Investigating Russia's Biggest Dam Explosion: What Went Wrong

Last August, a major failure occurred at Sayano-Shushenskaya hydroelectric dam in Russia. 75 people were killed, many were injured and 40 tons of oil were spilled in the Yenisei river. With nearly 100 gigawatts of installed electric dams in the United States, experts wonder, could it happen here? PM investigates.

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Just before 8 am on Aug. 17, 2009, workers on the morning shift stepped off a clattering Soviet-era tram and made their way past security and into position at the Sayano-Shushenskaya hydroelectric power plant in south-central Siberia. In the 950-foot-long turbine hall, custodians mopped the stone floors and supervisors handed out assignments.
On the roof, a technician began installing a new ventilation system. Above him soared a concave dam 80 stories high and more than half a mile wide at the crest. When operating at full capacity, the plant's 10 interior penstocks funneled water from the reservoir behind the concrete barrier to the hall below him, where it tore past the blades of 10 turbines, spinning them with tremendous force before being flushed out of the hydro plant and down the Yenisei River.

Completed in 1978, the Soviet-era hydro station is Russia's largest, with enough output to power a city of 3.8 million. It was undergoing extensive repairs and upgrades that morning, so more workers were in the hall than usual: 52 on the main floor and another 63 down in the bowels of the plant. Nine of the 10 turbines were operating at full capacity—including the troublesome Turbine 2, which had been offline but was pressed back into service the previous night when electricity production dropped because of a fire at the Bratsk power station, 500 miles to the northeast. A few minutes into his shift, the technician felt the roof begin to vibrate. The vibrations grew louder and gradually turned into a thunderous roar. Alarmed, he scrambled off the roof.

At 8:13 am, two massive explosions rocked the hall. Security guard Aleksandr Kataytsev told English-language news station RT that he was one level below the turbine hall when he heard "a loud thump, then another one, like an explosion, and then the room went pitch-black."

Turbine 2—a 1500-ton piece of machinery topped by a power generator—blasted through the floor and shot 50 feet into the air before crashing back down. The penstock water that had been spinning the turbine geysered out of the now-vacant shaft at a rate of 67,600 gallons per second. Like a massive industrial waterjet, it tore down the metal joists over Turbines 1, 2 and 3; the roof there crumpled like aluminum foil and collapsed in a tangle of glass and metal.

Water continued to pour into the hall, flooding its lower levels and eventually submerging other turbines. The plant's automatic safety system should have shut down the turbines and closed the intake gates on the penstocks at the top of the dam, but Turbines 7 and 9 still operated at full speed, in excess of 142 rpm, triggering the crackling short circuits that darkened the plant. Amateur video footage taken downstream at the time of the accident shows bright flashes and a huge explosion in the vicinity of Turbines 7 and 9 as a wall of water spews from the structural breach near Turbine 2.
As the water level rose, employees stampeded toward the main entrance. Fearing a total collapse of the dam, many phoned relatives downstream and urged them to seek shelter in the surrounding Sayan Mountains. Among the fleeing workers were several supervisors in charge of safety and emergencies, which added to the confusion. On the fourth floor, shell-shocked midlevel operators telephoned up the chain of command for a contingency plan. No one answered.

Using his mobile phone as a flashlight, security guard Kataytsev found his way to an exit and made for higher ground. At the crest of the dam, he and several other employees struggled to manually close the penstock intake gates. By 9:30 am they had sealed all the gates, and the destruction below ceased.

In the wake of the accident, rescue crews mobilized to search for survivors. RusHydro, the partially state-owned utility company that operates Sayano-Shushenskaya, assembled 400 employees to pump out the flooded turbine hall and pick through the twisted debris. Russian president Dmitry Medvedev dispatched Sergei Shoigu, his emergencies minister, and Sergei Shmatko, the energy minister, to oversee rescue efforts. Environmental clean-up crews attempted to contain the oil spill that stretched 50 miles down the Yenisei River and killed 400 tons of fish at trout farms. Over two weeks, 2000 rescuers removed 177,000 cubic feet of debris, pumped 73 million gallons of water and pulled 14 survivors from the wreckage. But 75 workers--those trapped in the turbine hall and in the flooded rooms below--weren't so lucky.

For Russians, the catastrophe called to mind the 1986 disaster at the Chernobyl Nuclear Power Plant in Ukraine, which was then part of the Soviet Union. Speaking on a Moscow radio station, Shoigu called the hydro dam accident "the biggest man-made emergency
situation [in] the past 25 years--for its scale of destruction, for the scale of losses it entails for our energy industry and our economy." Some commentators have called the events at Sayano-Shushenskaya the "Russian Chernobyl." And just as Chernobyl raised questions globally about nuclear safety, Sayano-Shushenskaya has made other nations wonder: Are other hydropower plants at risk?

Before: The turbine hall housed 10 640-megawatt turbines. Normally, 12 people manned the hall, but because of repair work, 115 people were on site on the day of the accident.

The Investigation

Immediately after the accident, Russia's Federal Service for Ecological, Technological, and Nuclear Supervision (Rostekhnadzor) launched an investigation. The official report, released on Oct. 3, blamed poor management and technical flaws for the accident.

According to the report, repairs on Turbine 2 were conducted from January to March 2009, and a new automatic control system--meant to slow or speed up the turbine to match output to fluctuations in power demand--was installed. On March 16, the repaired turbine resumed operation. But it still didn't work right: The amplitude of the machine's vibrations increased to an unsafe level between April and July. The unit was taken offline until Aug. 16, when the Bratsk fire forced managers at Sayano-Shushenskaya to push the turbine into service.

Back in operation, Turbine 2 vibrated at four times the maximum limit. As the control system decreased the turbine's output on the morning of Aug. 17, the vibrations increased. The unit acted like the engine of an automobile being downshifted on a hill, shuddering violently and stressing the fatigued metal pins holding it in place. LMZ, the
St. Petersburg metalworks that manufactured the plant's turbines, gave the units a 30-year service life. Turbine 2's age on Aug. 17 was 29 years, 10 months. Investigators determined that the power failure after the initial explosion had knocked out the safety system that should have shut down the plant—and a malfunction turned into a catastrophe.

Officials from RusHydro and the government have called for more stringent oversight of hydropower plants, but economic pressures may still put financial considerations ahead of safety. Six days before rescue efforts were halted on Aug. 29, repairs at Sayano-Shushenskaya were already underway. Rebuilding will take five years and cost approximately $1.3 billion—but a pair of nearby aluminum smelters, property of global aluminum giant RusAl, can't wait that long. They consumed 70 percent of the station's output and need replacement power to maintain production. RusAl and RusHydro are pressing the government for additional financing to accelerate completion of a joint venture at Boguchansk on the Angara River, now in its 29th year of construction.

Could it Happen Here?

The U.S. has an installed capacity of nearly 100 gigawatts and an annual production of 250 terawatt-hours, which make it the world's fourth largest hydroelectric producer. Yet even with a water-power history dating back to the 19th century, and more than 2000 such plants in operation, the U.S. has never had an event to match Sayano-Shushenskaya.

Experts agree that a similar accident is unlikely to occur here because American equipment is held to more stringent performance standards and rigid inspection regimes.
The Bureau of Reclamation manages 58 hydropower plants, which produce 44 billion kilowatt-hours per year. Dan Drake, chief of the Hydraulic Equipment Group, the unit responsible for upkeep at iconic Western dams like Hoover, says bureau turbines are taken offline at the first sign of abnormal performance, and redundant automatic systems are in place. "If a unit were experiencing violent or abnormal vibrations," Drake says, "it would shut down, and the gate at the top of the penstock would close." Regular equipment repairs and replacement also keep dams safe.

Russia's immediate solution to its power problem is to build more dams, but that won't fix a bureaucratic culture that seems to devalue safety. "If they were running a turbine with known deficiencies, in essence, they're putting economic concerns before human-life safety factors," says Eric Halpin, the special assistant for dam and levee safety for the U.S. Army Corps of Engineers, America's largest hydropower operator. "The principles we use are just the opposite. If it's not safe, if there's a risk of failure, all other benefits--be they economic, environmental or anything else--those all go away."

Anatomy of a Turbine Failure

This photograph of the Sayano-Shushenskaya hydroelectric power plant, located 2000 miles east of Moscow in Siberia, was taken after the Aug. 17, 2009, accident that destroyed a section of the 950-foot-long turbine hall (circled in white). Water from the Yenisei River flows through 620-foot-long penstocks to power 10 turbines, which generate up to 6400 megawatts. Turbine 2 had been offline until the previous night, when it was brought online to compensate for energy lost because of a fire at another plant. Here's how the disaster unfolded.
1. Fatigued by vibration, Turbine 2’s fastening pins break at 8:13 am. Water rushing down the penstock forces the 1500-ton unit through the turbine-hall floor and 50 feet into the air.

2. A geyser of water flowing at 67,600 gallons per second destroys the roof and floods the turbine hall. Power outages occur and communication systems fail.
3. The automated safety system also fails. Turbines 7 and 9 continue to operate even though they are submerged, causing short circuits, explosions and structural damage.

4. Employees close the intake gates at the top of the dam at 9:30 am, and the immediate crisis ends. In the following days, 14 people are rescued from the debris; 75 lose their lives.

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