The Lessons of Chernobyl

U.S. officials say they have learned little new, but the accident is raising old questions about the danger of steam explosions and the strength of containments

THE Nuclear Regulatory Commission seemed confident at a recent meeting that the Chernobyl accident will add little to the agency's expertise on reactor safety. Staff scientists said they could see no immediate lessons for U.S. nuclear plants.

The blast that ripped Chernobyl apart was triggered by a runaway fission reaction and powered by steam. The NRC seems to put most of the stress on the first half of the problem. It has focused on the differences between U.S. and Soviet methods of fission control, not on the common hazard of steam explosions.

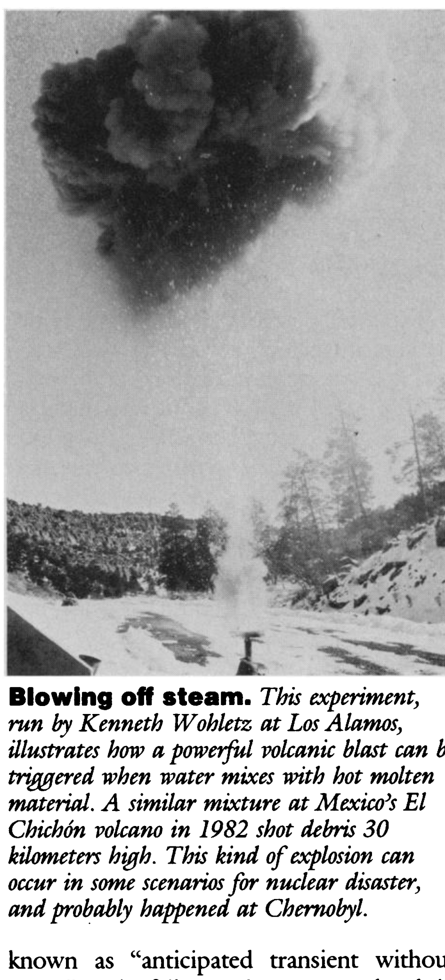
On returning from the International Atomic Energy Agency conference in Vienna, NRC staffers told the five commissioners that they gained a solid understanding of how the accident came about. They had a less precise picture of the physical event itself. The Soviets were frank and open, they reported, although not able to answer all questions about the blast. However, NRC officials found the record clear enough to feel that there were few technical surprises.

Studying this accident, one expert said, is like returning to "ancient history." It brings up problems in neutron physics that Americans eliminated from their designs decades ago. Experiments on a series of test reactors at the Idaho nuclear engineering lab convinced U.S. researchers in the 1960's that they fully understood the hazards of runaway power accidents.

Harold Denton, head of reactor regulation at the NRC, told the commission on 3 September that the staff needs time for the Soviet information to "seep in." With Chernobyl as a guide, the staff will "go back and look at things" in U.S. plants that once seemed troublesome and might need review. "But I don't see any areas in which we need to make any immediate changes in our regulatory basis," Denton said.

He was seconded by Themis Speis, the director of safety technology for NRC and another member of the delegation that went to Vienna. "We didn't see anything telling us immediately to make radical changes," Speis said in an interview. "But we have a number of candidate issues that we are going to take a look at."

Speis gave four examples. One is the assumption that it is safer to run reactors at low power than at high power. Chernobyl was running at less than one-tenth power when it ran amok. Another is the adequacy of U.S. measures to prevent a scenario known as "anticipated transient without scram" or the failure to insert control rods in a crisis. Chernobyl's rods had been deliberately disengaged. NRC officials want to review the chemisty of severe accidents, for Chernobyl released a far greater volume of lethal fission products than U.S. scenarios forecast, even for the worst accidents. Finally, the government may take a look at the quality of its evacuation plans. The Soviets had to scrap all of theirs because none anticipated the severity of the accident.


Courtesy of K. Wohletz

Blowing off steam. *This experiment, run by Kenneth Wohletz at Los Alamos, illustrates how a powerful volcanic blast can be triggered when water mixes with hot molten material. A similar mixture at Mexico's El Chichón volcano in 1982 shot debris 30 kilometers high. This kind of explosion can occur in some scenarios for nuclear disaster, and probably happened at Chernobyl.*

The prevailing view is that a Chernobyl-type accident could not happen in the United States. It rests on several assumptions about the differences between Soviet and American reactors. One is widely accepted: that U.S. reactors are not vulnerable to the kind of power surge that triggered the Chernobyl disaster.

U.S. commercial reactors are designed to lose power when the core loses water. It is conceivable that a U.S. reactor full of coolant could have a power surge if several control rods were ejected from the core instantaneously. But because the scenario is implausible, it has been little studied. In addition, it might be possible to increase power in a normally running reactor by pumping a large slug of supercooled water into the core. Again, it is hard to imagine how this could happen.

However, the design of the liquid metal fast breeder reactor—whose construction was planned at Clinch River, Tennessee, and has been postponed indefinitely—does have a positive void coefficient. This reactor could gain power with a loss of coolant, as Chernobyl did.

Military reactors fall into another category, one that for reasons of national security has been less examined. They operate outside the NRC's jurisdiction and are said to have strange power dynamics and weaker containment buildings. The Department of Energy has commissioned an 18-month study of their safety by a panel at the National Academy of Sciences.

Other assumptions about the superiority of U.S. reactors are not so widely accepted. For example, even before Chernobyl, critics of the NRC said the agency had understated the threat of explosions caused by molten fuel mixing with water or concrete. Critics also think the NRC has overstated the protection given by containment buildings.

The debate on molten fuel will intensify now, spurred on by Chernobyl and by research coming out of the agency's "source terms" study. This is an industry-inspired effort to define more precisely the damage that could be done by the worst possible accident.

By happenstance, Chernobyl blew up just as the source terms project was coming to an end. The industry believed this research would show that the old damage estimates were too large. It hoped NRC would use less cataclysmic terms to describe nuclear accidents—a hope that may have gone up in the smoke above Chernobyl.

The Chernobyl accident, several physicists say, must have included a "prompt neutron" power burst. The Soviets apparently did not stress this fact but referred to the accident simply as a "steam explosion."

Reactor fuel emits two kinds of neutrons, the "prompt" ones that appear in a millisecond, and the "delayed" ones that may take up to tens of seconds to appear. Reactors are designed to operate so that delayed neutrons sustain the chain reaction, for without the time lag they provide, it would be impossible to throttle the system up and down. No mechanism for controlling tons of fuel moves in fractions of a microsecond. For this reason, all reactors are designed to maximize the total neutron flux without allowing prompt neutrons to dominate the reaction in the core. In contrast, an atomic bomb relies strictly on prompt neutrons.

The big weakness of a Chernobyl-type reactor (RBMK-1000) is that when the system loses water, the power increases—so much so, it now appears, that prompt neutrons may take over. Last April, after disabling nearly all mechanical controls over the fission process, the operators at Chernobyl reduced the water flow. The inevitable followed: the water heated and allowed the power to increase. The reactor went into a rapid power surge, ending in an uncontrollable "prompt neutron burst." This blurs somewhat the distinction between a reactor accident and a bomb. But the distinction remains strong in terms of energy and speed, for the discharge from the fuel was far less energetic than a TNT blast.

Once the process was set in motion, neutron emissions in the core grew exponentially for several seconds, rapidly overheating the fuel. Then the power dropped as heat slowed the chain reaction (due to the Doppler effect) and vapor pressure burst the core apart.

A Soviet mathematical reconstruction of the event shows the core rising from below one-tenth power to 120 times normal in seconds (full power being 3200 megawatts thermal). It then dropped momentarily and finally surged up to 480 times full power. Speis thinks the second power surge may be the result of an error in Soviet calculations.

However, Richard Wilson, a Harvard physicist who chaired the American Physical Society's source term study and who went to Vienna as an NRC consultant, does not rule out the possibility that the reactor surged to over a million megawatts. "Can you design a containment to go around such a system?" he asks himself. "I doubt that you can."

According to Speis, the fuel was subjected to an average heat of at least 300 calories per gram, with some areas getting much hotter. It shattered and was ejected in particle form into the surrounding water, which immediately flashed to steam. The pressure shattered the 1000-ton concrete lid of the reactor and tossed hot graphite and bits of fuel through the roof of the building. In this sense, the Soviets are justified in calling the blast a steam explosion. But Speis and Wilson argue that what happened was very different from any steam explosion that is considered possible in a U.S. reactor.

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The "vast difference," Speis says, is that the fuel at Chernobyl mixed with the water in a fine particle form, whereas in the worst U.S. scenario, it would pour into the water as a large molten blob. Having a greater surface area, particles transfer energy more efficiently than blobs. U.S. research has concentrated entirely on blobs on the assumption that in a U.S. reactor, the overheated fuel would have to take that form. Speis notes that this research shows that it is very unlikely that a steam explosion could breach a containment structure. This is the settled NRC view, and, as a result, Speis says, "We were doing steam explosion research; we are now phasing it out."

Some disagree with this policy, one being the scientist whose budget for steam research is being phased out. This is Marshall Berman of the Sandia National Laboratories. In an NRC-financed analysis in 1984, he declared that the data were too variable to support a clear answer. Some steam explosions convert less than 1% of the energy present to mechanical force. Other experiments show a more efficient pattern of conversion, enough to drive the pressure vessel head through the roof.

Berman concluded that the likelihood of a steam explosion breaking a hole in a U.S. nuclear containment ranged between the impossible and the inevitable. The NRC was dissatisfied with this answer, and therefore commissioned a new panel of experts, the Steam Explosion Review Group.

The SERG experts were polled for their opinions of the likelihood of a steam-driven catastrophe. Without doing new research, they concluded in 1985 that it was almost impossible. In writing the report, they added that it would be helpful to conduct some experiments to confirm this opinion.

Berman then wrote a memo describing SERG's data as "gambler's estimates . . . essentially guesses" that "cannot be supported on technical grounds." He found the method of polling experts for their personal opinions to be nonscientific.

In a separate memo, NRC staff scientist Joram Hopenfeld rated the expert opinions for credibility. He noted that "none of the 13 experts provided an estimate of containment failure which is technically defensible." The fuel core contains more than enough energy to blow the top off the reactor vessel and send it through the containment. So the problem, Hopenfeld explains, is that to argue this cannot happen, one must have some fairly credible physical evidence. Yet, Hopenfeld wrote, "There is no indication that the members fully utilized the available large-scale industry steam explosion experience." He found that very little confidence could be placed in the SERG estimates.

Nevertheless, the NRC forged ahead, citing SERG's opinions in a source term document issued in July (NUREG 0956). It states that a catastrophic steam explosion inside the reactor vessel is "considered to have a low probability and its analysis is not included" in computer programs that are used to estimate the impact of a severe accident.

This issue may have to be reexamined now, along with others involving the strength of containment buildings. One who intends to see the debate revived is Daniel Hirsch, a critic of NRC policy at the University of California at Santa Cruz.

Hirsch claims that "U.S. containments, like the pressure boundaries for Chernobyl, are not required to be designed to withstand the challenges of core melt accidents." He ticks off some of the problems Chernobyl will bring forward: the risk of molten fuel reacting with concrete to produce an explosion, the possibility that melted fuel sprayed from a reactor vessel might overstress the containment, the particular weaknesses of the Mark I boiling water containment system (identified by the NRC as vulnerable), and the discrepancy between the large volume of iodine released from Chernobyl and the low amounts assumed to be released in U.S. accident models.

This is hardly an uplifting agenda from the nuclear industry's point of view. But after Chernobyl, it may prove unavoidable. ■ ELIOT MARSHALL