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From Far Labs, a Vivid Picture of Japan Crisis

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For the clearest picture of what is happening at Japan’s Fukushima Daiichi nuclear power plant, talk to scientists thousands of miles away.

Thanks to the unfamiliar but sophisticated art of atomic forensics, experts around the world have been able to document the situation vividly. Over decades, they have become very good at illuminating the hidden workings of nuclear power plants from afar, turning scraps of information into detailed analyses.

For example, an analysis by a French energy company revealed far more about the condition of the plant’s reactors than the Japanese have ever described: water levels at the reactor cores dropping by as much as three-quarters, and temperatures in those cores soaring to nearly 5,000 degrees Fahrenheit, hot enough to burn and melt the zirconium casings that protect the fuel rods.

Scientists in Europe and America also know from observing the explosions of hydrogen gas at the plant that the nuclear fuel rods had heated to very dangerous levels, and from radioactive plumes how far the rods had disintegrated.

At the same time, the evaluations also show that the reactors at Fukushima Daiichi escaped the deadliest outcomes — a complete meltdown of the plant.

Most of these computer-based forensics systems were developed after the 1979 partial meltdown at Three Mile Island, when regulators found they were essentially blind to what was happening in the reactor. Since then, to satisfy regulators, companies that run nuclear power plants use snippets of information coming out of a plant to develop simulations of what is happening inside and to perform a variety of risk evaluations.

Indeed, the detailed assessments of the Japanese reactors that Energy Secretary Steven Chu gave on Friday — when he told reporters that about 70 percent of the core of one reactor had been damaged, and that another reactor had undergone a 33 percent meltdown — came from forensic modeling.

The bits of information that drive these analyses range from the simple to the complex. They can include everything from the length of time a reactor core lacked cooling water to the subtleties of the gases and radioactive particles being emitted from the plant. Engineers feed the data points into computer simulations that churn out detailed portraits of the imperceptible, including many specifics on the melting of the hot fuel cores.

Governments and companies now possess dozens of these independently developed computer programs, known in industry jargon as "safety codes." Many of these institutions — including ones in Japan — are relying on forensic modeling to analyze the disaster at Fukushima Daiichi to plan for a range of activities, from evacuations to forecasting the likely outcome.

"The codes got better and better" after the accident at Three Mile Island revealed the poor state of reactor assessment, said Michael W. Golay, a professor of nuclear science and engineering at the Massachusetts Institute of Technology.

These portraits of the Japanese disaster tend to be proprietary and confidential, and in some cases secret. One reason the assessments are enormously sensitive for industry and government is the relative lack of precedent: The atomic age has seen the construction of nearly 600 civilian power plants, but according to the World Nuclear Association, only three have undergone serious accidents in which their fuel cores melted down.

Now, as a result of the crisis in Japan, the atomic simulations suggest that the number of serious accidents has suddenly doubled, with three of the reactors at the Fukushima Daiichi complex in some stage of meltdown. Even so, the public authorities have sought to avoid grim technical details that might trigger alarm or even panic.

"They don't want to go there," said Robert Alvarez, a nuclear expert who, from 1993 to 1999, was a policy adviser to the secretary of energy. "The spin is all about reassurance."

If events in Japan unfold as they did at Three Mile Island in Pennsylvania, the forensic modeling could go on for some time. It took more than three years before engineers lowered a camera to visually inspect the damaged core of the Pennsylvania reactor, and another year to map the extent of the destruction. The core turned out to be about half melted.

By definition, a meltdown is the severe overheating of the core of a nuclear reactor that results in either the partial or full liquefaction of its uranium fuel and supporting metal lattice, at times with the atmospheric release of deadly radiation. Partial meltdowns usually strike a core’s middle regions instead of the edge, where temperatures are typically lower.

The main meltdowns of the past at civilian plants were Three Mile Island in 1979, the St.-Laurent reactor in France in 1980, and Chernobyl in Ukraine in 1986.

One of the first safety codes to emerge after Three Mile Island was the Modular Accident Analysis Program. Running on a modest computer, it simulates reactor crises based on such information as the duration of a power blackout and the presence of invisible wisps of radioactive materials.

Robert E. Henry, a developer of the code at Fauske & Associates, an engineering company near Chicago, said that a first sign of major trouble at any reactor was the release of hydrogen — a highly flammable gas that has fueled several large explosions at Fukushima Daiichi. The gas, he said in an interview, indicated that cooling water had fallen low, exposing the hot fuel rods.

The next alarms, Dr. Henry said, centered on various types of radioactivity that signal increasingly high core temperatures and melting.

First, he said, “as the core gets hotter and hotter,” easily evaporated products of atomic fission — like iodine 131 and cesium 137 — fly out. If temperatures rise higher, threatening to melt the core entirely, he added, less volatile products such as strontium 90 and plutonium 239 join the rising plume.

The lofting of the latter particles in large quantities points to “substantial fuel melting,” Dr. Henry said.

He added that he and his colleagues modeled the Japanese accident in its first days and discerned partial — not full — core melting.

Micro-Simulation Technology, a software company in Montville, N.J., used its own computer code to model the Japanese accident. It found core temperatures in the reactors soaring as high as 2,250 degrees Celsius, or more than 4,000 degrees Fahrenheit — hot enough to liquefy many reactor metals.

“Some portion of the core melted,” said Li-chi Cliff Po, the company’s president. He called his methods simpler than most industry simulations, adding that the Japanese disaster was relatively easy to model because the observable facts of the first hours and days were so unremittingly bleak — “no water in, no injection” to cool the hot cores.

“I don’t think there’s any mystery or foul play,” Dr. Po said of the disaster’s scale. “It’s just so bad.”

The big players in reactor modeling are federal laboratories and large nuclear companies such as General Electric, Westinghouse and Areva, a French group that supplied reactor fuel to the Japanese complex.

The Sandia National Laboratories in Albuquerque wrote one of the most respected codes. It models whole plants and serves as a main tool of the Nuclear Regulatory Commission, the Washington agency that oversees the nation’s reactors.

Areva and French agencies use a reactor code-named Cathare, a complicated acronym that also refers to a kind of goat’s milk cheese.

On March 21, Stanford University presented an invitation-only panel discussion on the Japanese crisis that featured Alan Hansen, an executive vice president of Areva NC, a unit of the company focused on the nuclear fuel cycle.

“Clearly,” he told the audience, “we’re witnessing one of the greatest disasters in modern time.”

Dr. Hansen, a nuclear engineer, presented a slide show that he said the company’s German unit had prepared. That division, he added, “has been analyzing this accident in great detail.”

The presentation gave a blow-by-blow of the accident’s early hours and days. It said drops in cooling water exposed up to three-quarters of the reactor cores, and that peak temperatures hit 2,700 degrees Celsius, or more than 4,800 degrees Fahrenheit. That’s hot enough to melt steel and zirconium — the main ingredient in the metallic outer shell of a fuel rod, known as the cladding.

“Zirconium in the cladding starts to burn,” said the slide presentation. At the peak temperature, it continued, the core experienced “melting of uranium-zirconium eutectics,” a reactor alloy.

A slide with a cutaway illustration of a reactor featured a glowing hot mass of melted fuel rods in the middle of the core and noted “release of fission products” during meltdown. The products are radioactive fragments of split atoms that can result in cancer and other serious illnesses.

Stanford, where Dr. Hansen is a visiting scholar, posted the slides online after the March presentation. At that time, each of the roughly 30 slides was marked with the Areva symbol or name, and each also gave the name of their author, Matthias Braun.

The posted document was later changed to remove all references to Areva, and Dr. Braun and Areva did not reply to questions about what simulation code or codes the company may have used to arrive at its analysis of the Fukushima disaster.

“We cannot comment on that,” Jarret Adams, a spokesman for Areva, said of the slide presentation. The reason, he added, was “because it was not an officially released document.”

A European atomic official monitoring the Fukushima crisis expressed sympathy for Japan’s need to rely on forensics to grasp the full dimensions of the unfolding disaster.

“Clearly, there’s no access to the core,” the official said. “The Japanese are honestly blind.”