

The Nuclear Dilemma and Lessons from Chernobyl

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Nuclear energy as an alternative to fossil fuels is once again the topic of international political and scientific discussions. Fuel reprocessing, new reactor designs, and talk of international control of atomic energy are the focus of political leaders and scientists as fossil fuel costs escalate and nuclear weapons materials proliferate across the globe.

Nuclear energy has always been both an extremely promising and problematic technology. Unlike coal and petroleum, nuclear energy produces no atmospheric waste gases, which are widely regarded today as a major cause of global warming. Yet nuclear energy technology is still not significantly more cost effective than traditional energy sources, and its implementation produces hazardous wastes that to this day have not found a permanent storage facility anywhere in the world.

Recently the nuclear energy drama has been raised again with particular intensity in the former Soviet Union. In recent years the Russian Federation has proposed building a long-term storage site that would accept spent nuclear fuel from many nations. At the same time, some of the independent states of the Former Soviet Union (FSU) are angling away from Russian dominance and corrupt regimes: most prominently, the 2004 Ukrainian Orange Revolution signaled a remarkable and peaceful effort on the part of the Ukrainian people to throw off their repressive and corrupt Russian-leaning government. Since its declaring independence from the fallen Soviet Union in 1991, Ukraine has had an uneasy relationship with Russia, especially on energy issues.

Energy is a key tension point between these two nations since the Russian and Ukraine natural gas and power grids are strongly intertwined. In 2000 Russia accused Ukraine of stealing gas, and endless bickering between the two nations over gas rights and energy issues has ensued. Ukraine obtains slightly less than fifty percent of its electricity from nuclear energy, but is still energy-poor. In January 2006, during the coldest winter to hit in several years, Russia temporarily cut off gas supplies to Ukraine.

Russia's political tinkering with gas supplies is one reminder of the drastically increasing energy needs our world faces with its growing population and globalizing economy. Whether or not it will be a solution to these problems, nuclear energy is long overdue for serious, organized, global reconsideration.

The 1986 Chernobyl disaster galvanized a great deal of European, and to a lesser degree, American popular sentiment against nuclear energy. But the global geopolitical scene has changed drastically in the last two decades, and with nuclear energy again in prospect, the events of the Chernobyl accident and its aftermath deserve to be revisited. The accident site and its legacy are no longer closed to outsiders, and more importantly, those people who currently work at the Chernobyl site are free to voice their opinions in a way that they could not until recent years. They have some surprising perspectives on nuclear energy, waste management, and containment that the rest of the world could learn from.

The Accident

Prior to the 2004 Orange Revolution, Ukraine was perhaps best known in the West as the site of the world's worst commercial nuclear power plant disaster, which occurred on April 26, 1986. Chernobyl reactor unit number 4 at the V.I. Lenin Nuclear

Power Plant was a Soviet RBMK design, a high-power pressure tube device with graphite rod moderators that was cooled with water. While most western reactors are graphite-rod moderated as well, typically “light water reactors” that employ boiling or pressurized water, they are safe on a day-to-day operating basis, incorporating broad shutdown margins and employing big containment structures in case of an accident. Soviet-designed Chernobyl did not.

The RBMK has a positive void coefficient, where the nuclear chain reaction and power output increase drastically when cooling water is lost. During the night the accident occurred, the Soviet operators were running a routine test of the reactor’s electrical equipment to determine how the unit would respond to a loss of electrical power. The operators went about their work with an easy familiarity, disengaging several safety and backup cooling systems. As the cooling water surrounding the core turned to steam and evaporated, it caused a nuclear fission surge and a subsequent steam explosion at 1:26 AM, blowing the unit’s 1000-metric ton cover off the top. The explosion and fire released perhaps up to 30 percent of Unit 4’s 190 metric tons of uranium dioxide fuel and fission products.

As the residents of the nuclear plant workers’ city, Prip’yat, stood on their apartment balconies through the night watching in awe and confusion as Unit 4 burned and lit up the entire sky less than 2 kilometers away, Chernobyl’s local fire department was called to the scene of the accident only moments after the explosion. Dressed in standard-issue firefighting gear, and pumping water on the exposed burning reactor core that had blown graphite rods out like toothpicks, the firemen received a lethal dose of more than 1000 roentgens (R) within the first hour of their arrival at reactor 4. The men

worked for ten hours straight before helicopters arrived to dump thousands of tons of sand and lead on the site.

The initial explosion killed two of the plant workers. Twenty-eight people, including the plant crew, the firemen, and the emergency clean-up workers died in the first three weeks after the explosion from acute radiation sickness. One died of cardiac arrest. 106 persons with lower exposure levels were treated for radiation sickness and survived. A few additional deaths of area residents resulted from thyroid cancer in the following months. Over the course of several days following the accident, contamination spread unevenly across northern and western Ukraine, Belarus, and southern Russia while Soviet authorities hesitated to inform its citizens of the catastrophe and its dangers.

The Chernobyl Zone is still one of the most radioactive places on earth. Ukraine's government maintains that over time, 3.5 million people worldwide became ill from the accident and its fallout. Ukraine itself has registered 4,400 deaths that resulted directly or indirectly from the accident. According to the World Health Organization, about 6.7 million people in surrounding countries were exposed to fall-out. Belarus was hit particularly hard, and suffers to this day from birth defects and health-related problems affecting its citizens. The actual figures for those injured or maimed by the long-term consequences from the accident are hard to corroborate: human exposure to varying levels of radiation began from the moment of the accident and continues through the present, and the Soviet records on these figures prior to 1991 are unreliable.

In the summer of 1986, the Soviet government hastily began to contain the accident at ground zero. Their initial attempts to use remote-controlled robots to push the hot graphite rods and other highly radioactive debris back into the core failed as the machinery became entangled in the mess and the radioactivity destroyed the robots'

delicate electronic control systems. When the mechanical robots failed, the Soviet collective philosophy kicked in: military conscripts were sent in to act as “bio-robots,” instructed to dash into the area surrounding the core, pick up a rod or other piece of debris, throw it into the core, then run out. Around 200,000 people – called “liquidators” -- were involved in the immediate clean up effort in 1986 and 1987. As they constructed a giant, crude but solid, block-like concrete sarcophagus – which they simply call the “blok” -- over the entire destroyed reactor unit, the liquidators encountered between 10 and 50 R per hour per foray into the reactor and zone areas, orchestrated in stages over long periods.

Only the Soviet Union could have contained the accident in such a rapid, and crude, but effective manner that took great risks and sacrificed many lives. Today, the ambient radiation in the Zone varies according to which area one is in, and is mostly within safe limits for short term visits. But the reactor core is still hot, so much that it is inaccessible for measurement. When the core burned and melted it destroyed the reactor’s concrete base, fusing fissionable material with metal and concrete, burning its way through rooms below, and eventually hardening into undistinguishable shapes.

Pictures taken inside the core reveal a post-apocalyptic horror show: dark and labyrinthine, with radioactive dangers lurking around every corner. Concrete and metal debris are strewn everywhere along unstable passages, and the building’s structure is fractured. Highly radioactive hardened masses abound: one infamous landmark, the elephant’s foot, is so called because of the shape of the giant glassy radioactive formation composed of silicon from sand, uranium and zirconium from the reactors fuel rods. It is too hot inside for scientists to make very accurate readings of the risk levels, although Ukrainian and foreign scientists have assessed that there is no risk of another explosion.

But other potential dangers lurk in the slowly crumbling blok, as its scientific caretakers will lucidly and eagerly explain to foreigners who come to visit them in the Zone.

Ukraine and Chernobyl at Present

Even though it is one of the largest European countries, many Americans will admit that before the 2004 Orange Revolution they had no idea where Ukraine is located geographically. Students of European history and Soviet specialists often associated Ukraine with Stalin's brutal forced collectivization of its farms in the 1930s, an experiment in terror that starved at least 14.5 million people.

One of the few Soviet positive legacies was its educational system, which remarkably struggles on today. This system strongly emphasized science and engineering. The Academy held a high level of prestige within Soviet society and abroad. The Ukraine Academy of Sciences still boasts thousands of talented scientists with many specialties. Those who have not emigrated to the West or abandoned science for business enterprise try to scrape by on salaries of \$60.00 per month, sometimes supplemented by grants, or by holding second and third odd jobs to make ends meet.

In the spring of 2001 I resided as a guest of the Ukraine Academy of Sciences in Kiev, where I was researching the history of computing in the former Soviet Union. My colleagues were delightful and well-educated, and were more fluent in Russian – the language we spoke together - than Ukrainian. They were intelligent and witty people who were amazingly cool and collected about their local environmental and economic predicaments.

In April 2001 Kiev's evening news was full of stories about the fifteenth anniversary of the catastrophe. Naturally, this raised my curiosity: Chernobyl is officially

a closed area. Travel to the Chernobyl Exclusion Zone – or simply, the Zone, requires special permission that had to come down through layers of bureaucracy. After days of numerous phone calls and frustrating circular discussions with those above, my colleagues finally nailed down a concrete itinerary for me to visit the Zone.

Two computer scientist colleagues, Drs. Vitaliy Boyun and Mikhail Ivanovich Vasjuhin, agreed to escort me to the Zone. And early one morning in May we headed north out of the Kiev by car, roughly following the western side of the wide Dnepr river, which cuts Ukraine in half.

Our leisurely drive reminded me that Ukraine is a beautiful, rustic country, with rolling green fields and birch and *kashtani*, or chestnut trees; the famous chestnuts were in full bloom and powerfully fragrant. Vasjuhin pointed out a stork's nest high in one tree. The further we got from Kiev, the more cattle and chickens wandered alongside the road and in peasant gardens. Babushkas dressed in heavy sweaters, leggings, and headscarves sold vegetables and fruit from milk crates, while men drove horse-drawn wagons overloaded with hay. . . People rode bicycles along the sides of the road, and occasionally a Mercedes would overtake us at high speed, kicking road dust in our faces.

The Zone itself is whopping 4300 square kilometers. A guardhouse and gate mark the entry point, along with a sign indicating that the area is closed. We stopped, got out of the car, and all three of us presented our passports and *propusk* -- the critical official letter of invitation and itinerary, prepared by the head of the cleanup effort, whom we would meet in a little while. The guards examined our documents, called our contact at the Zone headquarters, and let us through.

The countryside inside the Zone is dotted with abandoned homes and dilapidated collective farms, although recently some former occupants have resettled there, having no

where else to live. We arrived at the Chernobyl State Complex for Specialized Enterprise on Radioactive Waste Management and Decontamination, housed in one of a few occupied buildings in the area. A young man appeared dressed in military fatigues, which workers use as disposable work clothes in case radiation is found on them. He escorted us to the Complex's general manager, Vladimir Zhilinski, who wore a white dress shirt and tie covered by a camouflage jacket. He had the office setup of an important Soviet bureaucrat: he sat behind an enormous wooden desk, while we sat at a small table perpendicular to it.

Zhilinski was a dark-haired, middle-aged, friendly man who grinned a lot. He was a former Soviet Army Colonel but explained that the Complex was entirely a civilian enterprise. Previously Zhilinski had held the important job of an Army supervisor at the Semipalatinsk continental nuclear test site in Kazakhstan, which had closed when nuclear testing ended. With that experience, he explained, he had no fear of working in the Chernobyl area despite the presence of radioactive hot spots in the area. His brave and rational attitude was impressive.

During the conversation he stopped abruptly and asked me several times if I was afraid. "Nyet" I replied. Then he went to great lengths to assure me that we were perfectly safe, that the alpha radiation levels were harmless. After all, he had been working there for many years, as had many other people. Vasjuhin, who sported a fine sense of black humor like our other compatriots, winked and asked me if I could feel the radiation yet.

Zhilinski then introduced us to our host for the day, Dr. Valery Antropov, a kind-faced, white-haired, middle-aged manager of the Complex's Information Center for Radioactive Waste Management. Like Zhilinski he sported a dress shirt and tie, complete

with camouflage jacket. Antropov was a Candidate of Engineering -- equivalent to an American Ph.D. -- and oversaw tasks such as inspection of radioactive waste depositories and reliability control of radioactive waste storage. He managed several employees but was prepared to spend the whole day with us and show us the entire complex.

Antropov's office computers controlled hundreds of the radioactive waste depositories within the Zone, and collected and kept information about the waste materials. The office sported new American-made PCs and other office equipment, most of which had been bought in Western countries. On the wall was a map of the Zone, indicating where hot spots remained. Among the worst is the reactor complex's cooling basin. Since the accident the basin has slowly leached radioactive waste into the Prip'yat River, a tributary to the Dnepr.

The reactor complex itself is actually ten or fifteen kilometers away from the town of Chernobyl, while the entire Zone is close to the Belarus border. While in his office Antropov gave us a brief layout to the area, along with a lot of friendly and open casual conversation. He then took us outside and we met Sergei, our driver for the day. He led us to a Soviet-made dark green jeep - the dashboard and interior plastered with tiny stickers of topless and naked women. Antropov insisted that I sit up in front so that I could see out well.

Sergei drove us first to Prip'yat, now a ghost town. Most of the buildings, grey and blockish in their Soviet form, had broken windows, and crumbling concrete steps and foundations. Weeds and trees grew through windows and doorways, through cracks in the concrete, and just about everywhere else. The area was silent except for the wind.

The Soviets often designed new towns around a theme reflecting the local industry or enterprise. Thus Prip'yat was decorated with huge public symbols touting

atomic energy, such as stylized radiation hazard signs and atomic nuclei orbited by electrons. Behind what had been the “Energetic” town cultural center, sat an abandoned amusement park. A giant ferris wheel stood immobilized, a bumper car pavilion contained a few cars rusted and lying on their sides while the few remaining scraps of its canvas cover hung in rags. It seemed as though the fabled neutron bomb had hit, wiping out all of the human beings and their pets, leaving behind only the buildings.

Now, Antropov explained, lush flora and wildlife thrived in the area; and as we climbed back into the jeep and pulled out of Prip’yat’s town square, a beautiful black and silver fox briefly ran alongside us. On the way out of town we passed an abandoned sporting goods store with a freestanding sign on its roof that now read in Russian, “SPO_TMAG,” with the Russian “r” missing. Vasjuhin asked me again, with a sly smile, “Could I feel the radiation now?”

We turned left to head to the reactor complex and the west side of the catastrophe site. Although it was still about a kilometer away, the blok was dauntingly large, and the entire area looked like a war zone. The pavement ended and was replaced by rough dirt tracks, and we weaved through scattered piles of scrap metal, abandoned containers, pipes, rusted vehicles, wood, and other industrial trash. Beyond this enormous and contaminated junkyard was a small museum and visitors’ center, where a pretty, well-dressed young woman greeted us. She quickly proceeded with her standard tour presentation, explaining the course of the accident and using a plastic model, demonstrated how the sarcophagus was designed. She then led us to the second floor of the visitors’ center, where we stood on an outdoor platform and viewed the sarcophagus, roughly 100 yards away. Digital radiation level monitors were prominently displayed in almost all the buildings we had been in, and the one in the visitors’ center read that the

radiation where we were standing was 1.33 milliroentgens per hour - a negligible enough amount.

Our hostess explained that all of the aid came to the Zone via the Chernobyl Shelter Fund, an international organization run by the European Bank for Reconstruction and Development, while we eagerly took pictures of ourselves with the blok in the background before leaving the visitor's center. Sergei then drove us around to the east side of the reactor complex, which sat close to the Prip'yat river. Operational reactor number 1 hummed with some experimental activities and personnel near or around it.

Of the people I met there, the Chernobyl containment workers' positive attitudes and sense of humor struck me as remarkable, even though they are well aware of the dangers of their workplace. Like many Ukrainians and Russians, they often accept their lot as *sudba* -- fate -- and make the best of it. And as long as there is work to do at the Chernobyl site, the elevated Ukrainian pay-scales -- although small compared with America's - are tempting.

But jobs were being eliminated at the Chernobyl plant: the closure of power-production reactor number 1 in late 2000 meant that many positions disappeared, even while the general decommissioning work carried on. Today a few hundred people still work in the area on monitoring or decommissioning tasks.

Antropov and I strolled alone together around the area. "Ironic, isn't it?" he remarked, "all this destruction and waste surrounded by such natural beauty!" His comment reflected not only our immediate surroundings, but also the Soviet government's blatant disregard of environmental degradation and the safety of its people. The Chernobyl reactor complex and the surrounding Zone are terrible relics of the Soviet

regime, which emphasized brute force development of gigantic technologies that functioned, but were peppered with dangerous flaws.

The demise of the Soviet Union exacerbated these issues, and also led to the bizarre mixture of the leftover, hard-line Soviet bureaucracy, multiple parties, reforms, and corruption that still dominate Ukrainian politics. After heading back to Antropov's office the four of us discussed Ukraine's colorful political characters: then-President Leonid Kuchma, a scheming thug who in 2001 had fired his Prime Minister, Viktor Yushchenko, out of fear of his high popularity. Antropov explained the large presence of organized crime in Ukraine, and how a great deal of the international monies given to assist with building and maintaining the Chernobyl blok were routinely slipped into individuals' private accounts while corners were cut in the sarcophagus's initial construction.

Then Antropov had carefully spelled out to me what was wrong with the blok: the then nearly fifteen-year-old structure itself was supposed to be a "permanent" containment facility, but with Plutonium-239's half life of 24,000 years, the present sarcophagus and subsequent ones will need to be completely replaced over the next projected 100,000 years. Reactor 4's core and its surrounding sarcophagus are an accident waiting to happen: remaining inside are roughly 200 tons of hardened highly radioactive lava and fuel that are gradually turning into dust. Somewhere between 75 to 97 percent of the reactor's nuclear fuel remains inside the destroyed facility. If the sarcophagus were to collapse due to decay or geologic disturbance, the resulting radioactive dust storm would cause an international catastrophe on par with or worse than the 1986 accident. Antropov's colleagues periodically run a sprinkler-like dust-suppression system within the sarcophagus, but this only slightly lessens the risk.

Today the sarcophagus is cracked. Rain and wet snow make their way in and freeze, causing the cracks to increase in size and weakening the structure through every hard Ukrainian winter. The whole apparatus is not even truly level, as the sarcophagus is mounted partly on the fractured reactor core and partly on its damaged cover.

Before we were scheduled to depart, Antropov said he wanted to show us one more thing. In front of the boarded-up Chernobyl fire station was a gray concrete sculpture of a group of firefighters dressed in their gear, holding water hoses, standing underneath an eerie atom-like symbol. The Ukrainian caption at the sculpture's base read: "They Saved the World." There is no doubt of this and of the sacrifice they made. Within hours of their exposure to the burning reactor core, the firefighters became gravely ill and died within weeks. They are buried in zinc-lined, lead coffins set in deep graves near Moscow.

The day ended quietly on that sad note. Boyun, Vasjuhin, and I said our goodbyes to Antropov and thanked him for the tour. We headed for Kiev through the empty Zone to the highway gate and guardhouse. There the guards inspected our car while we entered a small, dilapidated building to be scanned for radioactive particles on our clothing and shoes. We stepped into telephone booth-sized body scanners, were pronounced clean, and stepped through to the other side. If radiation is found on your garb during this inspection, they will cut the piece of clothing off you right there.

During our trip to and from Chernobyl, Boyun and Vasjuhin at times were almost apologetic for the poor state of their country, although they maintained a definite sense of national pride interspersed with a good natured and biting humor about their lives, while boasting about the regions of their country that were still "ecologically pure and good for the body and soul."

As much as Russians and Ukrainians feel a special cultural connection to nature, no one I met at Chernobyl was against nuclear power. Likewise no one was worried about radioactive materials being smuggled out of the Zone, a practically impossible scenario because the hot reactor core materials are fused with concrete and steel. Salvage scavengers routinely pilfer radioactive vehicle and machine parts from Chernobyl's vehicle graveyard to sell to unsuspecting buyers, but this does not pose a terror threat.

The European Bank for Reconstruction and Development, which manages the Chernobyl Shelter Fund, has been seeking pledges of support from many nations to build a new confinement structure that will cover the entire reactor and surrounding sarcophagus. Currently still in design phase, the new 20,000-ton steel shelter will consist of a 100-meter high steel arch with a span of 250 meters, looking like a mammoth quonset hut, where King Kong could comfortably lie down in. It will slide along rails to its final position over the sarcophagus. Once in place, robotic and human workers inside the shelter will begin to cut up the original wreckage and sarcophagus and organize and store the radioactive waste pieces. The huge shelter is intended to keep water out and contain radioactive dust for 100 years, until Ukraine can develop a permanent facility for the several hundred tons of waste materials remaining at the site. To build the new structure, the Chernobyl Shelter Fund is hoping to raise \$1 billion (in US dollars) in the near future, in hopes that the confinement structure will be completed in 2008-2009.

This is an ambitious project that will no doubt encounter unexpected glitches, but it is a step in the right direction and needs to go forward as an example of badly needed leadership in addressing the issue of nuclear energy today. The unwillingness of political leaders worldwide to deal with the future of nuclear energy and particularly its waste

storage is shameful: as of today there are still no serious plans for a permanent geological repository site for the world's nuclear waste.

The Future

Even though Ukraine has a long way to go in terms of modernizing its national infrastructure, establishing genuine rule of law, and attracting foreign investment, it will join the modern global economy in time. The openness now present in modern Ukraine is a breath of relief and optimism. People say what they want and when, and express their opinions openly. Curiously, the Chernobylites I met would like to see nuclear energy play a bigger role in their country's future. In fact, in early 2006 Ukrainian President Viktor Yushchenko – swept into power during the 2004 Orange Revolution - announced that his country should produce its own nuclear fuel for power plants, in order to reduce its dependence on Russian natural gas and make a positive gesture towards general economic cooperation with the West. Earlier, he had reached out to the West on the topic of nuclear containment: in April 2005 Yushchenko addressed a joint session of the US Congress, asking for American help in erecting Chernobyl's new shelter. A mutual scientific agreement to help in this area would be a positive step: further engaging former Soviet scientists in the nuclear waste problem will provide a great deal of insight, knowledge, and help. As their economies slowly improve, many scientists in the former Soviet Union are no longer looking for handouts as they were in the 1990s, but instead are seeking respect, collegiality, and cooperative projects with western counterparts.

Coming to terms with the nuclear energy and wastes dilemmas should be one such area of collaboration. Nuclear energy today supplies about 16 percent of the world's electricity. The world may be able to get on without nuclear power by using carbon

sequestration or advanced alternative fuels until the world's coal supplies are exhausted. But nuclear power plants contribute far less heat to earth's atmosphere and no carbon dioxide, which remains in our atmosphere as a product of fossil fuel consumption. If nuclear energy is to make a big dent in fossil fuel consumption, it will have to be deployed on a much more massive scale than it is now, meaning that many more countries would employ reactors and nuclear materials.

If nuclear energy does grow in the future, it must be tightly and effectively managed and controlled. In their own way, the Ukrainians have set an example of managing the Chernobyl site fairly well given their very limited resources. They do it low-tech: Antropov showed how after the accident cleanup workers constructed nearly 1000 *boorts* – mounds of earth – and trenches in which radioactive materials will remain until a permanent storage site is complete. They have no other choice but to engage in this kind of temporary and ultimately inadequate solution.

We do have a choice. In stark contrast to the scenario at Chernobyl, the US Energy Department has spent billions of dollars on Yucca Mountain over nearly twenty years, and not one ounce of hazardous waste has been deposited there. Instead, American politicians position themselves over Yucca Mountain in search of votes. France too, which derives 75 percent of its electricity from nuclear energy, has not come forth with a long term solution for nuclear waste products. As spent fuel sits in temporary cooling ponds or dry cask or vitrified storage, no one in a position of authority will step forward and boldly champion a permanent facility. In the meantime Antropov and his colleagues in far away Ukraine go about their jobs with little complaining.

Perhaps this is the biggest lesson to take away from Chernobyl today:

our nuclear waste products are not going to just disappear whether we build more power reactors or phase out nuclear energy entirely. These highly radioactive by-products will need to go somewhere, and for a long time. Where such a site might be located will be up to international political and business interests, which are too complex to predict right now. But the storage issue will need to move forward just as research towards more cost effective and renewable energy sources is absolutely essential. Solutions will come with the proper investment in people and technology.

The point is to push on. Never one to be put off from his job by the lurking radiation in the Zone, fearless Vladimir Zhilinski died in 2004. His example of dedication should be a lesson for the West and the world to deal with the nuclear energy storage dilemma head on, and now.