measurement, then equation (16.18) reduces to [66, 87–89]

$$CV = I^{\mathrm{T,S}} \frac{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{Ref}}(\lambda) S_{\mathrm{T}}(\lambda)\,\mathrm{d}\lambda}{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{Ref}}(\lambda)\,\mathrm{d}\lambda \int_{\lambda_1}^{\lambda_2} E_{\mathrm{S}}(\lambda) S_{\mathrm{T}}(\lambda)\,\mathrm{d}\lambda} \tag{16.23}$$

This method is appealing because the reference spectrum may correspond to the black-body spectrum, and it can be readily performed in the laboratory. This method only requires the relative spectral responsivity measurements. If a standard lamp is used and the reference spectrum is the terrestrial reference spectra in Table 16.2, then the spectral correction factor in equation (16.23) is typically 12 [89]. Commercial standard lamps are typically 1000-W tungsten lamps supplied with an absolute spectral irradiance at a 50-cm distance and specific lamp current. This method is sensitive to errors in $S_{\mathrm{T}}(\lambda)$, $E_{\mathrm{S}}(\lambda)$, positioning, and stray light [68, 89]. The sensitivity to positioning is because the light source (i.e. standard lamp or black body) is not collimated and changes in the total irradiance of 1% per mm distance from the source are not uncommon [89]. If a solar simulator is used as the light source in equation (16.23), then the ratio of the integrals involving $S_{\mathrm{T}}(\lambda)$ approach unity minimizing the sensitivity to errors in $S_{\mathrm{T}}(\lambda)$, $E_{\mathrm{S}}(\lambda)$ and positioning errors are reduced to less than 0.1% per mm of distance from the source [87].

Once the short-circuit current is known under a given $E_{\mathrm{old}}(\lambda)$, it can be translated to any other $E_{\mathrm{new}}(\lambda)$ with the following equation:

$$I_{\mathrm{new}} = \frac{I_{\mathrm{old}} E_{\mathrm{tot}}^{\mathrm{new}}}{E_{\mathrm{tot}}^{\mathrm{old}}} \frac{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{old}}(\lambda)\,\mathrm{d}\lambda}{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{new}}(\lambda)\,\mathrm{d}\lambda} \frac{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{new}}(\lambda) S_{\mathrm{T}}(\lambda)\,\mathrm{d}\lambda}{\displaystyle\int_{\lambda_1}^{\lambda_2} E_{\mathrm{old}}(\lambda) S_{\mathrm{T}}(\lambda)\,\mathrm{d}\lambda} \tag{16.24}$$

Equation (16.24) assumes that the current is linear with intensity. This method is especially useful for translating the calibration of primary AM0 reference cells to terrestrial reference spectra or vice versa.

The AM0 reference spectrum is by definition the extraterrestrial solar spectrum at one astronomical unit distance from the sun. This means that a small random error will exist because the solar spectrum varies slightly with solar activity. The AM0 community uses this fact to calibrate reference detectors by measuring their response in space or very high altitudes. By definition, there is no spectral error.

Extraterrestrial calibration procedures include using spacecraft, balloons, and high-altitude aircraft [15, 90–96]. There are no spectral corrections for balloon and spacecraft calibrations because the data are taken above the atmosphere. The high-altitude aircraft calibration procedure involves a Langley plot of the logarithm of I_{SC} versus absolute or pressure-corrected air mass over a typical range of 0.25 to 0.5 [92, 93, 95, 96]. The data are collected above the tropopause, thereby eliminating water vapor and most scattering, with the dominant spectral feature arising from ozone absorption [92, 96]. The Jet Propulsion Laboratory (JPL) balloon calibration program requires a custom package design for