The Forsmark-3 nuclear power plant in Sweden (Photo: Odd Hedberg/Forsmark)

Outage strategy well covered at Forsmark

BY DICK KOVAN

Forsmark's 90 percent availability is due largely to the plant's umbrella approach to plant maintenance work during outages.

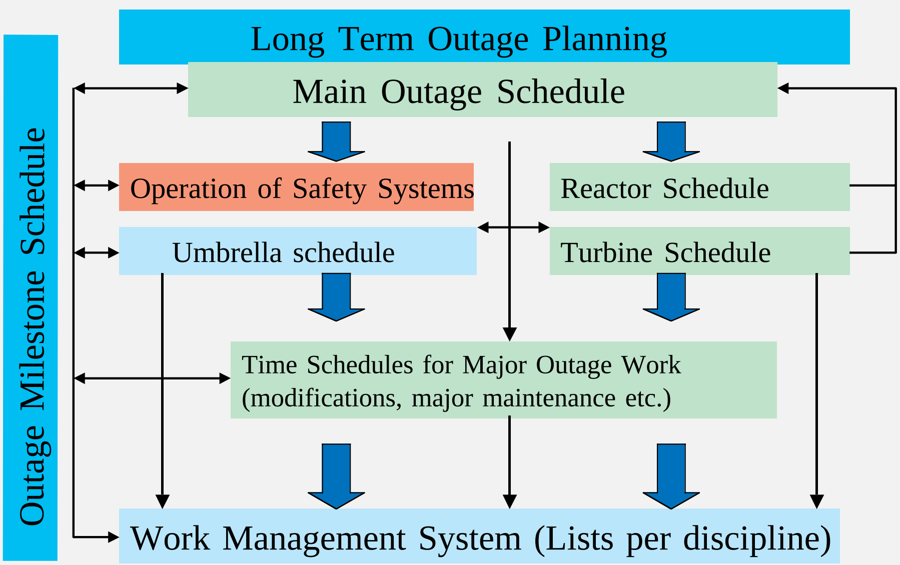
THE HIGH AVAILABILITY of the Forsmark nuclear plant in Sweden has resulted from several factors, including a very successful outage strategy. Each summer, two of the three units at the Forsmark station undergo a short outage and the third a long one. This strategy has achieved average availability figures of 90 percent, due in large measure to the plant's "umbrella" approach to outages.

To meet the challenge of electricity market deregulation, however, which has seen prices fall by as much as a third since 1996, Forsmark has switched its operating focus from *production*, based largely on achieving high availability figures, to *costs*. This has involved an examination of all the plant's processes to see where savings could be made.

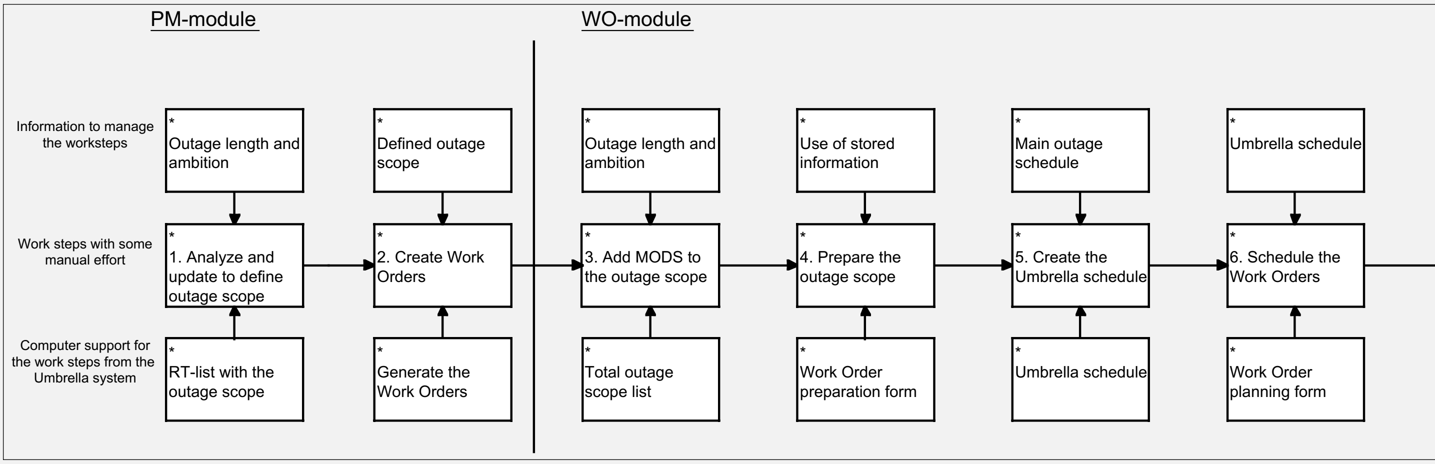
Forsmark's three units have a total net capacity of about 3100 MWe and provide between 15 and 20 percent of Sweden's consumption. The plants, located about 90 miles north of Stockholm, generate about 25 TWh per year. The company operating the station, Forsmark Kraftgrupp AB, has three shareholders: state-owned Vattenfall (66 percent); Sydkraft (8.5 percent); and a consortium of private and municipal electricity producers, Mellansvensk Kraftgrupp (25.5 percent), which includes Fortum, the company that owns the Loviisa plant, in Finland.

Unit 1 went into commercial operation in 1980, Unit 2 in 1981, and Unit 3 in 1985. Unit 3 is Sweden's flagship, said Rolf Hägglund, the unit manager, who explained that while Oskarshamn-3, an identical boiling water reactor supplied by ABB Atom (now Westinghouse Atom), started up the same month, Forsmark-3 has outperformed it.

The Forsmark units have all been uprated. In 1989, the production capacity of Unit 3 was increased by 9.3 percent, to 1155 MWe (net), 1198 MWe (gross). This upgrade re-



Outage scheduling overview at Forsmark nuclear plant (Forsmark Kraftgrupp AB)



Workflow for outage preparation at Forsmark nuclear plant (Forsmark Kraftgrupp AB)

quired only redoing the safety case to the satisfaction of the regulator, SKI. Units 1 and 2 have also been uprated by 8 percent each; this required some modifications, including the addition of reactor safety relief valves.

Immediately next to the plants is a 63 000 m^3 underground repository for low- and intermediate-level waste that Forsmark operates for SKB, the national radwaste company set up by the nuclear operators.

The company also owns the village of Forsmark, which includes a number of houses dating back to the 16th century. The village is house to the Forsmark Technical Institute, a college-level school that specializes in energy and information technology. Established in 1987, the school, which is sponsored by the company, takes some 150 students from all over Sweden.

Sweden's phaseout plans

The startup of Forsmark almost did not happen. Claes-Göran Runermark, executive vice president of the company, explained that startup was delayed by two years because of the heated debate over nuclear power in Sweden triggered by the TMI accident. This led in 1980 to a nationwide referendum in which voters approved a resolution to phase out nuclear power and to replace it with environmentally acceptable alternatives. After the vote, several decisions had to be made. First, the government decided that it would allow the startup of Forsmark and other reactors under construction, which meant there would be a total of 12 nuclear reactors operating in the country. Forsmark-1 went critical just a couple of months after the referendum.

The Swedish parliament then passed legislation setting a phaseout date of 2010, hoping that by then there would be adequate alternative sources of energy. But since then, it has become clear that replacing nuclear power with other sources would not be easy, and, while one reactor, Barsebäck-1, was closed, parliament has scrapped the 2010 phaseout date, which means that there is no time limit on the operation of the remaining reactors.

Hägglund: Planning for shortest critical path (*NN* photo)

Deregulation

Sweden is part of the fully deregulated Nordic power market. The first year of liberation, 1996, was a dry year in Sweden, which meant that hydropower production was low and the price of electricity remained high. This, however, did not last. Over the next year the price almost halved, dropping from 20 öre (about 2¢) to 10–12 öre (100 ö = 1 Skr); this was below the previously predicted bottom level. The price remained there until last year, when the medium spot market price rose to 18–19 öre. This compares to production costs at Forsmark of about 17.5 öre/kWh. This year the price is not expected to drop.

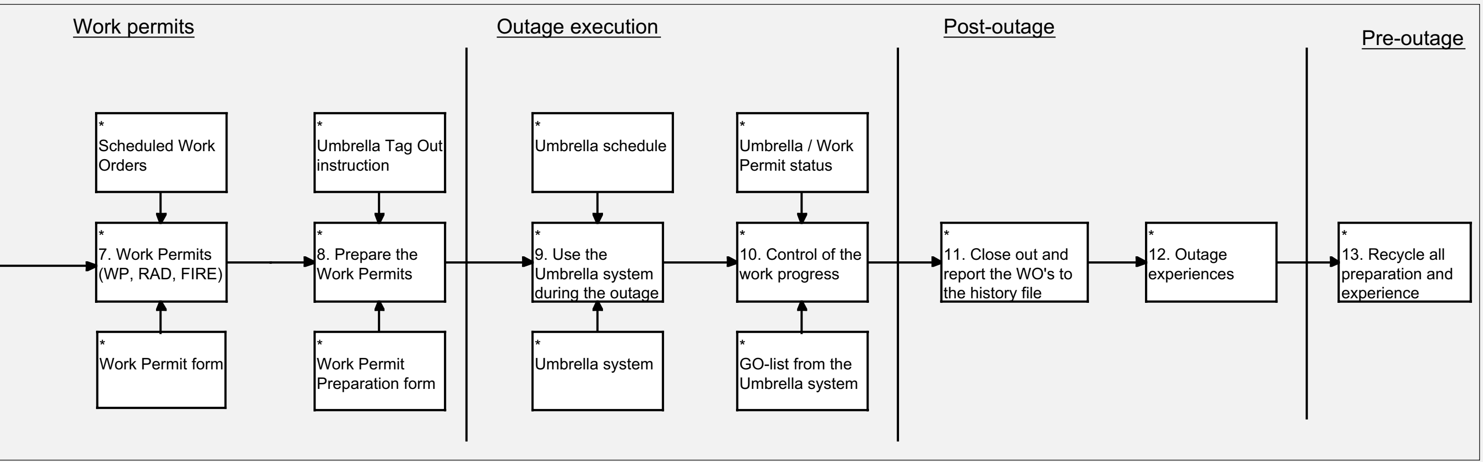
Runermark: Working smarter to reduce costs (*NN* photo)

The financial pressures on the company after deregulation led to a rethinking of how the plant was managed. For example, before 1997, the Forsmark units were all operated as separate businesses and encouraged to compete against each other. As successful as this has been, the company decided it would have to abandon that policy and combine administration and other functions to reduce staff numbers. Another pre-1997 policy was to focus operations and outages on production, and, in particular, keeping availability high. The plant's success in attaining high availability figures meant there was not a lot of room to raise production. After 1997 the focus was changed from *availability* to *cost*, to seek further financial improvements.

Measures to improve operation and cut costs were taken in many activities, including management, maintenance, plant renewal, human resources, business administration, and procurement. Their impact quickly produced a reduction in operation and maintenance (O&M) costs by some 20 percent: In 1997, O&M costs were Skr 1200 million ($120 million); in 2001, they were Skr 960 million ($96 million).

Unfortunately, much of this improvement in finances was grabbed by the government through a tax on production of nuclear generated electricity. To make it even more oppressive, the government changed the basis of the tax from delivered power to installed power, so that the plant pays the same during a bad year as well as a good one. The nuclear tax adds about $60 million per year to Forsmark's costs.

Making progress against this background requires a committed and competent organization, and considerable resources are de-



voted to inspiring staff and management. "We have to work smarter to drive down costs while retaining the same level of quality," said Runermark.

This also requires a strong investment in plant renewal programs designed to ensure continued high reliability of production, with a minimal risk of unplanned outages.

The first, Program 2000, was adopted by the Forsmark Board in 1994, and involved investments of $200 million through 2001. In 2000, the moderator tanks and core grids of Units 1 and 2 were placed.

The next program, P 40+, aims at securing high reliability up to and beyond the 40-year mark—that is, 2020–25. The investment decision was taken in 1999 and program activities will continue through 2011. A P 60 program is being considered.

Another change was in how maintenance is organized. Starting at the beginning of 2001, the three maintenance units were combined into a single department with all maintenance activities integrated. This not only led to a large reduction in maintenance staff, but also to an effort to use the new organization more effectively.

The success of this is shown by the reduction in the number of contractors used. The restructuring has required renegotiating its relationships with contractors, including Westinghouse Atom. The company is also committed to making further substantial investments in its maintenance program.

Forsmark now has a total staff of 730. Pre-2001, the three units acted as individual companies. In 2001, each unit was made an individual profit center, with many of its functions, including administration and maintenance, shared. Under the new setup, Hägglund and the two other plant managers act as internal purchasers of services from the maintenance department, which now has a staff of 170. During the reorganization, Hägglund was acting maintenance manager.

Outage strategy

The Swedish plants all have their outages in summer. Leading up to the outages, Forsmark follows a "coast down" strategy, which is a very fuel-efficient way to operate. This is possible because melting spring snow ensures a high hydropower production. Each unit follows a three-year cycle, with two short outages and one long.

The plant manager is ultimately responsible for outages, which are managed by operations, not the maintenance department. From the safety point of view, explained Runermark, who was previously the manager of Unit 3, the plant is always in operation, when generating or during an outage. "Going into an outage is not like putting an airplane in the hanger and leaving it to the maintenance people. We still operate the plant even when it is not producing electricity," said Hägglund.

This approach is also based on experience. During the early years of operation of Ringhals-1, said Hägglund, when maintenance was in charge, outages kept getting longer and longer until it became impossible to have an economic time table. "We came to realize that we cannot look at the outage from the needs of the maintenance."

The outage strategy grew out of the aim to achieve an average availability of 90 percent. That meant each unit could afford 70 days of outage over a three-year period. This led to the concept of two short outages of 18 days and one long outage of 34 days. And so, each year since 1984, one unit has a long outage and the other two have short outages. Having done better than the 18-day short outage and 34-day long outage in most years, the station usually hits the 90 percent availability figure including unscheduled stoppages—this in spite of ongoing problems with fuel damage from debris. Removing and replacing damaged fuel takes four to five days and costs some Kr 20 million ($2 million). Forsmark is looking for ways to prevent this.

To achieve its outage goals, Forsmark sets strict time limits, focusing on critical items. "We always plan for the shortest critical path," said Hägglund, asking maintenance for the best time that jobs can be done. We do not have air in the plan." Work can be moved to another outage, or done online, but the outage will not be extended.

Welders Maja Bjork and Stefan Hellstrom at Forsmark-3 fitting a new valve flange to hydraulic pipe to one of the valve servos. (Photo: Odd Hedberg/Forsmark)

Checking the number two low-pressure turbine rotor for signs of cracking at Forsmark-3 (Photo: Odd Hedberg/Forsmark)

Refitting cabling to one of the control rod actuator motors at Forsmark-3 (Photo: Odd Hedberg/Forsmark)

This makes it very important to coordinate online maintenance with outages.

An advantage of this design of boiling water reactor is its four fully separated safety divisions (trains) which satisfy a 4 × 50 percent redundancy criterion. The regulator allows each division to be taken out of operation for up to 60 days per year. There is a rotation of when work is done on each train. Over the year, there are four periods for doing online maintenance: two week-long periods for each safety division in spring and two periods in autumn. Although much maintenance work must be done during scheduled outages, the high level of redundancy at the plant allows a lot of work to be done on safety, as well as nonsafety, critical systems while the plant is on line.

At Forsmark-3, two fitters employed by a contractor prepare a pipe surface for welding of the pipe leading from the reactor vessel behind the fitters. (Photo: Odd Hedberg/Forsmark)

Runermark believes there is little or no benefit to shorter outages at Forsmark. The plant has done a benchmarking exercise with TVO's Olkiluoto plant, so it knows what the Finns do to achieve outages of eight to nine days. One difference is that the Finnish BWRs have a smaller core and less fuel to shuffle. Forsmark is satisfied that its strategy is about right.

Short outages are especially important when the electricity spot price is going up—when the price is low, less money is lost. In 1999, the Unit 3 outage was completed, and the plant was not started up immediately thereafter because the price of electricity produced elsewhere (i.e., by other sources) was so low. This is not expected to happen this year.

Continued

Working under umbrellas

Outages at Forsmark are done under “umbrellas.” The umbrella system began development in Sweden in the late 1980s, explained Peter Wedin, head of the planning department, and all plants now use it. Behind the concept is the idea of constructing “independent islands” in the outage schedule instead of having a network of outage activities that may influence each other. The effectiveness of these systems has been a major factor in enabling Forsmark to implement the two short/one long outage schedules.

Hägglund was one of the original developers of the umbrella concept. Working at the Ringhals-1 plant, he said, taught him and others that handling hundreds of work orders was a difficult planning task, and so they looked at other ways to package the work. For example, they discovered that one method some plants were using was grouping work orders together in a kind of a mini-outage for part of the plant. If there are 20 work orders for a feedwater pump, he said, then it would make sense to make the pump a complete maintenance package, take it out of operation and complete all the work orders at one time.

This developed into the idea of dividing the plant into zones or areas of systems and components, which are covered or bounded by umbrellas. Under an umbrella, systems will be isolated only once and all work orders completed within a single time window.

At Forsmark, the whole plant is divided into umbrellas. In the beginning, about 80 umbrellas were defined. There are now about 200 umbrellas to choose from, but for an ordinary outage, about 60 are used. Their size varies from major components, like the feedwater pump or turbine-generator, to more complex systems, such as a safety division. Over time, the umbrellas have evolved into very workable segments for maintenance.

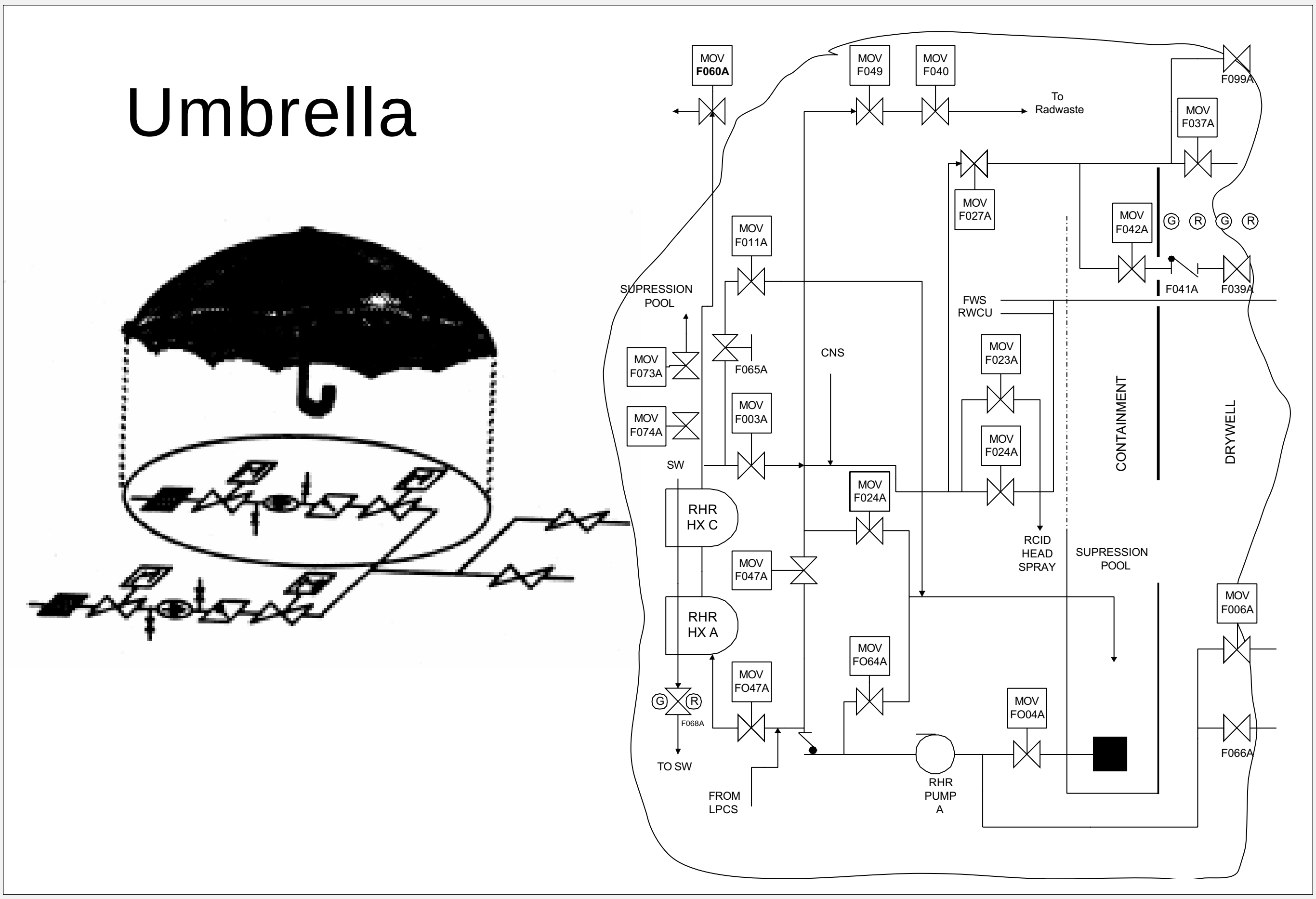
An umbrella comes with a description of what is included and instructions on what to do. The instructions say how to take it out of operation (for example, drain and isolate) and then to make measurements needed to confirm its status (that valves are closed, the pipes are dry, etc.) and that it is safe to commence maintenance. Once the work is complete, the instructions explain how to take it back into operation—to fill with water, supply power, and line up equipment, etc. The last sheets are for functional and operability testing. Attached to the umbrella is a list of all the work orders and work permits.

Umbrellas are very effective in managing outages and have resulted in shorter and safer ones. They make it easier to organize tasks in simple blocks and carry out plant tagout procedures, follow the progress of the outage, monitor safety status, sign off the work, and manage lineup and restart operations.

The Work Control Center (WCC) acts as a single point for administration and control of the outage. Throughout an outage, the shift supervisors are able to track work orders and work permits (which supervisors must sign), particularly as the outage moves from shift to shift, and monitor the status of systems that have to be kept in operation for safety reasons. Umbrellas also assist a systematic recording of what is done during the outage, which helps in planning subsequent outages and assessing the condition of the plant.

The plant’s umbrellas have been standardized but they can be modified, particularly if it simplifies the work. Components or subsystems in the umbrella can be excluded (not isolated) or the border can be extended to include items on the periphery. This will typically require moving the boundary out to the next isolation valve as indicated in the drawing.

If a job cannot be completed within its umbrella window, Hägglund said, “we have to look at connections with the next umbrella to see if extending it will cause other jobs to be delayed. If it is critical we can take it out of the umbrella, and complete it,” but he considers rescheduling during short outages risky. It is possible to forget something, he noted, and it may interfere with other work.



Forsmark’s umbrella approach to plant maintenance (Forsmark Kraftgrupp AB)

A generator rotor being exchanged with a spare in order to equalize operating hours on each, at Forsmark-3 (Photo: Odd Hedberg/Forsmark)

The umbrella system is used for maintenance throughout the year, not just at outages. But it is during an outage involving 1500 to 2000 work orders that the system is so useful.

Hägglund considers the umbrella concept as being quite natural. There has to be some system of isolating areas to work on. He added that the plant's particular design does facilitate dividing it up into independent segments.

End of the outage

For the end of the outage, Forsmark uses the "Standardization Multi-Barrier Operation Test Procedures" (ÖDS), which provides a systematic procedure to sign off umbrellas as they are completed and to close out the outage and return the plant to operation. ÖDS was devised to ensure that each stage is signed off in an ordered and safe sequence.

ÖDS was developed by shift supervisors to provide a simple and quick overview of the state of the station, particularly its safety. The work status is clearly shown on ÖDS sheets, providing the supervisor an easy means of tracking the outage and to pass on responsibility to the next shift. It tells him what work is completed and what is not completed, and what is in operation and what has been shut down (two safety divisions must be in operation at all times). The shift manager signs off each stage. The final testing and return to operation of the four safety divisions and nuclear sections of the plant must be signed off by the operations manager and by the plant manager.

Organization and planning

While outages are the responsibility of operations, the planning of the umbrellas as well as the work itself are the responsibility of the maintenance department. The planners focus on the umbrellas, taking account of the requirements of operations, refueling, plant modifications, and other technical concerns, and with support from other maintenance sections. They develop a list of umbrellas and schedules. Maintenance staff then do the detailed planning of the work within each umbrella.

As soon as one outage is completed, planning of the next outage can begin. The process starts with a time target. The group then assesses what can come into the outage and defines a preliminary outage scope. Then the planners look more specifically at what needs to be done and what else can be done in that time, such as upgrades and modifications. By January, a detailed work scope is defined and an umbrella schedule can begin to be determined. The work continues: preparing work orders, organizing resources (staff, contractors, spare parts, etc.), and ensuring that the safety and technical specifications will be fulfilled. Because all three units are done during the summer, staff vacations are a particular scheduling problem. All preparations should be completed by the middle of May.

About 90 percent of required maintenance jobs during an outage are already in the computer system, including under which umbrella they go. Forsmark has its own Work Management Computer System, which began development in 1975. A major upgrade of the system was done in 1996–97. While some work management programs available today have greater capabilities, the Forsmark system is tailored to the needs of the plant and staff hope to be able to maintain it.

The plant aims for unplanned work orders comprising only about 10 percent of total work orders during the outage. Experience, said Runermark, indicates "that too many added work orders during the outage force uncalled work, delay, frustration, and chaos."

Culture and practices

Forsmark's tight approach to outages means it is critical to get things right. This fits with the national culture, said Runermark: "In Sweden, if planning calls for two days, it must be done in less than two days."

Hägglund noted that practices and ways of doing things at the plant have proven successful over many years. "It would be a shame if after 15 years we were not able to do it. Ninety-nine percent of the time I can just point to an instruction or rule and say this is how we should do it."

While he admits there may be too many rules, he warns that it would be dangerous to lose contact with the past and have to invent new rules and ways of doing things. Too much change, particularly of people or rules, is much more risky, he says.

According to Runermark, the Forsmark staff is highly committed to the station, and Forsmark is committed to the staff. Communication is very important. Every morning, there is a plant meeting chaired by the plant manager or the operations manager. While this is done during outages in many plants, at Forsmark it is done every day so staff are always up to date.

Forsmark believes that staff attitude is vital to the company's future success and has introduced the concept of "management by inspiration," which seeks to go beyond staff's being "engaged—hard working" to the stage of being "inspired—creative." The plant also has a staff competence development program.

Staff aging remains a problem throughout the Swedish nuclear industry. At Forsmark the average age is 46, and since nuclear power is to be phased out in Sweden, it will remain difficult to recruit new people. So far, however, the plant has been able to attract enough new people, and is making efforts for the future. The company, along with the rest of the nuclear industry, is supporting technical high schools, from which it hopes to draw future recruits. Every second year, Forsmark takes 10–15 students for a year and a half training program. Next year the training includes a visit to Japan.

Forsmark is also committed to environmental protection. Last year, Forsmark became the first nuclear power plant to receive an "Environmental Product Declaration." This means that customers can buy electricity from Forsmark that is environmentally equivalent to other EPD sources, such as hydro and wind, if they are doing the same job. The plant previously achieved ISO 14001 environmental certification and is registered under the European Union's Eco-Management Audit Scheme. NN