacturer. The adjustment will scale the reported linear absorption coefficient specified at 60 pm to other wavelengths. The transformation follows equation 3.

$$\mu_{\text{eff}} = \mu_m \left[\frac{\left(\frac{1.24}{E} + 0.003 \right)}{0.06} \right]^{2.75} \quad (3)$$

where

μ_{eff} is the effective absorption coefficient;

μ_m is the minimum absorption coefficient at 60 pm;

E is the anode voltage in kV.

When μ_{eff} is substituted into the following equation, the result is the half-value layer HVL (in cm) at the chosen anode voltage.

$$HVL = \frac{\ln 2}{\mu_{\text{eff}}} = \frac{0.6931}{\mu_{\text{eff}}} \quad (4)$$

NOTE—Alternatively, HVL may be measured experimentally, if desired.

EXAMPLE 1—What is the HVL of a glass sample with a specified minimum μ of 28.0 cm^{-1} when the tube is operating at $E = 33.0 \text{ kV}$?

$$\mu_{\text{eff}} = 28.0 \times \left\{ \left[(1.24/33.0) + 0.003 \right] / 0.06 \right\}^{2.75}$$

$$\mu_{\text{eff}} = 9.549$$

$$HVL \text{ (cm)} = \ln(2) / \mu_{\text{eff}} = 0.6931 / 9.549 = 0.0726 \text{ cm}$$

$$HVL \text{ (in)} = HVL \text{ (cm)} (0.3937 \text{ in/cm}) = (0.0726)(0.3937) = 0.0286 \text{ in}$$