Ten years after Chernobyl: What have we learned?

by Marjorie Mazel Hecht

In the ten years since the explosion and fire at the Chernobyl-4 nuclear power plant in Ukraine, what stands out most starkly is what has *not* been done. The Western nations have bewailed the nuclear safety standards in the former Soviet Union, and the United States and Europe have taken measures to evaluate the safety of Soviet-designed plants, improve safety standards, and train workers into what is called the "safety culture." Some in the West, even some in the nuclear industry, have called for the shutdown of the Chernobyl-type reactors as never being safe enough, no matter how they are retrofitted, while the radical environmentalists have called for the shutdown of *all* nuclear reactors on principle.

But in all the diplomatic and technical meetings, summits, and negotiations over the past ten years, no one has mentioned the simple fact that the capability now exists, using state-of-the-art designs, to complete a standard, 1,000-megawatt light water reactor in less than six years, as the French regularly do (and as the Japanese recently demonstrated with the completion of a GE-designed advanced boiling water reactor in 52 months). Smaller, modular plants could be completed in even less time.

In other words, had there been the political will, during the past ten years, the Chernobyl-style reactors in Russia and the newly independent states could have been *replaced* with standard light water nuclear reactors.[1] And with a little more effort, we could have turned out, via factory production, some of the new, next-generation modular reactor designs, including a next-generation Russian design. Such a program might cost, conservatively estimated, $2 billion per new plant. But measured in lives improved, and productivity increased because of an assured source of electricity for powering industry and heating homes, such nuclear plants would in the long run pay for themselves.

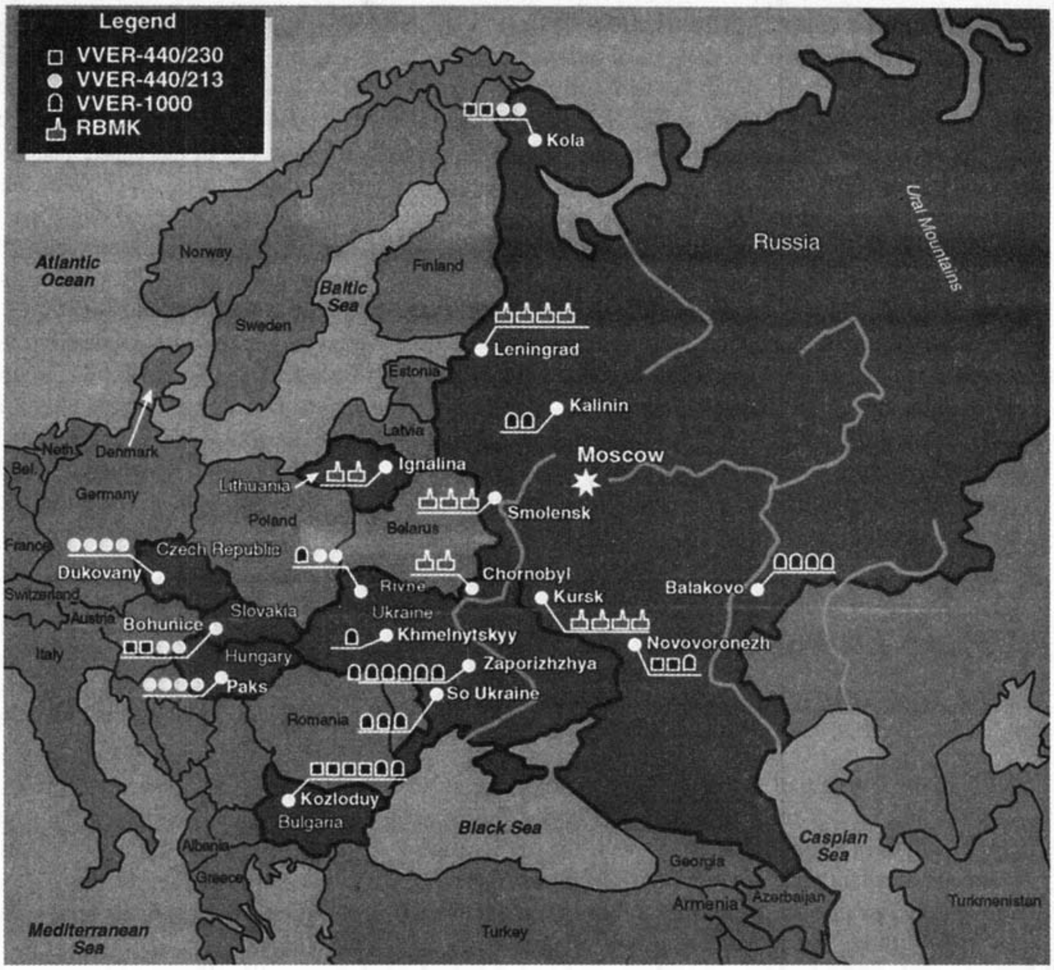
1. The only political figure to put forward a nuclear development program in this period was Lyndon H. LaRouche, Jr., whose "Productive Triangle" program for transforming Europe into a locomotive for Eurasian development included a power grid based on modular, high-temperature reactors (HTRs).

FIGURE 1

Nuclear reactors in eastern Europe

There are two basic types of Soviet-designed reactors: the RBMK design (Chernobyl reactors are of this type) and the VVER series, a more standard light-water reactor. Under an international agreement reached at the Group of Seven summit in 1992, the United States and other nuclear countries are working with the former East bloc States to upgrade the safety of the 59 Soviet-design nuclear reactors, including two at the Chernobyl site. The U.S. program for Soviet-Designed Reactor Safety is managed by the Pacific Northwest National Laboratory for the U.S. Department of Energy.

Source: Pacific Northwest National Laboratory, Soviet-Designed Reactor Safety Program.



But loans for such a crash development effort are excluded from the agenda of the World Bank and the International Monetary Fund. In fact, the United States and the European Union have struggled to eke out even the funds for retrofitting the Chernobyl-style plants and making safety upgrades on the other types of Soviet-built plants. (Since 1992, the Group of Seven nations have donated only $122 million in nuclear safety assistance to Ukraine.) Despite the clamor from the United States and Europe for the shutdown of the two remaining on-line reactors at the Chernobyl site and of the 13 similar plants in the former Soviet Union, there has been little consideration of how to replace the vital power now provided by these plants, an omission that has rankled both the political leaders and the nuclear scientists and engineers in those countries.

Negotiations with Ukraine have been very touchy on this point. There has been official "agreement" since December 1995 that Ukraine will close the two remaining Chernobyl units by the year 2000, *if* the funds are forthcoming to complete three nuclear plants of a more standard design now under construction in Ukraine, and to implement a safe shutdown of the Chernobyl site. (This would take about $4 billion.) Ukraine, already beset by brownouts caused by power shortages, cannot turn out the lights—and turn off the heat—by shutting down the Chernobyl units, for such a decision will mean the certain death of thousands of its citizens.

The most radical environmentalists advocate no replacement power sources—just conservation. The U.S. Department of Energy has not gone that far: The official DOE study of replacement alternatives for Ukraine, issued in July 1994, proposes (in this order): "wind power, which is a significant renewable energy option for Ukraine"; "substantial efficiency improvements, which are possible for industrial equipment in Ukraine"; "completion of five new nuclear power plants, which represent a potential source of 5,000 MW"; and "upgrading five fossil-fuel power plants, which could provide approximately 2,000 MW of electricity."

Ukraine intended to put the problem on the agenda of the mid-April summit of the industrialized nations in Moscow, the Group of Seven. As Ukrainian Foreign Minister Hennady Udovenko told Reuter on March 19: "We intend to raise this issue and tell the G-7 the real situation. Last year was completely lost on negotiations. Ukraine cannot resolve this issue on its own."

The real health effects of radiation

There are very real, specific dangers of radiation releases, and this subject has been much studied and refined since the atomic bombings of Hiroshima and Nagasaki in August 1945. Those bombings killed 67,000 people within the first day, and injured thousands. In the Chernobyl accident, 31 deaths occurred as a result of the immediate radiation release, all of them plant workers or others involved in the initial response to put out the fire at the plant. One of the deaths was immediate, and the others were within four months. There are about 200 other surviving victims of acute radiation sickness, and 400,000 uninjured exposed people.

Although the popular perception is that any dose of radiation is harmful and that the radiation release from the bombings and from Chernobyl were the same, this is not the case. Low-level radiation is not necessarily harmful, and may in fact be beneficial. The tremendous radiation releases from the atomic bomb are a different matter. The deaths from the atomic bomb explosions were directly proportional to the amount of energy released by the blast, the heat, and the radiation. In the bombings, 50% of the energy released was from the blast, 35% from the heat, and 15% from the radiation; the causes of death are in corresponding proportion. At Chernobyl, in contrast, the explosion's blast and heat released relatively small amounts of energy.

An interesting comparison of the radiation and health effects in both cases appears in *Health Effects of Low-Level Radiation,* by Sohei Kondo, a Japanese radiation expert at the Atomic Energy Research Institute of Kinki University in Osaka (published in English by Medical Physics Publishing of Madison, Wisconsin in 1993). Professor Kondo, now 84, discusses how he was motivated to write this book after

What happened at Chernobyl

Early in the morning of April 26, 1986, plant operators at Chernobyl's Unit 4 were testing the ability of the plant equipment to provide electrical power if the main power source at the plant were not working. The plant was being run at very low power. Adequate safety precautions were not taken; there was a sudden, out-of-control surge of power. The sudden increase in heat ruptured the fuel, which then reacted with water to cause a steam explosion. The force of the explosion blew the 1,000-metric-ton cover off the top of the reactor and destroyed the reactor core. A second explosion followed.

Highly radioactive fuel was released into the atmosphere—radioactive iodine, cesium, and other isotopes. Wind and rain then spread this radiation irregularly (depending on weather conditions) over a large area of Ukraine, Belarus, and Russia. The Soviet authorities did not immediately tell the residents of Pripyat, the town adjoining the Chernobyl complex, to stay indoors; nor were surrounding regions warned.

Pripyat was evacuated two days later, although the 45,000 residents were not told exactly what was happening, and left without their belongings. In early May, another 10,000 residents within a radius of 6 miles were evacuated, and then another 116,000 were evacuated within a radius of 18 miles. This exclusion zone is still in force, although many people, mostly elderly, have been allowed to return to their homes.

Firefighters from Pripyat, who were trained to know the dangers of fires at Chernobyl, arrived on the scene within three minutes and immediately set to work. They had two urgent tasks: to isolate the fire from the remaining three nuclear reactors on the site, and to make sure that the pool of radioactive water around the damaged reactor was pumped out of the way. Had more hot fuel from the damaged reactor come into contact with the water, there would have been another, more serious explosion.

Meanwhile, helicopters flew over to measure the radiation, while others dumped quantities of lead, sand, clay, boron, and dolomite onto the reactor to stop the radioactive emissions. By May 6, the radioactive releases from Unit 4 had stopped.

The radiation danger

The 31 deaths at Chernobyl occurred among the firefighters and others involved in the immediate cleanup, many of whom received massive doses of radiation. About 200 others in this group were also treated for acute radiation sickness and survived. Others who continued to work on the cleanup were officially limited to a dose of 25 rems, but the record-keeping concerning the dose received was slipshod. It is estimated that of the 600,000 cleanup workers at Chernobyl, one-third had radiation dose rates four times the normal annual dose for a radiation worker.

Radiation in high doses attacks the entire body. In addition to burns on the skin, internal organs are damaged. Both bone marrow and liver tissue transplants were carried out on all patients, even on those whom the doctors thought were certain to die. (It was later determined that such transplants were not useful.) American specialists joined the Moscow radiological specialists in early May, including Dr. Robert Gale, a hematologist.

At present, there are several joint programs with European nations to train medical personnel to carry out the record-keeping necessary for accurate follow-up health studies of the people in the contaminated areas.

Chernobyl, because he was so shocked at the proliferation of misinformation, even among professionals.

The main cause of death at Hiroshima and Nagasaki was bone marrow injury from gamma rays and fast neutrons,[2] Kondo reports. At Chernobyl, he says, "the major causes of radiation-induced death were skin burns and intestinal injuries due to irradiation with beta rays from externally or internally deposited radioactive nuclides."

Using the knowledge accumulated over the past 50 years in studies of Hiroshima and Nagasaki survivors, radiation experts have calculated what the expected increases in cancers and congenital abnormalities might be, based on the measured radioactive fallout in the areas around Chernobyl that were contaminated with cesium-137 and other radionuclides after the accident. The National Commission for Radiological Protection of the Soviet Union, estimated in 1990 that, over the next 70 years, the total number of cancer deaths above the normal expected number in the heavily contaminated areas, would be 21 from leukemia and 244 from other cancers. While no "excess deaths" are to be treated lightly, these very conservative estimates over a 70-year period contrast sharply with the frightening anecdotal reports in the media.

The projected figures for expected congenital anomalies caused by radiation for children born to parents who live in the highly contaminated areas are 1.9% above the spontaneous level of 6% for children born in the year of the accident. For children born within 30 years of the accident to parents in the highly contaminated areas, the estimated increase in congenital anomalies is 0.4%.

These estimates were completed in 1990. What are the latest figures of reported cancers? In the general population in the affected areas of Ukraine, Belarus, and Russia, there has not been a significant increase in the number of cases of cancer among adults, except thyroid cancer. This is as expected, based on previous knowledge; for many cancers, the latency period is more than ten years.

Measuring radioactivity

As an atomic nucleus decays, it breaks apart into particles—alpha particles (helium nuclei), beta particles (electrons), gamma rays, and neutrons. Radioactivity is measured in the number of nuclear disintegrations per unit of time.

The strength of a radioactive source is now measured in bequerels, with 1 bequerel being 1 disintegration of an atom per second. (Formerly, the standard unit was the curie, 1 curie being 37 billion nuclear decays per second.) How long it takes half of the original amount of an isotope to decay, is called the half-life of the radioactive isotope.

Radiation absorbed in living tissue is measured in rems and millirems, 1 rem being the radiation that transfers 6×10^7 million electron volts of energy to a gram of biological tissue.

A large dose of radiation, 750 rem, almost certainly means death within a few weeks (although some with this dose working on the Chernobyl cleanup lived). With a dose of 450 rem, there is a 50% chance of recovery; with a dose of less than 200 rem, recovery is almost certain. A dose less than 150 rem produces no other signs than a temporary lowering of the red blood cells, and for doses less than 25 rem, even this sign cannot be observed.

The International Commission on Radiation Protection recommends that the maximum permissible dose to the general public from nuclear energy sources be limited to 0.17 rem per year. On average, Americans receive 0.13 rem per year from natural radiation sources—cosmic rays, radioactivity in the body, and radioactivity in building materials.

The latest health statistics

At an international meeting on the Radiological Consequences of the Chernobyl Accident, held in Minsk, Belarus, March 17-24, the most recent reports are that there are about 1,000 cases of thyroid tumors among adults in Belarus, half of which may be attributable to Chernobyl, and 900 cases of thyroid cancer in children, of which about 850 are attributable to Chernobyl. Dr. Richard Wilson, a nuclear physicist at Harvard University who has been actively involved with scientists, medical doctors, and political figures in Russia, Belarus, and Ukraine from the outset of the accident, reported from the Minsk meeting that the medical work on the thyroid cancer is of high quality. There is a histopathology laboratory set up as part of a thyroid clinic, financed by German funds, in which each cancer is analyzed and preserved on slides for future study.

In a short report on the Minsk meeting, Wilson raised a few questions: "Are the cancers curable? Ninety percent of natural thyroid cancers in the U.S.A. are curable," Wilson says, "and almost all among children. These children in Belarus are getting the best treatments that Europe can offer and only 3 deaths out of the 900 cases are reported so far. But there may be recurrences."

Wilson also asks: "Will the childhood cancers cease after eight years, as [did] the childhood leukemias after *in utero* radiation? [He refers here to the sharp drop in the incidence of

2. There are five types of ionizing radiation: alpha particles, which do the most damage but can be stopped by paper; beta particles, which do less damage, but can penetrate living tissue; neutrons, which are both penetrating and damaging; and gamma rays and X-rays, which can be blocked only by concrete or lead.

The Soviet-designed RBMK

The four Soviet-designed RBMK reactors at the Chernobyl complex are light-water-cooled, graphite-moderated, 1,000-megawatt reactors. In the early years of nuclear power development, graphite reactors were used for research and for producing plutonium. But in the 1950s, the design was considered inappropriate by Western nuclear contractors for civilian power plant development. The Soviets began building RBMKs in the 1970s.

The RBMK is totally different from the standard light-water reactors used in the other nuclear nations. Most important, in the standard Western-style light water reactors, when the coolant is lost, the nuclear chain reaction automatically stops. This is called a *negative void coefficient.* In contrast, the RBMKs have *positive void coefficients.* This means that if the power goes up, the reactivity goes up. As the higher power boils more water, the coolant water inside the fuel channels is reduced in density, and the reactivity of the fuel is increased.

Another important difference is that RBMK reactors have no containment buildings—the standard containment structure of steel and concrete that is a final barrier against radiation releases outside the plant.

The RBMK has blocks of graphite with channels running through it for the fuel rods. The fuel elements are encased in zirconium and water-cooled both inside and out. Although graphite is a good moderator and is relatively cheap, it has a high chemical affinity for water vapor, carbon dioxide, and metals, and the energy stored in the graphite is unstable. If the stored energy is released suddenly, it causes an enormous release of thermal energy. Therefore, graphite-moderated reactors have procedures to allow for controlled and gradual periodic heating of the material so that "annealing" of radiation damage can take place in order to prevent a catastrophic temperature rise.

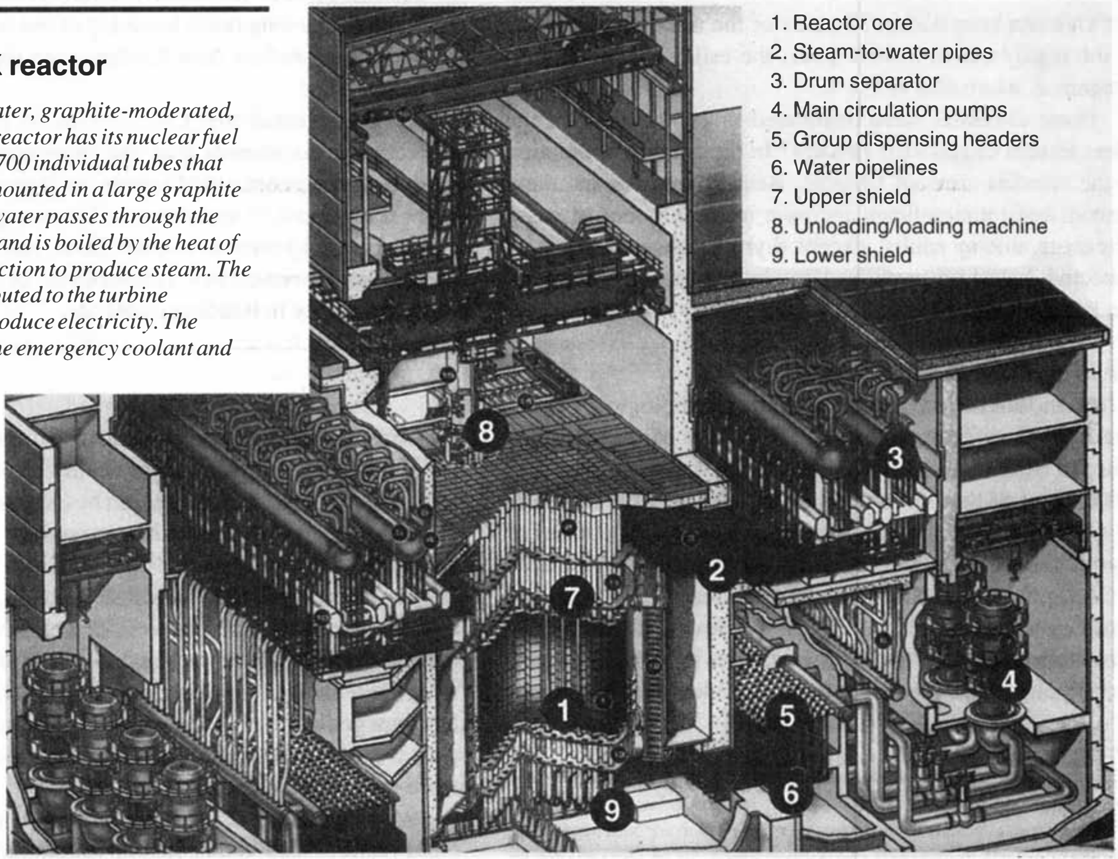
There cannot be a meltdown in a graphite reactor, because the graphite will not get hot enough. But, if the graphite catches fire, that fire is dangerous and very difficult to extinguish. And if water is poured on it, the water attacks the zirconium, opens the casings of the fuel elements, and lets out the fission products.

The Soviet-designed VVER reactor is a pressurized, light-water-cooled and -moderated reactor, more similar to Western models.

FIGURE 2

The RBMK reactor

This boiling-water, graphite-moderated, pressure-tube reactor has its nuclear fuel contained in 1,700 individual tubes that are vertically mounted in a large graphite core. Cooling water passes through the pressure tubes and is boiled by the heat of the nuclear reaction to produce steam. The steam is then routed to the turbine generator to produce electricity. The reactor lacks the emergency coolant and other safety systems found in standard light-water reactors in the West, and has no containment building.



Source: Pacific Northwest National Laboratory, Soviet-Designed Reactor Safety Program.

leukemia among children whose mothers were X-rayed during pregnancy.] If so, the 1,000 so far may be the total. Or will the relative risk stay high for the rest of life, in which case many tens of thousands will ultimately appear? Western medical help must assume the worst while hoping for the better."

Finally, Wilson asks why there are so many cases of thyroid cancer. He notes that of the multiple reasons, the saddest is the deliberate failure of the Politburo to take the simple preventive measure of warning people not to drink milk in the immediate period after the accident. Radioactive iodine, I-131, which collects and remains in the thyroid, has a half-life of only 8 days. If the population had been warned not to drink milk (the main pathway of I-131 through the food chain) for a week or so after the accident, these thyroid cancers would have been prevented.[3]

Wilson writes that he himself appealed to the Soviet authorities on this matter at the time, as did other Western scientists, to no avail. He also acknowledges the difficulty at that time of local officials going against the orders of the Politburo.

The other antidote against I-131 is to administer iodine tablets; once the thyroid absorbs this nonradioactive iodine, the radioactive iodine will be excreted through the body's urine harmlessly. But the Soviets refused a U.S. offer to supply iodine tablets on May 2, 1986. It was about May 25 before an official restriction on milk was issued and iodine tablets were distributed to 1.6 million children. By then, the damage had been done.

"This is a crime," stated radiation expert Dr. Zbigniew Jaworowski, of the Central Laboratory for Radiological Protection in Warsaw, Poland. He noted that at the time, the KGB had cut off all the telephone lines to Chernobyl. Based on the radiation readings in Poland after the accident, Jaworowski fought for immediate action. Prophylactic iodine administration began in Poland the evening of April 29, and milk restrictions began that morning. (Children were allowed powdered milk.) In all, 18 million people, including 10.5 million children, were treated. Jaworowski estimates that this speedy action saved 5,000 children from thyroid cancer in Poland.

Other cancers

Although there were predictions of massive increases in leukemia, especially among children, according to the reports at the Minsk meeting, these have not occurred. Richard Wilson notes in his summary of the Minsk meeting, "No other increases of cancer have been seen or were expected."

The politics of cancer reporting can be seen in this comment in Wilson's report: "Dr. Eugene Ivanov, who made some of the more pessimistic predictions, has studied the leukemias carefully. Until the end of 1995 there is *no* visible increase in childhood leukemia, although any increase should have started in 1991. This will shortly be published (in English) in a European journal. The (present) government of Belarus did not like this conclusion and it was reported to me orally that this is a reason that Dr. Ivanov is no longer director of the hematology clinic."

The other factors that must be taken into account in looking at the health effects of Chernobyl are the poor state of both health conditions and health reporting that existed before the accident, and the traumatic effect of the accident on the population psychologically. In an interview with *21st Century Science & Technology* in Summer 1993, Dr. Wilson comments: "One of the reasons it is very hard to assess the overall health situation in the Ukraine and [Belarus] at the present time is that the Soviet Union never had very good health records on anything except death rates. . . . To ask what are Chernobyl's effects on health, you have to know what the health facts were before, what they are now, and how they have changed. Since the only reliable measure we had before is death rates, we can only discuss death. There is a problem in assigning any specific disease to Chernobyl."

Wilson, who has helped set up computerized health record keeping in Belarus, noted that the number of deaths being attributed to Chernobyl at that time—15,000—were equal to the normal number of deaths reported in that area from natural causes.

The most drastic health statistic, however, is rarely reported: Throughout eastern and western Europe, in the few months immediately following the Chernobyl accident, there were an estimated 100,000 to 200,000 abortions that were motivated not by any real danger of radioactive fallout to the unborn fetuses, but by fear of radiation-caused birth defects.

A political problem

The political nature of the government response to the accident and the continuing health effects have been widely discussed over the past ten years. There is no question that the Soviet bureaucracy delayed public notice of the accident and then misinformed the public and the world concerning Chernobyl in the first few days. As noted above, the population was not even warned about a simple preventive measure concerning radioactive iodine.

The bureaucratic delays continued. In the first few years after the accident, scientists, engineers, and health workers at Chernobyl pointed to "the bureaucracy" as the enemy, the main obstacle in getting done what they, as experts, thought should be done immediately. A British documentary film made about the team of scientists who were building the sarcophagus to contain the damaged reactor, makes this painfully clear.

After the wall came down, the bureaucratic problem was compounded by the lack of funds, as the newly independent nations found themselves without the hard currency to keep basic infrastructure going, to pay wages, and to develop. The so-called free-market reforms, as amply documented in *EIR,* only made a bad situation worse. Living standards plummeted.

It is in this context that the indigenous claims of vast and awful health effects have to be looked at. The lies and misinfor-

3. The thyroid gland holds a limited amount of iodine, which it uses to make metabolic hormones. No other organ accumulates iodine.

mation on the part of the Soviet bureaucracy have created a situation where a great many things, physiological and psychological, are now blamed on radiation. Two parliamentarians from Ukraine told me four years ago that there were 100,000 dead because of Chernobyl. As much as I could empathize with their anguish at the disruption of lives and of the entire nation as a result of the accident, it was clear that they were using these inflated death figures to try and get Western funds in to help the dire economic situation in Ukraine. For the U.S. officials who pick up these figures without any evaluation—including some State Department officials—there is no excuse. They rank with the greens who cry about imaginary death counts and future death counts, while they fight for policies that would, without a doubt, kill millions.

Improving the safety of Soviet-designed plants

After Chernobyl, the nuclear community in the West mobilized to work with their counterparts in Ukraine and Russia, in order to increase the safety level at all 59 Soviet-designed nuclear power plants in Russia, Ukraine, and central and eastern Europe. Both multilateral and bilateral programs are ongoing, and a Nuclear Safety Account, funded by the countries of the G-7 and the European Union, has awarded grants to Bulgaria, Lithuania, and Russia for upgrading plants.

The United States established a Joint Coordinating Committee on Civilian Nuclear Reactor Safety with several working groups to study different safety problems. The Department of Energy and the Nuclear Regulatory Commission are both involved, along with the national laboratories. In addition to governmental programs, the World Association of Nuclear Operators (WANO) was created in 1989 in response to the accident, and has arranged visits for nuclear plant operators from the former Soviet states to plants in other nations, and vice versa.

The activities of the U.S. program were wide ranging: establishing basic fire safety systems in specific plants, working out a maintenance improvement program, establishing emergency operating instructions, and supplying a full-scope operator simulator for training in realistic operating conditions. At Chernobyl, for example, new fire detection and protection equipment and materials, specified by the nuclear power plant staff, are being supplied by Bechtel Power Corp. New nuclear training centers were set up and supplied with materials to provide structured safety training for plant operators.

One of the U.S. leaders of this program, in a recent presentation to scientists at Brookhaven National Laboratory in New York, stressed that safety procedures and safety equipment that are taken for granted in American plants simply don't exist in the Soviet designs.

Tragedy and heroism

Why this should be the case is not an easy question to answer. On the one hand, Soviet nuclear scientists are highly trained, dedicated, and proud of their achievements. On the other hand, the former Soviet regime had a crassly careless attitude about the lives of ordinary people. Still another point of view was put forward by Dr. Vladimir Minkov in a recent interview. Minkov, who heads the International Energy Technology Center at Argonne National Laboratory in Illinois, and who emigrated from Belarus in 1978, said, "Americans don't understand how poor countries, where people are starving, may decide to skimp on Western-style safety standards in order to stop starvation."

The tragedy of Chernobyl, and the tragedy of the Western nations' refusal to consider it a necessity to develop the States of the former Soviet Union and to build new nuclear power plants as part of a development program, was vividly brought to mind in a 1991 British documentary, "Inside the Chernobyl Sarcophagus." This film interviewed the team of nuclear scientists who were concerned after the accident to determine whether another chain reaction and explosion could occur inside the damaged reactor building. To answer this question, they had to find the remaining reactor nuclear fuel that had melted down; it was nowhere to be seen in the easily accessible areas of the damaged reactor. (In all, there was 190 metric tons of uranium dioxide fuel and fission products in the reactor core, of which perhaps 30% escaped into the atmosphere.)

The working conditions were extremely hazardous. There was radioactive dust that could be stirred up and escape the enclosure if they made a false move; debris from the explosion was everywhere. The damaged reactor, whose core had melted and sunk, had its 1,000-metric-ton reactor lid precariously poised inside the shell of the core.

The film showed some of the first shots of the inside of the damaged reactor building. The film crew, well-protected in Western-style protective suits and equipment, followed the scientists through the labyrinth of debris-laden reactor rooms, as they pursued their dangerous search. Sometimes they had to crawl through holes in the wall or cut their way through obstacles, all the while carefully keeping track of the radiation dose they were accumulating. The scientists matter-of-factly discussed the dangers they knew they faced: "We do not have the technology to work safely in these conditions, with high levels of radiation," said Viktor Popov, head of the sarcophagus diagnostics laboratory. "But the job has to be done. . . . Somehow, the problem has to be solved."

Popov and others were keenly aware of the high levels of radiation they were subjecting themselves to—without the usual protective gear. In one typical scene, as the scientists were discussing how long they could stay in an especially "hot" area, you could see that they were protected only by cotton masks on their faces and plastic bags over their shoes and clothing. Where was the Western aid back then—1988—which could have easily provided them with standard, not overly costly radiation protective equipment and special suits, at a time when they were carrying out one of the most difficult—and most important—engineering missions in the world?

Aleksander Borovoi, the leader of the expedition, raised the obvious question: "We don't understand why so few foreign scientists have come to help." Borovoi appealed for a joint scientific and engineering effort. "We are fighting for an international effort," he said.

There were also shots of earlier phases of the work, in preparation for building the sarcophagus, the enormous protective structure built to shield the damaged reactor. At one point, when robots were not available (and, in fact, were not able to function in the intense radioactivity), a human chain of 3,400 "biorobots," Army volunteers, spent one minute each running on the roof of the reactor to pick up debris and throw it into the smoldering core. In that minute, they received the allowable limit of radiation. The general in charge, who himself suffered from acute radiation illness, handed each volunteer a certificate, shook his hand, and told him, "I wish you good health, and may you live to be a general."

At other points in the project, the scientists improvised, putting a camera onto a toy tank, remotely controlled, and sending it in to explore collapsed areas of the building that they could not reach.

"The Complex Expedition," as this effort was named, succeeded, despite the lack of equipment and protective gear. After two years, they located the mass of molten reactor fuel four meters under the reactor core. The hot fuel had mixed with the sand surrounding and insulating the reactor core and fused into a glassy mass, still intensely radioactive. The scientists named it the elephant's foot, because of its shape. The scientists could now be satisfied that there would not be a new chain reaction and a second explosion. Now their worry was that the sarcophagus was not secure, and in some places was falling down. They also worried that any major disturbance of the structure could set of clouds of radioactive dust that would pose a danger for the workers in the other Chernobyl units that were still operating.

When the documentary's interviewer asked the scientists what their biggest problem was, they did not hesitate. The shortage of money and equipment was severe, but the biggest problem, they said, was "the bureaucracy."

Nuclear energy in the former Soviet bloc

According to the U.S. Department of Energy's International Nuclear Safety Program, here is the breakdown of nuclear power in selected nations of eastern Europe:

Russia: Nuclear power supplies 12.5% of Russia's electricity. Of its 29 reactors, 11 are RBMKs, 13 are a more standard light-water design called VVER, 1 is a breeder reactor, and 4 are another type of graphite-moderated reactor.

Ukraine: There are 15 operating Soviet-designed nuclear power reactors, which provide 32.9% of Ukraine's electricity. (This does not include Chernobyl units 2 and 4, which are not operating.) Of these, 2 are RBMKs, and 13 are VVER design types. Five other plants are in construction.

Czech Republic: Four operating VVER power plants supply 29% of the Czech Republic's electricity. Two other plants are in construction.

Hungary: There are four operating VVER reactors at the Paks site in Hungary, which supply 43% of the nation's electricity.

Lithuania: Two RBMK reactors at Ignalia provide 87.9% of Lithuania's electricity. These 1,500 MW plants are the world's largest.

Slovakia: Four VVER type reactors, all at Bohunice, provide 53.6% of Slovakia's electricity. Another four VVER reactors are under construction.

Lessons

Chernobyl is not the worst industrial disaster the world has seen, despite the continuing scare stories that dominate the news media. There can be a recovery of the land, of the people, of the industry. After all, Japan recovered after the atomic bombings.

But look at what has happened in the ten years since Chernobyl, and how matter-of-factly western society has tolerated the loss of human lives. Millions of people have died in needless wars in Africa and in the former Yugoslavia, or died from diseases or famine that could have easily been prevented, had the political will existed to stop them. Without this quality of political will, economic development in Africa—or in Chernobyl—will not take place.

The particular configuration of events that led to the Chernobyl accident could have been prevented, certainly, with a better reactor design. From the personal accounts of what happened, it is also the case that individual engineers in the plant at the time, who knew better, followed bureaucratic "orders" instead of doing what their knowledge told them had to be done. And once the accident occurred, the response of the Soviet government surely could have been different. Lives could have been saved.

It is also the case that the response from the West could have been different—and can still be different. The science and technologies exist to build advanced, safe nuclear plants relatively inexpensively. To ensure the political decision to use these technologies will require a different kind of thinking on the part of U.S. citizens, including the nuclear industry and the nuclear community. This will take the kind of personal courage displayed by the scientists who carried out "The Complex Expedition" at Chernobyl. As Popov said of their work: "But the job has to be done. . . . Somehow, the problem has to be solved.'