U.S. capacity factors: A small gain to an already large number

BY E. MICHAEL BLAKE

The median three-year design electrical rating net capacity factor in 2004–2006 was above 90 percent for the first time ever, but on the whole, performance was at about the same level as it was in the previous three-year period.

FOR SEVERAL YEARS now, industry sources have been saying that the power reactor fleet in the United States is running "at 90 percent capacity," and depending on which statistics one uses, this is either entirely true or so close to it that the discrepancy is insignificant. In the annual *Nuclear News* capacity factor survey, which uses design electrical rating (DER) net capacity factors over a three-year period, the median for the entire 104-reactor fleet has come in just below that—between 89.5 percent and 90 percent—since 2000.

In 2004–2006, for the first time, the median three-year capacity factor crossed the 90 percent threshold, coming in at 90.13 percent. But while this indicator and the others used in this survey were higher than they were in 2001–2003, the increases were very small. As was noted in last year's survey, the fleet's real accomplishment was not in raising its median capacity factor but in maintaining the high level of performance the fleet has achieved since the turn of the millennium.

It should come as no surprise that the capacity factors for 2004–2006 are better than ever before, because those three years were the most productive in the history of nuclear power in the United States. The 789 TWh produced in 2004 remains the highest ever, but 2006 came in second-best (787.2 TWh), and 2005 ranks third (782 TWh). To some extent, the greater output has been made possible by power uprates: The total DER of the 104 licensed reactors was 101 827 MWe at the end of 2006, 3890 MWe more than the total at the end of 2003.

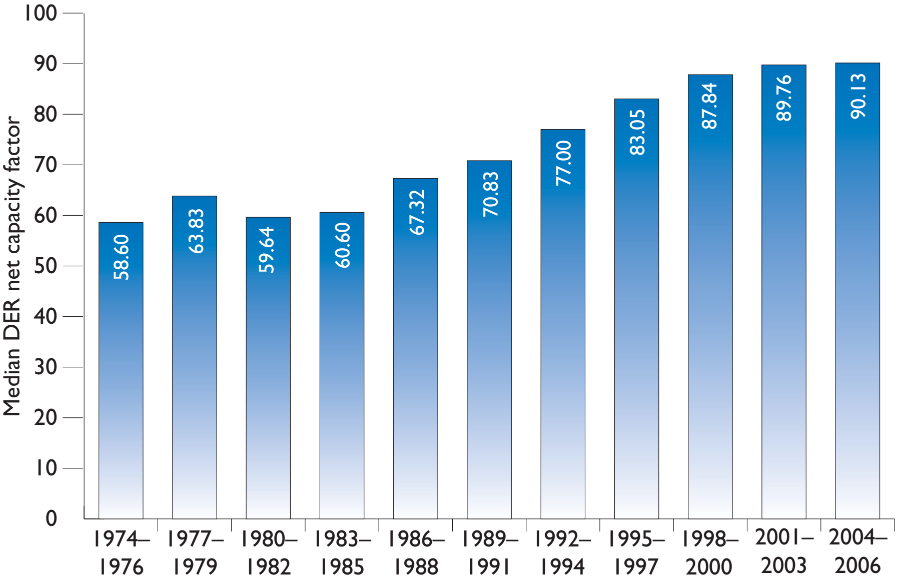

Fig. 1: All reactors. As had been observed last year, the median capacity factor of all U.S. reactors appears finally to have leveled off after two decades of fairly steady improvement. The chart shows only reactors that are still in service now; there were 20 such reactors in 1974–76, and in each succeeding period there were 43, 53, 60, 77, 97, 102, 103, and 104 in each of the last three. If closed reactors were included in the periods during which they operated, the median would differ by more than one percentage point in only one period, 1980–1982, when it was 57.57.

Licensees still managed to get more out of this extra capacity, however, as the slight increases in factors demonstrate.

The 2004–2006 median capacity factor of 90.13 percent for all reactors compares to a median of 89.76 in 2001–2003. The average factor in 2004–2006 was 88.64 percent, up from 88.02 in the previous three years. Both reactor types managed to get their medians above 90 percent, with boiling water reactors remaining above (90.51 now, 90.36 then) and pressurized water reactors getting there for the first time (90.13 now, 89.53 then). These all count as improvements, but in every case the rise was less than 1 percentage point.

The trend is also slightly positive for other portions of the data set. In 2004–2006, the top quartile factor for all reactors was 92.88 percent, up from 92.08; the bottom quartile was 86.70 percent, up from 86.02. The corresponding numbers for BWRs are 92.56 percent (down from 92.80) for the top quartile, and 86.94 percent (up from 86.01) for the bottom quartile. The PWR top quartile is 93.97 percent (up from 92.08), and the bottom quartile is 85.39 percent (down from 86.02). Because only one of these numbers is more than 1 percentage point different from the previous number, it appears that the situation observed last year is mostly continuing: Power reactor performance in this country has leveled off, chiefly because it seems close to the practical upper limit for reactors, which must shut down occasionally to refuel.

If it seems as though these largely positive results are being discounted, note that in Table II, 50 reactors had better capacity factors in 2004–2006 than in 2001–2003, and 53 had poorer factors. This might be seen as a negative result, but 68 of the reactors rose or fell by fewer than 5 percentage points. While some of the results can be

TABLE I.
2004–2006 DER NET CAPACITY FACTORS OF INDIVIDUAL REACTORS

Rank	Reactor	Factor[1]	Design Electrical Rating (DER), MWe[2]	Type	Operator[3]
1.	Calvert Cliffs-2	99.31	845	PWR	Constellation
2.	Ginna	99.15	585	PWR	Constellation
3.	Three Mile Island-1	98.67	819	PWR	Amergen (Exelon)
4.	Indian Point-3	97.29	1034	PWR	Entergy
5.	ANO-2	97.25	1032	PWR	Entergy
6.	Braidwood-2	96.59	1155	PWR	Exelon
7.	Byron-2	96.45	1155	PWR	Exelon
8.	Braidwood-1	96.18	1187	PWR	Exelon
9.	Peach Bottom-3	96.05	1138	BWR	Exelon
10.	South Texas-2	95.66	1250.6	PWR	STPNOC
11.	Comanche Peak-2	95.41	1150	PWR	TXU
12.	Surry-2	95.19	788	PWR	Dominion
13.	LaSalle-2	95.07	1154	BWR	Exelon
14.	Pilgrim	95.00	690	BWR	Entergy
15.	North Anna-1	94.95	907	PWR	Dominion
16.	North Anna-2	94.86	907	PWR	Dominion
17.	Calvert Cliffs-1	94.71	845	PWR	Constellation
18.	South Texas-1	94.69	1250.6	PWR	STPNOC
19.	Browns Ferry-2	94.43	1120	BWR	TVA
20.	Arnold	94.43	593.8	BWR	FPL
21.	FitzPatrick	94.42	816	BWR	Entergy
22.	Comanche Peak-1	94.33	1150	PWR	TXU
23.	Surry-1	94.15	788	PWR	Dominion
24.	Grand Gulf	94.10	1279	BWR	Entergy
25.	Byron-1	93.80	1187	PWR	Exelon
26.	Sequoyah-1	92.90	1173	PWR	TVA
27.	Limerick-2	92.86	1191	BWR	Exelon
28.	Seabrook	92.72	1246	PWR	FPL
29.	Nine Mile Point-1	92.56	613	BWR	Constellation
30.	Monticello	92.40	600	BWR	NMC
31.	Vermont Yankee	92.37	617	BWR	Entergy
32.	Beaver Valley-2	92.33	836	PWR	FENOC
33.	Peach Bottom-2	92.17	1138	BWR	Exelon
34.	LaSalle-1	92.10	1154	BWR	Exelon
35.	Nine Mile Point-2	92.06	1143.3	BWR	Constellation
36.	Catawba-2	92.02	1145	PWR	Duke
37.	Wolf Creek	91.97	1170	PWR	WCNOC
38.	Farley-2	91.96	855	PWR	Southern
39.	Limerick-1	91.89	1191	BWR	Exelon
40.	Millstone-3	91.66	1156.5	PWR	Dominion
41.	Hatch-2	91.65	908	BWR	Southern
42.	Vogtle-1	91.23	1169	PWR	Southern
43.	Crystal River-3	91.10	860	PWR	Progress
44.	St. Lucie-1	91.04	830	PWR	FPL
45.	Indian Point-2	90.85	1035	PWR	Entergy
46.	Summer	90.81	972.7	PWR	SCE&G
47.	Susquehanna-2	90.74	1182	BWR	PPL
48.	Waterford-3	90.57	1173	PWR	Entergy
49.	Dresden-3	90.51	867	BWR	Exelon
50.	Millstone-2	90.22	883.5	PWR	Dominion
51.	Salem-2	90.20	1131	PWR	PSEG
52.	Beaver Valley-1	90.14	835	PWR	FENOC
53.	Farley-1	90.13	854	PWR	Southern
54.	Browns Ferry-3	89.93	1120	BWR	TVA
55.	Sequoyah-2	89.71	1151	PWR	TVA
56.	Cook-1	89.67	1036	PWR	IMP
57.	Catawba-1	89.66	1145	PWR	Duke
58.	ANO-1	89.66	850	PWR	Entergy
59.	River Bend	89.42	967	BWR	Entergy
60.	Cook-2	89.32	1107	PWR	IMP
61.	Robinson-2	89.23	765	PWR	Progress
62.	Clinton	89.22	1062	BWR	Amergen (Exelon)
63.	Prairie Island-2	88.81	536	PWR	NMC
64.	Salem-1	88.77	1130	PWR	PSEG
65.	Harris	88.69	941.7	PWR	Progress
66.	Diablo Canyon-2	88.30	1119	PWR	PG&E
67.	Vogtle-2	87.93	1169	PWR	Southern
68.	Diablo Canyon-1	87.90	1103	PWR	PG&E
69.	Cooper	87.83	778	BWR	NPPD/Entergy
70.	Brunswick-2	87.64	980	BWR	Progress
71.	McGuire-1	87.55	1180	PWR	Duke
72.	Columbia	87.55	1153	BWR	Northwest
73.	St. Lucie-2	87.54	830	PWR	FPL
74.	Hatch-1	87.39	885	BWR	Southern
75.	Oyster Creek	86.95	650	BWR	Amergen (Exelon)
76.	Quad Cities-2	86.94	867	BWR	Exelon
77.	McGuire-2	86.89	1180	PWR	Duke
78.	Dresden-2	86.70	867	BWR	Exelon
79.	Prairie Island-1	86.70	536	PWR	NMC
80.	Brunswick-1	86.44	983	BWR	Progress
81.	Quad Cities-1	85.64	867	BWR	Exelon
82.	Perry	85.60	1260	BWR	FENOC
83.	Point Beach-1	85.49	522	PWR	NMC
84.	Point Beach-2	85.30	522	PWR	NMC
85.	Turkey Point-3	85.09	720	PWR	FPL
86.	Palo Verde-2	85.04	1336	PWR	APS
87.	Oconee-1	84.99	886	PWR	Duke
88.	Susquehanna-1	84.71	1177	BWR	PPL
89.	Oconee-2	84.70	886	PWR	Duke
90.	Palisades	84.58	805	PWR	NMC
91.	Oconee-3	84.53	886	PWR	Duke
92.	San Onofre-2	84.45	1070	PWR	SCE
93.	Watts Bar-1	83.51	1155	PWR	TVA
94.	Turkey Point-4	82.92	720	PWR	FPL
95.	Callaway	82.72	1228	PWR	Ameren
96.	San Onofre-3	81.95	1080	PWR	SCE
97.	Fermi-2	81.71	1150	BWR	Detroit
98.	Davis-Besse	81.12	906	PWR	FENOC
99.	Fort Calhoun	80.26	478	PWR	OPPD
100.	Palo Verde-3	80.06	1269	PWR	APS
101.	Hope Creek	78.46	1083	BWR	PSEG
102.	Kewaunee	70.45	574	PWR	Dominion
103.	Palo Verde-1	62.89	1336	PWR	APS
104.	Browns Ferry-1	0.00	1065	BWR	TVA

[1] These figures are rounded off. There are no ties. Browns Ferry-2 is in 19th place with a factor of 94.4343, and Arnold is in 20th place with a factor of 94.4302.

[2] The rating shown is effective as of December 31, 2006. If the reactor's rating has changed during the three-year period, the capacity factor is computed with appropriate weighting.

[3] As of December 31, 2006. In most cases this also means the reactor's owner, but the reactors listed for NMC are operated, but not owned, by Nuclear Management Company, LLC. Entergy is the contracted operator of Cooper, and Exelon is in the same role at Hope Creek/Salem (though only until January 2009). Exelon is also the sole owner of AmerGen.

seen as positive or negative for specific reactors, there doesn't appear to be a trend for the fleet as a whole.

The last zero?

A long-standing feature of Table I—Browns Ferry-1's capacity factor of 0.00—should appear this year for the last time. About the time this magazine goes to press, the BWR near Decatur, Ala., is to begin producing electricity for the first time in 22 years. Even if all goes well, Browns Ferry-1 will still be in last place in next year's Table I, with a three-year capacity factor of less than 20 percent, but by that time TVA Nuclear should be accumulating experience in working with what will be, in one sense, the newest power reactor in the United States.

At the time of its shutdown in 1985, Browns Ferry-1 had logged about six and a half effective full-power years (EFPY) of operation. Every other licensed reactor now has more EFPY, even the last one to begin commercial service—TVA's Watts Bar-1, in 1996—which now has about nine EFPY. Because of the extensive refurbishment carried out over the past five years, Browns Ferry-1 also has some of the newest equipment in the U.S. fleet.

As some licensees prepare to apply for licenses for new power reactors, TVA might soon be picking up some degree of "new" reactor experience, both in the operation of Browns Ferry-1 and in new construction. TVA is expected to decide this summer

TABLE II.
CAPACITY FACTOR CHANGE, 2001–2003 TO 2004–2006

Rank	Reactor	Change (percentage points)	Rank	Reactor	Change (percentage points)	Rank	Reactor	Change (percentage points)	Rank	Reactor	Change (percentage points)
1.	Davis-Besse	+44.85	27.	Oconee-1	+4.19	53.	Vogtle-1	-0.54	79.	Callaway	-3.29
2.	North Anna-2	+16.21	28.	Pilgrim	+4.18	54.	Indian Point-2	-0.54	80.	Robinson-2	-3.37
3.	South Texas-2	+14.49	29.	Surry-2	+4.13	55.	Peach Bottom-2	-0.63	81.	Byron-1	-3.38
4.	Palisades	+14.23	30.	Peach Bottom-3	+3.99	56.	Beaver Valley-2	-0.67	82.	Point Beach-2	-3.45
5.	Arnold	+11.06	31.	Beaver Valley-1	+3.71	57.	Palo Verde-2	-0.84	83.	Limerick-1	-3.57
6.	Three Mile Island-1	+10.69	32.	North Anna-1	+3.47	58.	ANO-1	-0.94	84.	Oyster Creek	-3.87
7.	Calvert Cliffs-2	+9.97	33.	Indian Point-3	+3.18	59.	Brunswick-2	-1.24	85.	Quad Cities-1	-3.90
8.	Cook-2	+9.86	34.	Millstone-3	+2.86	60.	Catawba-2	-1.25	86.	St. Lucie-2	-4.24
9.	Cooper	+9.49	35.	Salem-1	+2.76	61.	Byron-2	-1.68	87.	Fermi-2	-4.30
10.	South Texas-1	+9.30	36.	Nine Mile Point-2	+2.72	62.	Crystal River-3	-1.76	88.	Oconee-2	-4.90
11.	Comanche Peak-1	+8.78	37.	Salem-2	+2.37	63.	McGuire-1	-1.77	89.	Dresden-2	-4.98
12.	Nine Mile Point-1	+7.87	38.	Seabrook	+2.36	64.	FitzPatrick	-1.88	90.	Turkey Point-3	-5.74
13.	Cook-1	+7.16	39.	Oconee-3	+2.18	65.	LaSalle-1	-1.94	91.	Hatch-1	-5.83
14.	Browns Ferry-2	+7.14	40.	Ginna	+2.01	66.	Vogtle-2	-1.95	92.	St. Lucie-1	-5.85
15.	Monticello	+6.88	41.	Susquehanna-2	+1.84	67.	San Onofre-3	-1.99	93.	River Bend	-5.86
16.	Comanche Peak-2	+6.75	42.	Sequoyah-2	+1.38	68.	Waterford-3	-2.11	94.	Fort Calhoun	-6.05
17.	Summer	+6.74	43.	Hatch-2	+1.29	69.	Prairie Island-2	-2.12	95.	Watts Bar-1	-6.05
18.	Calvert Cliffs-1	+6.30	44.	Diablo Canyon-2	+1.01	70.	Catawba-1	-2.19	96.	Browns Ferry-3	-6.52
19.	Perry	+6.26	45.	Vermont Yankee	+0.68	71.	ANO-2	-2.24	97.	Hope Creek	-6.70
20.	Sequoyah-1	+6.15	46.	Dresden-3	+0.61	72.	Diablo Canyon-1	-2.36	98.	Brunswick-1	-7.21
21.	Columbia	+5.55	47.	Limerick-2	+0.11	73.	Braidwood-1	-2.54	99.	Susquehanna-1	-7.30
22.	Harris	+4.96	48.	Grand Gulf	+0.08	74.	McGuire-2	-2.82	100.	Turkey Point-4	-9.68
23.	Surry-1	+4.76	49.	Braidwood-2	+0.06	75.	Prairie Island-1	-2.83	101.	Palo Verde-3	-11.64
24.	LaSalle-2	+4.76	50.	Farley-1	+0.01	76.	Clinton	-2.89	102.	San Onofre-2	-14.11
25.	Farley-2	+4.69	51.	Browns Ferry-1	0.00	77.	Quad Cities-2	-2.99	103.	Kewaunee	-15.32
26.	Millstone-2	+4.48	52.	Wolf Creek	-0.04	78.	Point Beach-1	-3.01	104.	Palo Verde-1	-26.91

whether to revive Watts Bar-2, the only stalled previous-era project in the United States that was never officially canceled. The start of the next decade could find TVA with the most diverse project demands in the industry, with the operation of long-idled Browns Ferry-1, the construction of Watts Bar-2, and the pursuit of a construction/operating license (COL) for NuStart's AP1000 reactor at Bellefonte.

The revival of Browns Ferry-1 will mean that last place in Table I will soon go to a fully operational reactor. As has been pointed out many times in this survey, there should be no grading on a curve. If every reactor is performing well—as nearly every one of them is—then it should not matter if one finishes below 90th place on Table I, because this is still far better than the reactor was expected to perform when it was first included in a rate base, and it is only a few percentage points below the factor of reactors above 10th place. If a reactor is not doing well, however, last place is about to become available and will draw even more attention to its unfortunate occupant. Browns Ferry-1 is currently propping up Palo Verde-1, which has had equipment and performance problems in 2004–2006, and it did the same in the past few years for Davis-Besse, which was off line for over two years after the discovery of extensive erosion of its upper vessel head. Soon there will be nowhere to hide for a reactor that cannot uphold the standards of the rest of the fleet. Also, it may turn out that every reactor will perform creditably, and last place might sometimes go to a reactor with a capacity factor of over 85 percent.

Toward more meaningful DERs

While the statistical improvement in capacity factors was small, it was achieved amid numerous corrections to reactor DERs, most of which gave the reactors higher ratings and thus greater difficulty in maintaining the old factors, let alone bettering them. In most cases these corrections reflected power uprates or more efficient modes of operation, which in a few cases were belated and, strictly speaking, should have been adopted years earlier. DER modifications went into effect at 11 reactors at the start of 2006, and at four others later in the year, with 13 uprated and two downrated. One downrating was a correction to an earlier uprating, and the other reflected a change in which a pair of reactors at one site, which previously had equal ratings, were reconfigured so that one reactor is now considered the lead unit and has a higher rating. In that case, the total rating for the plant has risen by a net 4 MWe. In all, the changes at the 15 reactors reflect an extra

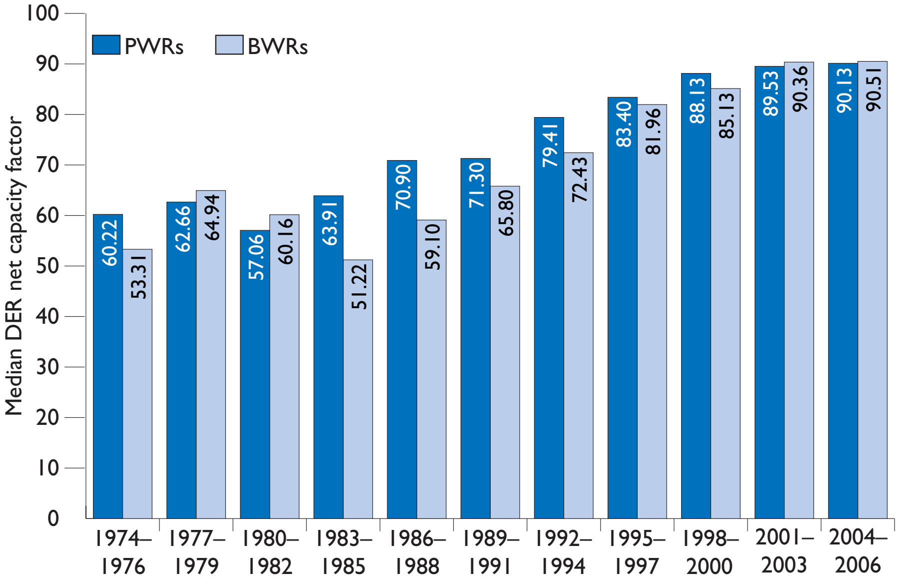

Fig. 2: Reactors by type. Pressurized water reactors recovered more quickly than boiling water reactors from downtime and modifications imposed in the aftermath of Three Mile Island-2, but in the last few periods, BWRs have finally caught up with PWRs. If closed reactors were included, the amounts would be similar, with only one median difference greater than two percentage points: PWRs in 1974–76, which would have been 63.67.

TABLE III.
DER NET CAPACITY FACTOR OF MULTIREACTOR SITES[1]

Rank	Site	Factor	Operator
1.	Calvert Cliffs	97.01	Constellation
2.	Braidwood	96.38	Exelon
3.	South Texas	95.18	STPNOC
4.	Byron	95.11	Exelon
5.	North Anna	94.91	Dominion
6.	Comanche Peak	94.87	TXU
7.	Surry	94.67	Dominion
8.	Peach Bottom	94.11	Exelon
9.	Indian Point	94.05	Entergy
10.	ANO	93.67	Entergy
11.	LaSalle	93.58	Exelon
12.	Limerick	92.37	Exelon
13.	Nine Mile Point	92.24	Constellation
14.	Sequoyah	91.31	TVA
15.	Beaver Valley	91.24	FENOC
16.	Farley	91.04	Southern
17.	Millstone	91.04	Dominion
18.	Catawba	90.84	Duke
19.	Vogtle	89.58	Southern
20.	Hatch	89.55	Southern
21.	Cook	89.49	IMP
22.	St. Lucie	89.29	FPL
23.	Dresden	88.61	Exelon
24.	Diablo Canyon	88.10	PG&E
25.	Prairie Island	87.76	NMC
26.	Susquehanna	87.74	PPL
27.	McGuire	87.22	Duke
28.	Brunswick	87.04	Progress
29.	Quad Cities	86.29	Exelon
30.	Hope Creek/Salem	85.94	PSEG
31.	Point Beach	85.39	NMC
32.	Oconee	84.74	Duke
33.	Turkey Point	84.00	FPL
34.	San Onofre	83.20	SCE
35.	Palo Verde	76.08	APS
36.	Browns Ferry	62.48	TVA

[1] Because Nine Mile Point and FitzPatrick have different owners, 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 2004–2006 factor of 92.93. 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 2004–2006 factor of 89.47. The figure given for Browns Ferry is for all three reactors, although Unit 1 has been out of service since 1985; the 2004–2006 factor for Units 2 and 3 only is 92.18.

344 MWe of rated capacity.

Previous *NN* surveys have taken some licensees to task for not reflecting uprates and other production improvements in their DERs. In fairness, we should also give credit when a licensee adheres to a policy of truth-in-capacity. We therefore call attention to Entergy, which has acknowledged the recent vast improvement resulting from a 7.5 percent uprate at ANO-2 in 2002. That reactor's new DER, 1032 MWe, was enough even for the one year it has been in effect to bring ANO's three-year factor back below 100, statistically more reasonable than, for instance, the 102.18 it achieved in 2003–2005. Entergy also raised the DER at Waterford-3, reflecting an 8 percent uprate in 2005, and in April 2006 made an adjustment for a comparatively small increase at Grand Gulf. Entergy even made an adjustment at River Bend, from 966 MWe to 967 MWe. Lest this survey be credited with more influence than it has, it should be noted that Entergy made all of these changes before last year's survey (which advised uprating ANO-2 and Waterford-3) was in print.

Other upward DER adjustments were made at Vermont Yankee and Ginna, recipients of large extended power uprates, and to a lesser extent at Brunswick, Cook, and Seabrook. Palo Verde-1 was officially uprated to 1336 MWe, to match Unit 2 at the site, but recent performance problems at this reactor have prevented it from operating at that power level for very long.

While these corrections are welcome because they put the reactors' electricity production in a proper context of performance, there remain a few reactors that continue to use DERs that do not reflect past uprates. We hope one day to see more appropriate ratings at Calvert Cliffs, North Anna, Surry, Wolf Creek, and one of Entergy's merchant reactors in the northeast, FitzPatrick.

Side by side

Each of these annual surveys not only covers the basic numbers and their most apparent trends but also tries to use the numbers to discern less obvious patterns. Two years ago we looked at whether a change in ownership or operating organization yielded clear results in performance. Last year we compared performance before and after power uprates. Eventually it may be useful to look at the licensees that are planning to submit COL applications to see whether this has an effect on the operation of their existing reactors, but for nearly every licensee, this planning has been going on for less than three full calendar years, and so it would be best to wait until more data accumulate.

This year, we will instead examine a different phenomenon: the apparent performance similarity of reactors within a multireactor site. This may not lead to any grand insights, and even if the situation is seen to exist, the explanations may be obvious: A plant's management and personnel would generally use similar practices for all reactors on the site, and so in the long run, each reactor's performance could be expected to be about the same. To give the investigation perhaps a bit more meaning, it will also be used on the whole fleets of individual licensees.

The following approach might cause apoplexy in a genuine statistician, but it should be useful for the purposes of this survey. Because 100 of the 104 reactors have three-year capacity factors between 80 percent and 100 percent, it seems reasonable to set those as the limits of the possible range of variation. The distribution of those reactors between 80 and 100 is not perfectly even, but neither is it severely skewed or clumped. If one reactor has a factor of 90, there would be (roughly) an even chance of any other randomly selected reactor's having a factor within five points either way (covering a 10-point span, half of the 20 points between the limits). The first step, then, is to compare the factor differences between the two (or among the three) reactors at each site to see how many differ-

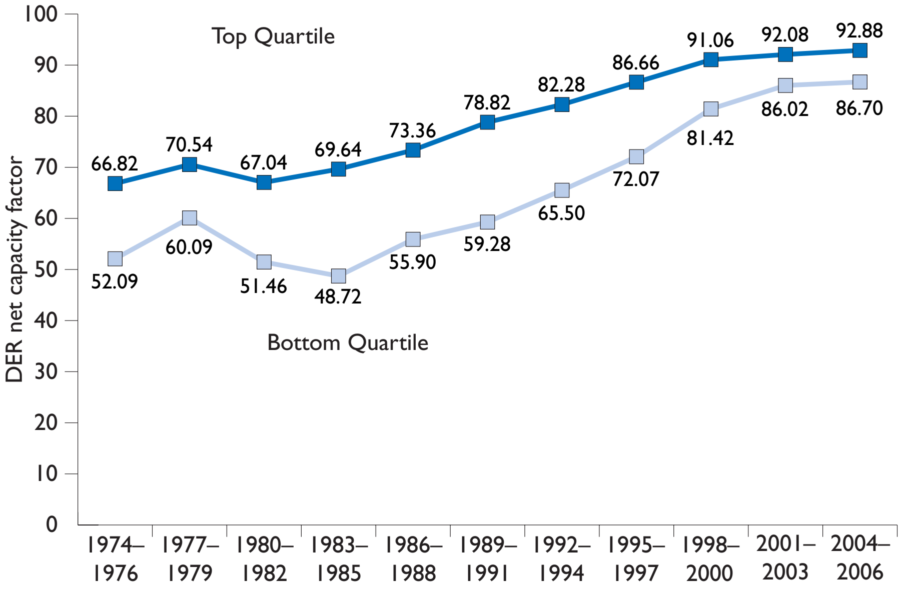

Fig. 3: All reactors, top and bottom quartiles. An indication of the improvement of the fleet as a whole is the narrowing gap between the top and bottom quartiles, from more than 20 percentage points to fewer than seven. The chart shows reactors still in service today; if closed reactors were included, the only amounts that would differ by more than two percentage points are the bottom quartiles in 1989–1991 (57.08) and 1995–1997 (68.18), the latter reflecting the reduced output of the last reactors to close.

ences are less than five points.

Table V shows the differences for 2004–2006, with Salem and Hope Creek taken together, FitzPatrick not included with Nine Mile Point, and Browns Ferry represented only by Units 2 and 3. It should be noted that the difference in capacity factors is not an indicator of performance; Palo Verde is at the top, and Oconee is near the bottom, and the two combined make up all of the reactors in the “degraded cornerstone” columns of the action matrix in the NRC’s reactor oversight process. We use this table only to see how the differences compare to the mean difference between two randomly selected reactors, and by the criteria established above, there does seem to be a pattern. Only five of the 36 plants have differences greater than five points, and only 15 have differences of more than two and a half points. Two of the five at the top of Table V have dissimilar reactors at the site, and two have three reactors instead of two.

To see if this is a recent development, historical data were checked all the way back to 1974–1976, the earliest three-year period in which there was more than one multireactor site in operation. For each period, a decision was made (perhaps arbitrarily) on what seemed like reasonable limits for top and bottom performance. In 1992–1994, for instance, 104 of the 108 reactors were in a range from 43 to 92, and so as one-fourth of the 20-point spread was used for 2004–2006, one-fourth for 1992–1994 turned out to be 12.25. Reactors that have since closed were used in these samples.

In the interest of keeping the length of this survey from overwhelming this entire issue of the magazine, we will skip to the results, shown in Table VI. Not only have the reactors at multiunit sites strongly tended to have three-year capacity factors close to the factors of the other reactor(s) at the same site, but the percentage has been about the same in every period, covering more than 30 years and many eras of operating philosophy, regulatory approach, equipment use, backfitting, and so forth.

TABLE IV.
DER NET CAPACITY FACTORS OF OWNERS OR OPERATORS OF MORE THAN ONE SITE[1]

Rank	Owner/Operator	Factor
1.	Constellation Energy	94.58
2.	Dominion Energy	93.38
3.	Entergy Nuclear	93.08
4.	Exelon (including AmerGen)	92.58
5.	Southern Nuclear Operating Co.	90.00
6.	Progress Energy	88.54
7.	FPL Energy	88.47
8.	Duke Power	87.45
9.	Nuclear Management Company	87.12
10.	FirstEnergy Nuclear Operating Co.	87.25
11.	Tennessee Valley Authority	75.93

[1] Exelon without AmerGen is 92.73. AmerGen alone is 91.63. TVA without Browns Ferry-1 is 90.08. Entergy’s contract operation of Cooper began during 2004, and so had been in effect for less than three years at the end of 2006, so it is not included here.

TABLE V.
DIFFERENCE BETWEEN HIGHEST AND LOWEST THREE-YEAR PLANT DER NET CAPACITY FACTOR AMONG ALL REACTORS AT EACH MULTIUNIT SITE

Plant	Difference	Plant	Difference	Plant	Difference
Palo Verde	22.15	Sequoyah	3.19	Comanche Peak	1.08
Hope Creek/Salem	11.74	LaSalle	2.97	Surry	1.04
ANO	7.59	Byron	2.65	Limerick	0.97
Indian Point	6.44	San Onofre	2.50	South Texas	0.97
Susquehanna	6.03	Catawba	2.36	McGuire	0.66
Calvert Cliffs	4.60	Beaver Valley	2.19	Nine Mile Point	0.50
Browns Ferry	4.50	Turkey Point	2.17	Oconee	0.46
Hatch	4.26	Prairie Island	2.11	Braidwood	0.41
Peach Bottom	3.88	Farley	1.83	Diablo Canyon	0.40
Dresden	3.81	Millstone	1.44	Cook	0.35
St. Lucie	3.50	Quad Cities	1.30	Point Beach	0.19
Vogtle	3.30	Brunswick	1.20	North Anna	0.09

The most reasonable inference would be that the smaller differences occur because most multiunit plants have replicate, or at least similar, reactors. This is true for 32 of the 36 sites, so let’s take a closer look at the other four: ANO, Hope Creek/Salem, Millstone, and Nine Mile Point. This is a fairly small sample, but it yields an interesting result: Three of these four plants have historically had smaller differences than the random interval exactly half of the time, making their long-term factor differences essentially the same as those between randomly selected reactors. Only Nine Mile Point has consistently had smaller differences (five of the six periods in which both reactors have operated). This suggests fairly strongly that over the three-year periods that this survey uses, a key to consistent operation is similarity in original reactor design. (Whether Nine Mile Point is the exception because both reactors are BWRs is by no means clear; Unit 2 has nearly twice the rated power of Unit 1.) Another indicator: If the two highly similar Salem PWRs are considered separately from the Hope Creek BWR, the factor difference has been smaller than the random interval seven times in the eight periods in which both reactors have operated.

It is more difficult to discern any tendency among all of the reactors owned or operated by a multisite organization, because this deals with larger groups of reactors. The five-point choice for a difference for two randomly selected reactors in 2004–2006 would not apply because these organizations operate more than two reactors, and so different values for the random selection of as many as 17 reactors would have to be worked out. Because this requires more statistical rigor than we have at our disposal, we will instead try to draw a reasonable inference from the data.

As it happens, three of the 11 multisite organizations—Dominion, Progress, and Southern—have top-to-bottom factor differences of less than five points for their entire fleet (six, five, and six reactors, respectively). Four others—Constellation, Duke, Entergy, and Nuclear Management Company—have differences between five and eight points, with four, seven, ten, and six reactors, respectively. Eight points seems to be a pretty narrow range for groups this large, and so it seems reasonable to infer that seven of the 11 are bunched more tightly than one would expect from random samplings. The differences of the other four organizations ranged between nine and 13 points. (Because of the fairly small number of these organizations and changes in ownership of some reactors over the years, no attempt was made to discern a pattern in previous three-year periods.)

This suggests that a unified organization tends to make capacity factors more uniform, regardless of reactor type and size, although this appears not to be as strong a factor as the similarity of original equipment. One hopes that this indicates the availability of improvement resources for all of an organization’s reactors—the performance trends of the past two decades seem to bear this out—and not just regression to the mean, with the best performers starting to suffer neglect while main-office attention goes to the squeaky wheels.

To reiterate, there isn’t necessarily anything good or bad about collocated reactors having similar capacity factors. Braidwood, with both reactors in the top 10 of Table I, has factors less than half a point apart. All

TABLE VI.
PERCENTAGE OF MULTIREACTOR SITES WITH CAPACITY FACTOR DIFFERENCES SMALLER THAN THE EXPECTED RANDOM INTERVAL

Three-year period	%	Three-year period	%
1974–1976	80	1992–1994	88
1977–1979	89	1995–1997	89
1980–1982	87	1998–2000	89
1983–1985	85	2001–2003	80
1986–1988	92	2004–2006	86
1989–1991	87		

three Oconee reactors are also within half a point, and all of them have factors lower than 85. Nor is capacity factor the only measure of good performance. Braidwood has been criticized for its effluent control and the seepage of tritiated water from the plant site into off-site drinking water wells.

Speaking of similarity . . .

It may be true, therefore, that similarity in original equipment leads to long-term similarity in collocated reactors' capacity factors. If a site has dissimilar reactors, the experience from an outage of one reactor may not be directly transferable to an outage of another, and thus downtimes may turn out to be very different and capacity factors could follow suit. It may also be true, to a lesser extent, that reactors in a large fleet will tend toward a consensus capacity factor as a result of management policies affecting all of the reactors.

Can anything worthwhile be learned from this? Perhaps not. If a plant's reactors are dissimilar, management has been dealing with the fact for several years, maybe being forced to accept some inefficiencies in work planning and outage management. Operators of a single reactor have had a long time to learn all of its relevant aspects. Multiunit plants may have had learning-curve advantages in the early years, but by now single-unit plants have probably pulled even.

It is also debatable whether this insight will be useful in the licensing and (presumed) construction and operation of new reactors. These reactors will be extensively standardized, and the operational and regulatory approaches for them might not closely resemble those for current reactors, however much they would be built on the present generation's knowledge base.

The announced plans for COL applications are all uniform in that each applicant would build one specific reactor type. In the case of UniStar, the reactors would not only be physically replicated but would be operated by a single organization, regardless of who buys (or "invests") in them. The experience with current reactors suggests that these new reactors would ultimately have very similar capacity factors within specific sites. At least 11 of these projects, however, would be built at sites where current reactors are already in operation. Would new reactors seek the performance level of the old, would the old reactors match the level of the new, or would the paradigms be so different that neither is seen to influence the other? In a decade or two, we may find out. NN

Where all of this came from

Each year, *NN* presents an analysis of U.S. power reactor capacity factors. The raw data—each reactor's annual electricity output and its design electrical rating (DER)—are provided to us by Tom Smith, at Idaho National Laboratory (thanks, as always, Tom).

The author then computes three-year capacity factors for each reactor in the belief that this time frame shows sustained performance and helps even out fueling cycles of different lengths. The historical material, shown in the figures, includes only reactors that were in service in those earlier time periods and are still in service today. The potential for discrepancies between three-year periods is declining because no reactors have started up since 1996, and none has closed since 1998.

DER has been chosen for each reactor's generating capacity in the belief that it provides the best indication of what a reactor was intended to accomplish. As noted in the text, even DER can be of dubious value if it is not altered to reflect a power uprate, but an attempt has been made to counteract any misleading results.—*E.M.B.*