



NATIONAL PHYSICAL LABORATORY

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0478

Certificate of Calibration

RADIANCE SOURCE LR-20-NERC, S/N 6073
ABSOLUTE SPECTRAL RADIANCE

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REPLACEMENT FOR CERTIFICATE/TEST REPORT REFERENCE NO
2013030091/RB4-13-1

FOR: NERC Field Spectroscopy Facility
University of Edinburgh
Grant Institute
King's Buildings
West Mains Road
Edinburgh
EH9 3JW

DESCRIPTION: The unit was a Sphere Optics radiance source. It was fitted with a rectangular aperture over the output port. The source was supplied with a control unit consisting of four power supplies and a digital voltmeter. The unit was controlled via software supplied with the instrument.

IDENTIFICATION: The radiance source had the model number LR-20-NERC and the serial number 6073. The control unit had the model number LR-20-H-NE and serial number 6073

DATES OF
CALIBRATION: 6 February 2014 to 18 February 2014

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Reference: 2013030091/RB4-13-1A

Page 1 of 10

Date of issue: 24 March 2014

Signed:  (Authorised Signatory)

Checked by:  THG

Name: B Duncan

on behalf of NPLML

NATIONAL PHYSICAL LABORATORY

Continuation Sheet

MEASUREMENTS

The radiance source was positioned with the sphere port vertical, and perpendicular to the measurement axis. The unit was operated from the control unit provided, using the manufacturers software. The current was set on the software before being supplied for calibration and was not changed during measurement. On each occasion of operation the radiance source was run for at least 15 minutes before measurements commenced.

The luminance calibration refers to a central area of the sphere port approximately 7 mm in diameter. The measurements were made using a telephotometer, with a spectral responsivity corrected to correspond closely to the CIE photopic standard observer function, $V(\lambda)$, and with a nominal 2° field of view. A correction, based on the measured spectral power distribution of the source, was applied to allow for the effect of the residual differences between the CIE photopic standard observer function and the measured spectral responsivity of the telephotometer.

The relative spectral radiance of the gauge was measured for a central area of the sphere port not exceeding 5 mm wide by 15 mm high. Measurements were carried out over the wavelength range 380 nm to 2500 nm using a spectroradiometer with an instrumental bandwidth of approximately 5 nm (FWHM) from 380 to 1000 nm and 10 nm (FWHM) from 1000 nm to 2500 nm. The reference source was an irradiance lamp and white reflectance standard, which were calibrated against the NPL₂₀₁₀ spectral irradiance scale and the NPL-traceable 2003 reflectance scale respectively. Values for the luminance and relative spectral radiance were combined to calculate the absolute spectral radiance.

Ambient temperature during measurement was 22 ± 2 °C.

RESULTS

The table on pages 4 - 10 gives values for the spectral radiance in $\text{mW m}^{-2} \text{sr}^{-1} \text{nm}^{-1}$ over the wavelength range 380 nm to 2500 nm at 5 nm intervals. The expanded uncertainty (%) at each wavelength is also included in the table.

Values for the chromaticity and correlated colour temperature, calculated from the unrounded spectral data, are given on page 3.

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Continuation Sheet

| Parameter | Value | Uncertainty |
|-------------------------------|---------------------------|--------------|
| x | 0.4415 | ± 0.0011 |
| y | 0.4097 | ± 0.0003 |
| u | 0.2511 | ± 0.0006 |
| v | 0.3495 | ± 0.0002 |
| Correlated colour temperature | 2969 K | ± 17 K |
| Luminance | 16440* cd m^{-2} | ± 1.3 % |

Result marked * is not within the UKAS schedule for accreditation

UNCERTAINTIES

The total expanded uncertainty of the absolute spectral radiance calibration was estimated not to exceed the value given in table 1 on pages 4 - 10 for each individual point.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a coverage probability of 95%.

The results and uncertainties quoted refer to on-the-day values, and no allowance has been made for subsequent drift.

NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 380 | 16.78 | 4.2 | 545 | 203.7 | 1.8 |
| 385 | 19.21 | 4.3 | 550 | 211.1 | 1.8 |
| 390 | 21.89 | 3.5 | 555 | 218.5 | 1.8 |
| 395 | 24.92 | 3.6 | 560 | 225.8 | 1.8 |
| 400 | 28.24 | 2.9 | 565 | 233.0 | 1.8 |
| 405 | 32.3 | 3.2 | 570 | 240.1 | 1.8 |
| 410 | 36.7 | 3.0 | 575 | 247.3 | 1.8 |
| 415 | 41.0 | 3.0 | 580 | 254.6 | 1.8 |
| 420 | 45.5 | 2.7 | 585 | 261.8 | 1.8 |
| 425 | 50.1 | 2.7 | 590 | 269.0 | 1.8 |
| 430 | 54.9 | 2.4 | 595 | 275.9 | 1.8 |
| 435 | 59.8 | 2.5 | 600 | 282.7 | 1.7 |
| 440 | 64.9 | 2.5 | 605 | 289.6 | 1.7 |
| 445 | 70.0 | 2.5 | 610 | 296.4 | 1.7 |
| 450 | 75.4 | 2.2 | 615 | 303 | 1.7 |
| 455 | 81.0 | 2.2 | 620 | 310 | 1.7 |
| 460 | 86.7 | 2.1 | 625 | 316 | 1.7 |
| 465 | 92.7 | 2.1 | 630 | 323 | 1.7 |
| 470 | 98.9 | 2.0 | 635 | 329 | 1.7 |
| 475 | 105.0 | 2.0 | 640 | 335 | 1.7 |
| 480 | 111.3 | 2.0 | 645 | 341 | 1.7 |
| 485 | 117.8 | 2.0 | 650 | 347 | 1.7 |
| 490 | 124.5 | 1.9 | 655 | 353 | 1.7 |
| 495 | 131.4 | 1.9 | 660 | 359 | 1.7 |
| 500 | 138.4 | 1.9 | 665 | 364 | 1.7 |
| 505 | 145.5 | 1.9 | 670 | 369 | 1.8 |
| 510 | 152.8 | 1.9 | 675 | 375 | 1.8 |
| 515 | 159.9 | 1.9 | 680 | 380 | 1.7 |
| 520 | 167.1 | 1.8 | 685 | 386 | 1.7 |
| 525 | 174.5 | 1.8 | 690 | 391 | 1.9 |
| 530 | 181.9 | 1.8 | 695 | 396 | 1.9 |
| 535 | 189.1 | 1.8 | 700 | 401 | 1.8 |
| 540 | 196.3 | 1.8 | 705 | 405 | 1.8 |

Reference: 2013030091/RB4-13-1A

Page 4 of 10

Checked by:  TMG

NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 710 | 409 | 1.7 | 875 | 472 | 2.5 |
| 715 | 413 | 1.7 | 880 | 472 | 2.5 |
| 720 | 417 | 1.7 | 885 | 472 | 2.5 |
| 725 | 421 | 1.7 | 890 | 471 | 2.5 |
| 730 | 424 | 1.7 | 895 | 470 | 2.5 |
| 735 | 428 | 1.7 | 900 | 469 | 2.5 |
| 740 | 432 | 1.7 | 905 | 469 | 2.5 |
| 745 | 435 | 1.7 | 910 | 469 | 2.5 |
| 750 | 437 | 1.7 | 915 | 469 | 2.5 |
| 755 | 440 | 1.7 | 920 | 469 | 2.5 |
| 760 | 443 | 1.7 | 925 | 468 | 2.5 |
| 765 | 446 | 1.7 | 930 | 467 | 2.5 |
| 770 | 448 | 1.7 | 935 | 465 | 2.5 |
| 775 | 451 | 1.7 | 940 | 464 | 2.5 |
| 780 | 453 | 1.7 | 945 | 461 | 2.5 |
| 785 | 455 | 1.7 | 950 | 459 | 2.5 |
| 790 | 458 | 1.7 | 955 | 458 | 2.5 |
| 795 | 460 | 1.7 | 960 | 457 | 2.5 |
| 800 | 462 | 2.6 | 965 | 456 | 2.5 |
| 805 | 463 | 2.6 | 970 | 456 | 2.5 |
| 810 | 465 | 2.6 | 975 | 454 | 2.5 |
| 815 | 466 | 2.6 | 980 | 453 | 2.5 |
| 820 | 467 | 2.6 | 985 | 452 | 2.5 |
| 825 | 467 | 2.6 | 990 | 450 | 2.5 |
| 830 | 468 | 2.6 | 995 | 449 | 2.5 |
| 835 | 468 | 2.6 | 1000 | 447 | 2.5 |
| 840 | 469 | 2.5 | 1005 | 445 | 2.5 |
| 845 | 469 | 2.5 | 1010 | 444 | 2.5 |
| 850 | 470 | 2.5 | 1015 | 442 | 2.5 |
| 855 | 470 | 2.5 | 1020 | 440 | 2.5 |
| 860 | 470 | 2.5 | 1025 | 438 | 2.5 |
| 865 | 471 | 2.5 | 1030 | 436 | 2.5 |
| 870 | 472 | 2.5 | 1035 | 434 | 2.5 |

Reference: 2013030091/RB4-13-1A

Page 5 of 10

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NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 1040 | 432 | 2.5 | 1205 | 342 | 2.5 |
| 1045 | 429 | 2.5 | 1210 | 340 | 2.5 |
| 1050 | 427 | 2.5 | 1215 | 338 | 2.5 |
| 1055 | 425 | 2.5 | 1220 | 336 | 2.5 |
| 1060 | 423 | 2.5 | 1225 | 334 | 2.5 |
| 1065 | 421 | 2.5 | 1230 | 332 | 2.5 |
| 1070 | 419 | 2.5 | 1235 | 330 | 2.5 |
| 1075 | 417 | 2.5 | 1240 | 328 | 2.5 |
| 1080 | 415 | 2.5 | 1245 | 326 | 2.5 |
| 1085 | 412 | 2.5 | 1250 | 324 | 2.5 |
| 1090 | 410 | 2.5 | 1255 | 321 | 2.5 |
| 1095 | 408 | 2.5 | 1260 | 319 | 2.5 |
| 1100 | 406 | 2.5 | 1265 | 317 | 2.5 |
| 1105 | 403 | 2.5 | 1270 | 315 | 2.5 |
| 1110 | 400 | 2.5 | 1275 | 312 | 2.5 |
| 1115 | 396 | 2.5 | 1280 | 310 | 2.5 |
| 1120 | 391 | 2.6 | 1285 | 307 | 2.5 |
| 1125 | 389 | 2.6 | 1290 | 305 | 2.5 |
| 1130 | 386 | 2.5 | 1295 | 302 | 2.5 |
| 1135 | 384 | 2.5 | 1300 | 299.7 | 2.5 |
| 1140 | 381 | 2.5 | 1305 | 297.1 | 2.5 |
| 1145 | 378 | 2.5 | 1310 | 294.6 | 2.8 |
| 1150 | 375 | 2.5 | 1315 | 291.8 | 3.1 |
| 1155 | 372 | 2.5 | 1320 | 289.1 | 3.5 |
| 1160 | 370 | 2.6 | 1325 | 286.1 | 3.9 |
| 1165 | 367 | 2.5 | 1330 | 283.0 | 3.5 |
| 1170 | 364 | 2.5 | 1335 | 279.4 | 3.1 |
| 1175 | 361 | 2.6 | 1340 | 275.8 | 2.8 |
| 1180 | 358 | 2.5 | 1345 | 269.0 | 2.5 |
| 1185 | 354 | 2.5 | 1350 | 262.4 | 2.5 |
| 1190 | 351 | 2.5 | 1355 | 254.1 | 2.8 |
| 1195 | 347 | 2.5 | 1360 | 245.9 | 3.5 |
| 1200 | 344 | 2.4 | 1365 | 243.5 | 2.9 |

Reference: 2013030091/RB4-13-1A

Page 6 of 10

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131 44444-000/10

NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 1370 | 241.2 | 2.7 | 1535 | 168.7 | 2.6 |
| 1375 | 236.5 | 3.5 | 1540 | 168.4 | 2.5 |
| 1380 | 231.9 | 5.5 | 1545 | 167.8 | 2.5 |
| 1385 | 225.5 | 4.4 | 1550 | 167.2 | 2.4 |
| 1390 | 219.1 | 3.5 | 1555 | 166.3 | 2.4 |
| 1395 | 212.0 | 2.8 | 1560 | 165.3 | 2.4 |
| 1400 | 205.0 | 2.6 | 1565 | 164.3 | 2.4 |
| 1405 | 197.0 | 2.7 | 1570 | 163.4 | 2.4 |
| 1410 | 189.1 | 3.2 | 1575 | 162.3 | 2.4 |
| 1415 | 183.5 | 3.8 | 1580 | 161.2 | 2.4 |
| 1420 | 177.9 | 4.5 | 1585 | 160.3 | 2.4 |
| 1425 | 174.4 | 5.3 | 1590 | 159.4 | 2.4 |
| 1430 | 170.8 | 4.5 | 1595 | 158.5 | 2.4 |
| 1435 | 168.2 | 3.8 | 1600 | 157.7 | 2.4 |
| 1440 | 165.6 | 3.2 | 1605 | 156.7 | 2.4 |
| 1445 | 163.9 | 2.7 | 1610 | 155.7 | 2.4 |
| 1450 | 162.1 | 2.5 | 1615 | 154.7 | 2.4 |
| 1455 | 162.3 | 2.6 | 1620 | 153.8 | 2.4 |
| 1460 | 162.4 | 2.6 | 1625 | 152.8 | 2.4 |
| 1465 | 162.0 | 2.8 | 1630 | 151.8 | 2.4 |
| 1470 | 161.6 | 3.0 | 1635 | 150.9 | 2.4 |
| 1475 | 162.3 | 3.2 | 1640 | 149.9 | 2.4 |
| 1480 | 163.0 | 3.0 | 1645 | 149.0 | 2.4 |
| 1485 | 164.1 | 2.8 | 1650 | 148.1 | 2.5 |
| 1490 | 165.1 | 2.6 | 1655 | 146.3 | 2.5 |
| 1495 | 166.0 | 2.5 | 1660 | 144.6 | 2.5 |
| 1500 | 166.8 | 2.5 | 1665 | 142.9 | 2.5 |
| 1505 | 167.7 | 2.5 | 1670 | 141.2 | 2.5 |
| 1510 | 168.6 | 2.5 | 1675 | 139.5 | 2.5 |
| 1515 | 168.8 | 2.6 | 1680 | 137.8 | 2.5 |
| 1520 | 169.0 | 2.7 | 1685 | 136.1 | 2.5 |
| 1525 | 169.0 | 2.9 | 1690 | 134.5 | 2.5 |
| 1530 | 169.0 | 2.7 | 1695 | 132.9 | 2.5 |

Reference: 2013030091/RB4-13-1A

Page 7 of 10

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NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 1700 | 131.2 | 2.5 | 1865 | 79.3 | 2.9 |
| 1705 | 129.6 | 2.5 | 1870 | 75.0 | 3.0 |
| 1710 | 128.1 | 2.5 | 1875 | 70.8 | 3.2 |
| 1715 | 126.5 | 2.5 | 1880 | 66.6 | 3.0 |
| 1720 | 124.9 | 2.5 | 1885 | 62.4 | 2.9 |
| 1725 | 123.4 | 2.5 | 1890 | 58.3 | 3.0 |
| 1730 | 121.8 | 2.5 | 1895 | 54.2 | 2.7 |
| 1735 | 120.3 | 2.5 | 1900 | 50.2 | 3.1 |
| 1740 | 118.8 | 2.5 | 1905 | 49.0 | 3.2 |
| 1745 | 117.3 | 2.5 | 1910 | 47.8 | 3.2 |
| 1750 | 115.8 | 2.5 | 1915 | 46.6 | 3.2 |
| 1755 | 114.6 | 2.5 | 1920 | 45.4 | 3.2 |
| 1760 | 113.4 | 2.5 | 1925 | 44.3 | 3.2 |
| 1765 | 112.2 | 2.5 | 1930 | 43.1 | 3.2 |
| 1770 | 111.1 | 2.5 | 1935 | 42.0 | 3.2 |
| 1775 | 109.9 | 2.5 | 1940 | 40.9 | 3.2 |
| 1780 | 108.7 | 2.5 | 1945 | 39.8 | 3.2 |
| 1785 | 107.6 | 2.5 | 1950 | 38.7 | 2.7 |
| 1790 | 106.5 | 2.5 | 1955 | 39.5 | 2.7 |
| 1795 | 105.3 | 2.5 | 1960 | 40.3 | 2.7 |
| 1800 | 104.2 | 2.5 | 1965 | 41.0 | 2.7 |
| 1805 | 103.0 | 2.6 | 1970 | 41.8 | 2.7 |
| 1810 | 101.8 | 2.6 | 1975 | 42.6 | 2.8 |
| 1815 | 100.6 | 2.6 | 1980 | 43.3 | 2.7 |
| 1820 | 99.4 | 2.6 | 1985 | 44.1 | 2.7 |
| 1825 | 98.2 | 2.7 | 1990 | 44.8 | 2.7 |
| 1830 | 97.1 | 2.6 | 1995 | 45.5 | 2.7 |
| 1835 | 95.9 | 2.6 | 2000 | 46.2 | 2.6 |
| 1840 | 94.8 | 2.6 | 2005 | 46.2 | 2.6 |
| 1845 | 93.7 | 2.6 | 2010 | 46.2 | 2.6 |
| 1850 | 92.5 | 2.6 | 2015 | 46.2 | 2.6 |
| 1855 | 88.1 | 2.7 | 2020 | 46.2 | 2.6 |
| 1860 | 83.7 | 2.7 | 2025 | 46.2 | 2.6 |

Reference: 2013030091/RB4-13-1A

Page 8 of 10

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NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave-length | Absolute Spectral Radiance | Uncertainty | Wave-length | Absolute Spectral Radiance | Uncertainty |
|-------------|--|-------------|-------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % | nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 2030 | 46.2 | 2.6 | 2195 | 39.5 | 3.1 |
| 2035 | 46.2 | 2.6 | 2200 | 39.3 | 3.0 |
| 2040 | 46.2 | 2.6 | 2205 | 39.0 | 3.0 |
| 2045 | 46.2 | 2.6 | 2210 | 38.7 | 3.0 |
| 2050 | 46.2 | 3.0 | 2215 | 38.4 | 3.0 |
| 2055 | 45.9 | 3.0 | 2220 | 38.2 | 3.0 |
| 2060 | 45.6 | 3.0 | 2225 | 37.9 | 3.0 |
| 2065 | 45.3 | 3.0 | 2230 | 37.6 | 3.0 |
| 2070 | 45.0 | 3.0 | 2235 | 37.4 | 3.0 |
| 2075 | 44.7 | 3.0 | 2240 | 37.1 | 3.0 |
| 2080 | 44.4 | 3.0 | 2245 | 36.8 | 3.0 |
| 2085 | 44.1 | 3.0 | 2250 | 36.6 | 3.1 |
| 2090 | 43.9 | 3.0 | 2255 | 35.7 | 3.1 |
| 2095 | 43.6 | 3.0 | 2260 | 34.8 | 3.1 |
| 2100 | 43.3 | 2.9 | 2265 | 33.9 | 3.1 |
| 2105 | 43.2 | 3.1 | 2270 | 33.0 | 3.1 |
| 2110 | 43.1 | 3.1 | 2275 | 32.1 | 3.1 |
| 2115 | 43.0 | 3.1 | 2280 | 31.3 | 3.1 |
| 2120 | 42.9 | 3.1 | 2285 | 30.4 | 3.1 |
| 2125 | 42.8 | 3.1 | 2290 | 29.55 | 3.1 |
| 2130 | 42.7 | 3.1 | 2295 | 28.71 | 3.1 |
| 2135 | 42.6 | 3.1 | 2300 | 27.88 | 3.0 |
| 2140 | 42.5 | 3.1 | 2305 | 27.53 | 3.1 |
| 2145 | 42.4 | 3.1 | 2310 | 27.18 | 3.1 |
| 2150 | 42.2 | 3.1 | 2315 | 26.83 | 3.1 |
| 2155 | 41.9 | 3.1 | 2320 | 26.49 | 3.1 |
| 2160 | 41.6 | 3.1 | 2325 | 26.14 | 3.1 |
| 2165 | 41.3 | 3.1 | 2330 | 25.81 | 3.1 |
| 2170 | 41.0 | 3.1 | 2335 | 25.47 | 3.1 |
| 2175 | 40.7 | 3.1 | 2340 | 25.14 | 3.1 |
| 2180 | 40.4 | 3.1 | 2345 | 24.81 | 3.1 |
| 2185 | 40.1 | 3.1 | 2350 | 24.48 | 3.1 |
| 2190 | 39.8 | 3.1 | 2355 | 24.16 | 3.7 |

Reference: 2013030091/RB4-13-1A

Page 9 of 10

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NATIONAL PHYSICAL LABORATORY

Continuation Sheet

Radiance Source LR-20-NERC, S/N 6073

| Wave- length | Absolute Spectral Radiance | Uncertainty |
|-----------------|--|-------------|
| nm | mW m ⁻² sr ⁻¹ nm ⁻¹ | % |
| 2360 | 23.84 | 3.7 |
| 2365 | 23.52 | 3.7 |
| 2370 | 23.21 | 3.7 |
| 2375 | 22.90 | 3.7 |
| 2380 | 22.59 | 3.7 |
| 2385 | 22.29 | 3.7 |
| 2390 | 21.98 | 3.7 |
| 2395 | 21.68 | 3.7 |
| 2400 | 21.39 | 3.7 |
| 2405 | 20.88 | 3.7 |
| 2410 | 20.38 | 3.7 |
| 2415 | 19.88 | 3.7 |
| 2420 | 19.39 | 3.7 |
| 2425 | 18.91 | 3.8 |
| 2430 | 18.42 | 3.7 |
| 2435 | 17.95 | 3.7 |
| 2440 | 17.48 | 3.7 |
| 2445 | 17.01 | 3.7 |
| 2450 | 16.55 | 3.7 |
| 2455 | 16.15 | 3.7 |
| 2460 | 15.75 | 3.8 |
| 2465 | 15.36 | 3.7 |
| 2470 | 14.97 | 3.8 |
| 2475 | 14.58 | 3.8 |
| 2480 | 14.20 | 3.8 |
| 2485 | 13.82 | 3.8 |
| 2490 | 13.45 | 3.8 |
| 2495 | 13.08 | 3.7 |
| 2500 | 12.71 | 4.4 |

Reference: 2013030091/RB4-13-1A

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Page 10 of 10