deviation was 1.1% [74]. Because the terrestrial PV calibration laboratories around the world could not agree on a calibration procedure that had a proven U_{95} uncertainty of less than ±2%, it was decided to establish a set of reference standards called the World Photovoltaic Scale (WPVS) [74, 75]. The four laboratories from the PEP '93 intercomparison that performed primary calibrations and were within ±2% of the mean were the NREL in the United States, Japan Quality Assurance Organization/Electrotechnical Laboratory in Japan, Tianjin Institute of Power Sources in the Peoples Republic of China, and Physikalisch-Technische Bundesanstalt (PTB) in Germany. A formal mechanism was established to include other laboratories in the future, provided their calibrations agreed with the four established WPVS calibration laboratories. The WPVS reference cells reside with the laboratory that provided them, providing each participating laboratory with reference cells traceable to the WPVS. A set of technical drawings was developed for future WPVS reference cells to prevent the problem with the existing set of 20 WPVS reference cells having incompatible cables, mounting holes, and temperature sensors [74, 75]. Sixteen of the 20 WPVS reference cells were recently recalibrated, along with six new candidate WPVS reference cells [102]. The new WPVS calibration values changed by 0.4% at most, with an average decrease of 0.2% [102]. The results of the PEP terrestrial intercomparisons were much closer than earlier intercomparisons, where deviations of ±3% were common and deviations of 5% from the mean were observed [103]. The year-to-year repeatability appeared to be no better than ±3% [103].

Surprisingly, the spread in I_{SC} temperature coefficients for the laboratories that performed them was greater than 50%, even though the temperature of the cells could be controlled and they had temperature sensors permanently attached to them [74]. This variation in temperature coefficient can be partly understood by noting that the temperature coefficient is a function of the light source that they are illuminated with [57]. For cells having a narrow response range, or for multijunction cells, the sign of the coefficient can even change depending on the light source [57, 104, 105].

The AM0 community has conducted intercomparisons between various groups over the years [90, 94, 106, 107]. In general, the agreement of primary AM0 calibrations on spacecraft, balloon, and high-altitude aircraft calibrations is better than ±1% over many years [90–92]. AM0 calibrations based on terrestrial measurements sometimes agree with primary high-altitude calibrations within 1% [91] and at other times the agreement is poor (>10%) [106].

16.3.6 Multijunction Cell Measurement Procedures

Spectrum-splitting series-connected multijunction devices are critical to achieving high-efficiency III-V-based (Chapter 9) and a-Si-based (Chapter 12) solar cells. The procedures to measure the $I-V$ characteristics of a multijunction device with respect to reference conditions are the same as those for a single-junction device with the added constraint that the simulator should be set such that each junction operates at the proper photocurrent. This is accomplished by satisfying the following j equations for the j junctions in a multijunction PV device [108–111]:

$$I_j^{\mathrm{R,R}} = M_j I_j^{\mathrm{R,S}} \tag{16.28}$$