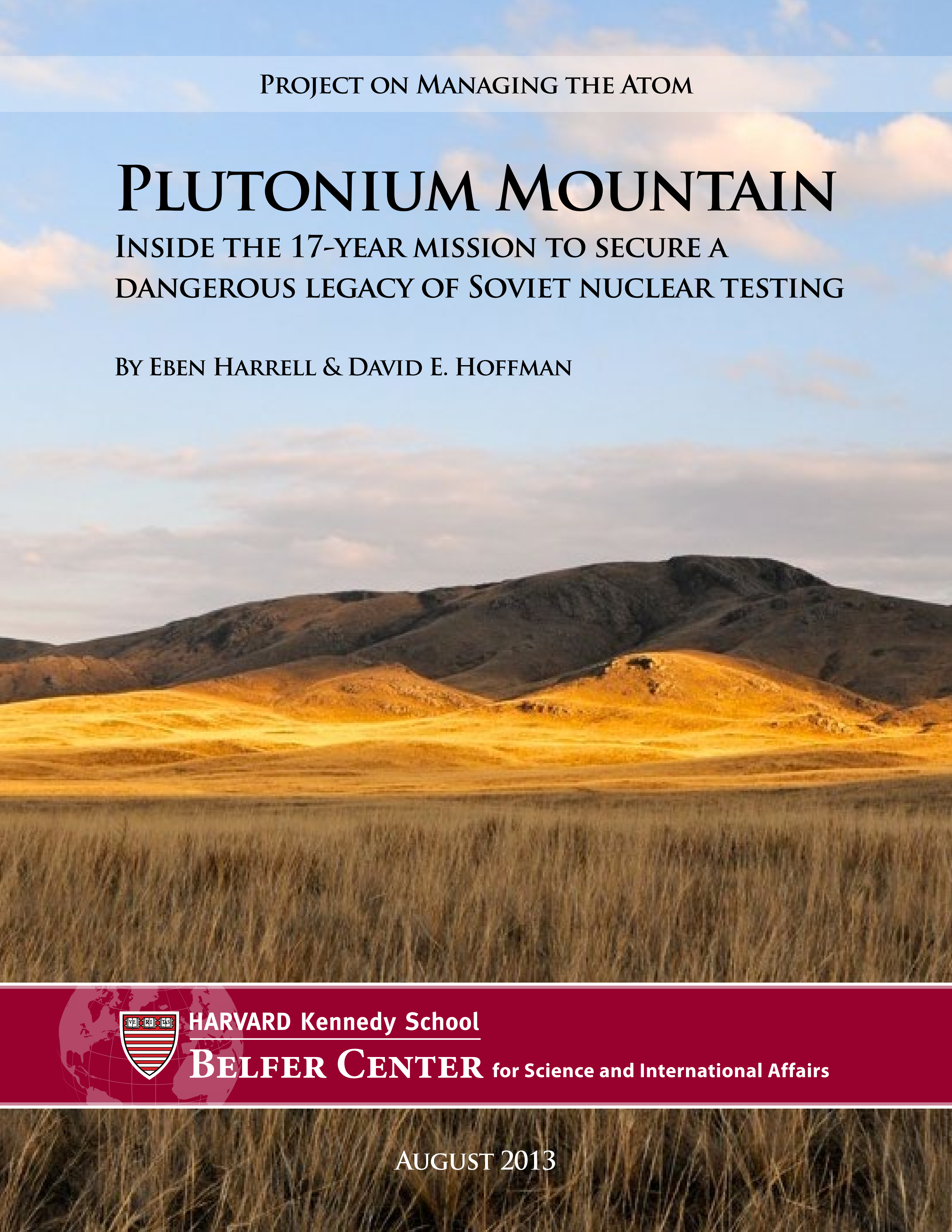

Project on Managing the Atom

Plutonium Mountain

Inside the 17-year mission to secure a dangerous legacy of Soviet nuclear testing

By Eben Harrell & David E. Hoffman

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Cover photo: View of Degelen Mountain, Kazakhstan. Part of the Seminpalatinsk Test Site, Degelen Mountain was the site of the Soviet Union's largest underground nuclear testing program.

Photo source: U.S. Department of Defense.

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Introduction

On the desolate steppe of eastern Kazakhstan, the Soviet Union carried out 456 nuclear explosive tests during the Cold War at the Semipalatinsk Test Site, which sprawls over an area approximately the size of Belgium. Of these, the Soviet Union performed 116 tests in the atmosphere, and 340 underground.[1] While some of the nuclear tests at Semipalatinsk involved atomic explosions, other experiments were designed to study the impact of conventional explosives on plutonium and highly enriched uranium (HEU), the fissile materials used in nuclear bombs, or to ensure the safety of nuclear weapons during a simulated accident such as a fire or nearby explosion.

Some of these tests—particularly tests involving plutonium—did not vaporize the material in a nuclear blast. It remained in tunnels and containers, in forms that could be recovered and recycled into a bomb. In addition, the Soviet Union discarded equipment that included high-purity plutonium that would have provided materials and information that could lead to a relatively sophisticated nuclear device if it had been found.

When scientists and military personnel withdrew from Kazakhstan following the collapse of the Soviet Union, they abandoned tunnels and bore holes filled with plutonium residue—enough plutonium, if fully reclaimed, for terrorists or a state to construct dozens of nuclear bombs. Between 1991 and 2012, scavengers looking for valuable metal and equipment from the former Soviet test site came within yards of the unguarded fissile material; in two cases the scavengers broke into the vessels used to contain some of the experiments, although there is no evidence that they removed any plutonium.[2]

In October, 2012, at the foot of a rocky hillside, at a spot known as Degelen Mountain, several dozen Kazakh, Russian, and American nuclear scientists and engineers gathered for a small ceremony that marked the completion of a 17-year, $150 million operation to secure the plutonium in the tunnels of Degelen Mountain and in surrounding bore holes by filling portions of the tunnels and holes with a special concrete, greatly reducing one of the largest nuclear security threats since the collapse of the Soviet Union.[3] They unveiled a three-sided stone monument, etched in English, Russian, and Kazakh, which declared:

> "1996-2012. The world has become safer."

The story of the operation at Semipalatinsk is a tale of scientists working together to achieve real results in reducing nuclear threats. It began in 1995, after the collapse of the Soviet Union, when experts from the Los Alamos National Laboratory were told during a visit to Kazakhstan that plutonium residue in recoverable form was likely to have been abandoned at the test site.

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1 Viktor Mikhailov et al, *U.S.S.R. Nuclear Weapons Tests and Peaceful Nuclear Explosions, 1949 through 1990*, Ministry of Atomic Energy, Ministry of Defense, Russian Federation, 1996; and "Semipalatinsk Test Site," Nuclear Threat Initiative http://www.nti.org/facilities/732/ (accessed January 22, 2013). Also see, Siegfried S. Hecker, "Dealing with Kazakhstan's Soviet Nuclear Legacy," presentation, Center for International Security and Cooperation Science Seminar, October 15, 2012, Stanford University.

2 Interview with Byron Ristvet, Assistant for Nuclear Matters, Test Technology Division, U.S. Defense Threat Reduction Agency, October 2012.

3 The White House, Office of the Press Secretary, "Fact Sheet: History of Trilateral Threat Reduction Cooperation at the Former Semipalatinsk Test Site," March 26, 2012.

Two years later, in 1997, Siegfried S. Hecker, just retiring as director of Los Alamos, decided to look more closely. Hecker, who helped pioneer cooperation with his counterparts in the Soviet and later Russian nuclear weapons laboratories, used personal connections to push for action. He succeeded in enlisting the cooperation of Russian nuclear scientists who had been involved in the testing program in Kazakhstan before the Soviet collapse.

Source: U.S. Department of Defense

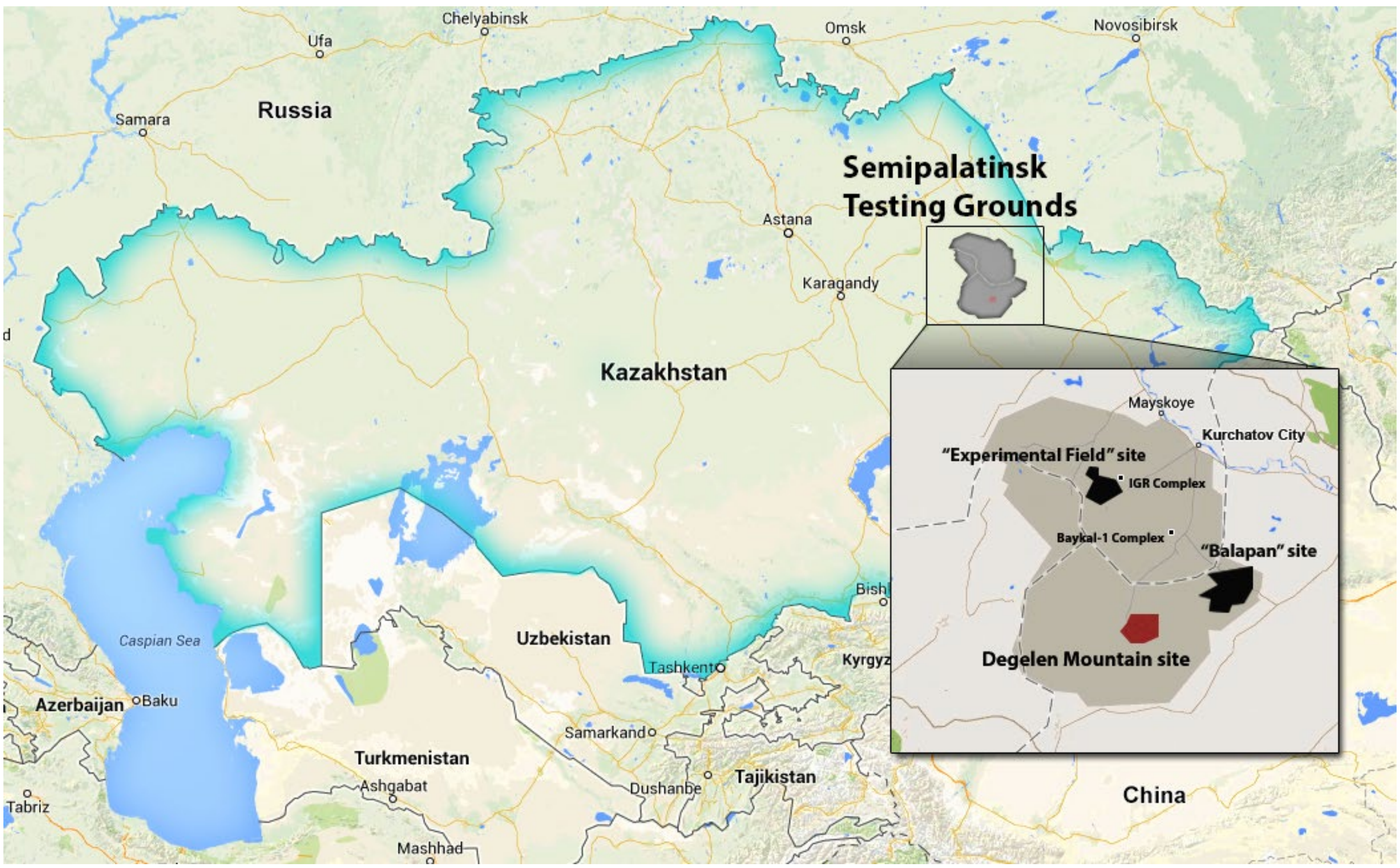
Monument commemorating the completion of the Degelen Mountain Proliferation Prevention Program in English, Kazakh, and Russian languages.

Scientists and engineers from the United States, Russia, and Kazakhstan overcame deep-rooted suspicions in their governments to find technical solutions to the plutonium threat at Degelen Mountain. The operation was based almost entirely on ad-hoc agreements struck at a lower level, and was carried to a conclusion without elaborate, negotiated state-to-state agreements of the kind used for arms control during the Cold War. Each country played a crucial role.

The operation took 17 years to complete, a period in history that saw the rise of al-Qaeda and its nuclear ambitions, the 9/11 attacks, and spanned three different U.S. administrations, the latter two of which proclaimed nuclear terrorism the greatest threat to U.S. security and spent billions of dollars to prevent it. Serious logistical difficulties were just one reason the Semipalatinsk operation took so long. Another was lingering mistrust, inertia and excessive secrecy. Until prodded by the scientists, the governments had done very little about the plutonium abandoned at the test site.

The informal approach was effective, but slow, and it left some issues unresolved or partly unexplored. For example, although Kazakhstan signed the 1968 Nuclear Non-proliferation Treaty in 1993 and had a legal obligation to declare all the fissile material on its territory, the three countries overseeing the operation decided not to formally notify or involve the International Atomic Energy Agency. Each country felt it had good reasons for excluding the IAEA. They shared a concern that information leaks from the agency would compromise the secrecy of the operation. Now, the IAEA and Kazakhstan face long-term uncertainties about whether the material can be safely left in its current form forever, or whether it may pose a risk that someone might seek to recover it someday, or that it could cause environmental contamination beyond the radiation already polluting some portions of Semipalatinsk.

This paper begins with a narrative reconstruction of the threat reduction work at Semipalatinsk. It is based on interviews with U.S., Russian, and Kazakh scientists and officials—conducted in the United States and Kazakhstan—and is supported by documents provided to the authors. It concludes with observations about the lessons for future efforts to reduce and ultimately eliminate the threat posed by nuclear weapons and the essential nuclear materials needed to construct them.



Source: Autonavi / Basarsoft / Google

Map of Soviet test site at Semipalatinsk within Kazakhstan.

The Mountain and its Legacy

The town once known as Semipalatinsk-21 is an isolated, misbegotten city built at great human cost on the steppes of eastern Kazakhstan by prisoners between 1947-1949 for the purpose of providing a staging ground for Soviet nuclear weapons testing.[4] In the post-Soviet vacuum of the early 1990s, the conditions at Semipalatinsk-21 resembled the apocalypse that nuclear weapons have long portended. A city of 40,000 that was once serviced by two daily direct flights from Moscow had been transformed into a dystopia of a few thousand stragglers and feral dogs whose main challenge was finding food and warmth.[5] Many regions of the former Soviet Union were impoverished in the first years after the collapse; this one was so poor and lawless that people who lived there resorted to scavenging the nuclear testing infrastructure. Even the highest-ranking officials were desperate. The Russian director of Semipalatinsk-21 was dismissed in 1993 on charges of selling equipment from the site's facilities.[6]

From 1949 to 1961, the Soviet Union had turned the area around Semipalatinsk-21 into the equivalent of a nuclear battlefield, detonating 116 nuclear blasts in the atmosphere.[7] The last Soviet air test was in December, 1962. Following a global outcry over the ecological and health effects of atmospheric testing, the Soviets moved the testing program underground, where they conducted 340 underground explosions. The United States had conducted atmospheric testing in Nevada, and primarily in the Pacific. The United States similarly shifted to underground testing in this period, and ceased atmospheric testing in 1963 upon entering into a limited test ban treaty with the Soviet Union.

Source: Carl Willis

Abandoned building in Center of Kurchatov City, 2012.

At Semipalatinsk, a sprawling network of tunnels built under a series of hills near Semipalatinsk-21 known locally as Degelen Mountain became a central location for the underground testing program. A ragged mound of granite, Degelen Mountain rises from the prairie grass of the steppes like the crested back of a half-submerged, prehistoric beast. To many local Kazakhs, the tests imbued it with a sinister air. "Out there," one senior Kazakh scientist once told a reporter,

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[4] After Kazakhstan's independence, the city was renamed Kurchatov City.

[5] See: Russian Television Network, April 28, 1994, in JPRS-TND-94-012, "Reduced Staffing Causes Problems at Semipalatinsk," June 7, 1994, p. 34 and "Glowing, But Not With Health," *The Economist*, July 25, 1998, pp. 3-4.

[6] See: *Izvestiya*, "Semipalatinsk Chief Removed from Test Site," December 28, 1993, in FBIS-USR-94-001, January 5, 1994, p. 31.

[7] Hecker, "Dealing with Kazakhstan's Nuclear Legacy," p. 16.

gesturing beyond the gates of Semipalatinsk-21 toward Degelen Mountain, "is a monster." The Soviet Union conducted 209 nuclear tests at Degelen Mountain, in 181 tunnels. Most tests involved small- or medium-sized nuclear explosions.[8]

The Soviets also dug bore holes for certain nuclear experiments at nearby fields known as Balapan and Sary-Uzen, and used giant steel drums known as "Kolbas" to contain other tiny nuclear explosions.[9] A full-blown nuclear explosive test does not consume most of the fissile materials in the weapon; instead, the material is atomized in the blast, and typically mixed with tons of rock. In many tunnels, including most of the vertical shafts at Balapan, it would be so difficult to recover any plutonium or HEU that the material did not present a serious threat. However, in experiments not involving a major nuclear explosion, or experiments that did not work, including many in the tunnels at Degelen Mountain, the plutonium or HEU remained underground, potentially vulnerable to theft. [10]

In the early 1990s, local citizens once employed to build the tunnels at Degelen Mountain began to scavenge the tunnels, using mining equipment to steal everything they could find, including copper from the electrical wiring, and rails once used to transport nuclear devices far underground.[11] In doing so, they risked exposing themselves to dangerous doses of radiation. There were other dangers, too. Five of the scavengers, sleeping in tunnels, died from gas inhalation poisoning due to improper venting of a diesel generator.[12]

In the winter of 1995, Kairat Kadyrzhanov, a metallurgist living in Semipalatinsk-21, confronted the scavengers at Degelen to alert them that radiation might be present in the tunnels. "My wife and children are starving," one of the scavengers told Kadyrzhanov, as he recalled it. "What am I supposed to do?" Scavenging in the testing site was not technically illegal—newly empowered local officials, desperate to do everything possible to spur local economic growth, had issued regional mining licenses for nonferrous metals without indicating permitted locations.[13] Kadyrzhanov and his scientist colleagues tried to enlist the few remaining Russian troops to help. The soldiers did not have ammunition, fuel, or even appropriate clothing; they were in no position to do anything. Kadyrzhanov went back to the area later in an attempt to reason with the scavengers. He noticed that the scavenging operation had blossomed into a full-blown enterprise: the scavengers now employed heavy mining machinery and protected their worksite by carrying guns. In the ensuing months, reports began to surface of radioactive copper popping up in metals markets in neighboring China. Kadyrzhanov and other Kazakh scientists became increasingly concerned; they felt a catastrophe was threatening to unfold on their doorstep.[14]

8 In total, the Soviet Union conducted 456 tests at Semipalatinsk and another 130 tests at the Novaya Zemlya test site in the Far North. Yet another 129 tests were conducted outside these two test sites, including 33 elsewhere in Kazakhstan. Overall, 156 tests were for industrial and peaceful nuclear purposes. Mikhailov, "USSR Nuclear Weapons Tests," pp. 1-10.

9 Hecker, "Dealing with Kazakhstan's Soviet Nuclear Legacy," p.16.

10 Hecker, "Dealing with Kazakhstan's Soviet Nuclear Legacy," p. 17. See also: "Degelen Mountain Tunnel Neutralization Project – 1996," http://youtu.be/kPLQ4yEXFPc (accessed January 22, 2013).

11 Russian, U.S., and Kazakhstan officials reported to us that many of the scavengers had an employment history with Degelen Enterprise, the organization commissioned to construct the tunnels during the Cold War by the Soviet Union.

12 Interview with Sergey Lukashenko, the director of Kazakhstan's Institute of Radiation Safety and Ecology, October 2012.

13 Interviews with Kazakh and Russian officials, October 2012.

14 Interview with Kairat Kadyrzhanov, October 2012. See also, Ellen Barry, "Old Soviet Nuclear Site in Asia Has Unlikely Sentinel: The U.S.," *The New York Times*, May 21, 2011 http://www.nytimes.com/2011/05/22/world/asia/22kazakhstan.

The Small Experiments

The United States began a voluntary suspension of nuclear weapons tests on October 31, 1958. The Soviet Union joined after two tests in November. On December 29, 1959, President Eisenhower said that he would honor the suspension, but the United States would continue to carry out research and development, including "laboratory-type experiments." At the time, the United States was headed toward building smaller, lighter nuclear warheads that would fit atop ballistic missiles. These and other weapons required safety testing to make sure they would not produce a fission explosion if an accident resulted in detonation of the chemical high explosives used in the weapon.

This gave rise to "hydronuclear" experiments, which involved using high explosives to crush fissile material, such as plutonium or HEU, without setting off a significant nuclear blast. It was realized that by reducing the amount of fissile material, the yield could be kept very low, much less than what most people envision when they think of a nuclear explosion. Such experiments are sometimes called "zero-yield" tests, but the energy released by fission, while small, is not necessarily zero. The United States began conducting hydronuclear tests on January 12, 1960.[15]

In the United States, the tests were aimed at achieving a safety standard known as one-point safe. This was defined as the assurance that in the event of a detonation at any single point of the high-explosive system of a nuclear weapon, the chance of a nuclear energy release in excess of four pounds equivalent of TNT would be less than one in a million. The first U.S. hydronuclear experiments were carried out in a deep hole at Technical Area 49 on the grounds of the Los Alamos National Laboratory in New Mexico; subsequent work was also performed at the Nevada Test Site, primarily by the Lawrence Livermore National Laboratory.[16]

The Soviet Union began its hydronuclear tests at the Semipalatinsk site in Kazakhstan in 1958, and over the next 32 years, the Soviets fired off 85 hydronuclear devices at three separate locations. While the Semipalatinsk site was closed and considered secret, the Soviet activities were observed by U.S. intelligence satellites. For a number of years, the satellite photos showed a

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html?sq=kazakhstan&st=cse&adxnnl=1&scp=4&pagewanted=all&adxnnlx=1358883389-3cLkFKRLYih964BQBu0HqA&_r=0 (accessed July 28, 2013).

15 Robert N. Thorn and Donald R. Westervelt, "Hydronuclear Experiments," Los Alamos National Laboratory, LA-10902-MS, February, 1987. Thorn and Westevelt note that the value of these tests was demonstrated in the 1966 accident when a B-52 bomber with nuclear weapons aboard collided in midair with a KC-135 tanker near the fishing village of Palomares, Spain. In one of the nuclear weapons that fell to the ground, the high explosive detonated, but there was not a fission explosion due to the safety measures that had been introduced.

Along with hydronuclear tests, certain safety and reliability tests—termed "studies of accidental modes" in U.S. testing parlance—were designed to ensure that the material did not fission at all. In the early days of the Cold War, such tests were quite crude: British scientists set nuclear weapons on fire in the Australian desert, according to John Carlson, the former director general of the Australian Safeguards and Nonproliferation Office. Carlson spoke to the authors in a September 2012 interview. More sophisticated experiments could potentially leave behind equally dangerous materials. So-called "popcorn tests," for instance, were designed to test whether a nuclear warhead will detonate unintentionally if a conventional explosion occurs nearby. "One-point safety" experiments test whether a weapons' physics package (i.e. plutonium and other elements that fuel a nuclear bomb) will ignite if only one section of the multiple conventional explosives arranged around it pre-detonated. These experiments involved a significant quantity of weapon-grade plutonium which was not dispersed by a large explosion and could potentially be recovered and used to make a bomb.

16 Thomas C. Reed and Danny B. Stillman, *The Nuclear Express: A Political History of the Bomb and Its Proliferation*, (Minneapolis: Zenith Press, 2009) pp. 62-63.

sequence of somewhat mysterious events. Trailers were brought to a remote area in Semipalatinsk known as Aktan Berli. Some kind of test was conducted, then the Soviets scraped the ground in the immediate vicinity. The material scraped from the site was deposited in trenches located several hundred meters downwind.[17] What the satellites did not show—and what U.S. officials did not know precisely until later—is what kind of tests the Soviet scientists were carrying out.

Siegfried S. Hecker became the fifth director of Los Alamos in January, 1986. At the time, he was told that some plutonium from the U.S. hydronuclear tests remained in the holes at Technical Area 49 on the grounds of the installation in New Mexico. While at first the U.S. hydronuclear experiments were carried out in deep holes, over the years, the study of the properties of plutonium and HEU became more refined. The experiments could be conducted in the equivalent of glove boxes, without high explosives.

Hecker recalled,

> If you want to study the shock-loading characteristics of plutonium, you take a little pellet of plutonium, you put it in a gas gun and you fire a projectile at that plutonium. And on the other end of the plutonium, you put a number of gauges, which tell you how the plutonium responds to that shock insult. That's how we studied the shock behavior.[18]

In most of the American hydronuclear tests, the plutonium was not removed from the hole after the test. It was just left there. Hecker knew that plutonium from these tests could be recovered and used for making a nuclear weapon—the United States had once done it. In 1958, amid concerns that the U.S. faced a plutonium shortage, U.S. specialists performed an experiment in which they recovered plutonium from two safety tests and used the material to build another bomb.[19] In another example, British scientists were forced to return to their test site in Maralinga, Australia in 1979 to collect plutonium, as well as highly-secret components used during a series of six experiments in 1962, although in that case there was not enough plutonium left behind to construct a bomb.[20]

Scientist-to-Scientist

A metallurgist trained at Los Alamos, Hecker appreciated the physics—and perils—of the nuclear age. His personal story was also caught up in the convulsions of the 20th century. His father, an Austrian who had been drafted into the German army, was lost at the Russian front in World War II. As a young boy in Austria, Hecker had grown up with only dark impressions of Russia, reinforced by the few male teachers who returned from the front with grim war stories. He emigrated to the United States in 1956 when he was 13 years old, and later earned a doctorate in metallurgy and materials from Case Western Reserve University before going to Los Alamos as a student

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[17] Memorandum, "Project Amber: Elimination of a Potential Source of Special Nuclear Materials," November 13, 1995, provided by Hecker to the authors.

[18] Interview with Siegfried S. Hecker, November 29, 2012, Stanford University, Calif.

[19] Interview with Ristvet, October 2012.

[20] Interview with John Carlson, the former director general of the Australian Safeguards and Nonproliferation Office, September 2012. See also, H.A.S. Bristow and S.A. Flook, "Repatriation of Plutonium Residues from Maralinga February/March 2012," Procurement Executive-Ministry of Defense of the United Kingdom, AWRE Report No. 24/80.

and later for post-graduate work. Hecker saw himself as a scientist, fulfilling his patriotic duty for his adopted country. He was never a weapons designer.[21]

In 1988, Hecker, then the Los Alamos director, and other U.S. scientists carried out a joint nuclear weapons verification experiment with Soviet scientists, a result of the Reagan-Gorbachev 1986 Reykjavik summit, and an important early bridge across the Cold War chasm of mistrust. Then, in February, 1992, just after the Soviet collapse, Hecker made a ground-breaking visit to Arzamas-16, which had been established as the first Soviet nuclear-weapons laboratory. These were the breathtaking days of a sudden openness between old adversaries, and Hecker used it to build trust with the Russian scientists. At Arzamas, on the tarmac upon his arrival, he met Yuli Khariton, who had designed the first Soviet atomic bomb under Igor Kurchatov, and who later became the first scientific director of Arzamas-16. Khariton extended his hand and said, "I've been waiting forty years for this." With the Soviet Union gone, the Russian scientists were suffering economically, but they told Hecker they saw themselves as equals of the Americans and only wanted to take part in scientific cooperation on that basis. Hecker established a vital line of communication to the Soviet weaponeers, a lab-to-lab program of joint projects that helped to overcome Cold War mistrust.[22] Other efforts later provided millions of dollars to Russia to assist in helping secure nuclear materials and find ways for weapons scientists to shift to civilian projects.

On November 3, 1997, Hecker completed his term as director and became a senior fellow at Los Alamos. He decided at the time to continue his work securing nuclear materials around the world. He knew plutonium and highly-enriched uranium—how they were made and why. But with the Cold War now over, he hoped to use his knowledge to improve global nuclear security and prevent fissile material from falling into the wrong hands.

Hecker knew that security at Russian nuclear installations at the time was often woeful. He and others had led a lab-to-lab effort to secure and account for nuclear materials, ultimately convincing the U.S. Department of Energy and Russia's Minatom to launch a broad program called Materials Control, Protection and Accounting, or MPC&A, to deal with the problem. But he was concerned that despite plans for security upgrades at the known sites, there might be material that remained completely off the radar—overlooked or forgotten, and therefore a greater risk.

Kazakhstan was known to be riddled with nuclear materials from the Cold War. In 1994, the United States airlifted out of Kazakhstan about 604 kilograms (1,332 pounds) of highly-enriched uranium left behind by the Soviet Union in an elaborate operation known as Project Sapphire, one of the most important and dramatic attempts to secure these materials.

The early 1990s were focused primarily on removing nuclear weapons and delivery vehicles from the three former Soviet republics outside of Russia where they were located: Kazakhstan, Ukraine, and Belarus. Among them, Kazakhstan had been most eager to denuclearize. The country's strongman leader, Nursultan Nazarbayev, who had been a member of the last Soviet Politburo, decided to give up nuclear weapons on his soil at least in part because of his horror at the ecological legacy left behind by the testing program at Semipalatinsk.[23] Encouraged by the

[21] Interview with Hecker, November 29, 2012.

[22] David E. Hoffman, *The Dead Hand: The Untold Story of the Cold War Arms Race and Its Dangerous Legacy*, (New York: Doubleday, 2009), p. 413.

[23] See, for example, Nursaltan Nazarbayev, *Epicenter of Peace* (Hollis, N.H.: Puritan Press, 2001).

United States, Nazarbayev agreed after the Soveit collapse to return the nuclear-armed ballistic missiles and all nuclear weapons in Kazakhstan to Russia. However, the last weapons did not leave until 1995, creating a four-year period after the Soviet collapse when Russians remained at some nuclear facilities in Kazakhstan, although most people at the test site had left.

During this period, Degelen Mountain itself received an upgrade: in 1993, the United States began a $6 million program that by 1997 had begun closing the portals to the nuclear-testing tunnels, a project intended to destroy the infrastructure of nuclear testing so it could never be resumed at the site. In total, 181 tunnels and 13 test shafts were sealed. Many U.S. officials felt the danger of nuclear material from Kazakhstan falling into the wrong hands was largely fixed by this tunnel-closing effort, and the United States had the problem under control.

But the tunnel sealing had not dealt with the fissile materials the Soviets had left behind—some of which were readily accessible if anyone got inside the tunnels, and some of which were in containers outside the tunnels. In the tunnel-sealing effort, U.S. officials were required to follow strict limits about how far into the shafts they could explore, according to a senior official.[24] Indeed, the full scope of the Soviet nuclear weapons archipelago—as well as the chemical and biological weapons research and development facilities—had yet to be discovered by the West.

Source: U.S. Department of Defense

External and internal views of a tunnel used for nuclear testing, from 1997.

'Project Amber'

When Hecker considered the potentially overlooked nuclear dangers, the test site at Semipalatinsk came to mind right away. Hecker concluded that, if there was unguarded fissile material, it would probably be there. "I knew that if I wanted to find vulnerable nuclear material I'd look at their test site," Hecker later recalled, "because I mirror-imaged what we did in the U.S."

While still Los Alamos director, Hecker had encouraged Danny Stillman, at the time head of the Technical Intelligence Division at Los Alamos National Laboratory, to explore Semipalatinsk. Stillman had spent years studying Soviet and Chinese nuclear testing programs. (He had also visited Arzamas-16 in the run-up to Hecker's visit in 1992.) In addition, Stillman was involved in

[24] Interview with Andrew C. Weber, assistant secretary of defense for nuclear, chemical and biological defense programs, June 18, 2012, Washington. Weber said the limit was 50 meters into the tunnel.

the U.S. hydronuclear experiments and had for years studied the mysterious activities recorded by satellites at the Semipalatinsk test site. He visited the area in early 1995, and from that and other sources, the details of the Soviet hydronuclear and safety tests were confirmed. The information suggested a "large number" of tests between 1967 and 1976 at the Semipalatinsk site.

In November, 1995, Stillman and colleagues at Los Alamos wrote a memo to Hecker about the potential for another nightmare scenario – that plutonium might be buried in the tunnels of Degelen Mountain or elsewhere around Semipalatinsk in forms that thieves could extract. They proposed a rapid effort to carry out an on-site assessment, and then develop a plan for cleaning the site up. Stillman titled his memo, "Project Amber: Elimination of a Potential Source of Special Nuclear Materials."[25]

The memo recounted that Kadyrzhanov and other Kazakh scientists had told Stillman of their concern that plutonium remained in a remote area unprotected by fences or guard posts. A summary of the information suggested that "problem will not go away," and added that there was more than 150 kilograms (330 pounds) of "special nuclear material" at the location (a term of art for material that can be used to fuel nuclear bombs), available for "collection without detection." There was no security, nomads and herdsmen roamed at will, and there had been "discovery of surface gold on site."[26]

Stillman wrote in the "Project Amber" memo:

> If the tests were similar to tests conducted in the US (in particular at TA-49 in Los Alamos), we would expect the material deposited in the trenches to contain several hundred … kilograms of weapons grade special nuclear materials (Pu, and possibly highly-enriched uranium)…. Because this site is so remote from the main test site, the presence of this significant amount of plutonium poses a serious threat to the proliferation goals of both the US and Kazakhstan. Deposits of gold have recently been discovered in the immediate area surrounding this site, thereby increasing the potential of increased access by the general public. This site provides a potential 'Pu mine' for a potential proliferator unless it is contained or cleaned up in the near future.[27]

Stillman and his colleagues laid out a plan for dealing with what they called "a potential and accessible source of weapons-grade nuclear material." At the time, the main proliferation concern was Iran, which was thought to be hunting in the former Soviet Union for weapons-grade nuclear materials. Stillman estimated that containment and remediation of the materials at the site might cost up to $1 million.

Nothing happened immediately. But within weeks of Hecker's retirement in late 1997, he began to focus on the problem outlined in the Project Amber memo. One of the side benefits of the 1994 HEU removal from Kazakhstan was that the U.S. provided funds, through the International Science and Technology Center, to Kazakh nuclear institutes.[28] This, in turn, promoted closer

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[25] The 1995 Degelen Mountain visit is reported in Hecker, "Dealing with Kazakhstan's Nuclear Legacy."

[26] Los Alamos National Laboratory memorandum, written by staff scientists for Siegfried S. Hecker, "Nuclear Proliferation Problem." The paper was probably written about the time of the Project Amber memo or shortly thereafter.

[27] "Project Amber: Elimination of a Potential Source of Special Nuclear Materials." November 30, 1995. Pu is the chemical symbol for plutonium.

[28] The International Science and Technology Center was established in 1992 by the United States, European nations, and Japan

collaboration between Kazakh nuclear scientists and their U.S. counterparts. On January 9, 1998, a delegation of Kazakh scientists came to Los Alamos. Among those who met with Hecker was Kadyrzhanov, the metallurgist and materials scientist, who had grown up near Semipalatinsk as a youth, and later studied in Moscow, doing graduate work in nuclear physics at the Kurchatov Institute. At that meeting, Hecker asked Kadyrzhanov about Semipalatinsk. “If you have a common bond, like the scientific bond, you can cut through a lot of the junk and get to the important issues very quickly,” Hecker recalled. Kadyrzhanov responded by saying he had deep concerns about the test site. He explained that Kazakhstan had recently set up the National Nuclear Center to which the Institute of Nuclear Physics in Almaty reported. He told Hecker that NNC scientists had carried out an instrument survey of the area and found signatures suggesting the presence of plutonium and enriched uranium.

Kadyrzhanov said the Kazakhs had turned to Russia for help, but received very little. “They’ve tried to get this information” about the type and quantity of material left behind, “from the Russians but they only get bits and pieces,” Hecker wrote in his notes of the meeting.[29] “The Russian specialists often react very surprised by the amount of plutonium” that the Kazakhs report having detected at Semipalatinsk.

Moreover, Kadyrzhanov told Hecker that the area where the plutonium was buried was wide open. The surrounding villages are very poor, he added. Kadyrzhanov described how scavengers were searching the area looking for copper cable used for various testing events, and which could be sold for profit. “They are beginning to penetrate the former test area,” Kadyrzhanov said. He also described how oil and gas drilling in western Kazakhstan was being planned in areas where the Soviet Union had carried out nuclear explosions for peaceful purposes such as excavating large caverns.

Although some of the dangers had been outlined in Stillman’s earlier memo on Project Amber, Hecker found the information from Kadyrzhanov disturbing. When the meeting ended, he wrote in his notes, “Pity there was so little time.” He decided that he had to get to Semipalatinsk to see for himself. After Kadyrzhanov returned to Kazakhstan, he wrote Hecker within days, imploring him to visit. He stated, “We are extremely anxious about the large quantity of scattered plutonium on the territory of Kazakhstan.”[30]

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to help ex-Soviet weapons scientists find civilian research work and keep them from proliferating their know-how.

[29] Excerpt from Siegfried Hecker’s notes, provided to the authors.

[30] Kairat Kadyrzhanov email to Hecker, February 13, 1998. Unless otherwise indicated, correspondence with Hecker was provided by him to the authors.

Source: Siegfried Hecker

Siegfried S. Hecker (right) and James W. Toevs (left) from Los Alamos National Laboratory on the Kazakh steppe in 1998.

'Completely Open to Whomever Wants to Come'

Hecker drafted a message to the United States Embassy in Kazakhstan, alerting them to the potential dangers and his desire to investigate. Describing the plutonium, he said, "This material would be easily accessible to recover by a group interested in obtaining weapons materials for nuclear proliferation." If recovered, he estimated, there might be enough plutonium to make five or 10 nuclear bombs.[31] "The potential amount of material available at this site is approximately one third to one half of the amount recovered from Operation Sapphire….Individuals could easily access the area and 'mine' the material without being detected."[32] Hecker also invited Russian officials from the nuclear weapons laboratory at Arzamas-16 to join him in Kazakhstan, but they declined, at least initially.[33]

Hecker and two other Los Alamos specialists went to Kazakhstan for nine days in April, 1998.[34] When he arrived at Semipalatinsk, Hecker found a lone, meager guard gate and no guards. He had been warned by Kadyrzhanov about the metal scavengers, but nothing prepared him for what he witnessed on the scene. "When I went out there, I was expecting to see guys on camels pulling on copper cables," he recalled. Instead, Hecker saw miles of trenches in the brown, dry steppe that could only have been dug by powerful excavating machines.

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[31] The actual amount of recoverable material underground at Semipalatinsk remains a matter of dispute. The official U.S. Government position is "approximately a dozen bombs worth of material," but this estimate includes large uncertainty about the state of the material, which would determine how much plutonium could actually be recovered and turned into a form suitable for weapons.

[32] "Possible Source of High-Grade Uranium and Plutonium Weapons Materials," draft note to U.S. Embassy, Kazakhstan.

[33] Hecker's letter to Radi Ilkaev, director of VNIIEF, or Arzamas-16, March 27, 1998. Ilkaev responded on April 7, 1998, saying he could not come because he could not obtain permission rapidly enough from the ministry in Moscow, where the leadership had changed.

[34] The other two specialists were John R. Phillips and James W. Toevs. The trip took place April 16-25, 1998. This account is based on Hecker's trip report and handwritten notes during the visit, as well as photographs and his recollections in the interview.

The scavengers were seeking copper cable, and when they found it, they burned off the insulation and wound it up for sale, reportedly in China. Hecker took photographs of the trenches, and wondered how close the scavengers had come to the plutonium that lay buried there. The Kazakh authorities had no idea how much of it was there, nor where it was located. As far as anyone knew, the scavengers were unaware as well. Hecker wrote in his notes, "People on the site—no way to keep them off." In another location, Hecker was shown one of the Semipalatinsk test tunnels which had been closed earlier in the decade by the U.S.-backed program. The front of the tunnel was plugged, but the scavengers—looking for steel rails which had been laid in the tunnels—broke in by drilling down from above, bypassing the plugs.

Hecker recalled he was "absolutely, totally alarmed by the size of the metal-scavenging operation. I really thought these were guys digging a little bit of copper out. Instead this was a major industrial enterprise. And the immediate concern I had is, where do the copper cables lead to? Well, they lead to where there were some tests. What the hell do we know is on the other side of that copper cable?"[35] In a trip report written upon his return in 1998, Hecker offered a possible answer: total plutonium in the area may approach 200 kilograms and "access is unimpaired; no gates are manned… we have a strong concern that a proliferation risk may exist—material in reasonably concentrated form, easily picked up, completely open to whomever wants to come."[36]

While Hecker was primarily worried about proliferation, the Kazakhs had other concerns as well. Contamination of the ground was potentially a huge environmental problem—one that might cost a fortune to clean up. The Kazakhs had plans to increase mining operations and introduce oil exploration at the site, which could grind to a halt if the fields turned out to be still laced with radioactive materials.[37] This concern was already anchored in reality elsewhere in the country. Two areas in western Kazakhstan where oil firms were eager to drill had been used by the Soviet Union for so-called peaceful nuclear explosions, experiments to blast out huge caverns in the salt formations for oil storage and other purposes. No one knew how much radioactivity still remained in the caverns.[38]

Source: Siegfried Hecker

Gate at edge of testing site, 1998.

The Kazakhs had signed a bilateral agreement with Russia in

[35] Interview with Hecker, November 29, 2012.

[36] Hecker, trip report.

[37] Through the early 1990s, local officials near Semipalatinsk encouraged mining through the easy access of mining permits. See, for example, "Russian-Kazakhstan Agreement on Semipalatinsk Test Site Criticized," *Zelenyy Mir*, No. 28, 1993, p. 13.

[38] These two sites were known as Azgir and Lyra. A total of 17 nuclear tests were conducted in salt domes at Azgir between 1966 and 1979 in an effort to make cavities for storage of wastes and gas condensates, but the tests did not work because the salt was unsuitable. Six detonations were conducted at Lyra, and some caverns were subsequently used for gas storage. From Hecker's trip report.

the early 1990s about Semipalatinsk under which Moscow was supposed to supply information about the test site, and the Kazakhs agreed to keep some aspects of the site secret. But the Kazakhs repeatedly complained to Hecker that Russia refused to share details of what had gone on in those desolate corners of the steppe. The Kazakhs, including Kadyrzhanov, chafed at Russia's secrecy. They wanted no part of it, despite the bilateral agreement, which they hoped to change.[39]

Hecker wrote down what he saw at Kurchatov City. "Mostly deserted buildings … most of them had the windows knocked out—a kind of eerie scene out of a ghost-town movie. This was especially true when I jogged in town early in the morning. The streets were deserted, not a soul. All I saw was a herd of horses running loose through the outskirts of town and an enormous number of ravens…"[40]

The trip to Kazakhstan had been a turning point for Hecker.

'You Left Some Stuff There.'

A few months later, in July, 1998, Hecker headed for Moscow. It was a turbulent time in Russia. Within a month, the country's fragile economy would collapse with a default and devaluation. From Moscow, Hecker took the overnight train to Sarov, the location of Arzamas-16. Hecker had developed personal relationships with his counterparts at the laboratory. Although Arzamas-16 was once among the most top-secret facilities in the Soviet Union, and was still isolated and considered sensitive, Hecker was known and respected by the scientists, and his arrival was warmly welcomed.

He carried an urgent request in his briefcase. He went to see Radi Ilkaev, the director, whom he had known from earlier projects. Hecker recalled that they met one evening at the House of Scientists, an informal setting where they could talk. Hecker brought up the subject of Semipalatinsk and the legacy of testing there, particularly the process of hydronuclear testing. Hecker mentioned that Los Alamos performed hydronuclear tests in bore holes at Los Alamos in 1960 and 1961, and left the plutonium in the bore holes, while making sure the areas remained protected. He added, "You guys must have done something like that at Semipalatinsk. And if you did, you left some stuff there."

As Hecker recalled it, Ilkaev responded cautiously, choosing his words. He said Russia was finished at Semipalatinsk, forever, and never wanted to go back. Hecker recalled that when he asked why, Ilkayev responded by saying the overriding issue at Semipalatinsk was the environment and the Russians feared the Kazakhs would insist they clean up all the residue, which would be expensive. Hecker pulled out the photos he had taken months earlier at Semipalatinsk. He showed Ilkayev the photograph of the trenches left by the huge earth-cutting machines. "Radi, that's your test site. Those are the copper cable thieves," he recalled saying to Ilkaev. "Radi was just silent. He just looked at me, and looked at the photos. And he said, 'I'll have someone to talk to you in the morning.'"[41]

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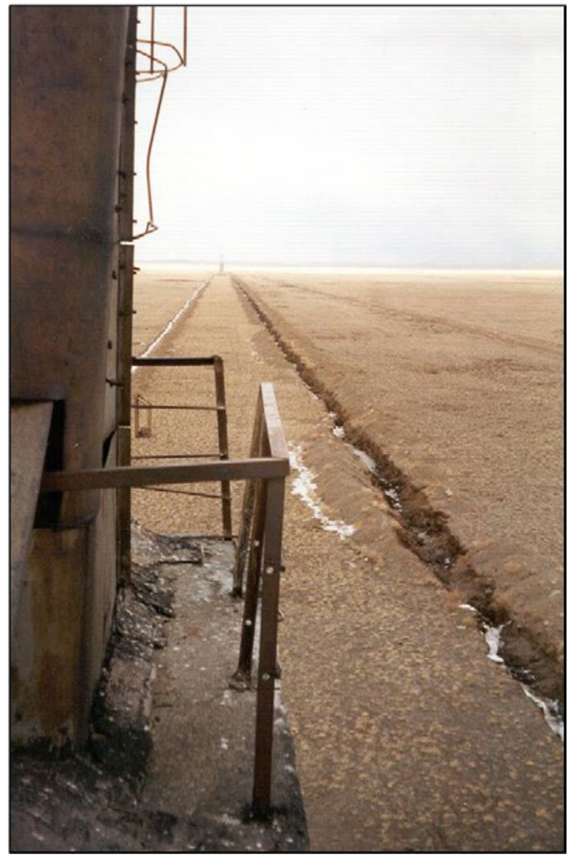
39 Hecker wrote in his notes of the Kazakhs, "They have no desire to keep anything secret."

40 Hecker, trip report.

41 Interview with Hecker, November 29, 2012, Stanford University.

The next day, Ilkaev introduced Hecker to a pair of scientists who were well informed about what had unfolded at Semipalatinsk. They were Yuri Styazhkin and Viktor Stepanyuk, both of whom had worked at the test site in earlier years. Styazhkin knew the whole story, but he did not reveal it all at once. "There are a lot of things we did out there," he told Hecker, "and it wasn't just the hydronuclear experiments."

This was the second turning point. Thanks to Ilkaev's apparent pressure on Moscow overnight—he had clearly taken a risk—and Styazhkin's sense of personal responsibility, Hecker had broken through Russia's wall of silence.



Source: Siegfried Hecker

Trenches dug by scavengers to extract copper cables from the test site.

'Who is Ever Going to Go Out There?'

Hecker next went to the second former Soviet nuclear weapons laboratory, known as Chelyabinsk-70 in Soviet times, located in the Ural Mountains. This laboratory was started nine years later than Arzamas-16. In the Soviet era, the two labs competed, working on different warhead designs. Hecker had also built bridges in the early years to Chelyabinsk-70 and was welcomed there, as well. He went to see Boris Litvinov, the chief weapons designer for 31 years, who was one of Hecker's early contacts in the Soviet nuclear weapons establishment. Hecker showed Litvinov the photographs from Semipalatinsk; both Soviet laboratories had carried out experiments on the test site.

Hecker recalled that Litvinov:

> ...explained to me how they did the hydronuclear tests. He said, 'We didn't bury it the way you guys did. We did [tests] out on the surface. We dug a little trench. We put our experiments in there. And we just blew it up. Then we took bulldozers and bulldozed that over, and we took care of it. We thought, who is ever going to go out there?'

In the meeting with Litvinov, Hecker learned that the Soviet tests were not only hydronuclear. The weapons designers had also carried out studies known as "equation-of-state" experiments to probe the behavior of plutonium. While the hydronuclear explosions probably had blown up the metal and dispersed it, the other experiments were done in shallow bore holes, and whole pieces of plutonium, rather than residue, may have been left in the ground, which would be even easier for someone to recover.

Yet another revelation followed. When Hecker asked Litvinov whether all of the Soviet nuclear explosions conducted in the tunnels had actually detonated, Litvinov said they had not. This added a new concern: the plutonium (or highly enriched uranium) that remained in the test tunnels from those duds, especially now that it appeared the scavengers were re-entering some of the previously-sealed test tunnels.

Lastly, Litvinov told Hecker that some of the tests had been carried out in large tank-car sized metal containers known as "Kolbas."[42] Where were they now? Still in place, at Semipalatinsk. Some were deep inside the tunnels at Degelen Mountain, others were outside.

These discussions with the scientists convinced Hecker that any hope of dealing with the plutonium at Semipalatinsk would have to involve the Russians. They had the knowledge of what tests had been carried out and what might have been left behind. "What tunnels actually still contained stuff that we should be worried about?" Hecker recalled asking. "Without the Russians, we have no chance whatsoever. It would be like looking for a needle in a haystack."

It would not be easy. Even in 1998, seven years after the Soviet collapse, suspicions from the Cold War still ran strong. While at Chelyabinsk-70, Hecker went to see Evgeny Avrorin, who had twice served as scientific director of the laboratory. Although he had extensive contacts with westerners over the years and had come to Los Alamos to help the lab celebrate its 50th anniversary in 1993, Avrorin was still cautious and suspicious. The nuclear weapons laboratories had been secret kingdoms for so long that the mindset was hard to change.

Hecker showed the photographs from Semipalatinsk to Avrorin, and implored him to support some effort to deal with the plutonium. Hecker recalled that Avrorin replied, "It sounds like intelligence to me."

Hecker added,

> What he was concerned about is that the work that they did there… the plutonium chemistry, the plutonium isotopics, are classified secret in Russia. …The type of test that they did, whether it was in the tunnels, whether it was in the Kolbas—that's all part of their trade, of the nuclear weapons trade. They don't want to give out that information. And Avrorin was concerned that I was doing this for intelligence collection.

Hecker recalled telling Avrorin that he was not spying but was concerned about the nuclear materials spread across the steppe, unprotected. Nonetheless, the Chelyabinsk-70 scientists decided to hold back, to see if Moscow allowed the project to move ahead, and to let Arzamas-16 go first. They eventually joined the project.

Next, Hecker came back to the United States and briefed high-level officials in the government about what he had found. He showed them photographs of the unmanned guard gate, of the trenches, and maps of the various sites at Semipalatinsk where the fissile material might be located. He urged them to join Russia and Kazakhstan in an effort to do something about the proliferation risks at Semipalatinsk.

Hecker warned them that the amount of recoverable plutonium was not trivial. He said there was perhaps as much as 200 kilograms, or about 441 pounds, enough for at least a dozen nuclear weapons and maybe more, given the quality of the material. And it was all lying about,

[42] "Kolba" is a term of art in chemistry to refer to containment chambers.

unguarded, on the test site and in the tunnels.[43]

Source: Siegfried Hecker

From left: Kairat Kadyrzhanov (Kazakhstan), Radi Ilkaev (Russia), and Siegfried Hecker (United States), together in Almaty, Kazakhstan, 1999.

As a result of Hecker's visits, the Russians began to cooperate. It took years for them to reveal everything, but in June 1999, Hecker invited Ilkaev to a NATO-sponsored conference on non-proliferation and environmental issues in Almaty, Kazakhstan. Hecker organized the conference with Kadyrzhanov of the Institute for Nuclear Physics. Ilkaev brought several of his specialists from Arzamas-16, including the key scientists who performed the experiments at the test site, Styazhkin and Stepanyuk, whom Hecker had met with on his trip to Russia. The Russians' attendance was a watershed—only a year or so earlier, Ilkaev had declared that they were never going back to discuss remediation efforts.

At the margins of the conference in Almaty, Hecker, Ilkaev and Kadyrzhanov signed a three-way agreement for a series of field studies that would determine the scope of the problem at Semipalatinsk. The three countries divided up their duties. The United States, through Los Alamos National Laboratory, would fund the effort; Russia agreed to loan the scientists and provide the vital information; Kazakhstan would do the fieldwork and provide necessary permissions. The U.S. government would fund both the Kazakh and Russian work. Hecker had brought Dr. Phil Hemberger, a Los Alamos colleague, with him to lead the scientific aspects of the project. Hecker described Hemberger's role as "essential in providing the trusted link to the Russian scientists, in helping to evaluate the seriousness of the proliferation risk posed, and in connecting to the Kazakhs to get the initial fieldwork started." Hecker recalled that during the first trilateral meetings, the Russians revealed that the problem at Semipalatinsk was much more extensive than anticipated. The most pressing concern was not the nuclear test tunnels, but rather the "equation-of-state" tests in shallow bore holes close to the Degelen Mountain area.

Hecker, in a talk to participants at the NATO conference, emphasized the importance of scientists working together. "It was said some time ago that 'religion preaches the brotherhood of man, but science practices it.' I believe that," he said. The three signers of the trilateral document and their colleagues celebrated with vodka and several rounds of toasts to the project. What they didn't know is that the plan they discussed that evening would take more than a decade to complete.

[43] The 200 kilogram estimate is from Hecker's trip report.

The Project Begins

Officials from the Russian Atomic Energy agency, then known as Minatom, remained deeply suspicious that the United States would use cooperation at Degelen Mountain to collect intelligence about Russian nuclear weapons. Specifically, Russian scientists were concerned that the spectrometry equipment needed to verify the presence of plutonium in shafts and tunnels could also be used to reveal the mix of different plutonium isotopes used in Soviet—and now Russian—nuclear bombs. The isotopic composition of Russia's weapons-grade plutonium was still a closely guarded secret.[44]

Meanwhile, the initial assessments of whether or not the situation in the shallow bore holes was a proliferation problem involved an enormous amount of work. Hemberger of Los Alamos was on the phone almost daily with Styazhkin and the head of the Kazakh nuclear center, Shamil Tukhvatulin. That field work, conducted by the Kazakhs under the direction of the Russians and Americans, convinced any remaining skeptic in the U.S. that the proliferation threat was real. Hecker went to the U.S. Defense Threat Reducation Agency looking for more help, and they agreed. Hecker also sought support from Andy Weber, then in the Office of the Secretary of Defense, and from Rose Gottemoeller, an assistant secretary of energy.

Next, an effort was launched to conclude an official, three-nation agreement to govern the effort. In May, 2000, Gottemoeller went to Moscow to meet Russian and Kazakh officials. The Russian representative was Lev D. Ryabev, first deputy minister of atomic energy, accompanied by Styazhkin. Hecker went as Gottemoeller's technical adviser. All three sides expressed a desire to move forward with work on the Semipalatinsk test site, but still struggled with the spectrometer issue. A breakthrough came in a technical agreement between Los Alamos and Arzamas-16 scientists in which Russia would allow the United States to use equipment to verify the presence of plutonium, but only if U.S. scientists promised to immediately erase all readings on the device, and then bury any samples of material taken during testing.[45] U.S. scientists could take a quick look at the spectrometer—long enough to verify the presence of plutonium—but not long enough to determine the isotopic composition of that plutonium.

Russian and U.S. officials also disagreed on the important issue of how to dispose of the plutonium. U.S. officials felt it should be dug up and returned to a secure storage in Russia. Russia was not interested in taking it.

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44 Most combinations of plutonium isotopes—the different forms of an element, having different numbers of neutrons in their nuclei—can be used to make a nuclear weapon. Not all combinations, however, are equally convenient or efficient, which is why Russia was concerned about sharing information about the isotopic composition of its bomb fuel. Nonetheless, given the sophistication of both U.S. and Russian nuclear weapons, the very modest difference between different mixes of isotopes still dominated by Pu-239, the isotope most suited for weapons, and the immense destructive effects of even unsophisticated nuclear weapons, it seems strange that the mixture of plutonium should be such a closely guarded secret in Russia. A similar concern, however, has cropped up again and again in bilateral discussions ranging from plutonium disposition (where the U.S.-Russian agreement allows Russia to mix its weapons plutonium with some reactor-grade plutonium to hide its original isotopic content), to verification of stored plutonium (where Russia has been similarly reluctant about letting U.S. experts take measurements). The United States, by contrast, has declassified the isotopic composition of its weapons plutonium. Russia may also have been concerned about protecting chemical information about gallium added to the plutonium to stabilize it in the desired crystalline form. The United States declassified the fact that gallium is used for this purpose in the 1990s, but Russia did not – and none of the weapon states has declassified the exact percentages used.

45 Viktor Stepanyuk, "Liquidation of Consequences of Nuclear Tests at the Semipalatinsk Test Site (STS) in Trilateral Collaboration," presentation, Sarov, February 2012.

There was also the question of what to do about the IAEA. Under its obligations as a signatory to the NPT, Kazakhstan was required to declare all weapons-usable nuclear material in its territory and place the material under IAEA safeguards. But all three countries wanted to keep the plutonium at Degelen Mountain a secret from the IAEA.

For Russia, this was secret material, and it was even more important to keep secrets from the IAEA (which includes staff from many non-nuclear countries) than from the United States. They were concerned that the agency would insist on performing an inventory of the plutonium, which could reveal the isotopic composition. U.S. officials had their own reasons to go along with the secrecy: they felt that involving the IAEA would slow down and complicate the operation, and perhaps jeopardize the confidential nature of the work.[46] According to U.S. officials, the Kazakhs also favored keeping the IAEA out of the picture. Kazakhstan President Nazarbayev had often promoted his nonproliferation credentials around the world, so admitting that Kazakhstan had undeclared nuclear material on its territory would have been embarrassing.[47]

All the parties agreed early on to refer to the plutonium in official documents as "nuclear waste" in order to maintain the charade that Kazakhstan was unaware it had undeclared fissile material on its territory.[48] Referring to the plutonium as nuclear waste, however, made returning the material in secret to Russia impossible. Russian customs law forbids importing radioactive waste to Russia other than in used fuel rods from Russian-origin reactors in foreign countries. Thus, any plan to return "nuclear waste" from Semipalatinsk would require the Russian parliament to change the law, which would have inevitably drawn attention from the nuclear industry, jeopardizing the security of the operation.

Though the material was never formally declared to the IAEA, one U.S. official said that the IAEA was kept in the loop about Semipalatinsk through informal channels, and "the diplomatic art of having non-conversations in hallways in Vienna" about the material there.[49] Olli Heinonen, the deputy director general for safeguards at the IAEA and a dogged investigator, reports that he was briefed on what the three countries were doing at Degelen both before and during a trip to Semipalatisnk in April, 2010 with U.N. Secretary General Ban-Ki Moon, and concluded the approach was reasonable.[50] Nevertheless, U.S. officials interviewed for this paper say they helped Kazkahstan keep Heinonen far afield of sensitive areas on the testing site.[51]

[46] Interview with DTRA officials, October 2012.

[47] This account of the reason Kazakhstan preferred to withhold information from the IAEA was provided by U.S. officials, who requested anonymity. Kazakh officials and scientists would not comment. Given that the U.S. and Russia had a strong preference to avoid involving the IAEA—and that the U.S. was funding the program—it seems at least possible that Kazakhstan went along at the behest of the United States and Russia.

[48] Interview with Hecker, November 28, 2012.

[49] Interview with Ristvet and a high-ranking Defense Department official, who spoke on condition of anonymity.

[50] Personal communication, July 2013.

[51] Other than Heinonen's visit, the IAEA seemed happy to play along. As part of its evolving 'state-centered approach,' in which the agency analyzes all information available to it about the nuclear activities of each state and focuses its safeguards resources most intently on those countries where the information seems to raise suspicions, agency officials felt confident that Kazakhstan had no intention of diverting or using the material at Degelen Mountain, according to two former IAEA officials knowledgeable of Kazakhstan's safeguards agreement. "We need solutions that are cost effective," said one. "We thought about safeguards and asked ourselves, 'Is it worth the agency's efforts to allocate scarce safeguards resources for this material?' We decided it was not worth the cost involved of taking an inventory." The IAEA itself, via a press spokesman, declined to comment for this report.

Though Hecker had not yet given up on finding a way to send the plutonium back to Russia, the obstacles on the Russian side were high and DTRA officials were worried about the costs, so scientists from the three nations turned their attention to how to secure the plutonium in place. For the bore holes still containing plutonium residue, inspiration came from the aftermath of the worst nuclear accident in history. Following the meltdown of a reactor at the Chernobyl Nuclear Power Plant in 1986, Soviet scientists constructed a giant concrete dome around the crippled reactor to halt the release of radiation and materials into the atmosphere. The Russians at Semipalatinsk pointed out that such a sarcophagus could work equally well for the shallow bore holes. The scientists thought a giant concrete envelope over the site might deter most scavengers from breaking into the bore holes.[52] And even if it didn't—the scavengers had already proven themselves remarkably determined—violating the dome would require a large industrial enterprise that could be quickly identifiable by basic monitoring techniques.

Operation Groundhog, as the dome construction effort was known, was to get underway in August 2000 with funding from the U.S. Cooperative Threat Reduction (CTR) program and with oversight from the U.S. Defense Threat Reduction Agency. But very soon the operation ran into delays. All work at Semipalatinsk ceased during the winter, when temperatures in eastern Kazakhstan regularly plummet to -40°C. Only a few months after Operation Groundhog began, the Kazakh crews put down their tools. When they returned to work in the spring of 2001, U.S. financial support for the project had been suspended. There were several reasons for the funding pause. The newly arrived Bush administration had ordered a complete review of the CTR program, which led to delays in 2001. Also, the administration carried out a "re-notification" to Congress of a shift in funds, a standard procedure, which also resulted in delays. The administration further had to certify to Congress that Kazakhstan was eligible to receive CTR money, but the overall umbrella agreement between the United States and Kazakhstan, signed in December 1993, had lapsed at the end of 2000. A new agreement wasn't approved by the Kazakh parliament until mid-2002.[53]

In the summer of 2001, scavengers returned to one of the test sites.[54] The only security put in place at the site in 2000 was a barbed-wire fence, which "did not provide the expected effect," Stepanyuk recalled.

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52 The concrete structure also contained an irrigation system, including a drain-pipe and external water stop to prevent the material from leeching into the water table. It should be noted that the concrete sarcophagus at Balapan was much smaller than Chernobyl—it contained 2075 cubic meters of concrete, compared to 400,000 cubic meters at the Ukrainian reactor. See Stepanyuk, "Liquidation of Consequences."

53 Between January and July 2002, CTR work in Kazakhstan remained at a standstill, in part because the country's new criminal code required that all such agreements be extended by parliamentary ratification only. In the ensuing debate over ratification, some parliamentarians expressed concern that the framework agreement might allow the 41 firms serving as subcontractors to avoid paying taxes on non-CTR-related transactions. The lower house approved the umbrella agreement in April, 2002, and the upper house in May. See: Nuclear Threat Initiative, "Kazakhstan Nuclear Chronology," pg. 16. http://www.nti.org/media/pdfs/kazakhstan_nuclear.pdf?_=1316466791 (accessed on August 7, 2013). On the 2001 delays, the authors received information from a senior Defense Department official, and also relied upon: John Booker, "Overview of Fissile and Radioactive Material Proliferation Prevention (FRMPP) Program: Operation Saiga, Operation Groundhog," Defense Threat Reduction Agency, 15 July, 2002, provided by the Defense Department.

54 Ristvet and other U.S. officials interviewed suspect that the scavengers were likely the same construction crews that had worked on constructing the dome the previous year. According to Ristvet, DTRA officials encountered scavengers brazenly using Degelen Mountain Enterprises mining equipment, though Ristvet could never prove that the company's management was aware of such security breaches.

Now Kazakhstan and Russia became alarmed. The unfinished sarcophagus had provided an obvious signpost to scavengers of an area of value. The Kazakhs became desperate for action, and decided to go public. In June 2001, Kenley Butler, a researcher at the Monterey Institute for International Studies, visited Kazakhstan on a trip through the former Soviet republics. He met with Vladimir Solodukhin of the Institute of Nuclear Physics in Alatau.

In a trip report written shortly after his return, Butler wrote,

> Solodukhin said that the world community should take immediate measures to address the proliferation risks presented by the Semipalatinsk Test Site. Solodukhin estimates there are over 290kg of plutonium…centered at Degelen. According to Solodukhin, he and another nuclear physicist could easily collect 5kg of plutonium [enough for a nuclear bomb] in one or two days using simple chemical extraction processes. Solodukhin is very troubled about mining operations at the site that currently extract gold, coal, beryllium and other materials, and about the illegal gathering of scrap metal. Bore tunnels have been breached by metal collectors. Mining and excavating machinery is used for both legal mining activities and illegal scrap metal gathering.[55]

Russian officials were also agitated, especially during the period when U.S. financial support was suspended. In October 2001, in the immediate aftermath of the 9/11 attacks, Ilkaev wrote a letter to Ryabev, the Russian first deputy minister for atomic energy, saying that while "…the issue of nuclear waste presence in the territory of the former [Semipalatinsk Test Site] is a common problem of the three sides (Kazkakhstan, Russia, USA)… at the present moment, when the works at the testing ground are suspended, its solution prospects are not clear."[56] Ryabev, in turn, sent a letter to U.S. officials stating that the Russian scientists were concerned that "due to the suspension of the dome construction, the situation at the testing ground became even more dangerous than it had been prior to the start of our collaboration."[57]

Hecker also heard of the stoppage from Russian and Kazakh officials, so he went to see Susan Koch, then a White House official at the National Security Council, to urge a resumption. Also at the meeting was Weber, who played a behind-the-scenes role in pushing for a resumption of funding.[58]

Source: U.S. Department of Defense

Scrap metal scavengers.

[55] Kenley Butler, Trip Report, "Almaty, Astana, Alatau," June 2001, KAZ010600, pp. 6-12. Excerpt provided by the author.

[56] Cited by Stepanyuk in "Liquidation of Consequences," section 2.1, Operation Groundhog, p. 8.

[57] At the outset, all three countries agreed that the United States would fund the project. In later years, Russia's financial resources improved considerably with oil revenues. In theory, Russia could have provided some of the funding but this was apparently never given serious consideration.

[58] Hecker, communication with the authors, April 2013. Weber recalled that a major issue was getting the Kazakh parliament to ratify the CTR umbrella agreement with the United States. Interview with Weber, May 17, 2013.

Chronology of Degelen Mountain Cleanup

1949: The first nuclear test conducted by the Soviet Union detonates at Semipalatinsk. Testing continued until 1991. There were 456 tests in total.

1991: The Soviet Union collapses and Kazakhstan becomes an independent state.

1991-2009: Local scavengers forage the testing site. They strip copper wiring and steel rails to sell as scrap metal. Access is unfettered in the 1990s. With U.S. and Russian threat reduction work in the 2000s, scavenging diminishes, but continues periodically during periods of inactivity at the site. In 2009, Kazakhstan adopts a law making sensitive portions of the testing site an "exclusion zone." Signs and security systems are put in place.

1993: The U.S. signs a $6 million program to close portals to testing tunnels at Degelen Mountain. Called the Degelen Mountain Tunnel Neutralization Project, the operation is designed to destroy the infrastructure so testing could never be resumed. It is not targeted at preventing scavenging or theft of nuclear material. About 181 holes were closed.

1994: The U.S. airlifts about 605 kg (1332 pounds) of highly-enriched uranium from Kazakhstan in "Project Sapphire."

1995: A team of scientists from Los Alamos National Laboratory (LANL) visits Semipalatinsk.

1995: A LANL official, Danny Stillman, drafts a memo, "Project Amber: Elimination of a Potential Source of Special Nuclear Materials." The memo warns that unsecured nuclear bomb fuel exists in the tunnels at Degelen Mountain and the complex could become a "plutonium mine."

1998: A delegation of Kazakh scientists from Semipalatinsk visit Los Alamos National Laboratory. They warn the recently-retired head of LANL, Sig Hecker, that scavengers are scouring Degelen Mountain.

1998 (**April)**: Hecker visits Semipalatinsk and takes photographs of the scavenging activity.

1998 (July): Hecker travels to the two main Russian nuclear weapons laboratories, Arzamas-16 and Chelyabinsk-70. In meetings with the lab directors, Hecker presents evidence of scavenging at Degelen Mountain and implores Russia to take action. Radi Ilkaev, the director of Arzamas-16, is initially reluctant, but then offers support.

1999 (June): Hecker and Ilkaev meet at a NATO-sponsored conference in Almaty, Kazakhstan. Also at the meeting is a senior Kazakh scientist, Kairat Kadyrzhanov. On the margins of the conference, Hecker, Ilkaev and Kadyrzhanov sign a three-way agreement for a series of field studies that would scope out the size of the problem at Semipalatinsk

2000: Several meetings take place between the three countries to agree on implementation. The most prominent occurs in May when Rose Gottemoeller, then assistant secretary of Energy, meets Lev Ryabev, Russia's first deputy minister for atomic energy.

2000 (August): Operation Groundhog, designed to cover bore holes containing plutonium near Degelen Mountain, is conceived. But funding is delayed because of a lapse in the U.S.-Kazakh umbrella agreement and the need to get a new agreement ratified by the Kazakh parliament. Work on Operation Groundhog is completed only in 2003.

2001 (June): A nonproliferation researcher, Kenley Butler, visits Kazakhstan and is warned by Kazakhstan scientists about loose plutonium and scavengers at Semipalatinsk.

2002 (Winter): An article in the journal *Science* articulates the problem of loose plutonium at Semipalatinsk.

2004: Operation Matchbox extends threat reduction work to three explosive chambers near Degelen Mountain called Kolbas that contain plutonium residue. After it is completed, Operation Nomad tackles three Kolbas in the tunnels of Degelen Mountain itself; that work finishes in 2005.

2005 (April): Russia reveals that around 100 kgs of recoverable plutonium still exists within Degelen Mountain even after the completion of Groundhog, Matchbox and Nomad. It is also revealed that the mountain also holds high-purity plutonium that would easily have provided materials and information that could lead to a relatively sophisticated nuclear device if it had been found.

2006 (June): In a trilateral negotiation, Russia agrees to accept two pieces of sensitive equipment back from Degelen and entomb the third in concrete in the tunnel.

2008: DTRA officials terminate a contract with a local Kazakh construction company—Degelen Mountain Enterprises—that they feel is responsible for slowing the work and also for various security breaches

2009: In the run-up to a gathering of world leaders at the Nuclear Security Summit in Washington D.C. in 2010, security and monitoring equipment is installed on the site.

2010: UN Secretary General Ban-Ki Moon visits Semipalatinsk with IAEA Deputy Director-General Olli Heinonen.

2010 (March): Presidents Obama, Medvedev and Nazarbayev pledge at the Nuclear Security Summit to complete the work at Degelen Mountain by 2012.To meet the deadline, crews work through the winters of 2010 and 2011, the first time the project continued through the harsh winter months.

2012 (March): Obama, Medvedev, and Nazarbayev announce the completion of threat reduction work at Semipaltinsk at the Nuclear Security Summit in Seoul. In fact, work would continue until October, 2012.

2012 (October): A ceremony attended by U.S, Russian and Kazakh scientists and officials mark the completion of threat reduction work at Semipalatinsk.

Source: Siegfried Hecker

"Operation Groundhog."

In early 2002, with work still suspended at Semipalatinsk, Kazakh scientists reported to U.S. officials that scavengers had broken into the bore holes, some of which had yet to be covered with cement. The holes were covered with only a thin soil layer.[59]

By sheer good fortune, Russia had performed a rough inventory of the bore holes before work on the sarcophagus began. Stepanyuk, the scientist from Arzamas-16, later recalled that this earlier survey was useful in checking whether there had been a breach. By comparing the earlier survey to a more recent one, "it was possible to draw a clear conclusion about the absence of unauthorized extraction" of plutonium during the period."[60]

But the scare again brought needed high-level attention to the operation. In 2002, the nuclear ambitions of Al-Qaeda were reconfirmed in documents seized during the invasion of Afghanistan, and U.S. officials clearly understood the urgency of preventing plutonium from falling into the wrong hands.[61]

In June 2002, Kazakhstan resolved the legal impediment blocking U.S. funding, and the concrete dome over the holes was eventually completed in August, 2003.

A few kilometers away, however, Degelen Mountain remained unattended. The Russians were slow in revealing information about nuclear materials there, waiting to see how the three countries would complete one problem before beginning the next one. Hemberger from the United States and Styazhkin of Russia were "absolutely indispensible" to getting the information, Hecker recalled. Their relationship was close enough that Styazhkin was willing to tell Hemberger where to look next. The specialists from Chelyabinsk-70 also came along, but were slower to overcome mutual mistrust.[62]

Scavengers continued to burrow away into the heart of the mountain, each day working in close proximity to significant quantities of weapons-grade plutonium. In the winter of 2002, with work

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[59] The breaches were an embarrassment to U.S. intelligence, which had been told to monitor the site using satellite surveillance, according to defence officials involved in the project.

[60] Stepanyuk, "Liquidation of Consequences."

[61] The organization ran a focused nuclear program that reported directly to the top of al-Qaeda command and had progressed to the point of carrying out crude explosive tests in the Afghan desert before the 9/11 attacks. See, for example, Rolf Mowatt-Larssen, "Al Qaeda Weapons of Mass Destruction Threat: Hype or Reality?" Belfer Center for Science and International Affairs January 2010; and David Albright, "Al Qaeda's Nuclear Program: Through the Window of Seized Documents. Nautilus Institute Special Forum 47," http://oldsite.nautilus.org/archives/fora/Special-Policy-Forum/47_Albright.html (accessed on March 11, 2013)

[62] Hecker, communication with the authors, April 2013.

again suspended for the season, Kazakh scientists hosted a reporter from *Science* magazine at Semipalatinsk-21. The resulting article, "Plutonium Fields Forever," relayed Kazakh concern over the test site and explicitly made clear that some Soviet nuclear experiments had "dispersed small chunks of plutonium" that could be a "proliferation risk."[63]

U.S. officials interviewed for this paper speculated that Kazakh scientists leaked the story to *Science* in order to galvanize U.S. attention, but the reporter for the story said he learned of it through his own initiative.[64] Either way, the article refocused high-level attention on the problem. The presence of plutonium at Degelen Mountain was now public information, providing new urgency to the project. A senior Pentagon official, Weber, who had been instrumental in carrying out Project Sapphire, met with Russian officials in Moscow on July 18, 2003 to rejuvenate cooperation and extend projects to other parts of the test site, including Degelen Mountain itself.

At that time, Russian officials were still reluctant to discuss Degelen Mountain. Despite clear evidence to the contrary, "the view of Minatom was that the security of these shafts was sufficiently high" following the original tunnel closure project of the 1990s, according to Stepanyuk. Minatom still suspected that the U.S. was interested in Degelen Mountain for intelligence collection. Without Russian support, work at Degelen Mountain was impossible. In its 1997 bilateral agreement with Russia, Kazakhstan had stipulated that Russia had full ownership rights to material left by the Soviet Union in Degelen Mountain.[65] By this reckoning, the plutonium residue was now Russian property.

Just as it proved decisive when Hecker met with Ilkaev in 1998, evidence of the successful metal scavenging at Degelen Mountain proved sufficient to overcome Russian reluctance. In 2003, Kadyrzhanov reported to his Russian counterparts that a survey of Degelen Mountain had found that over 70 percent of the tunnels at Degelen Mountain had been breached.[66] Realizing that "sooner or later we will have to return to the problem," Minatom's leadership agreed to move the work to Degelen Mountain itself, according to Stepanyuk, but they decided to reveal only the location of three experiments at two sites. Should work with this "sample" go well, and should the Russians feel confident that no espionage was being committed on the site, Russia would consider sharing further information with the Americans and Kazakhs.

As it turned out, the sample locations were not in Degelen Mountain. They were in a nearby bunker, in three Kolbas. Kolbas are 2.4 by 7-meter metal chambers reinforced with Kevlar and fiberglass and designed by Arzamas-16 to contain explosions up to the equivalent of 200 kilograms of dynamite.[67] They were usually placed deep within Degelen Mountain for tests. But three had been used above ground, and stored in the bunker.

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63 Richard Stone, "Plutonium Fields Forever," *Science*, May 23, 2003, pp. 1220-1224.

64 Stone said he met the Kazakh science minister at a conference in Brussels and expressed interest in visiting the Semipalatinsk region to learn of the health effects of nuclear testing. During reporting before his trip, a British scientist suggested to Stone in an interview that plutonium may still exist at the testing site; Stone asked his Kazakh host during his visit about this and learned about Operation Groundhog. Stone recalled, "There was a DoD researcher also visiting there at the time; we were chatting amicably and when I asked him about [Operation] Groundhog, he blanched—couldn't believe the Kazakhs had told a journalist about what was meant to be a secret project." Communication with Stone, March 2013.

65 Stepanyuk, "Liquidation of Consequences."

66 Stepanyuk, "Liquidation of Consequences."

67 Interview with DTRA officials.

The U.S. agreed to work on the three Kolbas, and yet again defer action on Degelen Mountain. The scientists determined that the easiest technique to secure the material would be to fill the Kolbas with a water solution containing cement and sand. The resulting grout-like mixture would be difficult to chemically separate on site, and too heavy to easily transport, providing enough of a barrier to thieves to allow for timely detection and intervention if they broke in to the site. Plutonium experts interviewed for this report said the cement mixture leaves the fissile material in a state that renders it very difficult to recover for use in a bomb.[68]

The long-term safety of this option for the environment is open to question. Cement immobilization of plutonium for permanent disposal has never been proven on a large scale before—the most ambitious laboratory experiments testing cementation as a disposal option have involved only a few grams of plutonium.[69] Over the course of hundreds or thousands of years, water is likely to work its way through the metal and may begin leaching away some of the plutonium-bearing cement. While plutonium does not move very far in most chemical environments, the long-term environmental impact of this disposal has not been analysed.

Before work began, Kazakh crews discovered that one of the Kolbas in the bunker had been already pried open by scavengers.[70] Again the scientists faced the prospect of theft of nuclear material, though in this case the Kolba in question did not contain enough plutonium residue for a nuclear weapon. At one point, Russian scientists inspected the inside of the Kolba unaccompanied by U.S. officials. They reported no evidence of excavation or scraping of the plutonium residue, and concluded that no material had been stolen. It was a close call, however.

The stage of the mission dealing with the three Kolbas was named Operation Matchbox and the work began in 2004; from the U.S. point of view, it proved a great success. But six years after Hecker first raised the issue with Ilkaev, Russian scientists continued to be reluctant to share information about the location of the remaining Kolbas at Degelen. The U.S. Defense Threat Reduction Agency did not have the necessary permission from Kazakhstan to search through the 116 square miles of the Degelen Mountain site to locate all the Kolbas and other containment chambers used to conduct nuclear tests. Russia continued to withhold information; in the end, it took another nine years before the United States and Kazakhstan had all the information needed to complete work at Semipalatinsk. And the timeframe may have stretched longer, were it not for the growing trust among the U.S. and Russian scientists, which included an extraordinary friendship between an American program manager and a Russian engineer who barely spoke each other's language.

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68 This view is not universally shared, however. A report by the British Royal Academy of Engineering in 2008 said that "Cement immobilisation [of plutonium] is not particularly attractive or effective because of…relative ease with which the plutonium could be recovered." See: The Royal Academy of Engineering, "Plutonium Management," October, 2008. http://www.raeng.org.uk/societygov/policy/responses/pdf/PlutoniumV6.pdf (accessed on February 2, 2013).

69 See, for example, Georgette Y. Ayers, Bill McKerley, Gerald W. Veazey and, Thomas E. Ricketts, "Development of an Alternate Pathway for Materials Destined for Disposition to WIPP," a paper presented at the 51st Annual Meeting of the Institute of Nuclear Materials Management, Baltimore, Maryland, July 11-15, 2010. At the Savannah River Site in the U.S., liquid waste containing mostly cesium and a little plutonium is mixed with grout and put in large concrete vaults and tanks for permanent disposal. This process is well underway, but there are concerns about the long-term safety of this operation. Interview with Thomas Cochran, Senior Scientist at the Natural Resources Defense Council.

70 Interview with Ristvet, October 2012.

‘Physics is Physics in Any Language’

Byron L. Ristvet is Assistant for Nuclear Matters in the Test Technology Division of the U.S. Defense Threat Reduction Agency. He is also one of the few scientists who participated in the U.S. nuclear testing program who is not yet retired. Hunched, short-sighted, and garrulous, he bears the manner of a man who has spent many years of his life underground. A geologist by training, it was his job to ensure the environmental safety of U.S. nuclear tests performed underground in the United States’ counterpart to Degelen Mountain: the Rainier Mesa complex in Nevada.

In the mid-2000s, Ristvet took over the project management for DTRA at Semipalatinsk. He recalled that he loved the work. It presented Ristvet, somewhat of a maverick, with technological challenges and the leeway to look for novel solutions. Ristvet didn’t like to follow rules, and Kazakhstan’s remote steppe provided freedom from bureaucratic oversight. His deputies in Semipalatinsk, who were both Navy pilots on secondment to DTRA, followed U.S. safety procedures by wearing dosimeters at all times while near Degelen Mountain. Ristvet didn’t bother, believing that low-dose radiation had a protective effect on his health. “Byron does his own thing,” Mark Sullivan, one of those Navy pilots said. “He loves it out here.”

“I’ve come to love this country,” Ristvet concurred when interviewed at Semipalatinsk in 2012 in a ceremony to celebrate the completion of the work at Degelen Mountain. “I have a real understanding with the Kazakhs and Russians working on this project.”

In the mid-2000s, Ristvet forged a particularly close bond with Valery Demen, chief engineer of Russia’s Institute for Geophysical Research, who died of lung cancer before the operation at Degelen Mountain was completed. Demen was a heavy smoker. But it was a death Ristvet (his disregard for dosimeters aside) believes may have been related to radiation exposure. In 2012, Ristvet oversaw the unveiling of a plaque at Degelen Mountain to commemorate Demen’s work. Before the death, Demen and Ristvet often drove out to the Degelen site together with blueprints and technical drawings. Demen had worked at Semipalatinsk for over forty years, and had overseen the construction of many of the tunnels at Degelen Mountain during the phase of active testing. Although they did not speak each other’s language, the duo worked without an interpreter, relying only on their shared scientific vocabulary and hand gestures. “Our friendship was based on science,” Ristvet recalled wistfully, “which made it easy and uncomplicated. Physics is physics in any language.”

Source: Siegfried Hecker

“Kolba” used for containing small explosions involving nuclear material.

Ristvet’s friendship with Demen was deepened by Ristvet’s sensitivity to the mixed emotions Demen and many of the Russian scientists felt upon returning to Semipalatinsk. He shared their nostalgia for the heady days of scientific exploration during Cold War nuclear testing. And he understood that for the Russians, many of whom had been involved in the testing program at Semipalatinsk in the early 1980s, this nostalgia was coupled with a sense of displacement, as they were now treated as visitors to the city where they were once venerated inhabitants.

"I was in my 20s when I worked at Semipalatinsk. I spent my youth here," said Sergei Borenkov, a scientist from Arzamas-16, who remembers emplacing many of the test devices in Degelen Mountain, "So there is a certain nostalgia for us here." When asked why he and his colleagues left so much plutonium behind, Borenkov shrugged. "When we left, Kazakhstan had become an independent country—it was not our responsibility anymore."[71] A number of other Russian scientists who also had experience at the test site felt a stronger responsibility to clean up the plutonium, but they also believed they had to respect decisions made at higher levels of the government not to return to Semipalatinsk. Once the decision was made to cooperate, Stepanyuk called it a "principled choice."[72]

Coaxing cooperation from the Russian scientists took years, according to Ristvet and other U.S. officials. The most useful tool to build trust was technical collaboration. As scientists, the Russians were naturally drawn into attempts to solve the conundrum of what to do with the material at Degelen Mountain. Asking the Russians for technical advice became a favorite tactic of U.S. officials attempting to elicit further insight into the threats at Degelen. But some Russian officials were more helpful than others.

Short, stout, and energetic, Vladimir Kutsenko had served five years as head of security at Semipalatinsk in the 1980s. By the mid-2000s, he had risen to become assistant to the head of Rosatom, the successor to Minatom. Like many of his senior Rosatom colleagues, Kutsenko had ambiguous feelings about the collapse of the Soviet Union. He often gave lachrymose vodka toasts to the patriotism of the Soviet scientists who worked at Semipalatinsk, and would confide to U.S. officials his belief that Kazakhstan should never have been given independence, U.S. officials recalled. But his bulldog loyalty also applied to his role as security manager at Semipalatinsk—he felt it was his responsibility to ensure that no nuclear material was stolen from Degelen Mountain. In his mind, his mission had not ended after his initial departure from Semipalatinsk.[73]

In the mid-2000s, Kutsenko witnessed the professional relationship blossom between Demen, Ristvet, and other scientists. One of the officials on the U.S. side, John Booker, was awarded the Kazakh Medal of Freedom upon his retirement mid-way through the project. Kutsenko felt the time was right to extend cooperation to the entire Degelen Mountain site. He assumed the role of main emissary for U.S. and Russian officials in this period, steadily lobbying Rosatom to release all remaining information to the United States. Negotiations were at times delicate: in several instances, Kutsenko insisted on talking to U.S. counterparts on his cell phone while driving in a car in order to speak freely, according to DTRA officials. "The work couldn't have been done without the cooperation from the Russian side," Kutsenko said. "The site itself contains materials that

[71] Interview at Semipalatinsk test site, October 2012.

[72] Stepanyuk, "Liquidation of Consequences…"

[73] This portrait of Vladimir Kutsenko draws from various interviews with U.S. officials. The authors conducted one brief interview with Kutsenko, but he was reticent to discuss the operation or his motivations in depth.

would be considered classified, so getting past export controls was not a simple process. Before we started work we had to come up with an understanding regarding transparency between our two countries. As soon as we agreed on that issue we could start work."[74]

Source: U.S. Department of Defense

Filling a test tunnel with a special cement compound that chemically bonds with the material in the tunnel, rendering it into a form unusable for weapons purposes.

Ristvet says that he was never tempted to use the Degelen Mountain operation for espionage, but the project yielded benefits for U.S. intelligence for other reasons. Analysts could study satellite images of the threat reduction work in Kazakhstan, form a hypothesis of what exactly had been done, and then test their hypothesis against trip reports prepared by Ristvet. The hope was that the process could later help U.S. intelligence analyze suspicious underground excavation work in Iran, China and North Korea. "This was a great test case for our imagery people," Ristvet said. Referring to the color-code of a military training exercise, he added, "It was a helpful, blue-on-red exercise."

After the completion of Operation Matchbox, Kutsenko convinced his superiors to reveal the location of three more Kolbas inside Degelen Mountain. Originally, Russian scientists suggested taking the Kolbas, which were mounted on rail-transport cars, out of the mountain, where they could be opened and filled with the cement and sand mixture that was used for Operation Matchbox. The U.S. protested. The plan would require re-opening the tunnels at Degelen Mountain that had been closed by the U.S. in the 1990s. What's more, returning the Kolbas back to the tunnel would be no simple feat given their weight once filled with cement. With discussions stalled, it was Kadyrzhanov who brought a solution to U.S. and Russian scientists—if the Russians could provide specific geographical coordinates for the locations of the underground Kolbas, Kazakh construction crews could drill from the surface, puncture the Kolba and, using a sealed conduit, pump cement into the structure. The Russians examined the plan, and decided it was feasible in one instance. For the other two Kolbas, they offered a compromise solution. The crews could fill all the space around the Kolba with concrete, mimicking the entombment technique of Operation Groundhog.

To add a further layer of protection, Ristvet proposed a novel tweak to the cementing plan. He suggested adding iron to the cement mixture in an effort to make it even harder to separate the

[74] Interview with Vladimir Kutsenko, October 2012.

plutonium chemically from the concrete and turn it into metal, which is what is required for a nuclear bomb. The mixture "added suspenders to our belt," Ristvet said – though only for the Kolba where the cement would actually be inside the canister with the plutonium. [75]

The work on the three Kolbas was called Operation Nomad. It was completed by the spring of 2005, nearly a decade after the original "Project Amber" memo. Kutsenko decided it was time for Rosatom to release all the remaining information about experiments performed at Degelen Mountain. This was the breakthrough U.S. scientists had long hoped for. In preparation, Russian scientists estimated the amount of material at each experiment site in the tunnels and rated the risk posed by the material.

In April, 2005, Kutsenko and Stepanyuk met with Ristvet, Weber and Sullivan in Kazakhstan and presented the information. The tally wasn't pretty. Even after Operation Nomad, Degelen Mountain still contained around 100 kilograms of recoverable plutonium—enough for more than one dozen nuclear weapons.[76] The material existed in more Kolbas inside the tunnels, but also in smaller, less secure "end-boxes," where experiments with lower explosive yields were performed.

Operation 'Golden Eagle'

Then came a surprising revelation. In several of these end-boxes, Russia had left behind not just material, but highly-sensitive components used to build nuclear weapons. According to Stepanyuk, the equipment carried "maximum risk."[77] According to a U.S. official who was involved:

> The 'equipment' included high-purity plutonium that would have easily provided materials and information that could lead to a relatively sophisticated nuclear device.[78]

This disclosure alarmed U.S. officials, who decided immediately (with Russian agreement) that the material should be the first priority in any further work at Degelen Mountain.[79] According to one participant, the admission by the Russians of the high-value sites probably would not have been possible were it not for several years of negotiations and efforts to build trust by U.S. and Russian officials.[80] Even so, the Russians were cautious. In their reports to the U.S. side, they

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[75] Ristvet said he proposed the idea after remembering an article by scientists from Los Alamos and Livermore National Laboratory explaining that reference samples of plutonium stored in steel containers after 25 years of storage had mysteriously reduced in quantity; the scientists discovered that plutonium was bonding to iron in the walls of the container. "This was my big contribution, remembering that this bond between iron and plutonium wasn't something that simple acid wash could remove," Ristvet says. Scientists interviewed for this article were split about the effectiveness of this intervention in preventing the recycling of plutonium into a bomb, and so is the literature. See, for example, Los Alamos Scientific Laboratory, "Large Scale Electrorefining of Plutonium from Plutonium-Iron Alloys," Los Alamos, New Mexico, August 1964, http://www.fas.org/sgp/othergov/doe/lanl/lib-www/la-pubs/00319923.pdf (accessed on March 7, 2013).

[76] Stepanyuk, "Liquidation of Consequences."

[77] Stepanyuk, "Liquidation of Consequences."

[78] U.S. official, private communication with the authors.

[79] Ristvet said the components would allow terrorists or a rogue regime to "reverse engineer and build something extremely sophisticated." There is a precedent for sensitive components left at a test site. Britain returned to Australia after completing its testing program at Maralinga to collect several proliferation-sensitive triggering devices used for a nuclear bomb. Interview with Carlson, September 2012.

[80] Private correspondence with U.S. official who participated.

used code names for some 16 sites involved, ranking them according to proliferation risk on a scale of one to four, with four being the maximum risk. Three of the sites were found to be at this level of maximum risk, and were given the codes X, Y, and Z.[81]

How best to remove the components was not immediately clear. The United States offered to pay for their repatriation to Russia. Stepanyuk said that Russia would accept the most sensitive piece of equipment but not two others, which Russian officials felt were likely to be so badly damaged as to pose little risk. The U.S. argued that there was no way to know for sure what condition the equipment was in until it was actually recovered. An agreement eluded the two sides until a meeting in St. Petersburg on June 1 and 2, 2006, when Russia agreed to accept two pieces of equipment back and entomb the third, at the "Z" site, in concrete in the tunnel.

The effort was called Operation Golden Eagle and was carried out in 2007. At one point during the work on the "Y" site, crews attempted to breach a concrete wall in order to provide access to the nuclear materials behind it. During the work, the entire concrete wall collapsed, exposing the materials. "This was an emergency," according to Stepanyuk. A decision was made by five experts from Arzamas-16, including Stepanyuk, to personally go in and retrieve the materials. A photograph made of them at the "Y" site on May 8, 2007 shows them in protective suits and wearing respiratory protection. Within a month, and with the help of Kazakhstan, the dangerous materials had been successfully moved to the "X" site for repatriation back to Russia.

In a familiar pattern, scavengers continued to raid the tunnels during these negotiations. Ristvet, like Kadyrzhanov and other Kazakh scientists before him, confronted them on several occasions, only to receive a similar rebuff. By the mid-2000s, Kazakhstan was becoming an economic success story in Central Asia, its economy blossoming thanks to its oil, gas and mining industries. But in part because of the legacy of nuclear testing, the area around Semipalatinsk remained very poor. "I would tell the scavengers how dangerous it was for them to be out here, and they would say 'my family is very poor and there's still copper, aluminium, and lead'" down in the tunnels, Ristvet remembered.

The Kazakh authorities were initially unwilling to take serious measures to stop the scavengers; mining in the region was a central feature of the government's economic rehabilitation program. At one point, U.S. Vice President Joseph R. Biden Jr. made a personal call to a high-ranking Kazakh official and implored Kazakhstan to take action to end the scavenging at Semipalatinsk, which had yet to be made officially illegal.[82] The intervention proved successful. Kazakhstan agreed to officially declare Degelen Mountain an "exclusion zone," which allowed U.S. officials to erect signs around a 60 kilometer boundary warning scavengers from mining. Kazakh security forces now had the authority to expel the scavengers from the site. In 2008, DTRA officials terminated a contract with a local Kazakh construction company—Degelen Mountain Enterprises—that they felt was responsible for slowing the work and also for various security breaches. A new company, Vostokavtoprom, was hired that proved capable of completing the work at a much brisker pace, Ristvet says.

These decisions—arguably long overdue—finally put an end to the foraging in the tunnels. But it did not stop legitimate mining operations from winning permits to work in startlingly close

81 Stepanyuk, "Liquidation of Consequences."

82 Interview with high-level DoD official on condition of anonymity.

Source: Siegfried Hecker

Members of Operation Golden Eagle at "Y site" in 2007.

proximity to Degelen Mountain.[83] Even today, a full-scale fluoride mine operates within eyesight of the Degelen tunnels.[84] Should they choose, the mining operation could drill an underground tunnel to Degelen Mountain in a matter of weeks.[85]

To prevent this and other theft scenarios, the U.S. funded and helped install an elaborate security system at Degelen Mountain in 2009. The protection around the site included barbed wiring fencing, two-meter-deep trenches and large stones to prevent vehicle access, 500 sensors, including seismic, motion and trip-wire detectors, five video towers, and a small, unmanned aerial vehicle for the Kazakhs to use for surveillance. Finding equipment that proved reliable in Semipalatinsk's harsh climate proved challenging. Equipment provided by Raytheon as part of a multi-million dollar contract broke the winter after it was installed.[86] One U.S. official said most of the detectors had been designed by Raytheon for the desert environment of the U.S.-Mexican border. The Kazakhs, on their own initiative, sourced equipment designed to withstand Siberian winters from a Russian military supplier; it cost half the amount of the U.S. contract, and easily survived the winter.[87]

With knowledge and trust acquired from Operations Matchbox and Nomad, the remaining Kolbas and end boxes were filled without major problems. But the work was still slow—and broken by long winter breaks. In 2009, newly-elected U.S. President Barack Obama announced an initiative to "secure all vulnerable nuclear material" within four years.

As part of that initiative, Obama hosted a summit of 46 world leaders in Washington D.C. in March, 2010. At the summit, Obama arranged a personal meeting with Nazarbayev to address

[83] For an example of legal mining operations in the former testing site, see the Naimanjal operation of Frontier Mining Ltd., a Cayman Islands incorporated company. http://www.frontiermining.com/index.html

[84] Upon visiting the site, one of the authors (Harrell) estimated that the mine is less than 2000 yards away from the mountain.

[85] An extensive literature exists about the proliferation risk associated with long-term underground burial of plutonium in the context of spent nuclear fuel—specifically, that the repositories could eventually become "plutonium mines for those searching for relatively low-cost sources of nuclear bomb fuel. Many of the issues would apply to buried plutonium residue at Degelen Mountain. See, for example, Swahn, J., *The Long-Term Nuclear Explosives Predicament*, Technical Peace Research Group, Institute of Physical Resource Theory, Chalmers Institute of Technology, Gothenburg, Sweden, (1992) and: Edwin S. Lyman and Harold A. Feiveson, "The Proliferation Risks of Plutonium Mines," *Science and Global Security*, Vol. 7, No. 1 (1998), pp. 119-128.

[86] Interview with DTRA officials, October 2012.

[87] Interview with DTRA officials, October 2012.

Source: U.S. Department of Defense

Degelen Mountain access road barrier erected in 2012.

the Semipalatinsk operation—one of a dozen such bilateral meetings during the summit process. As it turned out, it was also on the top of the Kazakh leader's agenda.[88] Officials for the two nations met with their Russian counterparts. The United States, Russia, and Kazakhstan agreed in confidence to complete the remainder of the work at Semipalatinsk by the next Nuclear Security Summit, scheduled for Seoul, South Korea in March 2012. The high-level commitment galvanized the operation. Kazakh crews worked through the winters of 2010 and 2011. DTRA officials stayed on site in Semipalatinsk with them. Increased funding from DTRA meant four crews could work simultaneously instead of one. Much had been accomplished over the previous decade, but there was still plenty to do in order to meet the deadline. "Beginning in early 2010," Ristvet said. "We really started cranking."

The Announcement

Presidents Obama, Dmitri Medvedev of Russia and Nursultan Nazarbayev of Kazakhstan announced the completion of the work as planned in Seoul, saying in a joint statement that it provided a "concrete example of cooperation." Nazarbayev told reporters, "All of the threats have been removed."[89] But the announcement received little attention, and was overshadowed by reports of an "open mic" gaffe in which Obama was overheard making unguarded remarks to Medvedev.

As it turned out, work at Semipalatinsk continued until October, when Ristvet, Kutsenko, Kadyrzhanov, Deputy Assistant Secretary of Defense Kenneth Handelman, and several dozen U.S., Kazakh, and Russian scientists gathered to mark the end of the Degelen Mountain operation. They unveiled a monument to the work, awarded medals, and made loquacious toasts over a make-shift picnic several hundred yards from the mountain.

The picnic was monitored by Kazakh security officials from a state-of-the-art situation room at Kurchatov City that provides real time data and video on a large screen. A response force is stationed approximately 20 minutes away.[90] The sustainability of all this security—particularly

[88] Interview with a senior U.S. official, March 2013.

[89] "'Russian-U.S.-Kazakh cooperation on Semipalatinsk site and example how to handle nuclear security'-Medvedev." *Interfax*, March 27, 2012.

[90] The security personnel are at a barracks where they are also on call in case of an incident at a nearby facility that that stores

the hundreds of sensors and other pieces of equipment that will eventually need to be replaced—is questionable, especially given the fact that Kazakhstan's nuclear regulators remain relatively weak, and funding for the site is limited. But U.S. officials say that the cementing of the tunnels provides enough of a barrier so that even a basic monitoring system should suffice.

The security at Degelen Mountain raises an uncomfortable reminder, however, of just how difficult it will be to sustain an effective security operation at Semipalatinsk for the duration that will be required. Plutonium's half-life is 24,110 years.[91] The plutonium at Degelen Mountain will potentially pose a danger for a time frame beyond human understanding. It is certainly true, as the plaque at Degelen Mountain attests, that the world has become safer than it was before the operation, but it also remains the case that the scars left by nuclear weapons testing during the Cold War will last for eons. Asked at the picnic when it will be possible for security to be withdrawn from Semipalatinsk, Sergei Lukashenko, the director of Kazakhstan's Institute of Radiation Safety and Ecology, ignored his Russian interpreter and spoke in stern, broken English. "Never we leave this area. Never."

And there may yet be further surprises at the test site. Only a few months ago, Ristvet said a Kazakh survey team discovered five more areas near Degelen Mountain where experiments left behind plutonium residue in high enough concentrations to pose a proliferation risk. "In some cases [the plutonium] is such that a guy with a pickup truck and a shovel could accumulate enough [for a bomb], removing only a few tons of soil," Ristvet said. Hecker said that while there are some areas that need attention, existing monitoring of the site is sufficient to limit concerns about potential theft.

At the urging of Ristvet, the United States is currently negotiating a project by which it will haul tons of soil into an empty tunnel in Degelen Mountain and fill the tunnel with the same cement and iron mixture used in the other Kolba projects. However, DTRA officials say that cuts to CTR funding have delayed the project. Asked how much plutonium remains at Semipalatinsk, even 17 years after U.S. experts first warned of the urgent need to secure the site, Ristvet says, "Enough."

Conclusions

The Semipalatinsk operation secured substantial amounts of plutonium and reduced the threat that it could fall into the hands of scavengers, terrorists, or a state with malevolent intentions. But it was a very close call. Had the governments of the United States, Russia, and Kazakhstan not been prodded, the large and expensive clean-up might never have been launched, or the bad actors might have arrived on the scene before the materials could be secured.

The Degelen Mountain operation highlighted the valuable and effective role of unofficial collaboration and contact among scientists and others who are devoted to achieving results without cumbersome negotiations. Yet securing the plutonium in Kazakhstan proved to be a laborious and long undertaking which required 17 years, including a decade after the 9/11 attacks, which

irradiated fuel from the old BN-350 breeder reactor, which contains tons of material near the 20% borderline of highly-enriched uranium, as well as tons of high-grade plutonium in spent fuel.

[91] One of the ironies of nature is that Pu-239 decays to U-235 – also a potential nuclear bomb material, and with a half-life of three quarters of a billion years.

raises the question of whether some combination of low-level cooperation and high-level oversight might have proven more effective.

The authors hope this paper will stimulate further interest in the lessons of Degelen Mountain and nonproliferation work. Here, we offer some preliminary thoughts about what was learned and what must still be done.

1. The Secrecy Barrier

At the core of the Cold War confrontation between the superpowers lay deep mistrust and misperception. The United States and the Soviet Union did not see each other clearly, and the intense secrecy on both sides often led to blunders and miscalculations, from the "missile gap" of the 1950s through the "window of vulnerability" of the late 1970s—neither of which really existed in the way officials perceived them. The secrecy has deep roots in the history of the Cold War and lasted well beyond it.

Nuclear testing was shrouded in this secrecy. The vast testing ground at Semipalatinsk was part of the highly sensitive Soviet nuclear weapons complex. The Chernobyl disaster of 1986 opened the eyes of General Secretary Mikhail Gorbachev to the dangers of secrecy, but in the years that followed, his policy of *glasnost,* or openness, barely cracked open the long-hidden Soviet nuclear establishment.

Source: U.S. Department of Defense

Site of the opening to a tunnel used for nuclear testing, following final remediation and landscaping.

In 1987, a proposal by a progressive Soviet physicist, Yevgeny Velikhov, to take a delegation of American scientists and journalists to Semipalatinsk in order to improve confidence in verification (and thus support a test ban) was rejected by the Central Committee. The Americans didn't go right away. Separately, in 1988, Hecker and other U.S. scientists carried out a joint nuclear weapons verification experiment with Soviet scientists, an important step which laid the groundwork for more cooperation. When Velikhov finally took a group of Americans to Semipalatinsk in 1989, they were still kept at a distance from anything sensitive, although they were permitted to install seismic detectors on Soviet territory.

As this monograph shows, the secrecy did not end when the Soviet Union collapsed and Moscow withdrew from the newly-independent state of Kazakhstan. Rather, the Soviets left behind the infrastructure and detritus of their mammoth Cold War weapons machine—the biological weapons factory at Stepnogorsk and the contaminated biological testing ground at Vozrozhdeniye Island, the chemical weapons facility at Pavlodar, and the Semipalatinsk nuclear testing polygon, among many others. In the case of Semipalatinsk, excessive secrecy prevented accountability within the Russian system so that materials were left unattended in the first place; it enabled complacency about the terrorism and proliferation risk posed by the unattended materials since very few people knew what was left behind and what risks it could pose; and it prevented key Russian decision makers from seizing the opportunity to act expeditiously when the US offered assistance.

One of the great challenges of carrying out threat reduction in the years after the Soviet collapse was penetrating this secrecy and discovering the source of potential threats. It was a long, arduous process often made even more difficult by lack of cooperation or simple disorganization on the part of Russian authorities. Cooperation to beef up security at some sites was delayed by months or years over disputes over American access to the sites and what secrets might be revealed. Even today, continuing secrecy has blocked all cooperation to improve security at Russia's nuclear weapons assembly and disassembly facilities, and there are no transparency measures for Russia's giant fissile material storage facility at Mayak, leaving the United States in the dark as to its use, although it was largely built with U.S. funds.

Many of the Russians were well aware of the dangers. At least some of them were interested in overcoming the mistrust of the past and addressing the threats. Through a step-by-step process of trust-building, many barriers were overcome; U.S. security experts visited and helped improve security at all but a few of the facilities in Russia where nuclear weapons and nuclear materials reside. But there were strong countervailing forces in Russia—institutional and bureaucratic inertia, fears about spying, and a sense of national humiliation—that lingered long after the Soviet Union collapsed. The secrecy remained through the Yeltsin era and has become more intense in the Putin era in Russia. In the last two decades, there was never a thorough overhaul of the Soviet-Russian military-industrial complex, nor of the nuclear weapons complex or the secrecy in which they are shrouded.

In the years immediately after the Soviet collapse, the Russians did not bother to alert Kazakhstan to the plutonium left behind at Degelen Mountain because it was a problem they did not want to address. They did not see it as a risk, at least until Hecker showed them the photographs of the metals scavenging. The secrecy alleviated the need for Russia to contribute financially to the clean-up. Although Russia could ill afford the expense of a clean-up in the 1990s, its finances recovered in the 2000s and Russia could have made a major financial contribution. As successor to the Soviet nuclear arsenal, Russia must share responsibility for the site.

An important lesson of the Degelen Mountain operation—a lesson that reverberates through all of the Cold War years—is the value and importance of seeking transparency. Facing the past is not easy for a country like Russia that suffered such an abrupt and turbulent collapse. It is hard to accept the idea of cooperation with a rich and powerful rival.

Our point here is not to criticize those in the U.S. and Russia who have labored for years on threat reduction in the former Soviet Union—a two-decade-long effort that continues—but rather to highlight the lessons from their experiences. These lessons will be important for the next mountain of fissile material, whether in North Korea, Iran or elsewhere. It will be important to coax the truth from those in a position to know about unattended risks, and find ways to overcome the barriers to mitigating them.

2. The Unofficial Approach

The experience of the post-Soviet period vividly underscores the value of scientific exchanges and contacts. The role played by Hecker, Ristvet, and others in reaching out to Russian and Kazakh colleagues highlights the crucial nature of unofficial ties between both governmental and non-governmental scientists. The two were accompanied by many other officials from all three governments who played important roles, including Hemberger from Los Alamos and Weber at the Pentagon; Styazhkin and Stepanyuk from Arzamas-16; Kutsenko from Rosatom; and Kazakh scientists, including Kadyrzhanov.

Could the same results at Semipalatinsk have been achieved if the three countries had carried out a treaty negotiation? It seems unlikely. Such high-level bargaining is often delayed for years by external and internal politics, and often becomes excessively legalistic. The informal approach has a successful track record in other threat reduction operations. Before the Degelen Mountain operation, Project Sapphire came about with similar personal relationships and contacts, nurtured by Weber; security upgrades were launched throughout the former Soviet nuclear complex thanks to Hecker's proactive engagement in the early days following the end of the Cold War. The same combination of initiative and low-level diplomacy on the part of U.S. officials and scientists led to the discovery and demolotion of the anthrax factory at Stepnogorsk in the 1990s.

At Semipalatinsk, the collaboration allowed scientists and engineers to develop a common language and an agreed set of facts upon which they could base decisions and actions, providing the legitimacy needed to overcome suspicions. It was an essential prerequisite and enabler of meaningful action. At the same time, the effectiveness of Obama, Nazarbayev and Medvedev's intervention at the Nuclear Security Summit in 2010 shows that while unofficial ties are helpful and even necessary, they aren't entirely sufficient. In the end, the job took as long as it did in part because the highest levels of government were not pressing for action until the very end.

The Degelen Mountain operation also suggests that government officials and experts on the ground, when faced with urgent security imperatives, may sometimes reach for temporary fixes rather than comprehensive and sustainable solutions. In the mid 1990s, the tunnel program eliminated the possibility that the Degelen Mountain test site could be used for further underground nuclear testing. But it was not designed to eliminate the threat of the theft of material in the tunnels. The recent work has dramatically reduced the threat that the remaining plutonium will be stolen and contribute to nuclear terrorism. But it may not have fully addressed longer-term dangers.

3. The Legacy of Nuclear Testing

Loose plutonium remains a concern at Semipalatinsk – and potentially at test sites elsewhere. This suggests several steps that should be taken:

- The United States, Kazakhstan, and Russia should make it a top priority to finish assessing the remaining plutonium and then securing whatever remains in vulnerable forms.
- Russia should take the lead in assessing and addressing similar issues that may exist at the other former Soviet nuclear test site. One hundred thirty nuclear explosions were carried out at the Novaya Zemlya site in Russia's Arctic north. That test site is still active, conducting conventional blasts with nuclear materials that are permitted under the Comprehensive Test Ban Treaty, possibly including tests that could leave recoverable nuclear material behind. Much less is known about the legacy of testing there.
- Test sites in other countries should be assessed as well. U.S. officials have concerns about the French testing site in the Algerian Sahara, and say that the French military has been uncooperative.[92] In the context of the nuclear security summit, the United States should seek to break through to the point where it feels ultimately reassured about the French test site. It seems plausible that testing sites in Pakistan, India, and North Korea may also pose a smaller threat—fewer and more primitive tests in these countries suggest that there is unlikely to be enough plutonium residue for a bomb, but ultimately no substantial amount of recoverable plutonium should be left unsecured anywhere in the world.
- The history of the Soviet test site at Semipalatinsk should also push the international community to press for entry into force of the Comprehensive Test Ban Treaty, which the United States and several other nations have yet to ratify. The testing of nuclear weapons is a messy, dangerous business that undermines global security; a strong international norm against testing already exists. The international community should give that norm legal backing. The CTBT does not prohibit subcritical testing, which is still being carried out to support the safety, security, and reliability of nuclear stockpiles, and is likely to continue. But a clear lesson from Semipalatinsk is that such work must be conducted in an environment in which the fissile materials can be protected.

4. Safeguards Forever?

While the concrete caps and plutonium-cement mixtures at Degelen Mountain have greatly reduced the proliferation risks posed by this plutonium, they have not eliminated them. Even for the cemented plutonium, a state-backed enterprise might have the means to remove the plutonium, reprocess it, and reassemble it into a weapon. Indeed, this undertaking would likely be no more expensive or difficult than the conventional means of plutonium production, which requires the construction of a nuclear reactor and the reprocessing of spent fuel from the reactor. And even substantial non-state enterprises – like the major scavenging operations that were underway before – might someday be able to reach the plutonium, if monitoring of the site ceases.

Legal mining operations within a few thousand meters of Degelen Mountain could be used to disguise a clandestine operation. The United States and Russia may wish to push President Nazarbayev to expand the exclusion zone around sensitive sites in Semipalatinsk.[93] President Naz-

[92] Interview with Ristvet and other DTRA officials.

[93] At the Seoul Nuclear Security Summit, Nazarbayev indicated that the threat reduction work at Semipalatinsk justifies the expansion of mining and development in the area. "All of the threats have been removed. The site exists today in totally different form. Kazakhstan can look into the future without any concerns and develop this territory," Nazarbayev told reporters at the summit. See: "'Russian-U.S.-Kazakh Cooperation on Semipaltinsk site an example how to handle nuclear security'-Medvedev,"

arbayev's commitment to nonproliferation has been solid, but he is now 72 years old, without a designated successor. His death could be followed by a period of uncertainty. Predicting the nuclear intentions of the next Kazakh regime is impossible – let alone those of whatever government may control this territory hundreds or thousands of years in the future.

Although the IAEA was left out of the Semipalatinsk operation, a decision is needed as to whether to put some form of safeguards in place for this material. The IAEA is planning to implement limited safeguards on geologic repositories containing plutonium-bearing spent fuel. But under IAEA rules, safeguards are not needed on material once it is "practically irrecoverable." That term is usually used to refer to the tiny percentages of plutonium left over in high-level waste from reprocessing.

U.S. officials told us that they hope the IAEA will declare the plutonium at Semipalatinsk practicably irrecoverable and therefore exempt from safeguards – but further assessment would certainly be needed to determine whether this material meets the practically irrecoverable standard.[94]

Establishing an accurate inventory of the Semipalatinsk plutonium and periodically accounting for that inventory would be impossible. But the IAEA has long planned other means for

Source: U.S. Department of Defense

Kazakh, Russian, and U.S. diplomats, scientists, engineers, and field workers at the dedication of the monument for the completion of the Degelen Mountain Proliferation Prevention Program, October 2012.

Interfax, March 27, 2012.

[94] In any case, this material was handled in a way that was outside the rules – Kazakhstan did not declare the material to the IAEA, and the three countries jointly decided not to bother with IAEA monitoring of it. So if it is determined to be practically irrecoverable, it will have gotten there by the opposite of the intended route with the states involved telling the IAEA what was done with previously undeclared material after the fact, rather than the IAEA having material under monitoring and then approving a plan for processing it to a form no longer requiring safeguards.

safeguarding plutonium-bearing geologic repositories once non-nuclear-weapon states begin to establish them.[95] Indeed, Semipalatinsk could be used as a test-bed to demonstrate the techniques that will be needed in any case to monitor deep underground repositories filled with plutonium-bearing spent fuel, which are scheduled to begin opening in non-nuclear-weapon states in the next couple of decades.

5. Longer-Term Worries

Plutonium remains dangerous for millennia; human institutions rarely remain durable for more than a few hundred years. With substantial amounts of plutonium only covered with concrete caps, and other collections in relatively shallow burial, might some future Kazakh government try to recover the plutonium in Degelen Mountain and elsewhere for use in a bomb? A hundred or a thousand years from now, might this area no longer be watched, and scavengers with sophisticated equipment return to retrieve the plutonium? What precedent will be set by establishing what is in effect a plutonium repository with no international safeguards in a non-nuclear-weapon state? Will either the concrete caps or the cement mixed with the plutonium prevent the plutonium from leaking out and causing environmental dangers hundreds or thousands of years from now? (The containment method used at Smipalatinsk was never analysed in detail as to whether it meets international safety standards for long-term storage of nuclear waste.) The unofficial approach, excluding the IAEA and other experts, did not encourage deep analysis of these questions, or independent questioning.

The mismatch between the lifetimes of plutonium and of human institutions is a problem that extends far beyond the steppes of Kazakhstan. The Cold War superpowers, and now more recent nuclear states, have accumulated over a thousand tons of weapons-usable nuclear material – enough for tens of thousands of nuclear bombs. Finding a sustainable means of rendering this material forever safe even without constant human intervention remains one of the central challenges of the nuclear age.

[95] Current thinking suggests that minimal unattended seismic monitoring will be required for geologic repositories for at least as long as human civilization continues pursuing nuclear activities on the surface. See, for example, Edwin S. Lyman and Harold A. Feiveson, "The Proliferation Risks of Plutonium Mines," *Science and Global Security*, Vol. 7, No. 1 (1998), pp. 119-128.

About the Project on Managing the Atom

The Project on Managing the Atom (MTA) is the Harvard Kennedy School's principal research group on nuclear policy issues. Established in 1996, the purpose of the MTA project is to provide leadership in advancing policy-relevant ideas and analysis for reducing the risks from nuclear and radiological terrorism; stopping nuclear proliferation and reducing nuclear arsenals; lowering the barriers to safe, secure, and peaceful nuclear-energy use; and addressing the connections among these problems. Through its fellows program, the MTA project also helps to prepare the next generation of leaders for work on nuclear policy issues. The MTA project provides its research, analysis, and commentary to policy makers, scholars, journalists, and the public.

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