U.S. capacity factors: Another small gain, another new peak

BY E. MICHAEL BLAKE

The overall performance level of the entire nuclear fleet has risen further into the realm of 90 percent capacity.

EACH YEAR THIS survey attempts to prepare readers for the moment—which still seems inevitable—when the capacity factor of U.S. power reactors stops rising. Leveling off isn't bad, we keep saying. Maintaining the same high level of performance would be as formidable an accomplishment as reaching that level had been—and so on. Each year, too, the numbers have shown that the fleet somehow managed to continue to improve, and so nobody needs to be consoled. Yes, it has happened again this time.

In 2005–2007, the median three-year design electrical rating (DER) net capacity factor of operating power reactors in the United States was 90.61 percent (compared with 89.77 in 2002–2004)—a new all-time high, topping the 90.13 in 2004–2006, which was the first median above 90. The three-year average capacity factor was 89.04 percent, up nearly a point from the average of 88.22 in 2002–2004 and the first whole-fleet average higher than 89. The tendency within the nuclear community to generalize power reactor performance at 90 percent has therefore come closer to having true mathematical justification.

Every statistical measure for individual reactors used in this survey showed a gain of a fraction of a percentage point. Among all reactors, the top quartile was 92.99 percent in 2005–2007, compared with 92.58 in the previous period, and the bottom quartile was 87.31 percent, up from 86.68. Among boiling water reactors, the median was 90.19 (up from 89.74), the average was 87.50 (up from 86.83), the top quartile was 92.98 (up from 92.59) and the bottom quartile was 87.14 (up from 86.83). For pressurized water reactors, the median was 90.74 (up from 89.80), the average was 89.83 (up from 88.93), the top quartile was 93.01 (up from 92.82), and the bottom quartile was 87.31 (up from 86.47).

For the 10th straight three-year period, the median capacity factor for multireactor

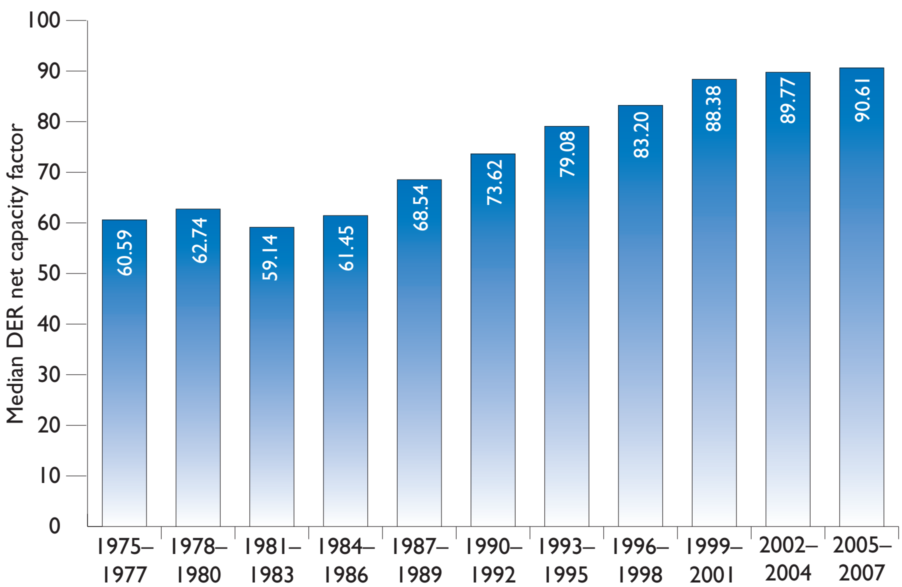

Fig. 1: All reactors. For the most part, median capacity factor has leveled off, but there has still been roughly a 1-point gain in each three-year period since 1999–2001. The chart shows only reactors that are still in service now; there were 32 such reactors in 1975–1977, and in each succeeding period there were 49, 55, 65, 85, 99, 102, 103, and 104 in each of the last three. If closed reactors were included in the periods during which they operated, no median would change by as much as 1 percentage point.

TABLE I.
2005–2007 DER NET CAPACITY FACTORS OF INDIVIDUAL REACTORS

Rank	Reactor	Factor[1]	Design Electrical Rating (DER), MWe[2]	Type	Operator[3]
1.	Calvert Cliffs-1	97.82	845	PWR	Constellation
2.	South Texas-1	96.88	1250.6	PWR	STPNOC
3.	FitzPatrick	96.69	816	BWR	Entergy
4.	Ginna	96.55	585	PWR	Constellation
5.	Braidwood-2	96.45	1155	PWR	Exelon
6.	Comanche Peak-2	96.20	1150	PWR	Luminant
7.	South Texas-2	95.87	1250.6	PWR	STPNOC
8.	Three Mile Island-1	95.84	819	PWR	AmerGen (Exelon)
9.	Calvert Cliffs-2	95.71	845	PWR	Constellation
10.	Peach Bottom-2	95.68	1138	BWR	Exelon
11.	Dresden-3	95.51	867	BWR	Exelon
12.	Surry-2	95.44	788	PWR	Dominion
13.	Braidwood-1	95.37	1187	PWR	Exelon
14.	Indian Point-2	94.59	1035	PWR	Entergy
15.	LaSalle-1	94.20	1154	BWR	Exelon
16.	North Anna-1	94.18	907	PWR	Dominion
17.	Nine Mile Point-2	94.17	1143.3	BWR	Constellation
18.	Byron-2	93.92	1155	PWR	Exelon
19.	Diablo Canyon-1	93.73	1103	PWR	PG&E
20.	Limerick-1	93.63	1191	BWR	Exelon
21.	Salem-1	93.63	1169	PWR	PSEG
22.	Clinton	93.56	1062	BWR	AmerGen (Exelon)
23.	ANO-2	93.33	1032	PWR	Entergy
24.	LaSalle-2	93.09	1154	BWR	Exelon
25.	Comanche Peak-1	93.02	1150	PWR	TXU
26.	Diablo Canyon-2	93.00	1151	PWR	PG&E
27.	Peach Bottom-3	92.98	1138	BWR	Exelon
28.	Surry-1	92.97	788	PWR	Dominion
29.	Vermont Yankee	92.96	617	BWR	Entergy
30.	Wolf Creek	92.82	1170	PWR	WCNOC
31.	Quad Cities-2	92.77	871	BWR	Exelon
32.	Byron-1	92.74	1187	PWR	Exelon
33.	Salem-2	92.70	1155	PWR	PSEG
34.	Prairie Island-1	92.62	536	PWR	NMC
35.	Beaver Valley-2	92.58	854	PWR	FENOC
36.	North Anna-2	92.36	907	PWR	Dominion
37.	Seabrook	92.15	1246	PWR	FPL
38.	Indian Point-3	92.11	1034	PWR	Entergy
39.	Summer	91.81	972.7	PWR	SCE&G
40.	Dresden-2	91.45	867	BWR	Exelon
41.	Sequoyah-2	91.44	1151	PWR	TVA
42.	Farley-2	91.37	855	PWR	Southern
43.	Browns Ferry-3	91.32	1120	BWR	TVA
44.	Nine Mile Point-1	91.16	613	BWR	Constellation
45.	Beaver Valley-1	91.02	868	PWR	FENOC
46.	Catawba-1	90.94	1145	PWR	Duke
47.	Sequoyah-1	90.91	1173	PWR	TVA
48.	Grand Gulf	90.89	1279	BWR	Entergy
49.	Millstone-3	90.81	1156.5	PWR	Dominion
50.	Millstone-2	90.74	883.5	PWR	Dominion
51.	Farley-1	90.68	854	PWR	Southern
52.	Vogtle-1	90.66	1169	PWR	Southern
53.	Pilgrim	90.57	690	BWR	Entergy
54.	Catawba-2	90.48	1145	PWR	Duke
55.	Harris	90.36	941.7	PWR	Progress
56.	Cooper	90.35	778	BWR	NPPD/Entergy
57.	Limerick-2	90.19	1191	BWR	Exelon
58.	St. Lucie-1	90.16	856	PWR	FPL
59.	Arnold	90.03	613.5	BWR	FPL
60.	ANO-1	90.03	850	PWR	Entergy
61.	Hatch-1	89.90	885	BWR	Southern
62.	Waterford-3	89.65	1173	PWR	Entergy
63.	Cook-2	89.59	1107	PWR	IMP
64.	Davis-Besse	89.53	898	PWR	FENOC
65.	Oconee-2	89.47	886	PWR	Duke
66.	Cook-1	89.45	1084	PWR	IMP
67.	Robinson-2	89.29	765	PWR	Progress
68.	Susquehanna-1	89.02	1177	BWR	PPL
69.	San Onofre-3	88.79	1080	PWR	SCE
70.	Brunswick-1	88.70	983	BWR	Progress
71.	River Bend	88.61	967	BWR	Entergy
72.	Hatch-2	88.50	908	BWR	Southern
73.	Crystal River-3	88.39	860	PWR	Progress
74.	Oyster Creek	88.38	650	BWR	AmerGen (Exelon)
75.	Quad Cities-1	87.70	866	BWR	Exelon
76.	Oconee-3	87.68	886	PWR	Duke
77.	Prairie Island-2	87.50	536	PWR	NMC
78.	Turkey Point-3	87.36	720	PWR	FPL
79.	Point Beach-1	87.26	522	PWR	FPL
80.	Monticello	87.14	600	BWR	NMC
81.	Browns Ferry-2	87.12	1120	BWR	TVA
82.	Palisades	86.94	805	PWR	Entergy
83.	McGuire-2	86.89	1180	PWR	Duke
84.	Susquehanna-2	86.81	1182	BWR	PPL
85.	Point Beach-2	86.46	522	PWR	FPL
86.	Callaway	86.30	1228	PWR	Ameren
87.	Palo Verde-2	86.00	1336	PWR	APS
88.	Hope Creek	85.88	1083	BWR	PSEG
89.	McGuire-1	85.74	1180	PWR	Duke
90.	Oconee-1	85.40	886	PWR	Duke
91.	San Onofre-2	85.37	1070	PWR	SCE
92.	Vogtle-2	85.34	1169	PWR	Southern
93.	Columbia	84.75	1153	BWR	Northwest
94.	Watts Bar-1	84.32	1155	PWR	TVA
95.	Brunswick-2	83.92	980	BWR	Progress
96.	Turkey Point-4	82.98	720	PWR	FPL
97.	Fort Calhoun	82.09	502	PWR	OPPD
98.	Fermi-2	81.36	1150	BWR	Detroit
99.	St. Lucie-2	79.75	856	PWR	FPL
100.	Perry	79.16	1258	BWR	FENOC
101.	Palo Verde-3	76.44	1269	PWR	APS
102.	Kewaunee	75.19	574	PWR	Dominion
103.	Palo Verde-1	60.71	1333	PWR	APS
104.	Browns Ferry-1	15.92	1120	BWR	TVA

[1] These figures are rounded off. There are no ties. Limerick-1 is in 20th, with 93.6309, and Salem-1 is in 21st, with 93.6264.

[2] The rating shown is effective as of December 31, 2007. 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, 2007. 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. Exelon is the sole owner of AmerGen.

sites was slightly higher than that for reactors in general, at 90.94, about a third of a percentage point higher. This difference has never been very great—always less than 2 ½ points—so it may not be statistically significant, but the fact that it is always there suggests that collocation offers some potential benefits over single-reactor sites (such as having to perform twice as many refuelings with similar hardware, providing more experience at how to get things done more efficiently).

The same cannot be said, however, about licensees with more than one site. The median for these 11 licensees was 89.01 percent, more than a point and a half below the all-reactors median and a decline from the 2002–2004 figure, 89.91. This is the fourth time in the last 10 periods that the multisite median has trailed the all-reactors median, and to some extent the cause of this may be that with only 11 points in the data set, there may not be enough statistical rigor. Also, reactor ownership changes are still taking place, and transition periods can affect plant operations. (This survey includes only the changes that took place through the end of 2004, and so each licensee has had at least three full years with each reactor; thus, Arnold, Kewaunee, Palisades, and Point Beach are not included in their new owners' data.)

Does this mean that the organizations that have made a point of buying reactors outside their traditional service areas are getting in over their heads? Not necessar-

Table II.
Capacity Factor Change, 2002–2004 to 2005–2007

Rank	Reactor	Change (percentage points)	Refuelings in each period
1.	Davis-Besse	+61.38	N/A
2.	Browns Ferry-1	+15.92	N/A
3.	South Texas-2	+12.44	2, 2
4.	Calvert Cliffs-1	+11.66	2, 1
5.	Diablo Canyon-1	+11.46	2, 2
6.	Cook-2	+10.28	3, 2
7.	Salem-1	+9.73	2, 2
8.	South Texas-1	+9.24	1, 2
9.	Dresden-3	+8.37	2, 1
10.	Hope Creek	+8.12	2, 2
11.	Diablo Canyon-2	+7.97	2, 1
12.	North Anna-2	+7.86	2, 2
13.	Salem-2	+7.78	2, 2
14.	Cooper	+7.37	1, 2
15.	Comanche Peak-2	+7.08	2, 2
16.	Quad Cities-2	+6.04	1, 2
17.	Comanche Peak-1	+5.65	2, 2
18.	Nine Mile Point-2	+5.63	2, 1
19.	Peach Bottom-2	+5.10	2, 1
20.	Sequoyah-2	+5.06	2, 2
21.	Clinton	+4.88	2, 1
22.	Indian Point-2	+4.57	2, 1
23.	Oconee-2	+4.27	2, 2
24.	Millstone-2	+4.12	2, 2
25.	Oconee-3	+3.89	2, 2
26.	Sequoyah-1	+3.64	2, 2
27.	Vermont Yankee	+3.64	2, 2
28.	Prairie Island-1	+3.46	2, 1
29.	FitzPatrick	+3.42	2, 1
30.	Oconee-1	+3.39	2, 2
31.	Susquehanna-1	+3.31	2, 1
32.	Cook-1	+3.20	2, 2
33.	Dresden-2	+3.10	1, 2
34.	LaSalle-1	+2.88	2, 1
35.	Surry-2	+2.87	2, 2
36.	Nine Mile Point-1	+2.76	1, 2
37.	Palisades	+2.53	2, 2
38.	Callaway	+2.12	2, 2
39.	LaSalle-2	+2.02	1, 2
40.	Summer	+2.02	2, 2
41.	Quad Cities-1	+1.94	1, 2
42.	Arnold	+1.64	1, 2
43.	Wolf Creek	+1.59	2, 2
44.	North Anna-1	+1.54	2, 2
45.	Beaver Valley-1	+1.53	2, 2
46.	Limerick-1	+1.43	2, 1
47.	Harris-1	+1.22	2, 2
48.	Surry-1	+1.18	2, 2
49.	Turkey Point-3	+0.79	2, 2
50.	Farley-1	+0.51	2, 2
51.	Columbia	+0.41	1, 2
52.	Calvert Cliffs-2	+0.38	1, 2
53.	San Onofre-3	+0.33	2, 1
54.	Palo Verde-2	+0.12	2, 2
55.	Catawba-1	+0.06	2, 2
56.	Hatch-1	-0.07	2, 1
57.	Farley-2	-0.08	2, 2
58.	Oyster Creek	-0.14	2, 1
59.	Point Beach-1	-0.24	2, 2
60.	ANO-1	-0.28	2, 2
61.	Millstone-3	-0.59	2, 2
62.	Three Mile Island-1	-0.67	1, 2
63.	Ginna	-0.68	2, 2
64.	Beaver Valley-2	-0.90	2, 2
65.	Braidwood-2	-0.92	2, 2
66.	Brunswick-1	-1.05	2, 1
67.	Vogtle-1	-1.09	2, 2
68.	Browns Ferry-3	-1.31	2, 1
69.	Robinson-2	-1.69	2, 2
70.	McGuire-1	-2.06	2, 2
71.	Point Beach-2	-2.12	2, 2
72.	Braidwood-1	-2.36	2, 2
73.	Seabrook	-3.04	2, 2
74.	Byron-2	-3.05	2, 2
75.	Pilgrim	-3.07	1, 2
76.	McGuire-2	-3.12	2, 2
77.	Waterford-3	-3.35	2, 2
78.	Peach Bottom-3	-3.42	1, 2
79.	Limerick-2	-3.49	1, 2
80.	Vogtle-2	-3.53	2, 2
81.	Byron-1	-3.56	2, 2
82.	Catawba-2	-3.57	2, 2
83.	Grand Gulf-1	-3.99	2, 2
84.	River Bend-1	-4.08	2, 1
85.	Hatch-2	-4.09	1, 2
86.	Fermi-2	-4.21	2, 2
87.	Indian Point-3	-4.61	1, 2
88.	Browns Ferry-2	-4.76	1, 2
89.	St. Lucie-1	-4.87	2, 2
90.	Susquehanna-2	-5.59	1, 2
91.	Monticello	-5.64	1, 2
92.	Prairie Island-2	-6.11	2, 2
93.	Watts Bar-1	-6.15	2, 2
94.	Crystal River-3	-6.65	1, 2
95.	Perry	-7.60	1, 2
96.	Brunswick-2	-7.75	1, 2
97.	San Onofre-2	-8.04	2, 2
98.	Fort Calhoun	-8.50	2, 2
99.	ANO-2	-9.03	2, 2
100.	Turkey Point-4	-9.40	2, 2
101.	Palo Verde-3	-10.18	2, 2
102.	Kewaunee	-11.72	2, 2
103.	St. Lucie-2	-12.29	1, 3
104.	Palo Verde-1	-28.03	2, 2

ily. First of all, we're still talking about a median of 89 percent, a high level of productivity by any reasonable measure. Second, four of the five organizations that have been most active in reactor acquisition are in the top four spots in Table IV, and so it appears that they know what they're doing. (This includes Exelon, which has essentially acquired the reactors nominally owned by AmerGen.) The fifth, FPL, is toward the bottom of Table IV, but for reasons mentioned later, this does not appear to have been caused by the corporate attention paid to the takeovers of Arnold and Point Beach.

The effect of refueling frequency

This survey has claimed for decades that the use of three-year periods gives a reasonable picture of sustained performance and helps minimize differences in the length of fueling cycles. It cannot be denied, however, that those differences exist, and if one demands extreme rigor in the numbers used here to indicate performance, it might be worthwhile to look at how often each reactor refueled in each period.

Most, but not all, PWRs operate for about 18 months between refuelings, and most BWRs go 24 months. This could have the effect of giving PWRs fairly steady trends, with two refuelings in each three-year period, while BWRs might show peaks and valleys, with one refueling in one three-year period and two refuelings in the next. This does not mean that BWRs are inconsistent, only that a series of three-year periods might give that impression.

Table II has been modified to include the number of refuelings in each period (for example, "2, 1" indicates two refuelings in 2002–2004 and one in 2005–2007). Refueling outages themselves vary in length, of course, and a key factor in the rising performance of the fleet as a whole has been a trend toward shorter outages. In general, however, a capacity factor difference of as much as 5 points (and perhaps more) between two periods may need no further explanation than whether one period had more refuelings than the other. (Davis-Besse and Browns Ferry-1 are shown as not applicable, since they were not in normal operation in 2002–2004; they are also excluded from the numerical breakdowns that follow.)

There were 181 refuelings fleet-wide in 2002–2004 and 185 in 2005–2007, essentially the same, given the duration differences among individual outages. Of the 53 reactors in full operation through both periods that had higher capacity factors in 2005–2007, 14 had fewer outages in the later period, 10 had more outages, and the other 29 had the same number. Of the 49 reactors with lower factors in 2005–2007, five had fewer outages in the later period, 13 had more outages, and the other 31 had the same number. This is the expected result, and it is sufficient to explain many of the gains and losses shown in Table II.

A few of the experiences merit coverage in more detail. This was Davis-Besse's first full three-year period since restart after its multiyear outage following the discovery of its extensive vessel head erosion, and it appeared to perform within the range of the rest of the industry. As far as multiyear outages go, however, there is no match for Browns Ferry-1, which was shut down from 1985 to 2007. TVA Nuclear appears to have restored it to productivity, although in the early going the frequency of unplanned scrams landed it in the "degraded cornerstone" column of the Nuclear Regulatory Commission's Reactor Oversight Process action matrix.

Before the refuelings are reviewed in detail, here is a side note on an oddity that arose from this survey's close look at outages in general. San Onofre-3 was taken off line for about a month last fall so that Southern California Edison could extend the life of the current fuel load and prevent the next refueling from taking place this coming August, during peak air-conditioning demand. This was a rare exception to the usual operating practice for power reactors, which is to run them as close to full power as can be managed, for as long as possible, to provide baseload electricity.

Both South Texas Project reactors are near the top of Table II, partly for avoiding the kinds of problems they had earlier in the decade (instrument penetration repairs on Unit 1, turbine vibrations on Unit 2), and partly for running breaker-to-breaker between refuelings in the latter period. Calvert Cliffs-1's 2002 refueling took four months, and there was only one refueling in 2005–2007. Diablo Canyon -1 had turbine trouble in 2002, and a long refueling in 2004, followed by a breaker-to-breaker run between the 2005 and 2007 refuelings; Unit 2 had only one refueling in the later period. Hope Creek/Salem, gaining more than 25 points among the three reactors, clearly benefited from its being operated by Exelon, which was to pave the way for its merger with PSEG. With the merger scrapped in September 2006 and the operational contract ending, PSEG will have to maintain this level on its own.

Cook-2 was dealing with a feedwater check valve steam leak in 2003, and it went breaker-to-breaker between the 2006 and 2007 refuelings. Dresden and Quad Cities appear to have finally overcome the steam dryer cracking problems that resulted from their extended power uprates and had them operating no higher than their original peak power levels for various lengths of time. North Anna-2's 2002 outage was protracted by a planned replacement of the vessel head. Cooper, despite having more refuelings in the later period, appears to have benefited from having its own new operator, Entergy, which unlike Exelon will not be leaving its new role.

A new owner or operator is no guarantee of immediate and lasting improvement. Dominion's acquisition of Kewaunee in 2005 was delayed until operation resumed following a long outage related to auxiliary feedwater pump performance, but even after Dominion's takeover, there has been significant downtime, including for a service water pipe leak.

Among the other reactors in the lower part of Table II, the extra refueling in the most recent period appears to be the primary cause of the comparatively lower factors at Pilgrim, Peach Bottom-3, Limerick-2, Hatch-2, Indian Point-3, Browns Ferry-2, Susquehanna-2, Monticello, and Crystal River-3. The extra refueling is at least a contributing factor at Perry and Brunswick-2.

Because the two-year fueling cycle is used to a great extent by BWRs, we will make another attempt to even out the refueling issue by looking at whole plants. There are 10 plants with two BWRs (counting Browns Ferry, with only Units 2 and 3 considered), and because of the tendency to time outages so that one reactor is in service while the other is off line, nine of the 10 have their refuelings exactly balanced, with three in each three-year period. Because Quad Cities had two refuelings in the first period and four in the second, it is not

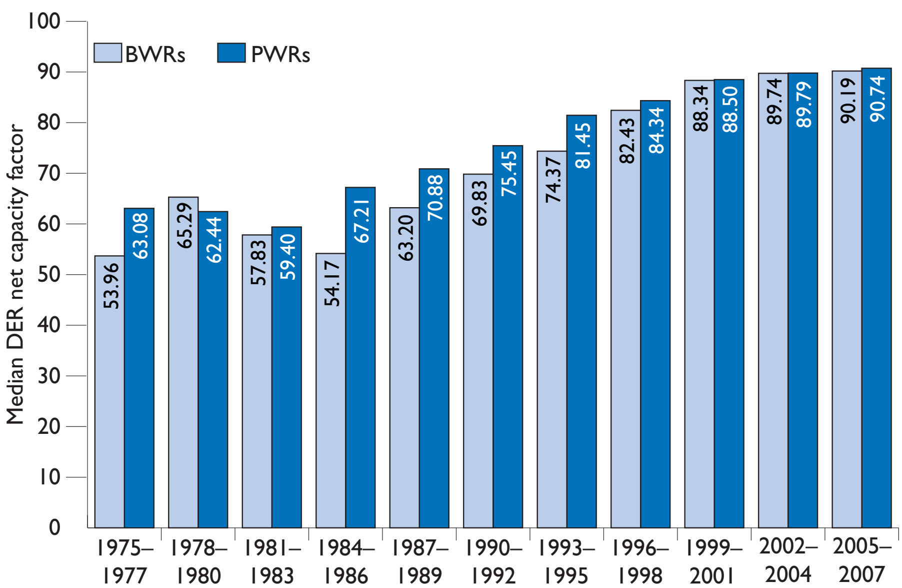

Fig. 2: Reactors by type. The median for boiling water reactors has been essentially even with that for pressurized water reactors in the last three periods. The chart shows only reactors in service now; if closed reactors were included, the only change greater than 2 percentage points would be for BWRs in 1990–1992 (67.10). There were 13 BWRs in the first period, and since then 20, 21, 23, 30, 34, and 35 in the last five. There were 19 PWRs in the first period, followed by 29, 34, 42, 55, 65, 67, 68, and 69 in the last three.

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

Rank	Site	Factor	Operator	Rank	Site	Factor	Operator
1.	Calvert Cliffs	96.77	Constellation	19.	Hope Creek/Salem	90.84	PSEG
2.	South Texas	96.37	STPNOC	20.	Millstone	90.78	Dominion
3.	Braidwood	95.90	Exelon	21.	Catawba	90.71	Duke
4.	Comanche Peak	94.61	Luminant	22.	Quad Cities	90.24	Exelon
5.	Peach Bottom	94.33	Exelon	23.	Prairie Island	90.06	NMC
6.	Surry	94.20	Dominion	24.	Cook	89.52	IMP
7.	LaSalle	93.65	Exelon	25.	Hatch	89.19	Southern
8.	Dresden	93.48	Exelon	26.	Vogtle	88.00	Southern
9.	Diablo Canyon	93.36	PG&E	27.	Susquehanna	87.92	PPL
10.	Indian Point	93.35	Entergy	28.	Oconee	87.52	Duke
11.	Byron	93.32	Exelon	29.	San Onofre	87.09	SCE
12.	North Anna	93.27	Dominion	30.	Point Beach	86.86	FPL
13.	Nine Mile Point	93.12	Constellation	31.	Brunswick	86.33	Progress
14.	Limerick	91.91	Exelon	32.	McGuire	86.31	Duke
15.	ANO	91.81	Entergy	33.	Turkey Point	85.17	FPL
16.	Beaver Valley	91.79	FENOC	34.	St. Lucie	84.96	FPL
17.	Sequoyah	91.17	TVA	35.	Palo Verde	74.43	APS
18.	Farley	91.03	Southern	36.	Browns Ferry	65.42	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 2005–2007 factor of 94.25. 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 2005–2007 factor of 93.17. The figure given for Browns Ferry is for all three reactors, although Unit 1 just returned to service last May; the 2005–2007 factor for Units 2 and 3 only is 89.22.

included. The remaining nine are shown in Table V, listed by the changes in their capacity factors from the first period to the next. Four of the plants had better factors, five had poorer factors, and all of the differences were less than 6 points. As noted earlier, however, the median factor of BWRs in general has risen in the later period.

Back to Table II, the oddest disparity of all was at St. Lucie-2, which as a result of scheduling, fuel use, hurricane recovery, and other factors, had one refueling in 2002–2004 and three in 2005–2007, accounting to a great extent for the decline in its capacity factor. FPL has also seen a downturn at Turkey Point-4, with hurricane response and recovery a factor here as well, but also plenty of equipment issues, such as a transformer fault, condenser tube sheet plugging, and coolant pump work. It does not appear that performance at St. Lucie-2 and Turkey Point-4, which is the main factor in FPL's ranking in Table IV, has anything to do with corporate attention to Seabrook or the newly acquired Arnold and Point Beach.

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

Rank	Owner/Operator	Factor
1.	Constellation Energy	96.12
2.	Exelon (including AmerGen)	93.31
3.	Dominion Energy	92.61
4.	Entergy Nuclear	91.83
5.	Southern Nuclear Operating Co.	89.25
6.	Nuclear Management Company	89.01
7.	Duke Power	88.13
8.	Progress Energy	88.07
9.	FirstEnergy Nuclear Operating Co.	87.13
10.	FPL	87.06
11.	Tennessee Valley Authority	74.43

[1] Exelon without AmerGen is 93.36. AmerGen alone is 92.97. TVA without Browns Ferry-1 is 89.02. Entergy is the contract operator of Cooper, but not its owner; Entergy with Cooper is 91.72.

Palo Verde's problems have been covered in the pages of *Nuclear News* in detail, and the three-reactor plant has essentially replaced Davis-Besse as the main focus of the nuclear community's concern (partly because there are so few reactors that are thought of as having several problems). Unit 1 lost operation time in 2006, for various reasons, and again in 2007 because of an auxiliary feedwater steam inlet valve. Unit 3 had a coolant pump oil leak and emergency core cooling system performance issues. Unit 2 managed to achieve about the same capacity factor in 2005–2007 as it had in 2002–2004.

Among the other reactors with declining factors, Prairie Island-2 had downtime in 2005 for work to resolve issues with the residual heat removal system and emergency diesel generators; Watts Bar-1 was down in 2006 for an assessment of turbine vibrations; San Onofre-2 needed an outage in 2005 for the repair of the component cooling water system and had a longer-than-usual refueling in 2006; and Fort Calhoun had long refuelings in 2005 and 2006, and also lost time because of a pump seal problem. ANO-2's decline is purely statistical: An earlier power uprate was reflected in an increased DER only recently, and the capacity factor in the most recent period (which is still very good) is more accurate than the pre-correction value in the earlier period. Speaking of power uprates, it is time to look at the ratings that have been changed, and others that have not been changed but should be.

Deriving the DER

Since last year's survey, our provider of basic data (see sidebar on page 34) has registered changes to the design electrical ratings of 16 reactors, which together have the effect of raising their total generating capacity by 334.7 MWe. Of that, 55 MWe are at Browns Ferry-1, which was restarted with a 5 percent power uprate in effect. Another recent change that was clearly influenced by an uprate is at Beaver Valley, where the NRC approved 8 percent increases for both reactors in July 2006. The DERs have been raised from 835 MWe to 868 MWe, and 836 MWe to 854 MWe. The potential peak allowed by the uprate is about 900 MWe, and so the DERs could be raised again after some operational experience at the current levels. That kind of second upward revision has occurred at Arnold, which was rated at 538 MWe before it was approved for a 15.3 percent uprate in 2001; after a rise in the DER of about 10 percent, to 593.8, it has now been readjusted to 613.5 MWe.

Among the other 12 reactors, however, the revisions do not appear to be related to recent uprates. Fort Calhoun's DER climbed from 478 MWe to 502 MWe, but the reactor's only uprate was in 1980, and the 5.6 percent rise was expressed at the time in a DER increase from 457 MWe to 490 MWe, but later dropped to 478 MWe. An uprate is based on a reactor's thermal output, and the electricity production depends on what the rest of the plant's equipment can do with the heat. The fact that Fort Calhoun's DER is now about 10 percent higher than it was 30 years ago has almost as much to do with such things as turbines and heat-rate efficiency as it does with the upper limit on reactions in the core.

Also gaining without recent uprates are St. Lucie-1 and -2, each revised from 830 MWe to 856 MWe. Like Fort Calhoun, they were uprated in the early 1980s, and to about the same extent (5.5 percent each at St. Lucie). Also like Fort Calhoun, they are Combustion Engineering–designed PWRs. Six of the first seven reactors to be uprated were made by C-E, and the revisions were part of a vendor-supported ef-

Table V.
Capacity Factor Change, Two-BWR Plants, 2002–2004 to 2005–2007

Rank	Plant	Change (percentage points)
1.	Dresden	+5.73
2.	Nine Mile Point	+4.63
3.	LaSalle	+2.46
4.	Peach Bottom	+0.85
5.	Limerick	-1.03
6.	Susquehanna	-1.18
7.	Hatch	-2.11
8.	Browns Ferry-2 & -3	-3.03
9.	Brunswick	-4.38

fort to improve output. Because these uprates were explored to some extent in the survey two years ago (*NN,* May 2006, p. 26), this time the discussion will be limited to noting that from the perspective of the original DER of 802 MWe, the new level is about 6.7 percent higher, another instance in which the output expected now is based not just on the higher thermal level of the uprate but also on general improvements in plant efficiency.

The new values for Salem—1169 MWe for Unit 1 (up 39 MWe) and 1155 MWe for Unit 2 (up 24 MWe)—are adjustments from earlier declines, which themselves followed even earlier increases. No significant uprates have been involved, and perhaps now the DERs—which should reflect what the basic, original plant is supposed to do, and not be subject to frequent tweaking—will settle down. Also making a significant jump was Cook-1 (from 1036 MWe to 1084 MWe), another reactor that has seen revisions in both directions. Smaller adjustments have been made at Quad Cities (Unit 1, now 866 MWe, down 1 MWe; Unit 2, now 871 MWe, up 4 MWe) after the earlier upward revisions that followed the 17.8 percent uprates approved in 2001.

There has never been a power uprate at Diablo Canyon-2, at least not in the strict sense of a license amendment for higher thermal output approved by the NRC. Nonetheless, the reactor's DER has been raised from 1119 MWe to 1151 MWe, or about 3 percent more electricity potential from the same reactor heat. The other DER changes are small declines, two of them rebalances after increases that followed earlier uprates (Palo Verde-1, 1333 MWe, down 3 MWe; Perry, 1258 MWe, down 2 MWe), and one of them perhaps reflecting a new vessel head and other significant changes in recent years (Davis-Besse, 898 MWe, down 8 MWe).

Yet to take place are upward DER revisions for the following plants that have had significant uprates (between 4 and 6 percentage points, all approved more than 10 years ago): Calvert Cliffs-1 and -2, FitzPatrick, North Anna-1 and -2, Surry-1 and -2, and Wolf Creek.

Can the old presage the new?

The reactors now in operation differ vastly from those that will be built if ongoing licensing projects are carried through to completion. This may not mean, however, that the experience with current reactors is completely irrelevant when it comes to starting up the new reactors and putting them into steady operation. The performance trends of the most recent operating reactors may provide some insights into what to expect.

There are 16 reactors that have begun commercial operation since the start of 1987. By that time, the lingering regulatory effects on operation from the aftermath of Three Mile Island-2 had been resolved, as had some widespread equipment issues (such as safe-end repairs in BWRs). The three-year capacity factors of these reactors will be examined to see if any early performance trends existed. Because the reactors started up at different times, the three-year factors used will not necessarily be those in the rest of this survey. For instance, Watts Bar-1 began commercial operation in 1996, and so its first three-year period is 1997–1999, not one of the periods shown in Fig. 1.

Table VI shows, among other things, some wild swings for what should have been, starting in the late 1980s, a fairly mature industry. This might yield a qualitative cue about the early years of the next group of reactors: The performance might show sharp peaks and valleys when plotted on a chart.

In some ways, however, there are some common threads in the experiences of the reactors in Table VI. From the first period to the second, 13 of the 16 improved their factors; from the second to the third, there were also 13 that improved (not the same 13). The net change from the first period to the third was that 15 of the 16 improved. Over the entire sample, the improvement from the first to the second was quite large, and the one from the second to the third was smaller. This could mean that most of the learning-curve benefits are gained by the six-year mark.

It should be noted that the industry as a whole was improving during this era, gen-

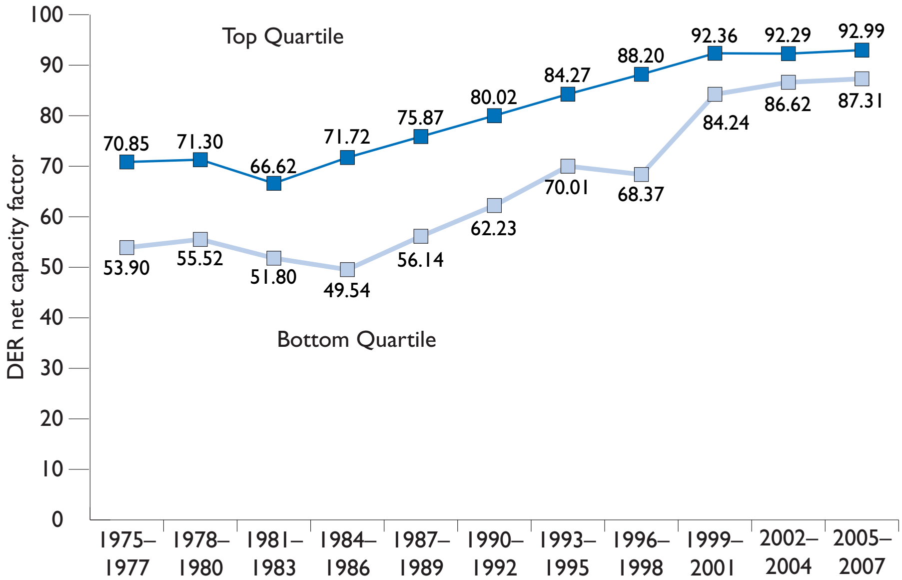

Fig. 3: All reactors, top and bottom quartiles. Perhaps the clearest measure of the improvement of the fleet as a whole was the increase of nearly 16 points in the bottom quartile between 1996–1998 and 1999–2001. Only reactors now in service are shown; if closed reactors were included, none of the figures would change by as much as 1 percentage point.

TABLE VI.
FACTOR CHANGES IN EARLIEST THREE-YEAR PERIODS OF NEWEST REACTORS

Reactor	Change, 1st to 2nd period	Change, 2nd to 3rd period	Change, 1st to 3rd period
Braidwood-1	+18.06	-3.19	+14.87
Braidwood-2	+9.20	+10.28	+19.48
Byron-2	+16.76	+7.23	+23.99
Clinton	+18.51	+8.03	+26.54
Comanche Peak-1	+18.00	+5.56	+23.56
Comanche Peak-2	+14.51	+4.47	+18.98
Fermi-2	-10.84	-0.79	-11.63
Harris	+6.47	+0.99	+7.46
Nine Mile Point-2	+21.46	+9.71	+31.17
Perry	+3.47	+3.41	+6.88
Seabrook	+2.32	+2.03	+4.35
South Texas-1	-10.18	+40.17	+29.99
South Texas-2	-22.50	+41.92	+19.42
Vogtle-1	+8.08	+0.67	+8.75
Vogtle-2	+8.10	+0.89	+8.99
Watts Bar-1	+6.88	-1.72	+5.16

erally by about 6 points every three years. This should not be taken to mean that every reactor was handed a guaranteed 6 points every triennium; each reactor staff had to make its own way, earning every performance gain. Still, if the most recent reactors were improving in about the same way as the older ones, it might not be conclusive that what was going on with the newer reactors was the result of their newness.

The wild swings noted above—such as at South Texas, from the second period to the third—have some odd effects on a set of only 16 data points. The median factors for the three periods are 66.22, 79.10, and 87.03, with changes of 12.88 from the first median to the second, and 7.93 from the second to the third. The first is about twice the industry trend, and the second is slightly more than the trend. The medians of the change amounts (shown in the second and third columns of Table IV), however, are not as pronounced: 8.09 from the first to the second, and 3.94 from the second to the third.

Undeniably, many of the reactors that did better in their second and third periods did so because their first periods were not very good. At South Texas, things got worse before they got better; a 40-point increase can happen only if there is perhaps too much room for improvement. It has been common, however, for reactors in their early years to have relatively low capacity factors. A rough compromise between the two computations of medians suggests that the 16 newer reactors, as a group, improved more steeply in the second period than the 6-point trend line followed by the older reactors, and roughly at the trend line from the second to the third. The median of the change amounts from the first period to the third (shown in the fourth column of Table VI) is 16.92, an average of about 8 ½ points over each of two change periods—well above the 6-point trend line.

This may mean that operators of the forthcoming power reactors will have to muster the patience shown by those in the earlier generation, perhaps putting up with sluggish performance in the early going and using the experience to develop strategies for better performance later. Whether this in fact turns out to be the case will have to be assessed after these reactors have been licensed, built, and operated for at least six years, and so this is something we'll have to wait at least 15 years to find out. NN

What was done with the data

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. Other surveys may use measures such as maximum dependable capacity, summer peak, or gross electricity generation. This survey draws most of its conclusions from medians within each group, but also computes averages in some cases.—*E.M.B.*