by Dana Sacchetti

Earth, Wind

Preparing nuclear power plants for nature's fury.

Nuclear power generation does not occur in a vacuum. Exposure to the outside world can bring dangers such as hurricanes, earthquakes, fires, tsunamis and volcanoes. With safety the first priority for nuclear plants, it is incumbent upon nuclear installation designers and builders to prepare for the worst that nature can bring to bear.

Mount Etna seen from space. Photo: NASA

and Fire

Since the early days of nuclear power, the primary concern regarding nuclear power plants has been the prospect of human error or mechanical failure, leading to a radiological release to the environment. The examples of Chernobyl and Three Mile Island left the impression that the greatest risk factors came from inside a plant's walls.

Yet, events in recent years have raised the spectre of new threats: that the greatest menace facing a plant's operation lay outside its walls, not inside. Nuclear power generation does not occur in a vacuum, and with plants dotted around the globe exposed to the elements, the chance for interference by natural phenomena is ubiquitous. Exposure to the outside world can bring dangers such as hurricanes, earthquakes, fires, tsunamis and volcanoes. With safety the first priority for nuclear plants, it is incumbent upon nuclear installation designers and builders to prepare for the worst that nature can bring to bear.

Seismic Vulnerability

One of the first external events to capture the nuclear community's attention happened over thirty years ago, when a 1977 earthquake occurred in Romania, affecting the Kozloduy nuclear power plant in nearby Bulgaria. The quake's shaking caused only superficial damage to parts of the plant which were not safety-related, but still alerted the international community to a possible Achilles' heel with some of the older Soviet-designed plants.

"The Vrancea earthquake in 1977 was a wakeup call for the Soviet-designed plants," explains Aybars Gürpinar, former director of the IAEA's Division of Nuclear Installation Safety. "It also propelled the Soviet Union to strengthen the plant in Armenia, and caused the IAEA to begin the first of many assistance missions to look at the designs of plants throughout the region."

The Chernobyl accident also triggered a lot of introspection about nuclear safety through Eastern Europe, the Soviet Union, and the international nuclear community. Alongside the more general issues related to nuclear safety, concern grew that not enough was being done to protect plants against possible external events.

Throughout the late 1980s and early 1990s, the IAEA dispatched several review missions to plants in Armenia, then Czechoslovakia, Bulgaria, and the Russian Federation to evaluate the Soviet-designed plants. Through the missions, the IAEA found that first generation Water-Water Energetic Reactor (WWER) plants, were designed without external hazards factored into their construction. The IAEA concluded its missions by recommending that certain plant equipment be reviewed, along with the installation of additional supports and upgrading of safety equipment.

In other regions, the seismic design limits of nuclear power plants have also come under question. Some plants in the US have exceeded the design basis for earthquakes on occasion, though none have resulted in any significant risk to safety.

A January 1986 earthquake of 4.9 Richter magnitude occurred close to Perry nuclear power plant, a single unit reactor located in north-eastern Ohio. Ground accelerations at the site were recorded as high as 0.19

to 0.23g, which surpassed the 0.1g design basis for the plant. The plant was offline at the time, though scheduled to be loaded with fresh fuel the following day. After the event, a team of engineers and seismologists was dispatched to the plant to check for any system failure and check for aftershocks in the days following. Small cracks in concrete and leaks in non-critical piping were observed, though both conditions could have existed prior to the quake. The Perry nuclear power plant quake set off a protracted legal battle, but the plant was found to have soundly withstood the earthquake and restarted soon thereafter.

The largest earthquake to ever affect a nuclear power plant occurred last year near the world's largest nuclear power facility in Japan. The strength of the quake killed 11 people in neighbouring areas, flattened nearly 400 structures, and disrupted auto production plants. The Kashiwazaki-Kariwa nuclear plant, a seven-unit facility sited along the Sea of Japan coastline, was walloped by the 6.6 magnitude quake on 16 July 2007, which caused the plant to safely shut down. Though the reactors performed well, the quake was found to have occurred on a fault that was unknown to plant designers, and its force greatly exceeded the limits for which the plant was originally designed.

Two IAEA expert visits to the site concluded that while the design basis was exceeded, the plant was engineered correctly and held up well, in spite of the unexpected strength of the quake. Yet the plant is still shutdown since the earthquake, and no timetable has been set for restarting of operation.

As Japan is one of the most seismically active nations in the world, it has strict sets of regulations designed to limit the impact of quakes on nuclear power plants. These standards call for constructing plants on solid bedrock to reduce shaking and by classifying all of the plant's components into different safety categories. As some aspects of the plant are more vulnerable than others, the design for ruggedness follows suit.

Tsunamis and Flooding

With a significant number of the world's nuclear plants drawing from seawater for cooling purposes, a second threat that nuclear power plants face is coastal flooding and more specifically tsunamis. The massive Indian Ocean earthquake of 26 December 2004 generated a series of devastating tsunamis, killing nearly a quarter of a million people and causing widespread catastrophic damage in eleven countries.

Two power units at Kalpakkam nuclear power plant in India were hit by the tsunami, though both weathered the waves well. Even though plant designers never planned for a tsunami to ever descend upon the plant, they did take the similar phenomenon of cyclone storm surges into account. Plant builders had estimated the maximum water level that could approach the plant in the case of a storm surge, and had built accordingly. Two wells, one far out at sea and one on land, were constructed to alert operators in the event of an approaching storm wave. Once the plant operator received the warning, the plant was immediately shut down. Even still, the reactor buildings were encased in meter-thick walls, so water was likely not able to enter the reactor units.

So even with rising levels of water and the crushing impact of a massive wave, the Kalpakkam plant performed well under duress.

"To make such vital buildings withstand earthquakes, a large concrete base mat is built," explained L. V. Krishnan, former director of the Indira Gandhi Centre for Atomic Research in Kalpakkam. "So if the structure moves it will move all together without getting cracked."

Severe floods also affected the Le Blayais nuclear plant in the Bordeaux region of France. During a severe storm that struck in December 1999, high waves crashed over a protective dyke installed at the plant, partly submerging portions of the facility. Water affected performance of the plant, namely units 1 and 2. Water pumps that would normally be used to draw water away from the plant were knocked out, forcing plant managers to take emergency action to prevent a possible core meltdown. Emergency feedwater systems were used to remedy the flooding, and the plant later returned to service.

French safety standards call for placing the platform that supports safety-relevant equipment at a level at least as high as the maximum water level and to block any possible routes through which external waters could reach reactor safety equipment located below the level of the site platform. As a result of the Le Blayais flooding, where both standards failed, French nuclear safety authorities were forced to re-examine standards with regards to flooding.

The Way Forward

The IAEA has worked to evaluate nuclear power plants for hazard readiness around the world since the late 1970s. Most of its early missions targeted developing countries, with the IAEA assisting in ensuring that nuclear installations were rugged enough to withstand certain environmental risks. The IAEA has also long published safety standards that set recommendations to countries seeking guidance on improving nuclear installation safety.

Roughly eight years ago, the IAEA began to devise safety standards that are more risk-informed and rely upon probabilistic evaluations. This change in approach calls for plant builders to integrate the likelihood of an external hazard occurring when constructing a plant, whereas older standards prescribed a more uniform set of standards to all plants around the world.

The IAEA also leads conferences and meetings among nuclear power states to discuss ways in which plants can be built and retrofitted for external events. In the past year, the IAEA held two such conferences regarding external hazards, focusing on seismic safety and threats posed by tsunamis.

The workload of the IAEA with respect to external hazards is expected to increase in the coming years.

"Now a lot of new build countries are coming to us, requesting the IAEA to assist in site evaluation and external events consideration," explained Mr. Gürpinar.

Still, determining the best way to protect nuclear facilities against mother nature's fury continues to be a learning process. "We're finding that our most significant learning about the effects of earthquakes on nuclear power plants always occurs after strong seismic events," said Antonio Godoy, Acting Head of the IAEA's Engineering Safety Section.

With continued communication and transparency among nuclear power countries, the IAEA, and regulators worldwide, are working to keep plants safe from all that nature can bring to bear.

Mr. S.N. Ahmad of the Indian Department of Atomic Energy, summed up the design of nuclear plants with respect to natural phenomena. "Man must live with natural calamities," he stated. "Wisdom lies in effectively meeting the challenges of such situations and ensuring safety of human life and property. In nuclear power plants the whole spectrum of such natural calamities and highly improbable accident conditions are factored in site selection and design."

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Steady Lessons from Shaky Events

Kashiwazaki, Japan — In the wake of the significant earthquake that struck the world's largest nuclear power plant, the Kashiwazaki-Kariwa nuclear power plant, last year there has been renewed international focus on the structural strength of nuclear facilities. From 19-21 June 2008, the IAEA organized a workshop with the goal of sharing recent technical knowledge and approaches on designing and maintaining the ruggedness of nuclear power plants to safely withstand such severe external hazards. The meeting convened over 300 attendees from various fields of expertise, and concluded in late June 2008 in Japan.

"We organized the workshop with the objective of sharing recent findings and information obtained from the occurrence of strong earthquakes that impact nuclear power plants, as well as good practices and lessons learned," explained Antonio Godoy, Acting Head of the IAEA's Engineering Safety Section and leader of the workshop.

Key conclusions of the workshop included:

❶ Seismic hazard evaluation continues to be a key element of assuring seismic safety of a nuclear plant;

❷ Site-specific information and a full understanding of the geological and tectonic features of a nuclear power plant's site are critical to seismic safety;

❸ In light of the July 2007 earthquake at the Kashiwazaki-Kariwa plant, it is clear that design and safety regulations play a critical role in keeping the plant robust in spite of an under-estimation on the original seismic input from the seismological studies performed at that time; and

❹ Learnings from the Kashiwazaki-Kariwa nuclear power plant experience is providing valuable input to the IAEA's safety standards.

"Science is making enormous progress, but we have to remain eager to acquire new findings and new information to ensure nuclear power plant safety. And we also need to maintain transparency as well," said Mr. N. Hirawaka, of Japan's Tohoku Electric Power Company.

The workshop was organized by the IAEA in cooperation with the Nuclear and Industrial Safety Agency (NISA), Nuclear Safety Commission (NSC), and Japan Nuclear Energy Safety Organization (JNES). The OECD Nuclear Energy Agency cooperated in organizing the workshop.

A related IAEA-led workshop on the effects of tsunamis on nuclear power plants was held on 23 June 2008 in Daejong, Korea.