Table 16.6 Uncertainty analysis of the tabular calibration method equation (16.22) [98]

Elemental error source	Systematic [±%]	Random [±%]	Total U_{95} [±%]
I_{SC} ($I^{T,S}$) measurement instrumentation	0.10	0.10	0.22
Absolute-cavity radiometer (E_{tot})	0.37	0.13	0.45
Spectral correction factor	0.20	0.20	0.45
Temperature correction & control @ ±1°C	0.15	0.05	0.18
$I^{T,S}$ linearity with varying E_{tot}	0.05	0.05	0.11
Thermal offset voltages	0.05	0.05	0.11
$I^{T,S}$ time constant different from radiometer	0.10	–	0.10
Total	0.47	0.27	0.72

to 20% of the magnitude of the spectral correction factor [68, 99]. A detailed uncertainty analysis of the error in determining the maximum power of a module measured outdoors using the ISO methodology was performed by Whitfield and Osterwald [100]. The ISO methodology has been adopted by all major calibration laboratories and replaces the previous ANSI methodology [101].

16.3.5 Intercomparison of Reference Cell Calibration Procedures

Typically, groups claiming to be able to calibrate primary reference cells with respect to reference conditions claim an uncertainty in the calibration value CV of ±1% [74, 80, 81, 94, 102]. Intercomparisons among the various calibration methods are the best way to determine if the uncertainty estimates are valid. Formal intercomparison of terrestrial calibration procedures sponsored by the Photovoltaic Energy Project (PEP) were conducted in 1985, 1987, and 1993 [74, 80, 81]. The PEP ’85 intercomparison involved PV calibration laboratories from the Commission of European Communities, France, Germany, Italy, Japan, United Kingdom, and the United States. The differences in I_{SC} with respect to the global reference spectrum between the laboratories in the PEP ’85 intercomparison were almost 8% for single-crystal and multicrystal silicon and 20% for amorphous silicon. However, in the PEP ’85 intercomparison, six out of the eight agencies agreed within 3% for the crystalline cells and 6% for the amorphous cells [81]. In the PEP ’87 and PEP ’93 intercomparisons, the participants provided uncertainty estimates. The level of agreement between the laboratories for the PEP ’87 intercomparison was 4% for single-crystal and multicrystal silicon cells and 14% for amorphous silicon [80]. This level of agreement was 2 to 10 times the labs’ estimated uncertainties, which ranged from ±0.7% to ±5%, indicating that the uncertainty estimates for some of the participants were overly optimistic [80]. Several of the participants based their estimated uncertainties on the standard deviation of repeated calibrations thereby neglecting nonrandom error sources. The PEP ’93 intercomparison also showed a rather large spread of 12% for the single-crystal and multicrystal silicon cells, even though the estimated U_{95} uncertainties ranged from ±1.0% to ±2.7%, again indicating that several laboratories underestimated their errors [74]. After excluding laboratories whose calibrations were based on reference cells and laboratories that had more than 50% of their calibrations exceed ±2% of the mean, the resultant average