# U.S. capacity factors: Close to a new peak

*The nation's power reactors—even those threatened with early closure—have shown that they can remain highly productive.*

*By E. Michael Blake*

Starting in the 1990s, the company once known as Middle South Utilities and then rebranded as Entergy Corporation was a leader in a trend that had the effect of continuing the operation of power reactors that might have closed long before their license expirations. In several states, electricity rates were being "deregulated," while the management of power reactors was seen as benefiting from full commitment to nuclear technology at all corporate levels. With the emergence of license renewal by the Nuclear Regulatory Commission, it became possible for well-run reactors to operate for much longer periods. A number of companies that were committed to nuclear power embarked on a campaign to buy reactors from companies that had generally considered nuclear to be just another power source, and thus the "merchant" nuclear era began—with Entergy pursuing this effort more widely than any other company.

Fast forward to 2017. Despite having obtained license renewals for most of its merchant fleet, Entergy has made decisions that are taking the company from having six merchant reactors in 2014 to having none by 2021. In some merchant acquisitions, the deals hinged on the sellers' signing power purchase agreements with the buyers, through to the expiration of the original licenses. When the new owners sought similar agreements for their renewed licenses, they found that their reactors had to compete with plants that burn natural gas, which had suddenly become cheap and abundant through hydraulic fracturing of domestic sources.

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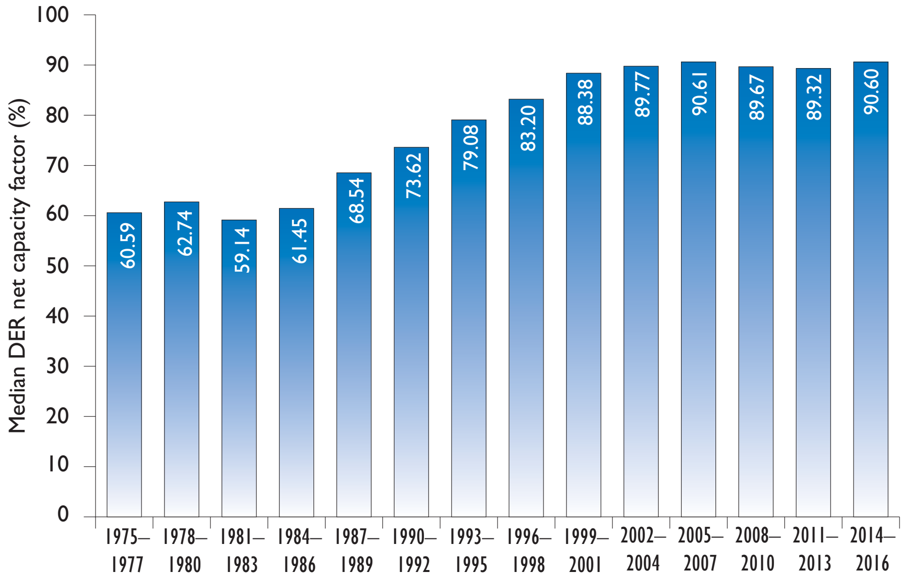


**Fig. 1: All operable reactors.** While some of the upward trend in the early three-year periods can be attributed to lessons learned from the Three Mile Island-2 accident in 1979, what was achieved with power reactors by 2000 had no precedent in any earlier period. From 1999–2001 through 2011–2013, 104 reactors were operable; in 2014–2016, 99 were in operation.

## Table I.
## 2014–2016 DER Net Capacity Factors of Individual Reactors

| Rank | Reactor | Factor[1] | Rating[2] | Type | Owner[3] |
|---|---|---|---|---|---|
| 1. | Quad Cities-1 | 100.04 | 963.99 | BWR | Exelon |
| 2. | Dresden-3 | 98.53 | 879 | BWR | Exelon |
| 3. | Calvert Cliffs-1 | 98.50 | 845 | PWR | Exelon |
| 4. | Calvert Cliffs-2 | 98.42 | 845 | PWR | Exelon |
| 5. | South Texas-2 | 98.00 | 1250.6 | PWR | STPNOC |
| 6. | Dresden-2 | 97.78 | 894 | BWR | Exelon |
| 7. | Three Mile Island-1 | 97.43 | 819 | PWR | Exelon |
| 8. | Nine Mile Point-1 | 97.03 | 613 | BWR | Exelon |
| 9. | Peach Bottom-3 | 96.98 | 1309 | BWR | Exelon |
| 10. | Oconee-2 | 96.35 | 872 | PWR | Duke |
| 11. | Farley-2 | 94.93 | 855 | PWR | Southern |
| 12. | Vogtle-2 | 94.34 | 1169 | PWR | Southern |
| 13. | Farley-1 | 94.12 | 854 | PWR | Southern |
| 14. | Ginna | 94.06 | 585 | PWR | Exelon |
| 15. | Comanche Peak-2 | 94.05 | 1207 | PWR | Luminant |
| 16. | McGuire-2 | 93.76 | 1187 | PWR | Duke |
| 17. | Browns Ferry-2 | 93.67 | 1120 | BWR | TVA |
| 18. | Clinton | 93.43 | 1062 | BWR | Exelon |
| 19. | Hatch-2 | 93.27 | 908 | BWR | Southern |
| 20. | Oconee-3 | 93.14 | 881 | PWR | Duke |
| 21. | Byron-1 | 93.06 | 1213 | PWR | Exelon |
| 22. | Indian Point-3 | 92.97 | 1048 | PWR | Entergy |
| 23. | Palo Verde-3 | 92.79 | 1334 | PWR | APS |
| 24. | Seabrook | 92.64 | 1248 | PWR | FPL |
| 25. | North Anna-1 | 92.60 | 973 | PWR | Dominion |
| 26. | Palo Verde-2 | 92.49 | 1336 | PWR | APS |
| 27. | North Anna-2 | 92.14 | 973 | PWR | Dominion |
| 28. | Comanche Peak-1 | 92.09 | 1218 | PWR | Luminant |
| 29. | Vogtle-1 | 92.06 | 1169 | PWR | Southern |
| 30. | LaSalle-1 | 91.90 | 1178 | BWR | Exelon |
| 31. | Catawba-2 | 91.85 | 1180 | PWR | Duke |
| 32. | Hatch-1 | 91.84 | 885 | BWR | Southern |
| 33. | Point Beach-2 | 91.76 | 615 | PWR | FPL |
| 34. | Limerick-2 | 91.75 | 1205 | BWR | Exelon |
| 35. | Byron-2 | 91.75 | 1186.4 | PWR | Exelon |
| 36. | Beaver Valley-2 | 91.35 | 933 | PWR | FENOC |
| 37. | Point Beach-1 | 91.34 | 615 | PWR | FPL |
| 38. | Peach Bottom-2 | 91.34 | 1308 | BWR | Exelon |
| 39. | Palo Verde-1 | 91.32 | 1333 | PWR | APS |
| 40. | Hope Creek | 91.31 | 1228.1 | BWR | PSEG |
| 41. | Diablo Canyon-1 | 91.29 | 1138 | PWR | PG&E |
| 42. | Catawba-1 | 91.14 | 1174 | PWR | Duke |
| 43. | Perry | 91.02 | 1268 | BWR | FENOC |
| 44. | Nine Mile Point-2 | 90.72 | 1299.9 | BWR | Exelon |
| 45. | Braidwood-2 | 90.72 | 1241 | PWR | Exelon |
| 46. | LaSalle-2 | 90.71 | 1178 | BWR | Exelon |
| 47. | Oconee-1 | 90.66 | 865 | PWR | Duke |
| 48. | Palisades | 90.63 | 805 | PWR | Entergy |
| 49. | Quad Cities-2 | 90.60 | 957.3 | BWR | Exelon |
| 50. | Braidwood-1 | 90.60 | 1268 | PWR | Exelon |
| 51. | Callaway | 90.36 | 1228 | PWR | Ameren |
| 52. | South Texas-1 | 90.27 | 1250.6 | PWR | STPNOC |
| 53. | Millstone-3 | 90.26 | 1229 | PWR | Dominion |
| 54. | Browns Ferry-1 | 90.05 | 1120 | BWR | TVA |
| 55. | Millstone-2 | 89.99 | 877.2 | PWR | Dominion |
| 56. | Columbia | 89.96 | 1153 | BWR | Northwest |
| 57. | Browns Ferry-3 | 89.94 | 1120 | BWR | TVA |
| 58. | Diablo Canyon-2 | 89.89 | 1151 | PWR | PG&E |
| 59. | Brunswick-2 | 89.85 | 980 | BWR | Duke |
| 60. | Limerick-1 | 89.74 | 1205 | BWR | Exelon |
| 61. | Waterford-3 | 89.67 | 1173 | PWR | Entergy |
| 62. | Beaver Valley-1 | 89.65 | 939 | PWR | FENOC |
| 63. | Turkey Point-4 | 89.42 | 840 | PWR | FPL |
| 64. | Harris | 89.22 | 973 | PWR | Duke |
| 65. | Pilgrim | 89.12 | 690 | BWR | Entergy |
| 66. | Susquehanna-2 | 88.91 | 1287 | BWR | SusqNuc |
| 67. | FitzPatrick | 88.84 | 816 | BWR | Entergy |
| 68. | Summer-1 | 88.68 | 972.7 | PWR | SCE&G |
| 69. | Surry-2 | 88.66 | 874 | PWR | Dominion |
| 70. | McGuire-1 | 88.55 | 1199 | PWR | Duke |
| 71. | Surry-1 | 88.52 | 874 | PWR | Dominion |
| 72. | Brunswick-1 | 88.39 | 983 | BWR | Duke |
| 73. | Sequoyah-2 | 87.74 | 1177.46 | PWR | TVA |
| 74. | Robinson-2 | 87.58 | 795 | PWR | Duke |
| 75. | Watts Bar-1 | 87.49 | 1160 | PWR | TVA |
| 76. | River Bend | 87.44 | 967 | BWR | Entergy |
| 77. | Turkey Point-3 | 87.28 | 831 | PWR | FPL |
| 78. | Cooper | 86.93 | 815 | BWR | NPPD |
| 79. | ANO-1 | 86.73 | 850 | PWR | Entergy |
| 80. | Arnold | 86.19 | 621.9 | BWR | FPL |
| 81. | Cook-2 | 86.13 | 1107 | PWR | IMP |
| 82. | Oyster Creek | 85.94 | 650 | BWR | Exelon |
| 83. | Cook-1 | 85.68 | 1084 | PWR | IMP |
| 84. | Susquehanna-1 | 85.10 | 1287 | BWR | SusqNuc |
| 85. | Indian Point-2 | 84.98 | 1035 | PWR | Entergy |
| 86. | Davis-Besse | 84.83 | 908 | PWR | FENOC |
| 87. | Fort Calhoun | 84.34 | 502 | PWR | OPPD |
| 88. | St. Lucie-1 | 84.03 | 1062 | PWR | FPL |
| 89. | Monticello | 83.61 | 656.3 | BWR | NSP |
| 90. | Salem-1 | 83.49 | 1169 | PWR | PSEG |
| 91. | ANO-2 | 82.58 | 1032 | PWR | Entergy |
| 92. | Prairie Island-2 | 82.06 | 557 | PWR | NSP |
| 93. | Prairie Island-1 | 81.98 | 557 | PWR | NSP |
| 94. | Sequoyah-1 | 81.84 | 1184.37 | PWR | TVA |
| 95. | St. Lucie-2 | 81.44 | 1074 | PWR | FPL |
| 96. | Salem-2 | 80.98 | 1181 | PWR | PSEG |
| 97. | Wolf Creek | 80.70 | 1200 | PWR | WCNOC |
| 98. | Fermi-2 | 80.36 | 1150 | BWR | DTE |
| 99. | Grand Gulf | 71.63 | 1485 | BWR | Entergy |

[1] These numbers are rounded off. There are no ties. Limerick-2 is in 34th place with 91.7489, and Byron-2 is in 35th with 91.7467.

[2] This is the net design electrical rating (DER) in megawatts (electric) as of December 31, 2016. If the reactor's rating has changed during the three-year period, the capacity factor has been computed with appropriate weighting.

[3] As of December 31, 2016. In most cases this also means the reactor's operator, but Entergy and Exelon have been the contracted operators of Cooper and Fort Calhoun, respectively. When 2016 ended, FitzPatrick was still officially owned and operated by Entergy.

**Table II.**
**Capacity Factor Change, 2011–2013 to 2014–2016**

| Rank | Reactor | Change (percentage points) |
|---|---|---|
| 1. | Fort Calhoun | +74.70 |
| 2. | South Texas-2 | +22.03 |
| 3. | Columbia | +15.44 |
| 4. | Turkey Point-4 | +14.42 |
| 5. | Turkey Point-3 | +14.26 |
| 6. | Monticello | +12.35 |
| 7. | Fermi-2 | +11.92 |
| 8. | Susquehanna-2 | +10.93 |
| 9. | St. Lucie-1 | +10.45 |
| 10. | Brunswick-2 | +9.51 |
| 11. | Seabrook | +8.94 |
| 12. | Nine Mile Point-1 | +8.58 |
| 13. | Perry | +8.55 |
| 14. | Wolf Creek | +8.42 |
| 15. | North Anna-1 | +7.89 |
| 16. | Hatch-2 | +7.85 |
| 17. | Browns Ferry-2 | +7.81 |
| 18. | Point Beach-2 | +7.66 |
| 19. | Prairie Island-2 | +7.42 |
| 20. | McGuire-2 | +7.37 |
| 21. | Oconee-2 | +7.13 |
| 22. | Oconee-1 | +6.33 |
| 23. | Palisades | +6.28 |
| 24. | St. Lucie-2 | +6.23 |
| 25. | Peach Bottom-3 | +5.83 |
| 26. | ANO-1 | +4.97 |
| 27. | Calvert Cliffs-2 | +4.92 |
| 28. | Pilgrim | +4.89 |
| 29. | North Anna-2 | +4.84 |
| 30. | Susquehanna-1 | +4.72 |
| 31. | Waterford-3 | +4.72 |
| 32. | Point Beach-1 | +4.59 |
| 33. | Palo Verde-3 | +4.05 |
| 34. | Ginna | +3.69 |
| 35. | Limerick-2 | +3.10 |
| 36. | Byron-1 | +2.78 |
| 37. | Browns Ferry-3 | +2.76 |
| 38. | Three Mile Island-1 | +2.70 |
| 39. | Calvert Cliffs-1 | +2.09 |
| 40. | Callaway | +2.08 |
| 41. | Robinson-2 | +1.99 |
| 42. | Sequoyah-2 | +1.86 |
| 43. | Diablo Canyon-2 | +1.85 |
| 44. | Palo Verde-1 | +1.51 |
| 45. | Millstone-2 | +1.47 |
| 46. | Palo Verde-2 | +1.39 |
| 47. | Dresden-3 | +1.21 |
| 48. | Cooper | +1.13 |
| 49. | Vogtle-2 | +0.96 |
| 50. | Hope Creek | +0.90 |
| 51. | Harris | +0.89 |
| 52. | Brunswick-1 | +0.88 |
| 53. | Nine Mile Point-2 | +0.61 |
| 54. | Oconee-3 | +0.60 |
| 55. | Indian Point-3 | +0.58 |
| 56. | Quad Cities-1 | +0.19 |
| 57. | Limerick-1 | +0.12 |
| 58. | Byron-2 | -0.02 |
| 59. | Hatch-1 | -0.04 |
| 60. | Watts Bar-1 | -0.22 |
| 61. | Dresden-2 | -0.48 |
| 62. | Catawba-1 | -0.58 |
| 63. | Browns Ferry-1 | -0.75 |
| 64. | Beaver Valley-2 | -0.90 |
| 65. | Comanche Peak-2 | -0.96 |
| 66. | Clinton | -0.96 |
| 67. | Farley-2 | -1.01 |
| 68. | Surry-2 | -1.05 |
| 69. | Vogtle-1 | -1.13 |
| 70. | Cook-1 | -1.26 |
| 71. | LaSalle-2 | -1.47 |
| 72. | Summer | -1.52 |
| 73. | Millstone-3 | -1.56 |
| 74. | Catawba-2 | -1.63 |
| 75. | Diablo Canyon-1 | -1.80 |
| 76. | McGuire-1 | -1.94 |
| 77. | LaSalle-1 | -2.02 |
| 78. | Beaver Valley-1 | -2.32 |
| 79. | Farley-1 | -2.55 |
| 80. | Oyster Creek | -2.57 |
| 81. | Quad Cities-2 | -2.80 |
| 82. | Comanche Peak-1 | -2.84 |
| 83. | River Bend | -3.44 |
| 84. | Prairie Island-1 | -3.53 |
| 85. | Peach Bottom-2 | -3.58 |
| 86. | Davis-Besse | -3.60 |
| 87. | ANO-2 | -3.62 |
| 88. | Braidwood-2 | -3.70 |
| 89. | Braidwood-1 | -4.06 |
| 90. | Arnold | -4.79 |
| 91. | FitzPatrick | -5.06 |
| 92. | Cook-2 | -5.12 |
| 93. | Surry-1 | -6.37 |
| 94. | Salem-1 | -7.10 |
| 95. | South Texas-1 | -7.48 |
| 96. | Sequoyah-1 | -7.59 |
| 97. | Indian Point-2 | -8.47 |
| 98. | Salem-2 | -9.75 |
| 99. | Grand Gulf | -12.96 |

The previous owners of the reactors were not interested in long-term purchases at the rates sought by the new owners.

As much as "market flaws" are blamed for the current state of power reactor economics, it should not be thought that the merchant approach itself was a bad idea. From 1992 to 1998, 10 power reactors closed. Three of them (Big Rock Point, Yankee, and the federally owned EBR-II) had low power ratings compared to reactors that came later, and power generation at EBR-II had always been a sideline. Two others (Haddam Neck and San Onofre-1) faced equipment upgrade costs that might not have been recovered in the future, given the reactors' modest power ratings. For the other five, however (Maine Yankee, Millstone-1, Trojan, and Zion-1 and -2), it could be argued that committed, nuclear-savvy ownership, the use of license renewal to help recover costs, and the improvement trend of the industry as a whole could have kept these reactors in operation. This argument might have also applied to Rancho Seco, which closed in 1989.

Merchant acquisition may have prevented the early closure of as many as 19 reactors—the six acquired by Entergy (FitzPatrick, Indian Point-2 and -3, Palisades, Pilgrim, and Vermont Yankee) and Arnold, Clinton, Ginna, Kewaunee, Millstone-2 and -3, Nine Mile Point-1 and -2, Oyster Creek, Point Beach-1 and -2, Seabrook, and Three Mile Island-1. Of these 19 reactors, two are now closed, and four are scheduled to close in the next four years. Another has apparently escaped that fate (FitzPatrick, which has been sold to Exelon). Two others (Millstone-2 and -3) may depend on the support of the Connecticut state government, which may be reluctant to provide it.

Taking a different approach, one of the companies that ultimately formed Exelon created a merchant system with the reactors it had built and operated under rate regulation, later acquiring other reactors in or near Exelon's original service areas. As profitable as this approach was for many years, Exelon has found itself at the mercy of grid operator decisions on auction pricing and has had to appeal to state agencies to support the reactors' established, low-emission power, eventually succeeding in New York and Illinois.

All of this doom and gloom seems odd in light of the fact that nuclear power in the United States has been prodigiously productive for most of two decades, continuing in the three-year period of 2014–2016 at about the same level that the nationwide fleet had established by 2000 after steady improvement over the previous 20 years (see Fig. 1). Among the 99 reactors in service during the three-year period of 2014–2016, the median design electrical rating (DER) net capacity factor was 90.60 percent. There were 104 reactors included in this survey for the 2011–2013 period, and the median DER factor for that group was 89.32 percent; for the 99 reactors now in service, the 2011–2013 median factor was 89.62 percent.

**Table III.**
**DER Net Capacity Factor of Multireactor Sites[1]**

| Rank | Site | Factor | Owner | Rank | Site | Factor | Owner |
|---|---|---|---|---|---|---|---|
| 1. | Calvert Cliffs | 98.46 | Exelon | 19. | McGuire | 91.16 | Duke |
| 2. | Dresden | 98.15 | Exelon | 20. | Limerick | 90.75 | Exelon |
| 3. | Quad Cities | 95.18 | Exelon | 21. | Braidwood | 90.65 | Exelon |
| 4. | Farley | 94.52 | Southern | 22. | Diablo Canyon | 90.58 | PG&E |
| 5. | South Texas | 94.13 | STPNOC | 23. | Beaver Valley | 90.50 | FENOC |
| 6. | Peach Bottom | 94.11 | Exelon | 24. | Millstone | 90.15 | Dominion |
| 7. | Oconee | 93.39 | Duke | 25. | Brunswick | 89.12 | Duke |
| 8. | Vogtle | 93.20 | Southern | 26. | Indian Point | 89.00 | Entergy |
| 9. | Comanche Peak | 93.07 | Luminant | 27. | Surry | 88.59 | Dominion |
| 10. | Nine Mile Point | 92.74 | Exelon | 28. | Turkey Point | 88.35 | FPL |
| 11. | Hatch | 92.56 | Southern | 29. | Susquehanna | 87.00 | SusqNuc |
| 12. | Byron | 92.41 | Exelon | 30. | Cook | 85.91 | IMP |
| 13. | North Anna | 92.37 | Dominion | 31. | Hope Creek/Salem | 85.34 | PSEG |
| 14. | Palo Verde | 92.20 | APS | 32. | Sequoyah | 84.78 | TVA |
| 15. | Point Beach | 91.55 | FPL | 33. | ANO | 84.45 | Entergy |
| 16. | Catawba | 91.50 | Duke | 34. | St. Lucie | 82.73 | FPL |
| 17. | LaSalle | 91.30 | Exelon | 35. | Prairie Island | 82.02 | NSP |
| 18. | Browns Ferry | 91.22 | TVA | | | | |

[1] Because Nine Mile Point and FitzPatrick had different owners in the 2014–2016 period, Nine Mile Point is listed here as a multireactor site, but FitzPatrick is not included, even though the plants are on adjacent properties; combined, Nine Mile Point and FitzPatrick would have a 2014–2016 factor of 91.58. Hope Creek and Salem are treated as a single site because they are adjacent and have the same owner; the two-reactor Salem had a 2014–2016 factor of 82.23.

The reactor closings that began in 2013 are tending to make the historical comparisons in the survey quite messy, but so far, the differences between the 104-reactor factors and the 99-reactor factors have mostly been small; the 2014–2016 median's advancement over the 2011–2013 median can be read as either just under one percentage point or just over a point and a quarter.

The 2011–2013 database also included Crystal River-3, which had produced no electricity during that time, and San Onofre-2 and -3, which had been off line for most of that period. Those reactors were later declared closed. Vermont Yankee was in service throughout 2011–2013, but closed at the end of 2014. The data for both 99 and 104 reactors in 2011–2013 show a more noticeable difference in terms of average capacity factor. The 99-reactor average was 87.96; the 104-reactor average was 86.03. In 2014–2016, the 99-reactor average factor was 89.89, up nearly two percentage points from the same group's average in 2011–2013.

The 2011–2013 performance showed a small dip from earlier periods, caused to some extent by the immediate aftermath of the Fukushima Daiichi accident in Japan. Regulatory and industry actions for post-Fukushima information-gathering and plant modifications led to more downtime than reactors would have had otherwise, and by 2014–2016, much of the work was finished. Perhaps aside from that, however, the U.S. fleet was very productive in the single year of 2016, providing 805.13 terawatt-hours of electricity to the grid (counting more than 1 TWh from TVA Nuclear's Watts Bar-2). This was the first year during which U.S. nuclear power had produced more than 800 TWh since 2010, when the 104 licensed reactors generated 806.97 TWh.

Pressurized water reactors as a group had better statistics than boiling water reactors in 2014–2016, but by margins so small that they may not be worth mentioning; they will, however, be mentioned anyway, because that is what we do here (see Fig. 3). PWRs had a median factor of 90.60, with a top quartile of 92.62 and a bottom quartile of 87.38. BWRs had a 90.33 median, a 91.90 top quartile, and an 88.39 bottom quartile. Making an even stronger point that there was no real difference between the reactor types are their average capacity factors: 89.95 for PWRs, 89.88 for BWRs. Had Entergy's Grand Gulf, the most powerful reactor in the country, not undergone a forced outage last September that continued until February, BWRs might have prevailed over PWRs by a comparably trivial amount.

The figures and tables provide the usual statistics, and the extent to which performance in 2014–2016 was an improvement is shown in Table II, with 57 of the 99 reactors having had higher capacity factors than they had in 2011–2013. Multiunit sites, shown in Table III, have continued to show their usual advantage over single-reactor sites; the 25 single reactors had a median factor of 88.68 and an average factor of 87.36. As with the comparison of 99 reactors now to those reactors earlier, there are now 35 multiunit sites, rather than the 36 when San Onofre was operable. The median of the 35 sites in 2011–2013 was 89.88; in 2014–2016, it was 91.22. There were 24 sites at 90 or better in 2014–2016, up from 17 in 2011–2013.

Among the finer details, it is worth noting that Duke's Oconee plant, having begun its fifth decade of operation, recorded its highest factor ever: 93.39, up from 88.70 in 2011–2013. Still, the fact that a change of less than five percentage points stands out underscores the consistency of nuclear performance throughout the current millennium. Also, while Nine Mile Point and FitzPatrick have always been shown here as different plants despite their adjacent sites, the sale of FitzPatrick to Exelon will eventually make it possible to show the three reactors as a single plant, like Hope Creek/Salem.

*Continued*

**Table IV.**
**DER Net Capacity Factors of Owners or Operators of More Than One Site[1]**

| Rank | Owner/Operator | Factor |
|---|---|---|
| 1. | Southern Nuclear | 93.39 |
| 2. | Exelon Generation | 93.36 |
| 3. | Duke Energy | 90.97 |
| 4. | Dominion Generation | 90.42 |
| 5. | FirstEnergy Nuclear | 89.39 |
| 6. | TVA Nuclear | 88.38 |
| 7. | FPL/NextEra | 87.76 |
| 8. | Entergy Nuclear | 85.59 |
| 9. | Northern States | 82.61 |

[1] Exelon and Entergy are the contracted operators of Fort Calhoun and Cooper, respectively. With Fort Calhoun included, Exelon's factor would be 93.16. With Cooper included, Entergy's factor would be 85.69.

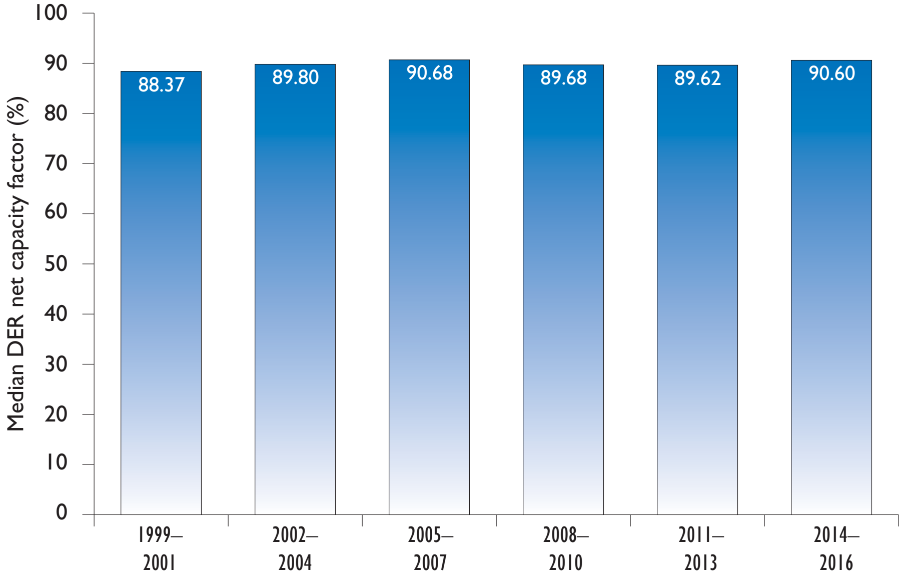


**Fig. 2: 99 reactors.** This is a like-for-like comparison of three-year median factors for the 99 reactors included in the 2014–2016 survey, with five closed reactors excluded from the earlier five periods. As strong as the 2014–2016 performance was, it falls just short of the median factor of these 99 reactors in 2005–2007.

The smaller the database, the less meaningful are the conclusions. With only nine entries in Table IV, there may not be much significance in the fact that this median is lower than those of the 99 individual reactors and the 35 multiunit sites. It could be worth noting that seven of the nine fleets had higher factors in 2014–2016 than in 2011–2013, perhaps again showing higher production following Fukushima-related work.

## From raw data to analysis

In the 1980s, *Nuclear News* began assessing the performance of licensed power reactors in the United States. It was decided that a reasonable measure of sustained performance is a reactor's DER net capacity factor over a period of three calendar years. The necessary raw data—electricity delivered during each of those years, and the reactors' DERs—have been publicly available in various ways; most recently, the data from licensees are collected by the Institute of Nuclear Power Operations (INPO), which shares them with the Nuclear Regulatory Commission, which posts them online.

By their nature, the tables may seem to show entries toward the top in a better light than entries toward the bottom. We encourage the reader, however, not to grade on a curve. Nearly every reactor is now, and has been for years, a high-level performer, as shown by the closeness of Fig. 4's curves of top and bottom quartiles (and the height of both on the chart). To give the proper view of absolute performance, the decision was made quite intentionally in this survey that the bars in the figures are shown at full height, rather than cut off to call extra attention to relative differences that have, in our judgment, very little meaning.

Thirty years ago, for many of these same reactors, a factor of 85 would have been considered outstanding; it would be unreasonable to suggest that a factor of 85 now is a severe disappointment. Many of the reactors, when they began operation, were included in electricity rate bases with expected factors of around 65. With factors now routinely 20 points or more higher than that and operation extended by license renewal, reactors are now delivering far more than originally obligated, although in many cases it took several years to get to that point.

Some judgment calls were made in the development of this survey. One was to include Omaha Public Power District's Fort Calhoun reactor, even though it closed last October. A similar judgment call was made three years ago, to keep Dominion's Kewaunee reactor in the 2011–2013 database, even though it closed during 2013. Vermont Yankee, however, is not included for 2014–2016 because it closed at the end of 2014 and thus was out of service for the majority of the period. TVA Nuclear's Watts Bar-2 is not included because it began commercial operation last October and cannot complete three full calendar years until the end of 2019.

As reactors close (and as new ones start up), the database changes. Most of the recent bars in Fig. 1 are based on 104 reactors having been in operation, which was the case starting in 1999–2001. It seems, therefore, to be reasonable to compare the 2014–2016 performance of those 99 reactors to their performance in the earlier periods, in addition to comparing the 99 now to the 104 that operated earlier. Figure 2 is a bar chart for the 99 over the past six periods.

As it turns out, the differences are small. In 2008–2010 (the most recent period in which none of the 104 reactors had ceased operation), the median of the 104 reactors was 89.67; the median of the 99 reactors was 89.68. The differences among the top and bottom quartiles were 0.17 and 0.04, respectively, in favor of the 99 reactors. To a great extent, this is because the five reactors that have closed were distributed fairly evenly through Table I, with two above the median and three below it. The

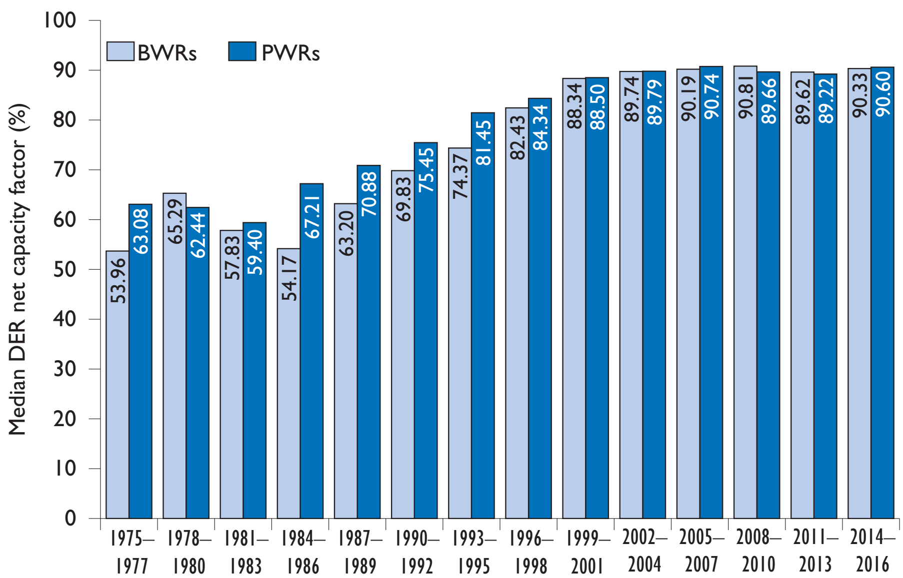


**Fig. 3: Reactors by type.** In the most recent six periods, one would be hard pressed to claim that pressurized water reactors have performed better than boiling water reactors, or vice versa. This chart shows data from reactors operable during each period; as noted in the main text of the article, correcting for closed reactors would make no significant difference.

use of the average rather than the median takes into account each reactor's generating capacity (notably with Kewaunee and Vermont Yankee having comparatively low power ratings). The average factor of the 104 reactors in 2008–2010 was 89.35, and the average of the 99 reactors in that period was 89.84—a difference of roughly half a point, still fairly small.

While Fort Calhoun has made its last appearance in the database and closures have been announced for Pilgrim, Palisades, Oyster Creek, and Indian Point in the next few years (and for Diablo Canyon, in more than a few years), their departure may not create a large difference in fleet-wide performance between a future group of reactors and the earlier group of 104. Note how many reactors are close to the median. As shown in Fig. 3, the top and bottom quartiles in 2014–2016 are just over five percentage points apart, meaning that half of the reactors are in that range. Removing several reactors would thus not alter the median greatly, unless a large majority of them were either very productive or very unproductive.

The discussion above, of course, is limited to capacity factors and does not address the benefit of maximizing nuclear electricity to meet goals ranging from air quality improvement to climate moderation. Fewer reactors would mean that total nuclear electricity production would never again approach 800 TWh per year or 20 percent of the nation's consumption. It should not be overlooked that by the end of 2016, the nuclear fleet in the United States had, in less than five years, lost the contribution of six reactors with a total generating capacity of 4,703 MWe.

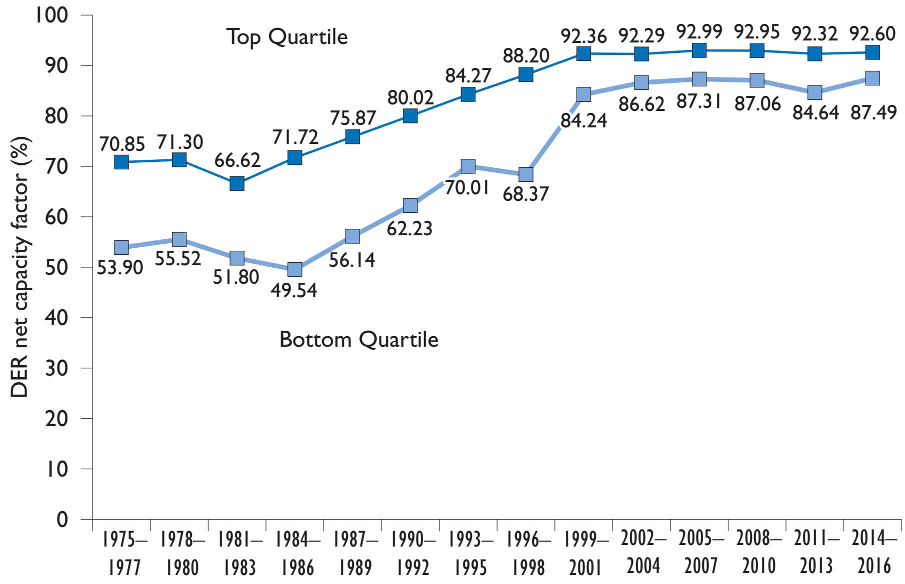


**Fig. 4: All reactors, top and bottom quartiles.** The narrow gap between the top and bottom quartiles continued in 2014–2016, with a slight decrease in the gap in 2014–2016 compared with 2011–2013. As with Fig. 3, the data are for all reactors operable in each period, with no significant difference if only the 99 reactors were included for all periods.

## Is the best good enough?

Quad Cities-1 is in first place in Table I. It was also in first place in the previous three-year period, 2011–2013. The reactor now has a chance to go for three firsts in a row, but only because in December, a law was passed in Illinois to provide various kinds of support for power reactors. Exelon had announced its intention to close Clinton and Quad Cities-1 and -2 if the state didn't take such action. Let's put that more bluntly: The reactor that had shown itself to be the best of a very good lot, for two triennials in a row, was threatened with closure because of those dastardly market flaws. Here again we see the way in which the marketing of electricity, the pricing of fracked natural gas, and the opportunities generally available to renewables (which in the case of Illinois are almost entirely wind turbines) can outweigh what a reactor's personnel can influence, which is the production of as much electricity as possible, 24/7.

Nuclear power has been called many things by many people (proponents and opponents), but only in the past five years or so has there been so much description of the technology as *dispatchable*. Yes, this word can actually be found in dictionaries, and by extension, one must accept the coinage of the related word *dispatchability*. The fact that a reactor can produce electricity nearly all of the time when it isn't being refueled allows the power to be dispatched by grid operators nearly all of the time, in vast quantity, when air isn't moving enough to turn wind turbine blades and sunlight isn't translating into electric current.

Reactor design, however, has never allowed for sudden changes in demand. Safe, reliable operation has always been thought to depend on getting close to full power and staying there. There has been some talk in recent years of developing reactor operation schemes for load following, but so far, none have been attempted, and it's not clear whether this would improve reactor economics. Fossil-fired plants use less fuel when cutting power to follow load, and fuel makes up a substantial portion of a fossil plant's operating cost. Uranium makes up a much smaller portion of nuclear operating costs. As has been noted here, relatively cheap fuel has gone from being a longtime advantage of nuclear power to an impediment to finding quick-fix cost reductions—there's much less cost to be reduced.

This has led to the recent emphasis on dispatchability, and the argument that reliance on nuclear at all times should be taken into account during those times of day when wind turbines and solar arrays are at their most productive and nuclear becomes relatively expensive (and can be "negatively priced" by grid operators). The actions taken at the state level in Illinois and New York are intended to recognize this reliance, and while an honest examination of these policies can allow the words "support" and "subsidy" to refer to the same thing, a sharp increase in early reactor closures would in fact leave grid operators with far less power that is dispatchable. (If one uses the word often enough, it may lose its ability to make one wince.)

While economic concerns appear to be the main factors in potential decisions on continued reactor operation, they may not be the only ones. Three of the five reactors that have closed in recent years did so mainly because of hardware issues. Concrete delamination in the Crystal River-3 containment building effectively led to the decision not to try to return the reactor to service after steam generator replacement. Replacement steam generators at San Onofre-2 and -3 showed excessive wear not long after installation. Those events were noticeable because things went very wrong. When comparable actions taken at other reactors have their intended results, the reactors resume operation and there may not be much attention paid to the actions beyond what is compiled in INPO reports and internal documentation. Economics factored into the decisions to close Crystal River-3 and San Onofre-2 and -3, because hardware issues added to recovery cost or limited the ability to recover costs through resumed operation. Reactor licensees would surely seek to avoid adding such hardware issues to their existing concerns.

## To close or not to close

As was made abundantly clear by the example of Quad Cities-1, in the current situation, performance can have little to do with whether a reactor remains in operation. One of the reactors that Entergy plans to close is Palisades, in Michigan (*NN*, Jan. 2017, p. 22). Although Palisades was licensed 46 years ago, in one respect it can be thought of as "newer" than many other reactors, including some that started up much later. In its first 18 years of commercial operation, Palisades had a capacity factor of 39.98 percent, so the hardware underwent about 7.2 effective full-power years (EFPY) during that time. Also during that time, Palisades was undeniably a poor performer, and the then owner, Consumers Power Corporation, and its customers might well have believed that the reactor was not justifying its cost.

Since 1989, however, the factor is 77.63 (and 88.55 in the past nine years), with help from a contract with Nuclear Management Company in 2001 and the sale to Entergy in 2007. The reactor went through just under 21 EFPY in those 27 calendar years, for a total of about 30.6 EFPY at the end of 2016. Assuming that its current performance level continues, Palisades would get to about 43 EFPY by the expiration of its renewed license in 2031. Having endured the low electricity production of Palisades' early years, shouldn't customers in western Michigan gain the advantage of the current high production from reactor hardware that has experienced relatively low neutron flux in its career?

Sadly, that argument would probably make little headway in a situation in which even Quad Cities-1 was facing early closure. Also, the various references to power reactors as essential resources for energy security have not carried through to the radical, perhaps-not-actually-legal acquisition of closure-threatened power reactors under eminent domain, presumably with federal ownership and continued employment of personnel already operating the plants. As things stand now, however, once an operating license is given up, there is no established way for it to be restored. For Palisades, Entergy's current plan calls for the reactor to be closed next year.

The grid-stabilization value of power reactors has been given some recognition by the Federal Energy Regulatory Commission and two state governments. Further actions for support/subsidies are being sought by licensees in other states, and this may be the main arena for the nuclear debate in the coming years. Meanwhile, as has been noted here previously, the main task for nuclear professionals is the one they have had all along: to keep the reactors operating safely and productively. If it is necessary to be thought of as dispatchable, then that is what nuclear power must be. **NN**