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Chernobyl: worst but not first

Until Chernobyl, only two nuclear reactor accidents had spread significant amounts of ionizing radiation beyond the site of the mishap: a fire at the Windscale No. 1 plutonium production pile in northwest England in 1957, and a 1961 accident at an experimental prototype reactor in Idaho which killed three servicemen.

Both the Stationary Low-Power reactor (SL-1) involved in the Idaho accident and the Windscale reactor were of novel and inadequate design; in a sense they were accidents waiting to happen. For that reason the Western nuclear industry now - perhaps too hastily - discounts those two accidents as minimally relevant to nuclear safety in the 1980s. It could make a similar mistake about Chernobyl.

The Windscale No. 1 pile was the first large-scale reactor built in Britain; a second was built beside it. Each was cooled by blowing air through the fuel channels in the graphite core and discharging the air directly back to the atmosphere through a tall stack. This primitive system was dictated by the political urgency of Britain's bomb program, but it made the responsible scientists and engineers acutely nervous.

While Sir John Cockcroft, head of Britain's Harwell nuclear center, was on a visit to Oak Ridge National Laboratory in the late 1940s, the reactor malfunctioned, sending radioactivity up the stack to settle on the site. Cockcroft returned to Britain insisting that a way be found to ensure that fuel damage in a Windscale reactor would not release uncontrolled radioactivity into the surroundings. Unfortunately, the concrete structures had already risen well past ground level. Filters could be installed only at the top of the stacks, which were duly modified to include filter galleries: cumbersome crosspieces that became known as "Cockcroft's folly."

In a graphite-moderated reactor, neutron bombardment eventually displaces carbon atoms in the crystal structure, storing energy which can be suddenly released in a surge of heat. After disconcerting experiences with this effect, the Windscale authorities instituted a procedure to shut down the cooling fans and allow the reactor core to heat up, releasing the energy under controlled conditions. On October 8, 1957, the operator on the No. 1 pile was carrying out this procedure. According to instrument readings the core temperature had not risen sufficiently to release all the stored energy from the graphite. At about 11:00 a.m. the operator shut down the fans again, to boost the temperature. He did not know that the thermocouples in the core were inappropriately placed to register the temperature profile with the fans shut down. Part of the core was much hotter than he realized, and one or more of the aluminum-clad uranium metal slugs caught fire.

For some hours no one even noticed, but when the cooling fans were restarted the fresh air accelerated the fire. Instruments in the filter gallery atop the stack began to register radioactivity, alerting the staff that something was wrong. By looking directly into the open ends of the fuel channels - a foolhardy measure - they saw just how wrong: both the uranium and the graphite were burning.

No one had any convincing idea how to quench the fire. Water might react with blazing metal to produce hydrogen, threatening not only a fiercer fire but an explosion that could blast open the reactor and scatter radioactivity far and wide. Switching off the cooling fans reduced the oxygen supply, but the reactor temperature rose alarmingly and the fans had to be restarted. A tankerload of liquid carbon dioxide for the nearby Calder Hall reactors was diverted to the burning Windscale pile. But the temperature of the fire was so high that the oxygen from the carbon dioxide simply intensified the blaze.

While the site staff grappled with the fire, the United Kingdom Atomic Energy Authority, operators of Windscale, said nothing to the outside world. Not until the early hours of Friday, October 11, after the fire had been burning for well over two days, did the Authority notify the local chief constable of a major emergency. During the night, in desperation, the staff attached fire hoses to the line of fuel channels just above the fire. The Windscale general manager and his deputy, together with the local fire chief, then ordered the evacuation of everyone else from the site. At 8:55 Friday morning the three men turned on the fire hoses.

There was no explosion. Slowly the fire died. The Authority publicly declared that the radioactivity from the stack had been carried harmlessly out to sea. The government nevertheless decreed that milk from the surrounding farmland, an area of some 500 square kilometers, had to be poured away, to avoid exposure to radioactive iodine. The filters on the stack had, however, trapped most of the particulate radioactivity, amply justifying Cockcroft's stubborn insistence on them.

Only in subsequent years did it become clear how incomplete and misleading the official information was at the time of the fire. The radioactive iodine had not been carried out to sea; on the contrary, the wind had borne some 20,000 curies of it the breadth of England and across much of Northern Europe. Furthermore, as was revealed only in the 1980s, the reactor had been irradiating material to produce bomb triggers; the release had also included a significant quantity of the dangerous alpha-emitter poloniurn 210. British nuclear critics published an analysis indicating that the population exposure resulting from the Windscale fire, far from presenting no hazard to the public, would have caused upwards of 30 extra deaths from cancer. The government's National Radiological Protection Board confirmed these findings in November 1983.

The official inquiry into the Windscale fire made its report in 1958, but the full text was never published. The inquiry concluded that it would be too expensive to modify the No. 2 reactor; both reactors were permanently shut down and plugged with concrete.

Today the massive concrete stacks at the site, now called Sellafield, are showing obvious signs of age. British Nuclear Fuels, which has operated the site since 1971, concedes that something will have to be done about the two defunct reactors. However, dismantling them - especially the heavily contaminated No. 1 pile - and disposing of the radioactive rubble, with minimal radiation exposure of workers and the public, will pose a daunting technical challenge. No one yet knows how much it will cost, but one way or another the funds will come from Britain's taxpayers.

A more immediate cleanup had to be undertaken in the United States in 1961, after the accident that destroyed the SL-1 reactor at the National Reactor Testing Station at Idaho Falls (T.S. Thompson and J.G. Beckerley, *The Technology of Nuclear Reactor Safety,* MIT Press, 1973; personal communication, Diana Orr, director of the film *SL-1*, May 1986.). The SL-1, with an output of three thermal megawatts, was a water-cooled reactor with a compact core. By a lack of foresight that was later severely criticized by Atomic Energy Commission analysts, the design was such that withdrawing a single control rod, the one in the center of the core, could produce prompt supercriticality.

On January 3, 1961, three young servicemen were carrying out maintenance on the control-rod drive motors. To this day no one knows precisely why, but somehow, at about 9:00 p.m., the central control rod was lifted - not to the normal 10 centimeters, but to about 50. Subsequent investigations have suggested that the withdrawal might even have been intentional - that one of the three might have chosen a bizarre and gruesome form of suicide. Whatever the reason, the effect was instantaneous. The surge of heat flashed the coolant to steam, shattering the core, blowing the control rods out of their channels and lifting the entire reactor vessel three meters, demolishing the floor above it. Alarms sounded in nearby locations, but when site staff attempted to enter the SL-1 building they were driven back by radiation fields of more than 500 rem per hour.

A rescue party nevertheless dragged out two of the SL-1 workers. One was already dead; the other died in an ambulance on the way to Idaho Falls. The rescue operation and removal of the briefly surviving victim spread radioactive contamination on rescuers' clothing, equipment, and vehicles well beyond the SL-1 site itself. At first the rescue team could not account for the third worker; his body was finally found impaled by a control rod against the roof of the reactor building. Recovering the body was an extraordinary task, with the outdoor temperature some 15 degrees below zero and the radiation levels inside the building far too high to permit direct access for more than a few minutes per person. Heavy machinery cut a hole through the outer wall of the reactor building; a crane thrust a net through the hole. Relays of staff took turns with poles to pry loose the frozen, heavily contaminated body and drop it into the net. It was lowered into a shielded container on a flat-bed truck, to be taken for remote-handling examination and eventual burial. All three victims were so radioactive that they had to be interred in lead-lined coffins.

Cleaning up the contamination scattered around and away from the site by the futile rescue operation was the first priority; then the ruins of SL-1 were decontaminated and dismantled. Before the end of 1962, the building and its demolished contents had been removed for disposal as radioactive waste. In the course of the operation several hundred workers are known to have received significant radiation exposure.

Some evidence indicates that exposures to rescue workers during the night of the accident were much higher than subsequent official records suggest. In the emergency, workers were not necessarily scrupulous about wearing film badges; later they minimized the estimates of their possible doses to avoid being reassigned to non-nuclear duties. Similar behavior patterns occurred during the Windscale fire (personal communication, Windscale staff, various dates).

Despite differences in technology, scale, and circumstances, the Chernobyl accident has much in common with the Windscale fire and the SL-1 explosion, as well as with a number of other nuclear mishaps. Although each incident was unique, each involved an unexpected collision between humans and hardware, giving rise to confusion and threatening to burgeon into a major catastrophe. At Chernobyl the threat became reality.

Several common threads run through these events:

* *Unexpected technical conditions.* The Windscale fire occurred during a procedure devised to cope with a problem unforeseen in the original design. The operator was misled by instruments giving an inaccurate picture of the status of the reactor during this abnormal procedure. The 1966 accident that crippled the Enrico Fermi-1 fast breeder in Detroit was caused by a safety device added belatedly at the insistence of the Advisory Committee on Reactor Safeguards. The device came loose inside the core and blocked the coolant, causing a meltdown of two fuel elements.

* *Immediate confusion.* After the Three Mile Island accident, the authorities released so much inconsistent and contradictory information that no one knew what to believe. The British nuclear authorities were at least as secretive about the Windscale fire as were the Soviets about Chernobyl. The desperate frenzy of the hours after the Chernobyl accident makes the failure to communicate

understandable, if culpable. In all three accidents monitoring of off-site releases was limited and ad hoc, and emergency planning ineffectual.

* *Human error*: Humans do bizarre things to nuclear technology. Electricians using a lighted candle to check for drafts set fire to cable insulation at Brown's Ferry, Alabama, in March 1975 and came close to destroying the plant. A technician dropped a tiny light bulb into the control panel at Rancho Seco, near Sacramento, California, in March 1978; it short-circuited a main electrical supply and scrambled the input from instruments to the plant computer. For more than an hour the computer started and stopped pumps and opened and closed valves on the basis of spurious data, while the operators fought to get the reactor back under control. During the Three Mile Island accident, incorrect instrument readings told operators that the water level was dangerously high, when in fact it was dangerously low; they then shut off the emergency cooling systems just when they were most essential.

Any operating power reactor, of whatever design or size, contains a substantial inventory of hazardous radioactivity and a reservoir of energy capable of discharging it into the environment., Safety engineering tries to reduce to the minimum the probability of such an event and to mitigate the consequences should it occur. Yet human error affects nuclear technology not only in the control room but also at the drawing board and on the construction site. Every nuclear accident is ultimately the result of human error at some point. Given the potential for widespread, long-term catastrophe, the fundamental human error may be to believe that fallible humans can design, build, and operate any technology that does only what it is expected to do. After Chernobyl we should know better.