Outlook On Life Extension

SPECIAL REPORT TO THE READERS OF NUCLEONICS WEEK, INSIDE N.R.C., AND NUCLEARFUEL

As the nuclear industry tries to hang on in an increasingly competitive marketplace, considerations of extending plant lifetimes beyond their allotted 40 years sometimes seem an academic exercise. Yet whether the U.S. will have nuclear power as a future energy option—regardless of the cost or availability of other options—depends in large degree on license renewal and life cycle management decisions being made today.

The licenses of 49 of the 110 nuclear units in the U.S. are set to expire in the coming two decades, by 2014 (though some could be further delayed by recapturing their construction period and adding it to the license period). Will utilities refurbish and recertify them as safe to produce power beyond their current 40-year licenses? Or will they be shuttered one by one as their licenses run out, with some forced into premature shutdown?

NRC Chairman Ivan Selin counts license renewal as the "number one topic" before the commission. He is optimistic that at least some utilities will apply to extend the operating lives of their plants. "Interest is higher now than it has been for two years. I'm certain that many reactors will come in for license renewal," he asserted.

Selin says the NRC is on the verge of coming out with a rule that will make the process of applying for plant life extension simple, cheap, and predictable: "I feel good about the license renewal process we're developing—though my satisfaction is tainted by the fact that we should have got things right the first time."

Among government and industry experts, the NRC chief's may be a lone voice of optimism. A recent study by the Edison Electric Institute concluded that—far from life extension being the question—cost-related, premature shutdowns are likely to be an issue for utilities as early as this year (Nucleonics Week, 17 March, 1).

Even traditional boosters of nuclear energy express serious doubts about how many—if any—plants will see life beyond their 40th birthdays. "I'm relatively sure some plants will go in for license renewal, although it all depends on load growth at the time they go in," said Scott Peters, a spokesman for the Nuclear Energy Institute (NEI). The organization—born March 16 when four U.S. nuclear trade groups consolidated—is emblematic of the squeeze nuclear utilities face: paring down and cutting costs as they navigate the uncertainties economic competitiveness has thrust on the industry. Ultimately, the decision to seek license renewal "will be an economic decision utilities will make, taking into account many factors," said Peters.

"There may be people who, out of sheer stubbornness, continue to pursue license renewal—and NRC may let them—but whether it will be viable for these plants to continue after 30 years is questionable," said Jim Riccio, an attorney with Washington, D.C.-based Public Citizen, a Ralph Nader lobby. Riccio doubts that any of the U.S. nuclear units will even get to the ends of their licenses. "It won't be the antinuclear forces that force them to close, but the people who do their ledger books," he said, adding, "Economic and safety considerations will shut these plants down."

Only 46% of electric utility executives expect to see operating licenses extended for most plants, according to a survey released by the Washington International Energy Group in January. Odds remain in favor of most units continuing to operate through their first 40 years, the executives said. But only 37% of respondents believed there would be a resurgence of nuclear power in the U.S. "Privately, CEOs talk about someday turning over title of [nuclear] plants—even the best run ones—to the government," said the report, "1994 Electric Utility Outlook."

Those utilities that set their sights on plant life extension will have to brave uncharted territory. A few years ago, the path appeared relatively straightforward. The industry would develop pilot license renewal submittals for a lead BWR and a lead PWR, which would pave the way for other utilities to follow with renewal applications. But the process has taken unexpected turns. Yankee Rowe's experience as a lead PWR led ultimately to its shutdown, and the other utilities have hung back.

Competition has changed the landscape of the electric utility industry entirely in two years. Economic decisions to seek license renewal will be made on a plant-by-plant basis, industry experts say. Few generalizations can be drawn to predict likely candidates: some utilities view their nuclear units as albatrosses, others embrace them as assets. The price of other energy sources in a given region, the philosophy of state regulators, public perceptions about nuclear power in a county or state, the number of units a utility is operating, and the age, condition, and operating history of each plant—not to mention the cost and degree of hassle involved in meeting NRC's forthcoming rule—will all influence the life extension decision.

Key players and issues to watch include:

- Virginia Power, the only utility to announce plans to apply for life extension. It surprised industry peers and NRC by unveiling plans to initially seek five-year license renewals—instead of 20 years—for Surry and North Anna.
- The Babcock & Wilcox Owners Group, which plans to submit a license renewal application on one of its PWRs by 1997. Duke Power's Oconee-1 is one of the top candidates for their submission.
- Baltimore Gas & Electric Co., which has spent \$15-million on a combined life cycle management and license renewal program. The company may decide to apply to extend the Calvert Cliffs licenses for 20 years.
- NRC's rule rewrite, ordered by the commissioners in February. Will the new rule provide the cheap, simple, predictable application basis Selin has promised? And how will utilities implement it?
- Other nations' experience. Electricite de France (EDF) has taken the lead in grappling with many of the aging issues that U.S. utilities must evaluate in the technical assessments of their plants. EDF has developed a list of 18 essential components. In Sweden, the clash between politics and performance once again is coming to a head, where nuclear power opponents want to see lifetimes limited on plants considered by U.S. analysts to be among the best performers in the world.

VIRGINIA POWER TAKES THE BULL BY THE HORNS

Virginia Power Co. could be the first utility to test NRC's promise of a simpler and cheaper approach to license renewal. The company unveiled plans in February to file an application early in 1995 to renew the operating licenses for the Surry and North Anna nuclear stations for five years (Inside N.R.C., 21 Feb., 1).

Virginia Power's nuclear units are "very competitive," said William Stewart, vice president-nuclear. "Our production costs are excellent. Our units were built in the 1970s, so the [capital] cost was low." Stewart characterizes the decision as one that could make the utility even more competitive. "We're not in a scramble here," he said. "We're just looking ahead.

Stewart said the five-year life extension initiative has received the support of Wall Street utility analysts, whom he briefed on the plan in February. "Their response was favorable. The feeling was that a five-year renewal is feasible."

Reducing Busbar Costs

Company officials concede the decision to pursue five-year license renewals is "an economic rather than an operational" one, primarily driven by the current climate of economic competitiveness. Martin Bowling, manager of the utility's nuclear licensing programs, said that renewing the licenses at its two dual-unit nuclear stations by five years would lower "busbar" costs—the amount it costs to produce electricity at the point it leaves the plant, including capital costs, taxes, fuel, and operations and maintenance costs.

In 1992, Virginia Power's busbar costs were 2.84 cents per kilowatt-hour (KWH) at Surry and 3.42 cents/KWH at North Anna. Overall busbar costs for nuclear generation are 3.1 cents/KWH, Stewart said.

Costs would be lowered by changing depreciation rates and reducing near-term decommissioning trust collections. Lower costs would help hold down future rate increases and keep the utility competitive, Bowling explained. In their economic analysis, utility officials calculated that, as a near-term effect, "depreciation expense is reduced each year, \$21-million the first year and up to \$49-million by 2011."

Virginia Power has replaced steam generators at three of the four units and plans to replace the steam generators at North Anna-2 in 1996 at a 1996 dollar equivalent to the \$120-million spent last year to replace the steam generators in unit 1.

Stewart said the company has spent more than \$5-million to date on license renewal work, most of it on technical analyses under the old NRC rule. Surry-1 began operating in December 1972 and its license expires in May 2012; Surry-2 started up in May 1973 and its license expires in January 2013. North Anna-1 started operating in June 1978 and its license expires in April 2018; unit 2 began operations in December 1980 and its license expires in August 2020.

Company officials recently proposed a streamlined integrated plant assessment (IPA) process to NRC staffers. They say the technical analyses under their IPA would be done no differently whether they were applying for a five-year extension or a 20-year one. Utility plans call for submitting a license renewal application during the first quarter of 1995, but that could change if NRC's revised license renewal rule is not out yet, Stewart noted.

Assuming Virginia Power's license renewal application proceeds on track, the utility should provide a case study on how NRC will have utilities show compliance reliance on the maintenance rule, completing the reviews needed for a license renewal application is not going to be a piece of cake. There will be considerable documentation required.

Thermal fatigue monitoring of the primary system is an example of how life extension work provides short-term and long-term benefits, Doroshuk said. Engineers analyzed all the Class 1 piping, for instance, and created a computerized data bank that not only is used to track aging mechanisms like fatigue, but can be used in operations. "We've been able to provide an analysis of the plant and respond to transients that [operators] see during a startup and allow them to continue on without doing holds and analysis," an engineer on the team said.

A priority of the life cycle management program has been evaluating the reactor pressure vessel. Calvert Cliffs-1 is currently going to exceed NRC's pressurized thermal shock (PTS) screening criteria between 2004 and 2006. Unit 2 was built using lower-copper weld material, so it doesn't have the same problem.

"There are plant-specific differences that make us believe unit 1's embrittlement is much less than NRC's correlation would predict," said Marvin Bowman, an engineer on the life cycle management team. "These include fabrication process differences, heat treatment differences, materials differences, weld materials, weld fluxes that were used—they're all part of that embrittlement process."

BG&E officials submitted the technical evaluation to NRC last November and are expecting to receive NRC's review by this summer. "We think we have a very sound technical basis for continued operation of unit 1," Doroshuk said.

"We've done substantial flux reduction and we can do much more aggressive flux reduction if we have to, involving radical fuel management," Bowman added.

The conclusion of BG&E's plant assessment activities to date: "We've found that, materially, the plant should last for 60 years," Doroshuk said. "We haven't found the show-stopper—even in the reactor vessel."

REACTOR VESSEL INTEGRITY, COSTS, CRUCIAL TO LIFE EXTENSION

Coping with reactor vessel embrittlement is a priority for managing plant life extension, as several U.S. reactors likely will face the problem after about 40 years of operation.

PWR vessels are more susceptible than BWRs' because the PWR vessels are narrower and contain less coolant, so more neutrons reach the vessel walls. Most PWR vessels in the U.S. are made of steel known as A533-B alloy, an alloy of iron, carbon, and manganese with some nickel. In a number of older vessels, the welds joining the vessel's curved plates contain some copper. As neutrons from the core strike the steel, they change the crystalline structure of the A533-B alloy. The weld material is especially affected, with the neutrons disrupting the crystal lattice, creating clumps of copper atoms and vacancies in the matrix. This process makes the steel more brittle.

The brittleness is measured in two ways: the upper shelf energy loss and the reference temperature at nil ductility temperature (RT-NDT). The loss of ductility can leave the metal vulnerable to ductile fractures, a tearing that can take place in seconds or minutes, and to pressurized thermal shock (PTS). The latter could occur if, during an accident, coolant is suddenly restored to an overheated vessel, and it could cause an abrupt fracture of the metal. Reactor operators must show NRC that their vessels are proof against both types of failure.

Because ductility loss is cumulative, operators plot the time it will take their vessel to reach the RT-NDT and upper shelf criteria that NRC selected as a conservative danger signals of growing embrittlement, set in 10 CFR 50 and its Appendix G. Utilities have a number of ways to cope with embrittlement as operating lifetime progresses, including flux reduction through fuel management, such as installing neutron absorbers on the core periphery. Utilities can also analyze their vessels' metal to prove they won't approach the NRC criteria within their operating lives, and monitor the accuracy of those analyses by regularly removing and testing specimens of vessel material, which are kept inside the vessels in capsules.

As vessel lifetime is lengthened, a rate of embrittlement which was no concern for 40 years of operation may become a barrier to reaching 60 years, and utilities that did not previously have to be concerned about PTS are having to look again.

NRC has required utilities to submit information on the status of their vessels with regard to PTS and upper shelf energy. From this information, the agency has deduced a list of especially vulnerable reactors that has fluctuated from around one to six reactors, as utilities take measures to alter the rate of embrittlement. Calvert Cliffs, Duquesne Light Co.'s Beaver Valley, and Consumer Power's Palisades have been mentioned as particularly vulnerable. While opinions within NRC and the industry appear to vary, the utilities generally hold that further analysis of the metallurgy of their reactors will prove that the vessels will last to the ends of their license periods.

According to the latest NRC list, seven units' vessels likely will encounter PTS concerns before the ends of

REACTOR VESSELS WITH PRESSURIZED THERMAL SHOCK (PTS) CONCERNS

Plant Name	Estimated Year PTS Screening Criteria will be Reached	License Expiration Date per NUREG 1350
Palisades	1997-2005	03/14/2007
Fort Calhoun	2013	06/07/2008
Calvert Cliffs-1	>2005	07/31/2014
Point Beach-2	>2013	03/08/2013
Point Beach-1	>2010	10/05/2010
Beaver Valley-1	2014	01/29/2016

PTS CONCERNS BEYOND CURRENT END-OF-LICENSE LIFE

Zion-1	2011	12/26/2008
Oconee-2	2019	10/06/2013
Surry-1	>2012	05/25/2012
Salem-1	2020	09/25/2008
Zion-2	2023	12/26/2008
Ginna	2026	04/25/2006
Diablo Canyon-1	2034	04/23/2008
Cook-1	2037	03/25/2009
Farley-1	>2050	06/25/2007
St. Lucie-1	>2050	03/01/2016

Source: NRC

their licenses, and nine other units' vessels will fall in the category after their current licenses expire (see table).

Annealing: The Last Ditch

Utilities that look soon enough can alter the rate of embrittlement early in a vessel's life, but for older reactors the standard methods may not be able to change the rate enough. That can leave utilities facing an expensive problem for life extension. YAEC chose to close Yankee because the process of proving the vessel's stage of embrittlement was too expensive—and NRC's requirements for that proof too open-ended—to be justified economically for a 185-MW reactor.

One option is to replace the vessel, which has never been done and is estimated to cost as much as $100-million. Another choice being viewed with increasing favor by reactor owners is annealing the vessel, or heating it to the point where the crystalline structure of the steel is partly or fully restored to its original fracture resistance. Estimates for annealing range around $10-million.

Annealing is a routine process in metallurgy and has been extensively modeled, but it is complicated by vessel radioactivity. For U.S. vessels, it would involve heating the beltline weld, and in some cases the axial welds or some vessel plates, to about 850 degrees F for about a week. The longer the heat is applied, the more complete the restoration of the metal's crystalline structure. Theoretically, heating the vessel for as much as two weeks could restore the metal 100%.

Different annealing specialists offer different estimates of how long the repair done by an annealing job would last. Some estimate annealing could restore a vessel to service for five or six years, while others say field experience indicates 60 to 70 years. Researchers say more study is needed.

Alan Hiser, of the materials engineering branch of NRC's Office of Nuclear Regulatory Research (RES), said that the level of restoration of embrittlement due to annealing, and the rate of re-embrittlement, is dependent on a number of factors. If the material is a weld, rather than a plate, the annealing repair will be less effective and the re-embrittlement rate faster. The chemistry of the material is crucial, as well—steels or welds containing nickel or copper are more subject to both embrittlement and re-embrittlement.

Hiser emphasized that the difference between the reactor operating temperature—around 550 degrees F—and the temperature of annealing (850 degrees) has an important effect. The greater the difference between the two temperatures, the more successful the annealing will be and the longer its effects will last. NRC has funded research on annealing that was carried out by

DOE at Oak Ridge, and Hiser's views also take into account research performed by Westinghouse on behalf of EPRI, the U.S. Navy, and Russian annealing specialists.

Hiser said that most studies have considered annealing for 168 hours, or one week. On the basis of 168 hours and 850 degrees, Hiser said that an annealing job can restore as much as 100% of the damage due to neutron flux, depending on the factors mentioned. "From the data we've seen so far, it appears that (after annealing) you get the same embrittlement rate you got initially," he said.

The American Society of Testing & Materials' Standard E509-86 model posits that re-embrittlement occurs

YANKEE EFFORT FOUNDERED ON VESSEL

Zeus does not bring all men's plans to fulfillment.
—Homer

At the time, it seemed logical. Yankee Atomic Electric Co.'s (YAEC) Yankee was by far the oldest PWR operating in the U.S. Though small and unique in design, it had a good operating record and YAEC wanted to extend the operating license that was to expire in 2000.

When DOE and the Electric Power Research Institute (EPRI) were looking for candidates to test the license extension waters, the 185-MW Yankee got the nod for PWRs, despite EPRI's expressed reservations about using older, smaller plants as license extension guinea pigs and despite the fact that Virginia Power had already done extensive initial screening of possible license extension roadblocks for Surry-1, an 824-MW PWR of a more common design.

The issues were timing and money. Surry's license wouldn't expire until 2012. The Yankee plant was YAEC's only asset. Therefore, YAEC had no choice but to go forward with license extension, even if it wasn't chosen as a lead plant. "We were going to file a license extension application," said YAEC's Bill Szymczak, a member of the Yankee license extension team. "There was sentiment at the time that (the lead plant) should have been Surry, but we were going to be in the queue anyway."

"As a single-asset company, regardless of what anyone else was doing, we were going forward," Szymczak added. Having YAEC before the NRC for a license extension at the same time the pilot plants were going through would have been a "complicating factor," he said.

DOE and EPRI were, in fact, very concerned about maintaining a uniform front on license renewal before the NRC. When YAEC signed on as lead PWR, a provision in its contract with DOE and EPRI required that its licensing submittals be "sufficiently consistent" with those filed by Northern States Power Co. for the lead BWR, Monticello, that NRC wouldn't be able to "leverage one plant against the other."

If YAEC had filed a license extension application as a third party, it would not have been constrained to maintain that uniformity.

Ultimately, Yankee's unique design proved to be its undoing. On February 26, 1992—41 months after YAEC received DOE's proposed contract for the five-year lead plant effort—the YAEC board voted to permanently close the unit. Yankee had been "voluntarily" shut down the previous October after the NRC staff recommended that it be laid up until questions regarding the degree of embrittlement of its reactor pressure vessel (RPV) could be resolved. They never were.

Yankee's RPV design made it virtually impossible—or at least extremely expensive—to answer the questions NRC and intervenors had posed. The RPV's configuration severely limited inspection of the beltline weld region. Yankee's vessel consists of a rolled 0.109-inch-thick stainless steel sheet welded in several locations—but not completely bonded—to the shell. That incomplete bond made ultrasonic inspection of the welds very difficult, because the "gap" between the cladding and the vessel shell hindered the ultrasonic instruments' ability to accurately identify and size weld flaws.

Yankee's RPV also has a thermal shield just inside the vessel wall. The proximity of the shield to the vessel shell restricts the accessibility to the beltline region and restricts inspections of critical welds. To position instruments for inspection, the thermal shield would have to be destroyed and removed, unless new tools were manufactured to make the welds accessible. YAEC started investing in new inspection equipment, but that cost a lot and the economics of saving Yankee—which already wasn't selling electricity at a competitive price in recession-ravaged New England—just didn't add up.

YAEC even briefly considered replacing the RPV. Though DOE's Sandia National Laboratories concluded that the replacement was "technically achievable," the decision on replacement was ultimately an economic one. It was estimated that RPV replacement could be paid off over 20 years with a rate increase of 1/2 to 1 cent per KWH for the first year, which would drop to 0.1 cent the last year. Of course, that payback scenario assumed license extension.

at the same rate as before annealing, but that embrittlement restarts from a point of greater ductility—a "lateral shift" in the embrittlement curve. Russian experience in annealing 13 reactor vessels has verified the lateral shift approach to analyzing re-embrittlement, Hiser said. Even if an annealing job does not repair all flux damage, he said. "You will always end up better (after an annealing), but there's no significant impact on the rate of embrittlement."

However, each reactor vessel responds to fluence according to the particular circumstances of its construction, including the type of material used in the steel and the welds. The rate of fluence accumulation before and after annealing will also have an effect, Hiser said.

"Assuming the same rate of fluence accumulation of the vessel and 100% recovery (from embrittlement), the vessel should be good for the same period as before you annealed," Hiser said.

Hiser's views on annealing and re-embrittlement are based on more than a decade of research on the topic in the U.S., where sample coupons have been tested many times for embrittlement rates and response to annealing, and on full-vessel annealing in Russia.

Westinghouse has moved strongly into the nascent field. David Howell, manager of engineering services for the vendor, said, "The nuclear industry needs this program for life extension and to meet license requirements, plus we see annealing as a sales opportunity."

Westinghouse has raised more than $2-million of $4-million it is seeking from the industry to conduct an annealing demonstration at the never-completed Marble Hill reactor in Indiana. Westinghouse plans to use indirect gas-fired heating to raise the vessel's temperature. Extensive monitoring will be designed to answer critical engineering questions, such as how the process affects nozzles and pipes attached to the vessel.

Westinghouse faces competition from a team formed of Framatome subsidiary B&W Nuclear Technologies, MPR Associates Inc. of Alexandria, Va., and a consortium called Russian Annealing Moht. The moht, or consortium, is formed of Moscow's Kurchatov Institute; vendor Gidropress; Cnittmash; and other Russian organizations, which has annealed 13 vessels in Russia. MPR Associates principals Bill Schmidt and Noman Cole praise the Russian technology, which relies on electric resistance heating, as simple and reliable. Schmidt said that Electricite de France (EDF) specialists who met with his company said that they were concerned that the Westinghouse process could not be licensed in France because of the dangers of working with natural gas.

U.S. annealing specialists visited Novovoronezh in 1992 to witness the annealing of a VVER-440 vessel. The Russian approach is different, the specialists say, because Russian vessels are made of ring forgings, so the circumferential weld area to be annealed is only about three feet wide. U.S. reactors, which are longer and have axial welds, would have to be annealed in a band about 12 feet wide. Also, some U.S. reactors would require annealing on plate sections.

MPR's Cole said that the recovery in RT-NDT at Novovoronezh was greater than 80%. While Russian annealing specialists have achieved recovery of 100% in that index of PTS vulnerability from some annealing projects, they guarantee recovery of 80% from their annealing process.

Keith Wichman, annealing specialist with NRC's research arm, agreed Russian annealing projects have achieved recovery rates over 90%. That level of recovery is equivalent to full recovery for his purposes, Wichman said, adding that above 90% recovery, distinctions are meaningless.

No full-scale annealing project is now on the drawing boards at an operating U.S. reactor, despite the optimism of the annealing vendors. Utilities have reason to be cautious, since the first utility to anneal almost certainly will have to pay extra to defray the costs of licensing the process and the extra costs associated with the learning curve on the technology.

In any event, the first U.S. annealing likely will not take place before the turn of the century, since other methods of lowering embrittlement rates will work until then. Jack Hanson, an annealing specialist at Palisades, said his utility's decision on annealing would be governed by the economics of the process when license renewal is evaluated years from now. Hanson added that the most important factor in that calculation will be the price of natural gas—the strongest competitor to nuclear power plants.

NRC DRAFT ENVIRONMENTAL REVIEW RULE ANGERS STATES

In addition to the safety reviews, NRC will require an environmental review as part of the license renewal process. NRC's proposed amendments to tailor the existing environmental review rule (10 CFR Part 51) to the license renewal process have come under attack by states for what they view as an attempt by NRC to preempt their traditional review of need for generating capacity and alternate energy sources.

The amendments include a draft Generic Environmental Impact Statement (GEIS), published in September 1991, in which NRC decided to treat the issues of need for power and alternative energy sources in the same way they are handled in an operating license review. While the agency performs a detailed analysis