JOURNAL FOR PEACE AND NUCLEAR DISARMAMENT
https://doi.org/10.1080/25751654.2019.1698504



# Citizen Scientist: Frank von Hippel's Adventures in Nuclear Arms Control

## PART 2. Engaging with nuclear-weapons policy

Frank von Hippel and Tomoko Kurokawa

**ABSTRACT**

This section covers von Hippel's first engagement with nuclear-weapons issues, starting with a review of a US Secretary of Defense's claim that a Soviet nuclear first strike on US nuclear weapons would kill only 15,000–25,000 people, through his efforts to revive the proposal for a treaty to ban the production of more plutonium and highly-enriched uranium for nuclear weapons, and ending with the beginning of a collaboration with a group of Gorbachev's advisors to end the Cold War. It also includes his and his colleagues' engagement in the successful effort to end the US government's promotion of of a nuclear weapons material, plutonium, as a nuclear fuel, and a failed effort to require the doubling of the average fuel efficiency of US automobiles.

**ARTICLE HISTORY**
Received 11 September 2019
Accepted 26 November 2019

**KEYWORDS**
Limited nuclear war; spent fuel reprocessing; nuclear-weapons freeze movement; automobile energy efficiency; fissile material production cutoff

## Limited Nuclear War

***Tomoko Kurakawa (TK)***: Before you left the National Research Council in 1975, did you do any work related to nuclear-weapon policy?

***Frank von Hippel (FvH)***: I did. It related to the new 10-warhead MX intercontinental ballistic missile[1] that then Secretary of Defense James Schlesinger was promoting.

Schlesinger presented his arguments to the Senate Foreign Affairs Committee in March 1974. He argued that a "limited" Soviet (USSR) first strike on US nuclear forces or, in the jargon of nuclear-war planners, a "counterforce" strike, was credible. The USSR's ten-warhead intercontinental ballistic missile, the SS-18, could play a leading role in such an attack. Schlesinger's concern was that the US had no comparable missile with which to threaten the USSR.

After Schlesinger made his argument for the MX, a senator asked him how many people in the United States would this "limited nuclear war" kill? Secretary Schlesinger responded, "I am talking here about casualties of 15,000, 20,000, 25,000 – a horrendous

**CONTACT** Frank von Hippel fvhippel@princeton.edu Program for Science and Global Security, Princeton University, 221 Nassau Street, Princeton, New Jersey 08542-4601 USA

[1]The MX or "Peacekeeper" missile was proposed by the US Air Force in 1972. Originally, 200 were to be deployed. At the same time, however, the Air Force was warning that the Minuteman missile silos were becoming vulnerable to attack by increasingly accurate Soviet missiles. Its proposal to deploy the MX in Minuteman silos was therefore questioned and led to long delays in the MX deployment. Ultimately, 50 MX missiles were deployed in Minuteman silos starting in 1986. As part of the START Treaty reductions process, the US decided to shift to single-warhead intercontinental missiles to make them less attractive as targets. The new ten-warhead MX missiles were therefore retired in favor of the older Minuteman III missiles, downloaded from three to one warhead each.

event, as we all recognize, but one far better than the alternative" of all out nuclear war targeted on cities.[2]

Some of the Senators were astonished at the small number of casualties Schlesinger estimated and asked the newly-created Congressional Office of Technology Assessment (OTA) for a peer review of the Department of Defense (DOD) estimate.

OTA assembled a committee of senior nuclear-weapons experts including Sidney Drell and Richard Garwin. The staff director for the study, Henry Kelly, a physicist, had heard about my work on the consequences of reactor accidents and invited me to be an unpaid consultant for the review. I therefore went over to the Pentagon to talk to the people who had done the calculations.

In the end, I didn't have much of an impact on the peer review. But the panel did make some striking findings.

One of them related to the assumed height of burst of the attacking Soviet warheads over the 1,000 underground reinforced-concrete "silos" scattered across the northern Great Plains sheltering the US Minuteman intercontinental ballistic missiles. It turned out the Pentagon casualty analysts had assumed a "height of burst" for the incoming Soviet missile warheads too high for the fireballs to touch the ground and therefore too high to produce fallout. But an explosion that high would not hurt the silos or the missiles within them either. The OTA panel suggested that the calculation be redone with the height of burst optimized for destroying the missile silos[3].

***TK***: Why did the Pentagon assume such high-altitude explosions?

***FvH***: My guess is that, for some reason, they wanted to find a low number of US casualties and since the silos are in the Great Plains, far away from cities, the main cause of casualties from low-altitude bursts would be massive plumes of fallout from hundreds of nuclear explosions that could be lethal up to 1000 miles downwind.

The Pentagon casualty-calculation group also assumed that, to the extent there was fallout, everybody downwind would find the best available place to be sheltered and would stay there for one to four weeks.

When the Pentagon analysts made more realistic assumptions, they found up to 18 million fatalities from fallout, one thousand times higher than Schlesinger's original claim.[4]

***TK***: Wow!

***FvH***: The worst-case attack assumed two 3-megaton warheads on each silo. The lethal fallout extended from the missile-silo complexes all the way to Chicago and beyond (Figure 1).

This was my first exposure to the idea of "counterforce" attacks where nuclear missiles would be targeted against each other like World War I artillery, except with warheads with explosive yields equivalent to on the order of a million tons of chemical explosives each. In the course of my discussions with the people who did the calculations for

[2]*U.S.-U.S.S.R. Strategic Policies*, Hearing before the Subcommittee on Arms Control, International Law and Organization of the Committee on Foreign Relations, United States Senate, 4 March 1974, 19.

[3]"Office of Technology Assessment – Response of the Ad Hoc Panel on Nuclear Effects," in US Senate Committee on Foreign Relations (1975, 4).

[4]"Sensitivity of Expected Fatalities to Attack Scenario," in US Senate Committee on Foreign Relations (1975, 21).

Schlesinger, I learned some of the vocabulary the Pentagon uses when discussing nuclear war. For example, when millions of people get killed unintentionally, as in this case where the targets would be the other country's nuclear weapons, that is called "collateral damage."

When the explosion of one of your warheads destroys another of your warheads before it can explode over its target, however, that is called "fratricide."

I had nightmares for weeks after my discussions with these people.

After the OTA staff analysis (US Senate Committee on Foreign Relations 1975, 46–99) and the Pentagon's recalculated results[5] were presented to the Senate Foreign Relations Committee, Henry Kelly, the OTA staffer, suggested that Drell and I write an article in *Scientific American* telling the story of this amazing discussion of "limited nuclear war." We did so in 1976 (Drell and von Hippel 1976, 27). That was my first publication on a nuclear-weapon issue.

***TK***: The OTA did not publish the report?

***FvH***: The Senate Foreign Relations Committee printed up the OTA report along with the transcript of a second hearing with Secretary Schlesinger in September 1975 – probably in a few hundred copies. But that was very low visibility compared to an article in *Scientific American*, which sold about half a million copies in those days.

***TK***: I see. So who wrote the *Scientific American* article?

***FvH***: I wrote it mostly but it was Drell's co-authorship that made it easy to get published.

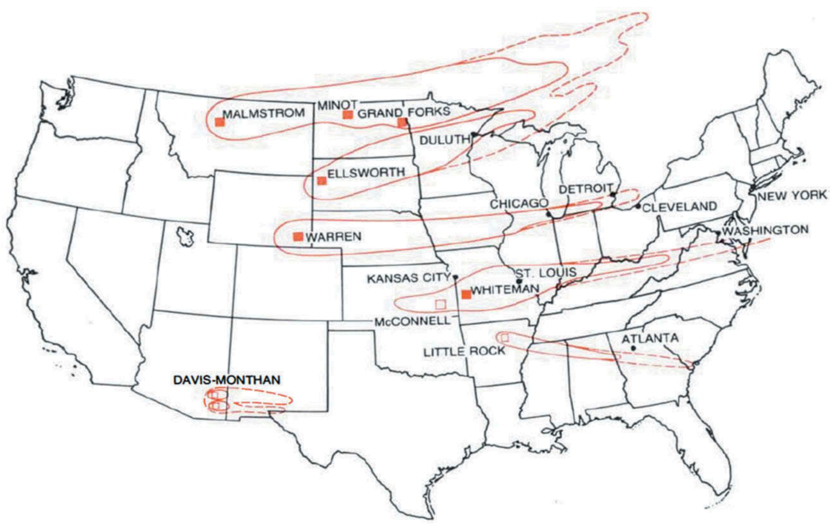


**Figure 1.** Fallout contours from a counterforce attack on US intercontinental ballistic missile silos assuming typical March winds. Solid lines, 50-percent fatilities indoors; dashed lines 50-percent hospitalized. Calculated by Henry Kelly and published in the Drell-von Hippel 1976 *Scientific American* article.

[5]Presentation by Secretary of Defense Schlesinger in US Senate Committee on Foreign Relations (1975, 103–156).

***TK***: So what was the impact of that *Scientific American* article?

***FvH***: I think it was significant but I don't recall that there was much news coverage. Harold Agnew, the Director of Los Alamos National Lab, wrote a letter to the editor advocating tactical nuclear weapons and the Air Force funded its think tank, RAND, to show that the Soviets could devise a counterforce attack that reduced US fatalities to 1 to 3 million, which was still one hundred times Schlesinger's original claim.

I wanted to do my own calculations and, eventually, during the 1980s after officials in the Reagan Administration started talking again about the possibility of fighting and winning a nuclear war, my collaborators and I wrote a series of articles on the casualties from counterforce attacks culminating in another *Scientific American* article in 1988 (Von Hippel et al. 1988, 36).

For the effects of blast, we used the DOD approach, which was to use the data on the probability of death as a function of distance from ground zero in Hiroshima and then scale those distances to the higher yields of modern nuclear weapons. We calculated the fallout using the government's manual, *The Effects of Nuclear Weapons* (Glasstone and Dolan 1977).

But with regard to the effects of fire, one of my co-authors, Ted Postol,[6] made an important contribution. He pointed out that, on a clear day, the radius of the fires ignited by the heat from a nuclear fireball would grow with yield faster than the effects of blast. The blast overpressure fills the volume around the detonation point. The radius of the volume and the radius of a given blast overpressure therefore increases as the one third power of the explosive yield. For a 1,000-times-more powerful explosion, the radius for a given blast overpressure would be ten times larger and the area affected would be 100 times larger. But the heat radiates out through the surface of the sphere so that, if the atmosphere were clear, the intensity of the heat pulse would decrease as the square root of the distance. For a 1,000-times more powerful nuclear explosion, therefore, the radius of the fire zone would be 32 times larger and the area of the fire zone would be 1000 times larger. In Hiroshima, 20 minutes after the detonation, the fires coalesced into a fire storm that people could not escape.

***TK***: The heat killed many people in Hiroshima.

***FvH***: So, in our casualty estimates, we considered the effects of potential firestorms, which had not been included in government estimates.

The Pentagon didn't want to include the effect of fires because they said, unlike blast effects, fire effects are not certain. They wanted to make sure they destroyed everything within a certain radius. And, with regard to collateral deaths, I suspect that they didn't want to look for more. There had been defense contractors talking about the consequences of fires but they had been ignored by the Defense Department's nuclear targeting people.

Postol's contributon therefore was very important. Lynn Eden, a Stanford sociologist, wrote a whole book about it: *Whole World on Fire* (Eden 2004).

In 1983, we calculated the casualties from reciprocal nuclear attacks on the nuclear-weapon bases in East and West Germany (Arkin, von Hippel, and Levi 1982, 163).[7] Then, in the mid-1980s, we calculated the casualties from nuclear counterforce attacks

[6]MIT nuclear physicist who has made major contributions to our understanding of the limits to the effectiveness of ballistic missile defense.

[7]See also "Addendum," Vol. XII, #1, 1983, p. 57. Translated into German in Arkin, von Hippel, and Levi (1983).

on the nuclear bases in the Soviet Union and the United States (Daugherty, Levi, and von Hippel 1986, 3; Levy, von Hippel and Daugherty 1987/88, 168). Finally, we published our casualty estimates for the US-USSR counterforce exchange in *Scientific American*.

Then I got a call from Livermore National Laboratory, one of the three US nuclear-weapons design laboratories. The person calling said, "I wish we had your resources!" This comment requires explanation because, in today's dollars, Livermore had a billion-dollar annual budget and our program's budget was less than one thousandth as large. I learned that what my caller meant was that he had not been given permission to do calculations of the casualties from a counterforce attack on the US until he was asked to check our results.

Recently, I found a little cartoon that I cut out from *The New York Times* editorial page in 1980. It showed two mushroom clouds. One was labeled "limited" and the other "all out." There is no difference. At that point, I decided that we had won.

## Princeton

***TK***: You moved to Princeton in 1975. What brought you to Princeton University?

***FvH***: I was invited by Robert Socolow, another young physicist who was interested in policy but who had moved out of a traditional physics career faster than I did.

Socolow had been an assistant professor of physics at Yale when he became interested in environmental issues. In 1969, he participated in a summer study on a proposal to build an airport just north of the Everglades National Park in Florida. The summer study was co-led by Marvin Goldberger, chairman of Princeton's physics department at the time. After the summer study, Goldberger suggested that Princeton establish a Center for Environmental Studies (CES) and that Socolow should organize it, initially under the figurehead directorship of a senior physics professor. Socolow joined Princeton's engineering faculty in 1971. While I was involved in the 1974 APS summer study on reactor safety, he was co-leading another APS summer study on energy efficiency.

Socolow and I had met when we were both post-docs and he visited me while I was an assistant professor at Stanford. When he became aware of what I was doing in the area of reactor safety, he suggested that I join CES. He had a $25,000 grant from a small foundation to do something related to nuclear-energy policy. That supported me for a year.

## Plutonium Breeder Reactors

***TK***: Another topic in the 1970s was breeder reactors and plutonium.

***FvH***: When I first arrived at Princeton, I was finishing up my work on the reactor-safety issue: articles, Congressional testimony, etc. Harold Feiveson, who was already at CES (soon to be renamed the Center for Energy and Environmental Studies, CEES), was worrying about the Atomic Energy Commission's proposal to use plutonium as a nuclear fuel.

Feiveson had a master's degree in physics. He went to work in the Arms Control and Disarmament Agency where he drafted the Nonproliferation Treaty's article on safeguards. Then he did a PhD at Princeton's Woodrow Wilson School on Public and International Affairs.

The title of his PhD thesis was *Latent Proliferation*. His concern was that stockpiles of separated civilian plutonium could quickly be converted into nuclear weapons.

In May 1974, just months before I arrived in Princeton, India realized Feiveson's nightmare when it used plutonium from its civilian nuclear program to test the design of a "peaceful" nuclear explosive.

I thought this was an important issue and that perhaps I could work part time with Hal on it. There were reactors involved and I had learned about reactors for the summer study on reactor safety. And I was interested in the problem of controlling nuclear weapons.

Now let me introduce three others who became collaborators in our work on plutonium policy during the 1970s: Bob Williams, Ted Taylor and Tom Cochran.

*Robert H. Williams*. I had met Williams in Washington where he was the chief scientist for the Ford-Foundation-funded Energy Policy Project during 1973–74. At the time, the US was involved in a great debate over the risks of nuclear power. One of Williams' contributions was to focus attention on the possibilities for using energy more efficiently. He commissioned a number of studies on energy efficiency opportunities that became the basis of many of the US energy efficiency regulations promulgated after the 1973 Arab oil embargo.

Socolow and I invited Williams to join the Center. He arrived in 1975, a year after I did and stayed until he retired in 2017.

*Theodore B. Taylor*. Williams had become aware of the plutonium issue through a report by Ted Taylor, a former US nuclear-weapon designer who had become worried about the security of plutonium. Taylor's concern was nuclear terrorism. Unlike most of his weapon-designer colleagues, he believed that a terrorist group might be able to make a bomb out of plutonium. It may have taken geniuses to master plutonium implosion in 1944 but the progress of technology, including fast electronics and plastic explosives, had made it much easier by the mid-70s.

Williams commissioned Taylor and Mason Willrich, a law professor, to co-author a book on the plutonium security problem for the Energy Policy Project. Willrich told John McPhee, a *New Yorker* writer, what he was working on and McPhee decided to write a profile on Taylor for the magazine. The profile was then published as a book, *The Curve of Binding Energy: A Journey into the Awesome and Alarming World of Theodore B. Taylor* (1974). McPhee's article and book made Taylor and his concerns famous.

Socolow persuaded Princeton's Department of Mechanical Engineering to hire Taylor as a visiting lecturer. Taylor worked with us on the plutonium problem and later on nuclear-warhead dismantlement; but his primary interests turned to inventing new ways to use renewable energy, including rollup solar panels and making ice in the winter for air conditioning in the summer.

*Thomas B. Cochran*. I also met Tom Cochran during the year I was in Washington. Tom had come to Washington in 1971 with a PhD in experimental physics and spent his first two years at Resources for the Future, an environmental think tank. During that period, he wrote a book, *The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique*. Breeder reactors were the primary focus of the Atomic Energy Commission's research and development effort on nuclear energy.

In the course of his research, Cochran became skeptical about the economics of breeder reactors and worried about their safety. He took the issue to the Natural Resources Defense Council (NRDC), then a new environmental-law group funded by the Ford Foundation, and the NRDC successfully sued to require the AEC to produce an Environmental Statement (ES) on its Liquid Metal Fast Breeder Reactor program. The resulting multi-volume draft ES opened up the program's justification for outside review (AEC 1974).

Thus, we had assembled in Princeton a group of people with complementary expertise who were all worried about the dangers of the proposed use of plutonium as a nuclear fuel. The four of us started in 1976 by publishing an article in the *Bulletin of the Atomic Scientists*, "The Plutonium Economy: Why We Should Wait and Why We Can Wait" (Feiveson et al. 1976, 10).

We argued that we *should* wait because of the dangers of using plutonium, a nuclear-weapons material, as a commercial fuel. And we argued that we *could* wait because the growth projections for nuclear power that were being used to justify the need for breeders were much too high.

***TK***: Did you believe in the potential of the breeder reactors?

***FvH***: The nuclear-energy people argued that they were necessary. For the growth projections for nuclear power that they were assuming, the price of uranium would soon rise to prohibitive levels for the current generation of nuclear reactors, which use efficiently only the 0.7 percent uranium-235 in natural uranium.

## President Carter versus the Plutonium Program

***TK***: In the meantime, Jimmy Carter also had become concerned about this issue because of the Indian test.

***FvH***: After the Indian explosion, the Ford Administration decided it was time to end leaving the promotion of nuclear power abroad to an unsupervised Atomic Energy Commission. The AEC had helped the Indians produce and separate plutonium to support India's breeder-reactor program but the Indians had used some of the plutonium for a nuclear test. The Indian government claimed at the time that the test was of a "peaceful nuclear device" that could be used – as Edward Teller, the "father of the H-bomb," had argued – to create harbors, etc. However, no one in the US government believed that India was not interested in having, at the least, a nuclear-weapon option.

The Ford Administration looked for other civilian plutonium programs that looked suspicious and managed to stop those in Brazil, South Korea, Pakistan and Taiwan. The governments of all those countries were under military control at the time.

Despite the Ford Administration's actions, Carter continued to make nuclear proliferation a campaign issue. In particular, the Ford Administration had not fully addressed the question of the United States' own plutonium program. Carter thought that the example the US set mattered.

After winning the election, President Carter therefore decided to launch a review of the US plutonium breeder reactor program to see whether it was necessary and economically competitive.

At this point, the Atomic Energy Commission no longer existed. In 1974, Congress had split off the Nuclear Regulatory Commission and the rest of the AEC had been renamed the Energy Research and Development Administration (ERDA) as an interim step toward what would become the Department of Energy in 1977.

The White House asked the head of ERDA to set up a panel to review the breeder reactor. ERDA selected mostly pro-breeder nuclear-utility and nuclear-research and development people for the panel,[8] and then invited Tom Cochran to join and to bring along a few other critics.

Tom asked Russel Train, who had just stepped down as head of the Environmental Protection Agency during the Nixon and Ford Administrations, plus Bob Williams and me.

***TK***: How many members were on the panel in total?

***FvH***: A dozen. Its chairman was Floyd Culler, deputy director of the Oak Ridge National Laboratory, Tennessee. The AEC and now ERDA was planning to build a demonstration breeder reactor in Oak Ridge and Culler was furious that the future of the project was being put at risk by proliferation concerns. He argued that separating plutonium would not make the proliferation problem worse because any country that had a nuclear reactor and wanted plutonium could clandestinely build a "quick and dirty" reprocessing plant and get as much plutonium as it wanted out of power-reactor spent fuel. To make his point, Culler did something I considered terribly irresponsible: he commissioned the reprocessing experts who he supervised at Oak Ridge National Laboratory to design a quick-and-dirty reprocessing plant and he then spread that design all over the world.

During the spring of 1977, the committee had a series of meetings with briefings. At the first briefing, the AEC (now ERDA) people who did the government's projections of the growth of US electricity consumption and the likely nuclear share, showed us a projection that had the US building the equivalent of about one thousand large nuclear power reactors by the year 2000 and about two thousand, mostly breeder reactors, by 2010 (Figure 2).

I asked, "What is the basis of the projection? To my amazement, rather than answer, the briefer withdrew the projection. At lunchtime, while we were standing next to each other in the cafeteria line, I privately asked our briefer the same question again and he

[8]The pro-breeder majority were: the deputy director of Oak Ridge National Laboratory (next to which the Clinch River Breeder Reactor was to be built); the deputy director of Argonne National Laboratory (the center of US research and development on breder reactors); the chairman of Commonwealth Edison, (an Illinois utility with seven nuclear power reactors operating and seven more under construction); the president of the Philadelphia Electric Company (with 2 nuclear power reactors operating and 2 under construction); the president of the Electric Power Research Institute; the president of the Atomic Industrial Forum (the nuclear-energy industry's lobbying group), Manson Bendict, a senior MIT professor of nuclear engineering; and the president of the National Academy of Engineering (who did not attend the committee meetings but nevertheless signed the majority report).

responded, "Well, Carter is a little bit more antinuclear than Ford so I adjusted the projections down a little."

But then one of the utility presidents on the panel said that the projection by the Edison Electric Institute, the electric utility association and lobbying organization, was about the same and they mailed me a big book that described how their projection had been obtained (Edison Electric Institute 1976, Table 6–26).

***TK***: I'm sure you studied the book.

***FvH***: I did. The problem was that the projection had been done by Data Resources Inc. (DRI) using a proprietary computerized econometric model with about one thousand parameters.

I guessed, however, that all those parameters must be fit to past history. So I looked at the history of electric power production in the United States and learned that, for the 50 years between 1920 and 1970, electricity consumption in the United States had grown about twice as fast as the economy.

I wondered how this could be possible? Bob Williams knew the answer: the cost of electricity had gone down throughout that period, in large part because of economies associated with the increasing scale of electric power production. As a result, the percentage of the gross national product that was going to electricity had been approximately constant during those fifty years. So I looked for what DRI had assumed for the future price of electricity and discovered that they were assuming that it was going to continue to go down.

So I went to the next meeting and asked the utility presidents on the panel whether they expected the price of electricity to continue to go down? The answer was "no." They mentioned in particular the fact that the nuclear power plants they were building were becoming very expensive.

***TK***: How did you respond?

***FvH***: So I said, "Well, guess what your econometric model assumes!"

In retrospect, the utilities were projecting four to nine times more electric power would be produced in the United States by nuclear power in 2000 than actually happened. Because of increased energy efficiency, electricity consumption in the United slowed down and then plateaued. US nuclear capacity doubled to about one hundred nuclear power reactors in the following decade and then plateaued to produce about 20 percent of US electric power. About 120 planned nuclear power reactors were cancelled. More than 40 of those cancelled reactors were already under contruction.

The breeder review committee ended up with a majority pro-breeder report and a minority anti-breeder report by Tom Cochran and the three of us he had recruited.

Including all the appendices, which contained all the briefings we had recieved, the panel produced about a foot (30 cm) of paper. ERDA sent out this pile of paper with the majority report on the top and the minority report in the bottom underneath all the appendices.

***TK***: Wow!

***FvH***: I telephoned the ERDA staffer who had assisted the committee and asked, "why did you do that?" He responded, "Frank, you've got to understand, we're fighting for our lives down here."

***TK***: So those two reports were published?

***FvH***: Copies were sent to the steering group members. I guess a few were sent to the White House, and ERDA must have kept a few for its files. There was no public report. I have made a copy of the minority report available on my web site (Cochran et al. 1977).

But we made sure to get copies of the minority report to Jessica Mathews on the National Security Council staff, with whom I had worked when she was on Representative Morris Udall's staff, and to Gus Speth,[9] one of the Yale Law School graduates who founded the NRDC. At NRDC, Speth had worked with Cochran on the breeder lawsuit. He was now in a member of the Carter Administration's White House Council on Environmental Quality.

I don't know how much impact we had. There is a saying, "Success has many fathers but failure is an orphan." There was another study, *Nuclear Power: Issues and Choices* (Keeney Jr. 1977), by a high-level group, sometimes called the "Ford-Mitre Study" because it was funded by the Ford Foundation and administered by the Mitre Corporation, a think tank. That report was also critical of the breeder program and its authors were invited to brief President Carter.

So, I don't know what share of the credit our minority report should get but Carter did decide that he would try to stop the US plutonium program. He asked the Nuclear Regulatory Commission to stop the licensing processes for the

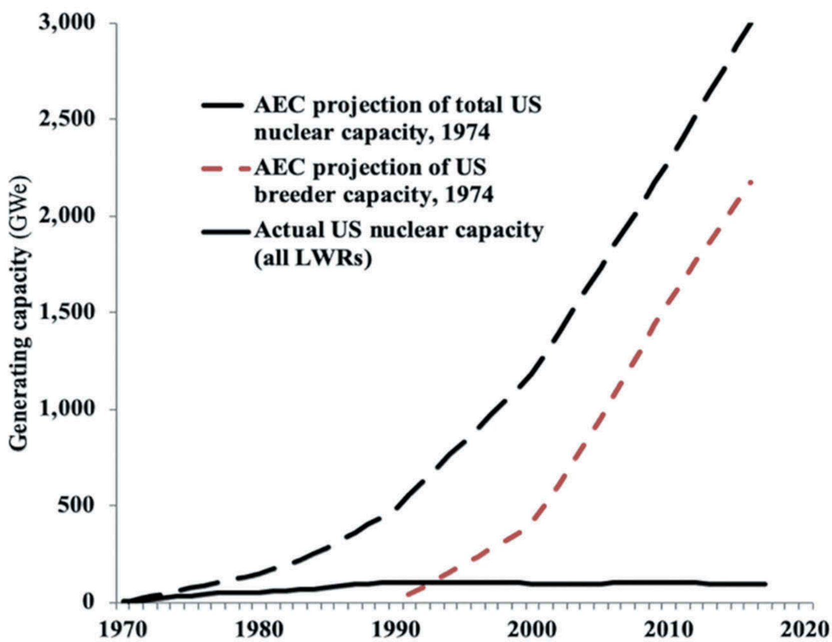


**Figure 2.** AEC (1974) projection of US plutonium-breeder and total nuclear-generating capacity and what actually happened (AEC 1974, Fig. 11.2–27).

[9]Speth went on to found the World Resources Institute, serve as the administrator of the UN Development Program and then serve as the Dean of Yale University's School of Forestry and Environmental Studies.

construction of the demonstration breeder reactor, and also the licensing process for a big reprocessing plant that was nearing completion in South Carolina next to the AEC's military plutonium production complex on its Savannah River Site.

The minority leader of the Senate at the time was Howard Baker[10] from Tennessee where the breeder reactor was to be built. He managed to keep funding for the Clinch River Breeder Reactor in the budget until the end of the Carter administration. But its estimated cost increased five-fold and, in 1983, Congress finally voted to kill it.

When President Reagan came into office in 1981, he reversed President Carter's policy against reprocessing but the nuclear utilities were informed that the government would not subsidize the reprocessing of their spent fuel. The utilities decided that burial would be less costly and persuaded Congress to pass a law that instructed the Department of Energy to build a deep underground repository for its own radioactive waste and the utilities' spent fuel. They agreed to fund their share of the cost with a charge of one tenth of a cent per kilowatt hour generated by their nuclear power plants.

In 1981, I wrote an article in *Physics Today* reporting on my experiences with the peer review of the AEC-NRC *Reactor Safety Study*, the Pentagon's calculations of the consequences of limited nuclear war, and the AEC's projections for the growth of nuclear power. The title of the article was "The Emperor's New Clothes, 1981" (Von Hippel 1981b, 34). The article was later republished with the title, "Peer Review of Public Policy," with some of my other articles on public policy in a book titled *Citizen Scientist* put out in the American Institute of Physics' Masters of Modern Physics series (Von Hippel 1991).

***TK***: Carter also tried to persuade the international community to stop civilian use of plutonium. Were you involved with that effort?

***FvH***: A little bit. What happened first was that, in parallel with its domestic efforts to end the US plutonium program, the Carter Adminstration tried to convince Japan not to operate the pilot reprocessing plant at Tokai that had just been completed. But Prime Minister Fukuda stated that he considered Japan's plutonium program "a matter of life or death for Japan" – apparently because he had been convinced that it would relieve Japan to a significant degree from its dependence on fuel imports. In the interest of the larger Japan-US relationship, the Carter Administration decided to back off and let Japan proceed.

The Carter Administration also organized the International Fuel Cycle Evaluation (INFCE), involving officials from 40 countries to discuss whether reprocessing and breeder reactors were in fact necessary. There were 134 working-group meetings over three years. I was a delegate to one of the eight working groups but went only once because I decided that nothing was going to happen.

I remember talking to a Brazilian delegate who told me that Brazil was going to require 20 breeder reactors by the year 2000. In reality, Brazil abandoned its plans for breeders and had only completed its second light-water power reactor by 2000.

[10]Baker was a Republican Senator from 1967 till 1985, the last four years as majority leader. He was White House chief of staff during the last two years of the Reagan Administration (1987–88); and US ambassador to Japan during the first four years of the George W. Bush Administration (2001–2005).

The result of INFCE was that the US and the countries advocating breeder reactors agreed to disagree. The overall report included very high projections for nuclear growth, however: the equivalent of between sixteen hundred and four thousand 1000-megawatt nuclear power reactors worldwide by 2020 (International Atomic Energy Agency 1980, Summary volume, Figure 1). The actual number is about four hundred.

With this defeat for the Carter Administration's effort at persuasion, the US adopted a policy of trying to prevent the spread of civilian reprocessing beyond where it was already established: in Europe, India, Japan and Russia. This policy has been largely successful. Other than China, no new country has started reprocessing since; and Belgium, Germany, Italy and the UK have stopped.

***TK***: So, after you worked so hard to stop reprocessing and breeder reactors in the United States, you just went to one INFCE meeting?

***FvH***: Yes. When I went through my files recently, I found an exchange with the person in the State Department who was in charge of my working group on alternative fuel cycles. I asked why they hadn't been sending me materials and he responded, "Oh. we thought you weren't interested." So it may have been in part that they weren't so eager to have me participate. In fact, my working group did make one recommendation of lasting importance unrelated to plutonium: to reduce the use of weapon-grade uranium as a research-reactor fuel.

***TK***: So you couldn't imagine that Carter could persuade other countries to stop reprocessing?

***FvH***: Hundreds of people were involved in INFCE and, because the talks were mostly technical, most of those attending were nuclear engineers. Even the US delegation was dominated by people who didn't believe in President Carter's policy.

***TK***: So the diplomats could not follow that. But wasn't it a missed opportunity for you and the entire anti-plutonium community?

***FvH***: I think it was fated that we wouldn't persuade anyone. I could have challenged the growth projections but I was not placed in that working group.

***TK***: But, in the late 1970s, US influence on Japan and Europe was still strong and, once US froze its reprocessing and breeder reactor projects, that must have had a big impact on other countries.

***FvH***: The nuclear-energy communities in the other countries with breeder programs, including France, Germany, Japan and Russia, were furious with the Carter Administration – as was the US nuclear-energy community. They were united in opposition and believed that US policy would change once Carter left office.

***TK***: The Nonproliferation Treaty went into force in 1970. And there was a nuclear test by India in 1974. And, in 1975, there was the first Nonproliferation Treaty Review Conference and almost nothing happened there. But the Ford

Administration did organize the Nuclear Suppliers Group[11] in 1974 before the Review Conference.

***FvH***: The US was successful in stopping new countries from reprocessing. For example, It ultimately did succeed in persuading Germany not to export a reprocessing plant to Brazil. As INFCE showed, however, the US was not successful in persuading countries to stop already ongoing reprocessing programs.

At the same time, proliferation was beginning through another route, the spread of gas-centrifuge technology for uranium enrichment. There the impact of US policy was not helpful.

At the time, the US was still supplying most of the enrichment services outside of the Soviet Union. Ironically, however, the US believed its own projections for the growth of nuclear power and decided that it would soon not have enough enrichment capacity even to supply itself. So, in 1974, the US declared that it would not be able to accept any more foreign orders for enrichment services. This helped justify Brazil's decision to develop its own enrichment program, which became a major proliferation concern in the 1980s. As Scott Kemp has shown, the US also facilitated proliferation by publishing the design of a very simple gas centrifuge that had been developed in the Soviet Union.[12] That centrifuge is not economically competitive for supplying enrichment services to power reactors but it would be adequate to produce weapons-grade uranium for a nuclear-weapon program.

***TK***: The accident at the US Three Mile Island (TMI) nuclear power plant happened in March 1979, late in the INFCE process. If it had happened earlier, perhaps it would have strengthened the argument that the projections for nuclear-power growth should be lowered.

***FvH***: TMI did have one immediate impact on reprocessing. At the time, Germany was considering building a reprocessing plant in Gorleben, Lower Saxony. Partially as a result of the TMI accident, the governor of Lower Saxony became very concerned about the possibility of an accident at the proposed reprocessing plant. Germany's nuclear utilities therefore decided to build the reprocessing plant in pro-nuclear Bavaria. Even there, however, there were huge demonstrations against the plant by protesters from elsewhere in Germany and from Austria. Eventually, the utilities gave up and decided to contract for their reprocessing with the UK and France where reprocessing was already well established because of plutonium separation for nuclear weapons.

The US didn't have much influence over the Soviet Union. It tried to persuade Europe and Japan not to reprocess. But the shock of the 1973 Arab oil embargo was very much in peoples' minds and, like the Japanese, the European governments at

[11]The Nuclear Suppliers Group is a group of advanced nuclear countries that have agreed to restrict the transfer of nuclear technologies to other countries – especially technologies related to enrichment and reprocessing – in the interest of preventing the proliferation of nuclear-weapon states.

[12]Kemp, one of my very few PhD students, is now a professor of nuclear science and engineering at MIT. He published the argument made in his thesis in Kemp (2017, 101).

the time were convinced that breeders were a matter of life or death for their energy futures. The US did not want to endanger its relationship with its key allies and decided to live with their reprocessing programs.

## Thyroid Protection against Radioactive Iodine

***TK***: Please tell us about your involvement with the Three Mile Island accident.

***FvH***: In the APS Reactor Safety study, I learned that quantitatively the largest number of casualties caused by the radioactive releases from a nuclear accident would be people who developed thyroid tumors from inhaling radioactive iodine. The thyroid concentrates iodine and therefore would get a magnified dose – perhaps 100 times higher than the rest of the body. My uncle, Herman Lisco (my mother's brother-in-law), was a pathologist for the Manhattan Project and knew the researchers who had done the epidemiological studies on the effects of radiation on thyroids.

One of the cases of mass irradiation of thyroids was due to parents being worried about "sudden infant death syndrome," the sudden deaths of apparently healthy babies for unexplained reasons. One of the theories in the early 1900s was that the babies' thymus glands were enlarged. These glands, located behind the breastbone between the lungs, are part of the immune system.

Some doctors proposed shrinking the infants' thymus glands by giving them large doses of X-ray radiation. Hundreds of thousands, possibly millions, of babies were irradiated over a period of decades before the medical community realized that the standard size of babies' thymus glands given in the reference books was wrong.

The infants' thyroids, located at the base of the neck above the thymus received high doses as well and the result was an epidemic of thyroid cancer in the United States.

Fortunately, the thyroid cancers were almost all nonlethal but they were treated by surgical removal of the thyroids or destroying them with high doses of radioactive iodine. If you don't have a thyroid, you must take daily doses of thyroid hormone for the rest of your life.

The man who first did the epidemiology that established the relationship between the incidence of thyroid cancer as a function of reconstructed doses to the babies' thyroids was Louis Hempelman who had been medical director at Los Alamos during the Manhattan Project. My uncle introduced me to him and Hempelman sent me copies of his papers.

A second study by another of my uncle's colleagues, Robert Conard, was of thyroid damage among islanders in the fallout zone downwind from the second US thermonuclear test, a 15-megaton test in 1954 on Bikini atoll. Sixty-four islanders from Rongelap Atoll were evacuated after three days. Fortunately, they were located on the southern part of the atoll when the fallout arrived and therefore none received a lethal dose. But all drank water contaminated by radioactive iodine. In subsequent years, almost all of the children developed thyroid tumors and their thyroids were removed.

As a result of this event, civil defense analysts thought about how to protect people – especially young people with growing thyroids – from ingestion of radioactive iodine in fallout areas and came up with the idea of including tablets of potassium iodide in civil defense kits. Potassium iodide is the form of iodine is used in very dilute concentrations in iodized salt to prevent goiters. If taken in appropriate doses before or early during exposure to fallout, the nonradioactive iodine will saturate the thyroid so that it will not absorb more iodine from the bloodstream and the radioactive iodine will be excreted in the urine.

I therefore suggested in the 1975 American Physical Society report that potassium iodide tablets be mass produced and stockpiled in appropriate doses for thyroid blocking, arguing that it would be a very low cost safety precaution. In 1978 – perhaps independently – the US Food and Drug Administration (FDA) recommended potassium iodide for thyroid blocking in case of a reactor accident.

The accident at the Three Mile Island nuclear power plant occurred a few months after the FDA made its recommendation. I called up the White House and recommended that the government get some potassium iodide for distribution to the population around the nuclear power plant. They may have received the same advice from the FDA.

***TK***: Then, what happened?

***FvH***: The FDA quickly had about a quarter million bottles of potassium iodide solution made up and flown to Harrisburg, Pennsylvnia. Harrisburg, the city adjacent to Three Mile Island, is also the capitol of Pennsylvania. The governor of Pennsylvania vetoed distribution, however, because he was afraid that it would panic the population. Fortunately there was not a significant release of radioactive iodine from the reactor containment.

After the accident, I wrote a letter to *Science* about thyroid protection (Von Hippel 1979). Then a reporter from *Science* magazine interviewed me about a report that Jan Beyea[13] and I had written for the White House Council on Environmental Quality urging that potassium iodide be available virtually nationwide in case of a future accident (Carter 1979, 201). In March 1982, I and others were invited to testify on the subject before a House of Representatives subcommittee chaired by Edward Markey (Von Hippel 1982a).[14] One of the others was Rosalyn Yalow, an American medical physicist who had shared the 1977 Nobel Prize in Physiology/Medicine for developing techniques that involved using radioactive iodine as a tracer. She expressed concern that the hazards of widespread use of potassium iodide might exceed the risks. We exchanged a few rounds of letters in *Science* magazine. Finally, she argued that large amounts of radioactive iodine had been given for therapeutic purposes with no increase in cancer being observed. I responded that there is a functional relationship between thyroid radiation dose and the probability of incurring thyroid cancer. The function goes up but, beyond a certain point, you kill the thyroid, which was the purpose of those therapeutic doses, and a dead thyroid can't get cancer. She was a great scientist but was shooting from the hip in this case (Yalow 1982a; Von Hippel 1982b; Yalow 1982b; Von Hippel 1982c; Simon and Shils 1983, 1983a).

For decades thereafter, Markey (now a Senator) fought for potassium iodide predistribution against the opposition of the US nuclear industry and the Nuclear Regulatory Commission. I also criticized the NRC (Von Hippel 1980a, 44).

[13]Beyea worked in our program on reactor-safety issues from 1976 to 1980.
[14]The hearing and the controversy created by Rosalyn Yalow were reported by Holden (1982, 1485).

The responsible NRC official said at one point that she did not want to give people the idea that a reactor accident is probable. She didn't want bottles of potassium iodide pills delivered to people's doors "just in case" of an accident at the neighboring nuclear power plant. That is an understandable view on the part of the industry but is inappropriate in a regulatory agency. Today, in the US, potassium iodide is available in appropriate doses as a nonprescription drug and is made available in some states to people within ten miles (16 kilometers) of a reactor. For a large release, however, significant thyroid doses from radioiodide inhalation could occur up to hundreds of kilometers downwind.

I was invited to be on President Carter's Commission on Three Mile Island but was absorbed by the plutonium debate and suggested Ted Taylor instead. The Commission produced a good report, including that "an adequate supply of potassium iodide … should be available regionally for distribution to the general population and workers affected by a radiological emergency" (President's Commission on the Accident at Three Mile Island 1979, 75) but it did not have much of an impact on US nuclear-power regulation. Both the US nuclear industry and the Nuclear Regulatory Commission have developed a siege mentality. Any suggestions for improvements are seen as attacks on the industry. Also, as nuclear power has become more costly relative to other sources of electrical power, the industry has come to see even relatively minor additions to its costs as threats to its existence.

Jumping ahead, as soon as I heard about the Chernobyl accident in April 1986, I sent a message to Evgeny Velikhov, Gorbachev's arms control advisor with whom I had been brainstorming about possible arms control initiatives since 1983 (see below). This was before the era of e-mail but Princeton University had a telex machine so I sent the message to the Soviet Academy of Sciences' telex machine (Figure 3).

In the telex, I advised Velikhov that the Soviet government should distribute potassium iodide to the people downwind from the accident.

***TK***: Did the Soviet government follow your advice?

***FvH***: The Soviet authorities too did not want to alarm people, so potassium iodide was not widely distributed. The only country that did distribute potassium iodide widely was Poland, 500 kilometers from the accident. Poland's government distributed it to everyone sixteen years and younger. There were a few allergic reactions but nothing serious.

This strengthened the FDA's position that potassium iodide should be available in the United States. But the US nuclear utilities and the Nuclear Regulatory Commission (NRC) continued to block requirements for the states and utilities to have potassium iodide available for distribution to populations more than ten miles from nuclear power plants.

In Belarus and Ukraine the main route by which people ingested radioiodine was contaminated milk. This could have been avoided if the cattle had been fed with stored hay or if the milk had been interdicted or processed into cheese or powdered milk (the isotope of radioactive iodine that would dominate the thyroid doses, iodine-131, has a halflife of eight days). The Soviet authorities were so focused on not alarming people, however, that they did not systematically sequester the contaminated milk. As a result, there was an epidemic of thousands cases of thyroid cancer among those exposed as children – especially in Belarus and Ukraine.

TELEX NO: 871411964B+/ANS SU

ACADEMICIAN EVGENIY P. VELIKHOV, VICE PRESIDENT
PRESIDIUM OF THE SOVIET ACADEMY OF SCIENCES
C/O YURI SHIHAN
LENINSKIY PROSPECT 14
117901 GSP-1 MOSCOW
USSR
&&&
DEAR VICE PRESIDENT VELIKHOV,

YOU PROBABLY ALREADY KNOW THIS BUT I HAD TO INFORM THE WHITE HOUSE OF THE FOLLOWING FACTS TWO DAYS AFTER THE ACCIDENT AT THREE MILE ISLAND BEGAN: BECAUSE THE THYROID CONCENTRATES IODIDES, MORE PEOPLE ARE LIKELY TO SUFFER THYROID DAMAGE FROM A REACTOR ACCIDENT THAN SUFFER ANY OTHER INJURY. INHALATION DOSES OF MORE THAN 100 REMS TO THE THYROID ARE POSSIBLE 100 KILOMETERS DOWN WIND. LARGE DOSES EVEN FURTHER AWAY ARE POSSIBLE AS A RESULT OF DRINKING RADIOIODIDES IN CONTAMINATED WATER AND IN MILK FROM COWS THAT HAVE GRAZED ON CONTAMINATED FIELDS. EXPOSURE TO RADIOACTIVE IODIDE WILL THEREFORE REMAIN A CONCERN EVEN AFTER THE RELEASES FROM THE REACTOR HAVE ENDED.

HOWEVER, THYROID PROTECTION IS AVAILABLE. THE US FOOD AND DRUG ADMINISTRATION ADVISES THE USE OF POTASSIUM IODIDE FOR THYROID PROTECTION FOR ANY PERSON IN DANGER OF RECEIVING A RADIATION DOSE TO THE THYROID FROM RADIOACTIVE IODIDES GREATER THAN 25 REMS. THE RECOMMENDED DOSAGES OF POTASSIUM IODIDE ARE 130 MG PER DAY FOR TEN DAYS FOR ADULTS AND CHILDREN ABOVE ONE YEAR, AND 65 MG FOR CHILDREN BELOW ONE YEAR OF AGE.

I WOULD BE PLEASED TO ORGANIZE A DELEGATION OF EXPERT ADVISORS ON REACTOR ACCIDENT CONSEQUENCE MITIGATION TO COME TO THE USSR UNDER THE AUSPICES OF THE FEDERATION OF AMERICAN SCIENTISTS OR ORGANIZE SHIPMENTS OF ANY USEFUL SUPPLIES IF YOU THINK THAT IT WOULD BE HELPFUL.

WITH BEST REGARDS

FRANK VON HIPPEL
CENTER FOR ENERGY AND ENVIRONMENTAL STUDIES
PRINCETON UNIVERSITY
TELEX 499-1258

RECEIVED BY WESTERN UNION OPERATOR #198, 29 APRIL 1986

**Figure 3.** Telex to Velikhov advising that the Soviet Union distribute potassium iodide to protect the thyroids of the populations around the Chernobyl accident from radioactive iodine.

After Fukushima, the distribution of potassium iodide was also delayed and limited. Fortunately, much less radioactive iodine was released from the Fukushima accident than from the Chernobyl accident and also contaminated food was interdicted.

***TK***: There has been some rise of thyroid cancer in Japan since the Fukushima accident, but some doctors say that is because they are monitoring children's thyroids more carefully. That's why they keep finding cancers.

***FvH***: The same argument was made in Belarus by those interested in minimizing the consequences of nuclear accidents. This effect has been studied, however, and it has been found in Belarus that the thyroid cancers would have been reported even in the absence of screening because the tumors grew so large. Fortunately, very few were fatal.

***TK***: So, after Berkeley, it seems as if you were simultaneously studying nuclear non-proliferation and nuclear safety.

***FvH***: The nuclear safety issue was a legacy of my involvement in the APS reactor-safety study. I got involved in the plutonium-nuclear proliferation issue after I came to Princeton. With regard to the US-Russia nuclear confrontation, the limited nuclear war issue was the only aspect I got involved with before the Reagan administration.

***TK***: Why?

***FvH***: I was interested but it wasn't until the freeze movement in the early 1980s that I had an opportunity to become involved in mainline arms control. Until then, the older generation of physicists – Bethe, Drell, Garwin, Panofsky and others – dominated the contributions to the policy debate from the physics community.

***TK***: If you think back over the 1970s compared to the 1950s and 1960s, how do you see the changes in the United States in this respect?

***FvH***: In the 1950s, there was not much political activism and the generation of students to which I belonged focused on pursuing their careers. This changed in the 1960s with the civil rights movement and the Vietnam War and, in the 1970s, with Watergate and the environmental movement.

Most of my generation of college students grew up with the belief that the government was led by wise people and the civil service was populated by dedicated and able officials. That was a legacy of the Roosevelt Administration, which believed that government should and could regulate powerful interests and help ordinary people. That is why the Watergate scandal was such a shock and Joel Primack's and my revelations in our Stanford report about the misuse of science advice drew so much attention.

Young people today are growing up in a very different world. Many people have become cynical about government and there is a struggle between the idealists and the nihilists for control. If the idealists win, it could be a great time again for public policy.

***TK***: Mr. Carter became President because of the Watergate scandal and President Ford's pardon of President Nixon.

***FvH***: I went to a speech President Carter gave during that campaign. It was in New York City – probably at the Council on Foreign Affairs. It may have been his first speech on foreign affairs.

Somehow, although I was very inexperienced myself, I sensed that Carter was very inexperienced in foreign affairs – which was true. Carter had been farmer and governor of Georgia. He had good values but very little familiarity with who was who in Washington.

As a result, for example, Carter appointed James Schlesinger to be Secretary of Energy, the same man who, as Secretary of Defense under Ford, had underestimated the deaths from limited nuclear war by a factor of at least hundreds. Reportedly, Schlesinger was appointed by Carter because he had coached Carter before a debate on foreign affairs with President Ford. That debate turned out to be a disaster for Ford. Although he certainly knew better, he argued that Eastern Europe was not captive to the Soviet Union.

I worry today that many of the Democratic candidates for president are similarly inexperienced, and could, if they won, lose the important opportunities the moment will present by appointing self-important Washington insiders to key positions rather than people committed to change.

***TK***: Compared to the very visible social movements in the 1960s, the 1970s were clearly quiet years in the United States.

***FvH***: In the US, the environmental movement accomplished huge progress in the 1970s. We got the Environmental Protection Agency, the Environmental Protection Act, the Clean Water Act, the Clean Air Act, and the Endangered Species Act. But perhaps those were the legacy of the environmental activism in the 1960s.

***TK***: And we had the UN Stockholm Conference on the Human Environment in 1972 because of the industrial pollution in the developed countries such as in Japan.

***FvH***: And there were anti-nuclear-power movements in the US, Japan and Germany that were very strong in the 1970s. And, in the late 1970s we had the anti-nuclear-missile movement in Western Europe that laid the basis for the 1987 Intermediate-range Nuclear Forces (INF) Treaty and, in the early 1980s, we had the Nuclear Weapons Freeze movement that laid the basis for the 1991 START Treaty.[15] So there was a period of activism that lasted from the 1960s through the 1980s.

The Senate Watergate hearings began in 1973, during the last spring I was in Chicago. I was mesmerized by the majesty of the process. In the end, the result was a victory for democracy and the rule of law. I hope we will be as successful this time.

## Automobile Energy Efficiency

***FvH***: In the late 1970s, I became very interested in automobile energy efficiency.

***TK***: How come?

***FvH***: Bob Williams had infected me with the importance of energy efficiency. After the 1973 Arab oil embargo, Congress had required a doubling of the fleet energy efficiency of new US automobiles by 1985.[16] So, in 1979, after the Shah of Iran fell and the price of gasoline went way up in the United States, I wondered whether we could double the energy efficiency of automobiles again by 1995.

I looked around and could not find anyone who had studied the technical feasibility of another big increase in automobile fuel efficiency.

[15]Under the START Treaty, Russia and the United States agreed to each reduce to 6,000 nuclear warheads deployed on intercontinental and submarine-launched ballistic missiles plus long-range bombers. (The bombers were counted as carrying one warhead each.) The 2002 Strategic Offensive Reductions Treaty (SORT) reduced that number to a range, 1700–2200, and the 2010 New START Treaty reduced it to 1550.

[16]The doubling was according to simulated driving cycles on dynamometers. The decrease in actual fuel consumption was somewhat less.

Then I got lucky and met Charles Gray who was in charge of measuring the fuel efficiency of US cars for the US Environmental Protection Agency's automobile emissions laboratory in Ann Arbor, Michigan, a suburb of Detroit. Gray turned out to be a policy activist and he taught me how to understand the energy inefficiencies in current-generation automobiles.

We ended up writing an article in *Scientific American* in 1981 about how it would be possible to more than double the efficiency of US cars by 1995 (Gray and von Hippel 1981, 48).

We visited Volkswagen's (VW's) engineering center in Germany after our *Scientific American* article had been published in the German edition. German newspapers reported that we "American experts" claimed that automotive fuel economy could be doubled.

The VW engineers were irritated that we got so much attention. They had actually just *built* a prototype that *did* that. They let us drive it around. It was a five-passenger car with a three-cylinder direct-injection diesel engine and a continuously-variable transmission. The engine turned off when the car stopped but, when the traffic light turned green again, restarted almost instantly using energy stored in a flywheel.

Subsequently, I went to a meeting on automobile energy efficiency with General Motors people. They said at first, "You can't make cars that much more efficient." I responded, "VW has built one and I've driven in it!" Then they responded, "But who would want such a car?"

I later concluded that they were worried about competing in the production of small cars with the Japanese automobile companies. But, of course, the Japanese started making big cars too and Detroit had to compete with them anyway.

There was congressional interest in our proposal. A group of senior senators put together a bill and, in the spring of 1981, there were Senate hearings at which Gray and I testified (Von Hippel 1980b; 1981a).

But the Reagan Administration had arrived.

In the spring of 1981, soon after President Reagan took office, a sympathetic Congressional staffer arranged a meeting for me with a senior official in the Office of Management and Budget.

I told him that there was a combination of technologies that could double the fuel efficiency of US automobiles by 1995. The cars would be a little more expensive but the owners would recover the the extra cost by buying less gasoline over the life of the cars. And we would reduce US dependence on Persian Gulf oil. Finally, I said that, because of the flatness of the total cost curve for auto owners (Figure 4) and their greater sensitivity up front to automobile purchase costs than to subsequent fuel costs, if the government did not intervene, the US automobile fleet would be only a little more efficient in 1995 than it was in 1981.

His response was. "If people want inefficient cars, that's what they should have! The market is always right!" And then he added, "And don't worry about our dependence on Persian Gulf oil. That's what we have the Rapid Deployment Force for."

***TK***: In 1979 there was an Iranian revolution and the oil price went up. That's why you became involved in energy policy issues?

***FvH***: The degree of US dependence on Persian Gulf oil also had became a major public-policy concern and a potential cause of a US war if the supply was cut off by, for example, Iran. Unfortunately, it took me two years to understand the technology well enough to be able to make a credible argument for doubling automobile fuel efficiency again. By that time the window of political opportunity had closed. If someone had been prepared to make that argument in 1979, I think we could have increased the fuel economy standards. In 2011, the Obama administration did increase the fuel efficiency standards. (President Trump is trying to roll them back.) But we lost 30 years. The founder of the Boy Scouts had a motto "Be Prepared." You have to be prepared for political opportunities.

***TK***: Timing *is* important. But how were you able in two years to learn automotive energy technology to a level where you could contribute at a professional level?

***FvH***: I didn't learn enough to be an automotive engineer, but I did learn enough to understand what automobile engineers were saying so that I could do approximate calculations that were good enough for policy purposes.

Charles Gray and his people opened up to me the literature on the difference between the average and the lowest air and tire rolling resistances for practical cars and the feasibility of offsetting with better designs the effects of weight reduction on safety (Figure 5).

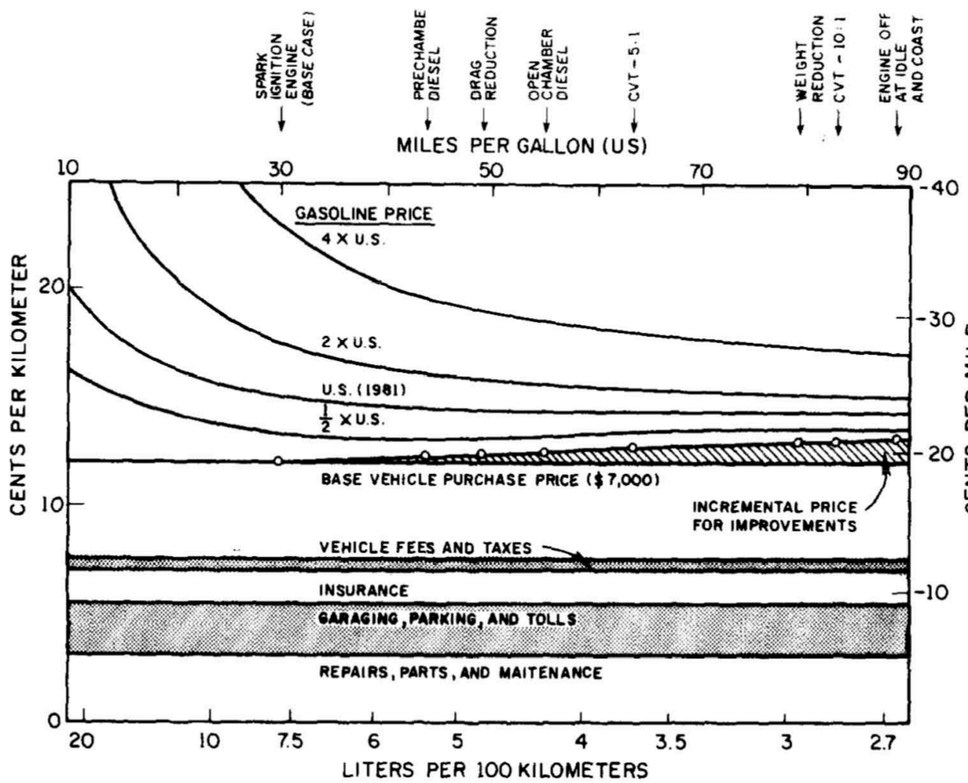


**Figure 4.** The cost of driving is almost flat over a large range of fuel efficiencies. This provides an opportunity for government intervention to reduce $CO_2$ emissions (Von Hippel and Levi 1983).

I also learned from them that you can make big gains if you have an efficient engine operated at its most efficient speed for any particular power requirement. Wide-range, continuously-variable transmissions (CVTs) have made that possible. The idea for CVTs goes back to Leonardo daVinci but Subaru only introduced it commercially in 1988.

When I understood these basic points, it became possible for me to calculate to an adequate approximation the amount of fuel that would be required to power a light-weight, aerodynamic auto with low-rolling-resistance tires through the standard driving cycles used to measure automobile fuel efficiency.

***TK***: Did any automotive company try to recruit you?

***FvH***: No. But Charles Gray knew engineers at all the auto companies because he tested their cars each year. That made it possible for us to visit VW and Volvo, which also had an advanced fuel-efficient prototype.

Gray was the technical expert in our collaboration, and I was able to use his insights to develop an approximate model and then make the policy arguments.

I have been lucky in my collaborators, in terms of their passion as well as their expertise. It is hard to know enough to do policy work alone.

***TK***: When you were thinking about automobile energy efficiency, was that interest related to your interest in the future of nuclear energy?

***FvH***: It was related more to a worry about the possibility of war over Persian Gulf oil. There was very little substitution between oil and nuclear electricity. Oil is mostly used for transportation and electric cars were not in sight at the time. Also, although some oil was burned to produce electricity before 1973, when oil was cheap, after oil became expensive, it was very quickly phased out of electricity production worldwide. Globally, about 3 percent of electricity is produced from oil today.

## The Movement to "Freeze" the Nuclear Arms Race

***TK***: In 1979, you were elected chairman of the Federation of American Scientists (FAS).

***FvH***: That turned out to be the beginning of a great adventure. Jeremy Stone, the full-time president of FAS, was a deep thinker about the nuclear arms race and a world-class activist. I don't remember much of what we did before 1981 but, when the Reagan administration came into office, all hell broke loose in nuclear-weapons policy.

Many of the people President Reagan put into the leadership positions in the Defense Department were members of an organization called The Committee for the Present Danger. They were convinced that the Soviets were preparing to fight and win a nuclear war. Their evidence was the fact that the Soviet Union had big missiles with up to ten multiple independently-targeted reentry vehicles on them (MIRVs). They were convinced that the purpose of these missiles was to be able to attack the one thousand US nuclear missile silos simultaneously in a first strike. If the MIRVs were accurate enough (they weren't), one Soviet missile could in theory destroy up to ten US missiles in a first strike.

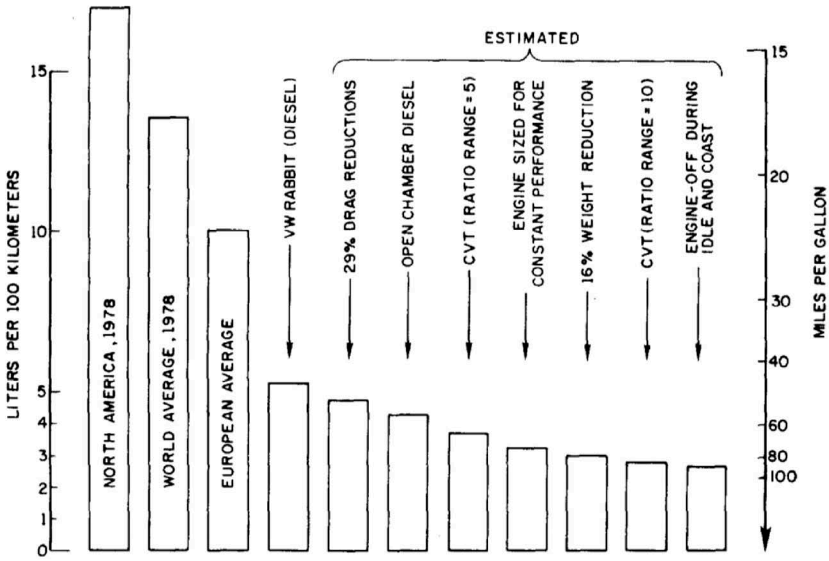


**Figure 5.** Potential fuel efficiency improvements starting with the already fuel-efficient VW Rabbit diesel (Von Hippel and Levi 1983).

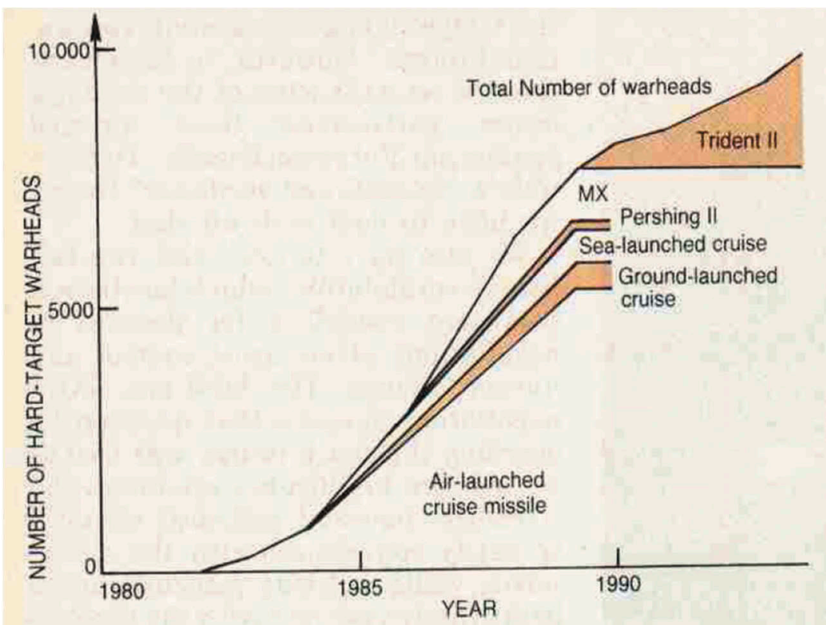


**Figure 6.** Buildup of counterforce nuclear warheads proposed by the new Reagan Administration (Feiveson and von Hippel 1983a, 36, 1983b).

They therefore argued that the only way for the US to deter a Soviet nuclear attack was to be prepared to fight a nuclear war. Their rhetoric scared a large fraction of the public and fueled the growth of the Nuclear Weapons Freeze movement in the United States.

I found the rise of the "freeze" movement exciting. Finally, we had a political debate over the nuclear arms race and an opportunity to get Congressional attention to arms-control proposals. In 1983, Hal Feiveson and I wrote an article titled "The Freeze and the Counterforce Race," pointing out that the Reagan administration was proposing to deploy 10,000 accurate counterforce warheads on long-range ballistic and cruise missiles (Figure 6).

The Freeze movement started its campaign to make nuclear-weapons policy a political issue in the US by campaigning for support at the local and state government level.

We've been trying to do it again. In May 2019, as a result of the initiative of our Assemblyman, Andrew Zwicker, the New Jersey State Assembly urged,

> "the federal government to spearhead a global effort to prevent nuclear war by renouncing the option of using nuclear weapons in a first strike, ending the President's sole authority to launch a nuclear attack, taking the nuclear weapons of the United States off hair-trigger alert, canceling the plan to replace its entire nuclear arsenal with enhanced weapons, and actively pursuing a verifiable agreement among nuclear-armed states to eliminate their nuclear arsenals [and] to ratify the Treaty on the Prohibition of Nuclear Weapons"[17]

California's State Legislature had already passed a similar bill in August 2018.[18]

***TK***: So are your papers on the casualties from limited nuclear war and on counterforce related?

***FvH***: Yes. The papers on limited nuclear war estimated the civilian casualties from counterforce attacks with nuclear weapons. The article on the counterforce race points out that counterforce weapons destabilize the nuclear balance of terror because they give an advantage to the side that goes first. Ballistic missile defense also incentivizes going first because it would be easier to defend from a force of ballistic-missiles that has been depleted by a first strike than from an undamaged force.

## A Debate with Edward Teller about Surviving Nuclear War

***TK***: In 1983, you also got into a debate with Edward Teller, the "father" of the US hydrogen bomb.

***FvH***: Teller had written an article, "Dangerous Myths about Nuclear Arms" (Teller 1982) in *Reader's Digest*, one of the largest-circulation US magazines at that time. He argued that the Soviet Union had a vast superiority over the US in terms of nuclear megatonnage and also that it had a civil defense system so effective that Soviet deaths in an all-out nuclear war with the US might be fewer than the 20 million the USSR suffered in World War II. He also argued that the Freeze would stop the development of a nuclear-explosion-powered X-ray laser system he claimed could destroy Soviet ballistic-missile warheads in outer space before they could reach the US. Finally, he argued that the radiation from nuclear fallout could be easily shielded against, and that the US could survive a nuclear war if it undertook some simple civil defense measures.

[17]State of New Jersey, Assembly Resolution No. 230, passed 23 May 2019, https://legiscan.com/NJ/text/AR230/2018.
[18]California Assembly Joint Resolution No. 33, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AJR33.

I found all this to be outrageous exaggeration and wrote to the editor of *Reader's Digest* proposing to write a rebuttal. The editor asked Herman Kahn for advice on the matter. Kahn had become famous after 1962 when he published the book, *On Thermonuclear War*, which helped inspire Stanley Kubrik's 1964 film classic, *Dr. Strangelove*.

Kahn responded, in effect, "Teller and von Hippel are both wrong. Just forget about it." The editor informed me that he would follow Kahn's advice.

I then went to Ruth Adams, the editor of the *Bulletin of the Atomic Scientists*, and the *Bulletin* reprinted Teller's article and my rebuttal (Von Hippel 1983b).

Teller responded in the next issue, repeating his arguments and equating nuclear arms control with Neville Chamberlain's appeasement of Hitler, and I responded to his response (Teller 1983).

Teller ended his response with a paragraph noting that I was a grandson of James Franck,

> "a giant in physics with an understanding heart, who was my mentor and dear friend. A few months ago, I spoke in Chicago at the centennial of his birth. If he and his grandson had been present, perhaps jointly we could have accomplished more than a printed and repetitious controversy."

In fact, I had been at the centennial where Teller gave quite a lucid talk on the physics that James Franck had done. Teller had been a post-doc with Franck, who also helped Teller come to the United States as a refugee.

I believe that Teller's statement about Franck's "understanding heart" referred to an exchange the two had after Teller had testified against J. Robert Oppenheimer in 1954. The AEC conducted secret loyalty hearings that resulted in Oppenheimer losing his clearance and his influence on US nuclear-weapon policy. Teller had never forgiven Oppenheimer for not backing with sufficient enthusiasm Teller's pursuit of thermonuclear weapons dating all the way back to the Manhattan Project (McMillan 2005). Most of Teller's physics colleagues refused to have anything to do with him after his insinuations about Oppenheimer's loyalty became public. My grandfather told Teller, however, that, while he disagreed with what Teller had done, he would not end their relationship.

## A Fissile Material Production Cutoff

***FvH***: Returning to the subject of the Nuclear Weapons Freeze movement, I started wondering whether there was a piece of the proposal that I could analyze. I decided that the freeze should include an end to the production of fissile materials for nuclear weapons.

In 1956, the Eisenhower administration had proposed a bilateral agreement with the Soviet Union to end the production of plutonium and highly-enriched uranium for weapons. It was a somewhat cynical proposal because, at that time, the US had produced much more of these materials than the Soviet Union. Unsurprisingly, the Soviets said "no." By the early 1980s, however, they had caught up and were in process of surpassing the US in their stocks of weapons-grade fissile materials.

This subject was a natural for me because I'd already been dealing with plutonium separation as a proliferation issue. I decided to make my own estimates of the quantities of nuclear-weapons materials, the US and Russia had produced. The US had not yet declassified how much material it had produced, but it had declassified how much radioactive waste it had produced as a result of its production of military plutonium and tritium and how much enrichment work it had done in mostly producing weapon-grade uranium. On the basis of that information, I was able to make relatively good estimates of how much plutonium and HEU had been produced.

Then the question was, how much did the Soviet Union produce? I wasn't able to figure out the amount of HEU. But, in the case of the plutonium, there is a fission product, krypton-85, that, like helium, is a "noble gas" that hardly reacts chemically. Therefore, when a reprocessing plant dissolves or chops up irradiated uranium to extract the plutonium, the krypton-85 goes into the atmosphere. It has a radioactive half-life of about 11 years. In the early 1980s, it was still being released into the atmosphere faster than it was decaying.

I found some German historical measurements of the concentration of Kr-85 in the atmosphere. Then, from my reconstruction of the history of the US plutonium production and the published history of reprocessing in Europe I was able to subtract out the krypton-85 that we and the Europeans had released. When I corrected for decay, the remainder must have been almost all from the Soviet plutonium production (Figure 7).

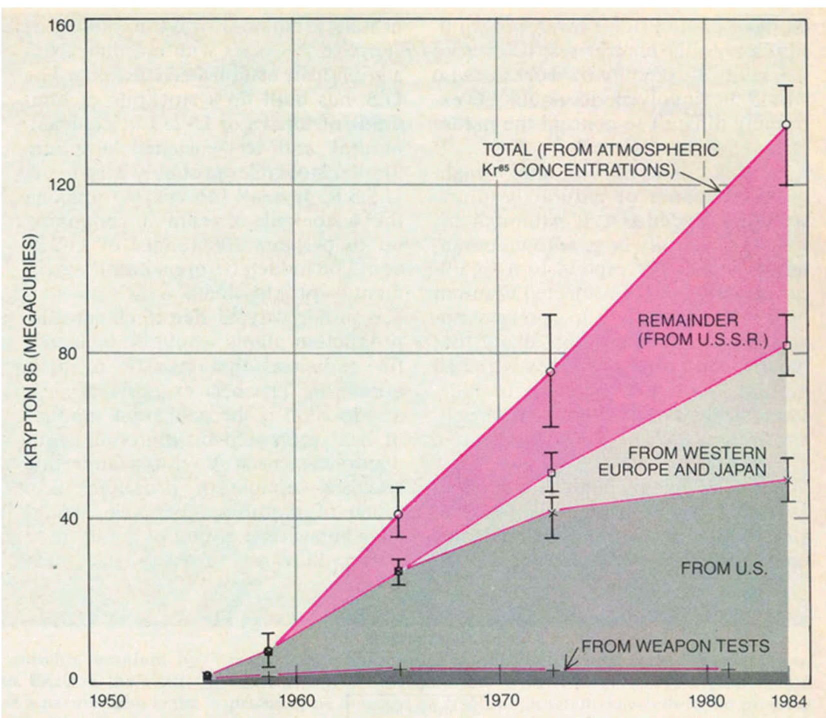


**Figure 7.** The estimated contributions to the atmosphere's Kr-85 inventory from the US and Western Europe left a residual that yielded an estimate of Soviet plutonium separation (Von Hippel, Albright, and Levi 1985, 40).

I published the results with David Albright and Barbara Levi in a 1985 *Scientific American* article, "Stopping the Production of Fissile Material for Weapons" (Von Hippel, Albright, and Levi 1985).

***TK***: Why did you make these estimates?

***FvH***: My point was that, by 1985, unlike in 1956, the quantities of plutonium – and probably the quantities of highly-enriched uranium – that the two countries had separated were both huge and comparable. Therefore, this time, they should be able to agree to a verified halt.

*Scientific American* is translated into several languages including Russian. I was going to Moscow regularly during that period and learned that our article had not been published in the Russian edition. I asked why and was told that the censors refused to let the article pass because the amount of plutonium the Soviet Union had produced was a secret. Eventually, Velikhov (see below) told the censors that Gorbachev said it could be published and it was, although delayed by almost two years.

Our article helped get some in Congress and those around Gorbachev interested in the idea of a Fissile Material Cutoff Treaty. But the Reagan Administration was not interested. Later, in 1989, when I testified in Congressional hearings, the person the Republicans chose to testify against my idea was Frank Gaffney, who had been Deputy Assistant Secretary of Defense for Nuclear Forces and Arms Control Policy in the Reagan Administration. At one point, I said the Soviet Union was producing several tons of plutonium a year and I thought we could verify a cutoff to better than a ton per year, which would have been less than a percent of the Soviet Union's already existing stock. Gaffney argued that, if there was an uncertainty of an ounce (0.000028 tons) of plutonium, he would be against a cutoff treaty![19]

## The Committee of Soviet Scientists for Peace and against the Nuclear Threat

***TK***: Well, what about the Strategic Defense Initiative (SDI)? When you listened to the speech by Mr. Reagan on 23 March 1983, what was your first reaction?

***FvH***: I waited for people who were more expert on ballistic missile defense than I – especially Garwin – to speak. But I knew by then that the idea of having an effective defense against ballistic missile warheads was crazy. Relatively cheap countermeasures such as decoys would allow the offense to overwhelm the defense.

Reagan's "Star Wars" speech led, however, to my very consequential interaction with a group of Soviet scientists led by Evgenyi Velikhov.

After the Star Wars speech, a large group of Soviet scientists signed an open letter to the scientists of the world expressing alarm that the US buildup of counterforce weapons, combined with a deployment of US missile defenses might convince the US that it could

[19]Hearing on "Nuclear Material Production Cutoff as an Arms Control Mechanism" before the Procurement and Military Nuclear Systems Subcommittee and Nuclear Systems Subcommittee and Department of Energy Defense Nuclear Facilities Panel of the House Armed Services Committee, 6 June 1989, pp. 1875–1899; "Hearing on the *International Plutonium Control Act. – H.R. 2403* before the Subcommittee on Arms Control, International Security and Science of the House Committee on Foreign Affairs, 20 June 1989, 338 pages.

undertake a first strike against the Soviet Union and defend itself against retaliation by any surviving Soviet nuclear missiles.

Jeremy Stone had traveled to Moscow five times before 1972 to make the case for the 1972 Soviet-US Treaty on Limitation of Anti-Ballistic Missile (ABM) Systems. He wrote a letter in response to the President of the Soviet Academy of Sciences that I co-signed saying that

> "We want the ABM Treaty strengthened rather than weakened. And we consider this Treaty to be the fulcrum on which new limitations on offensive weapons can, and must be, based. Without this Treaty, the arms race would soon speed up, and become still more dangerous than it is even today."[20]

The FAS may have been the only group of US scientists that responded to the letter from the Soviet scientists. Jeremy followed up by proposing that we send a delegation to Moscow for discussions and the Soviet Academy sent us an invitation in response.

We flew to Moscow over the long Thanksgiving weekend of 1983. In addition to Jeremy and myself, the group included John Holdren, FAS Vice Chair, who 25 years later would become President Obama's science advisor; and John Pike, the FAS's new space policy expert.

At the airport, we were met by Evgenyi Velikhov, chair of the new Committee of Soviet Scientists for Peace and Against the Nuclear Threat (Stone 1983).

***TK***: Who was the head of Soviet nuclear science?

***FvH***: The head of both the Soviet Academy of Sciences and the Kurchatov Institute of Atomic Energy at the time was Anatoli Alexandrov who, coincidentally, was the lead designer of the Chernobyl-type reactors. Velikhov was a Vice President of the Academy and also the head of the Soviet Union's fusion energy program.

Although we did not know it at the time, it was just weeks after a NATO nuclear exercise, "Able Archer," had almost triggered a nuclear war (Atomic Heritage Foundation 2018). Velikov didn't seem to be nervous but there were a lot of stories in the Soviet press about the Americans threatening the Soviet Union with nuclear attack. Velikhov's group took us to Tbilisi, Georgia over the weekend and Holdren and I used a break to walk up a small mountain with a Soviet colleague. Somebody hearing us talk in English realized that I was an American and asked me, "why do you Americans want war?"

There were TV cameras filming our discussions at our first session in Tbilisi. The cameras made Jeremy very nervous. He feared the tapes would be used in Soviet propaganda, which could discredit us in the US debate. So I asked Velikhov if he could get rid of the cameras, which he quickly did. The person who had been interviewing us for the cameras was Anatoly Gromyko, a political scientist and the son of Andrei Gromyko, who had been the Foreign Minister of the Soviet Union since 1957.

[20]"Appeal to all scientists of the world from Soviet scientists" and "FAS Answer to Soviet Scientists," *FAS Public Interest Report*, May 1983, pp. 11–12, https://fas.org/faspir/archive/1982-1989/May1983.pdf.

Later, however, I did make a brief statement on Soviet national TV, that the Soviet and US scientists in the meeting were in basic agreement on four fundamental points:

(1) Nuclear war would be the ultimate catastrophe;
(2) There can be no effective defense against nuclear weapons;
(3) The nuclear forces of the two superpowers were roughly equal; and
(4) This would be a good time to stop the arms race.

My statement was followed by a partial showing of the new US TV film, *The Day After*, about the catastrophic consequences in two US towns in the Midwest after a US-Soviet nuclear exchange. In the US, the film was seen by an estimated 100 million in its first showing on ABC television on 20 November 1983, the night of our flight to Moscow (Stone 1983).

Most of the Soviet academicians slowly disappeared until we were down to the leaders of the Committee of Soviet Scientists for Peace and Against the Nuclear Threat: Velikhov (chairman); Roald Sagdeev, the head of the Soviet Space Research Institute (deputy chairman); Sergei Kapitsa, a physicist who had a regular program on national TV interviewing scientists and who was the editor of the Russian edition of *Scientific American*;[21] and Andrei Kokoshin, a political scientist and Deputy Director of the USA-Canada Institute. Kokoshin was there as a political advisor to the scientists.

This was the first of 25 trips I took to Moscow before the disintegration of the Soviet Union at the end of 1991. The second trip was in September 1984 when I was joined by Hal Feiveson, Rob Socolow and Bob Williams to discuss energy policy – especially energy efficiency – in meetings organized by Velikhov.

## Disclosure Statement

No potential conflict of interest was reported by the authors.

## Notes on Contributors

*Frank von Hippel* is a Senior Research Physicist and Professor of Public and International Affairs emeritus at Princeton University's Program on Science and Global Security. He was a founding co-chair of the Program and of the International Panel on Fissile Materials. During 1993–94, he served as Assistant Director for National Security in the White House Office of Science and Technology Policy.

*Tomoko Kurokawa* has worked since 1996 with Tokyo Broadcasting System (TBS), one of the major nationwide TV networks in Japan. She is an experienced journalist in covering nuclear disarmament, non-proliferation and nuclear energy issues. She was a Visiting Scholar at Carnegie Endowment for International Peace (CEIP) from 2012 through 2013 and is now a non-resident scholar of CEIP.

## ORCID

Frank von Hippel http://orcid.org/0000-0002-7934-9584

[21] Sergei's father was the great Nobel-Prize-winning physicist, Peter Kapitza, the Soviet Union's most outspoken senior scientist before Sakharov. Sergei took my wife and me to visit Peter Kapitza's "dacha" (country retreat) outside Moscow and we learned that Peter Kapitza had been exiled there by Stalin for seven years to keep him from being imprisoned and potentially murdered by the Lavrenti Beria, the head of Stalin's internal security apparatus.

## References


AEC. 1974. "Liquid Metal Fast Breeder Reactor Program." *Proposed Final Environment Statement, US Atomic Energy Commission, December 1974*, https://www.osti.gov/servlets/purl/4200425-4GWbYl/

Arkin, W. M., F. von Hippel, and B. G. Levi. 1982. "The Consequences of a 'limited' Nuclear War in East and West Germany." *Ambio* Vol. XI (#2 3): 163–173. sgs.princeton.edu/pdf/arkin-1982.pdf

Arkin, W. M., F. von Hippel, and B. G. Levi. 1983. "Kollectiver Selbstmord? Atomkrieg in Deutschland." *Spektrum De Wissenschaft*, March 1983.

Atomic Heritage Foundation. 2018. "Nuclear Close Calls: Able Archer 83." Atomic Heritage Foundation. https://www.atomicheritage.org/history/nuclear-close-calls-able-archer–83

Carter, L. 1979. "Nationwide Protection from Iodine-131 Urged." *Science* 201. doi:10.1126/science.482935.

Cochran, T. B., R. E. Train, F. von Hippel, and R. H. Williams. 1977. "Proliferation Resistant Nuclear Power Technologies: Preferred Alternatives to the Plutonium Breeder." sgs.princeton.edu/pdf/cochran-1977.pdf

Daugherty, W., B. Levi, and F. von Hippel. 1986. "The Consequences of 'limited' Nuclear Attacks on the US." *International Security* 10 (4): 3–45. doi:10.2307/2538949.

Drell, S., and F. von Hippel. 1976. "Limited Nuclear War." *Scientific American* 27–37. doi:10.1038/scientificamerican1176-27.

Eden, L. 2004. *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation*. Cornell University Press, Ithaca, New York.

Edison Electric Institute. 1976. *Economic Growth in the Future: The Growth Debate in National and Global Perspective*. McGraw Hill, New York, NY.

Feiveson, H., T. Taylor, F. von Hippel, and R. H. Williams. 1976. "The Plutonium Economy: Why We Should Wait and Why We Can Wait." *Bulletin of the Atomic Scientists* 10–14. doi:10.1080/00963402.1976.11455664.

Feiveson, H., and F. von Hippel. 1983a. "The Freeze and the Counterforce Race." *Physics Today,* 36 (1): 36–49. doi:10.1063/1.2915443.

Feiveson, H., and F. von Hippel. 1983b. "Letters to the Editor." *Physics Today,* 36(5): 11–13.

Glasstone, S., and P. J. Dolan, eds. 1977. *The Effects of Nuclear Weapons, 3rd Edition*. US Departments of Defense and Energy, Washington, DC. https://www.dtra.mil/Portals/61/Documents/NTPR/4-Rad_Exp_Rpts/36_The_Effects_of_Nuclear_Weapons.pdf

Gray, C. L., Jr., and F. von Hippel. 1981. "The Fuel Economy of Light Vehicles." *Scientific American* 48. doi:10.1038/scientificamerican0581-48.

Holden, C. 1982. "Potassium Iodide and Nuclear Accidents." *Science* 1485. doi:10.1126/science.215.4539.1485.

International Atomic Energy Agency (IAEA). 1980. *International Nuclear Fuel Cycle Evaluation*. IAEA, Vienna.

Keeney, S. M., Jr, et al. 1977. *Nuclear Power: Issues and Choices*. Ballinger, Cambridge, Massachusetts.

Kemp, R. S. 2017 "Opening a Proliferation Pandora's Box: The Spread of the Soviet-type Gas Centrifuge." *Nonproliferation Review* 24 (1–2): 101–127. doi:10.1080/10736700.2017.1368649.

Levi, B., F. von Hippel, and W. Daugherty. 1987/88. "Civilian Casualties from 'limited' Nuclear Attacks on the USSR." *International Security* 12 (3): 168–189. doi:10.2307/2538804.

McMillan, P. 2005. *The Ruin of J. Robert Oppenheimer and the Birth of the Modern Arms Race*. Viking, New York.

President's Commission on the Accident at Three Mile Island. 1979. "The Need for Change: The Legacy of TMI." https://www.hsdl.org/?view&did=769775

Simons, N., and M. Shils. 1983. "Potassium Iodide Policy in New York." 318.

Stone, J. 1983. "FAS Visit to Moscow Initiates Star Wars Dialogue." *F.A.S. Public Interest Report*. 1–12. December 1983. https://fas.org/faspir/archive/1982-1989/December1983.pdf

Teller, E. 1982. "Dangerous Myths about Nuclear Arms." *Reader's Digest*. Reprinted in *The Bulletin of the Atomic Scientists*, 39 (3): March 1983, 6–12: 7 November 1982.

Teller, E. 1983. "On Facts and Hopes" (With Frank Von Hippel's Response)." *Bulletin of the Atomic Scientists*. 42–44. April 1983. sgs.princeton.edu/pdf/teller-1983.pdf

US Senate Committee on Foreign Relations. 1975. *Analyses of Effects of Limited Nuclear Warfare*. Washington DC: US Senate Committee on Foreign Relations.

Von Hippel, F. 1979. "Available Thyroid Protection." *Science*. doi: 10.1126/science.451546.

Von Hippel, F. 1980a. "Frank Von Hippel, "The NRC and Thyroid Protection - One Excuse after Another." *Bulletin of the Atomic Scientists* 44. doi:10.1080/00963402.1980.11458769.

Von Hippel, F. 1980b. "Why the U.S. Needs Ambitious Post 1985 Automotive and Light Truck Fuel Economy Standards." In *Hearing on Automotive Technology and Fuel Economy Standards*, Subcommittee on Science, Technology, and Space, U.S. Senate Committee on Commerce, Science, and Transportation, Washington, DC. 304–330.

Von Hippel, F. 1981a. "Why the U.S. Needs an Automotive Fuel Economy Policy," In *Hearing on Energy Conservation in Transportation*, Subcommittee on Energy Conservation and Power, US House of Representatives Committee on Energy and Commerce, Washington, DC, 29–54, 66–79.

Von Hippel, F. 1981b. "The Emperor's New Clothes – 1981." *Physics Today*. doi:10.1063/1.2914645.

Von Hippel, F. 1982a. "Frank Von Hippel, "The Thyroid Protection Problem: To Predistribute or Not to Predistribute Potassium Iodide?" *Oversight Hearing on Emergency Preparedness for Radiological Accidents: The Issue of Potassium Iodide*. Subcommittee on Oversight and Investigations of the House Committee on Interior and Insular Affairs, Accessed 5 March 1982. https://babel.hathitrust.org/cgi/pt?id=uc1.31210024919357&view=1up&seq=1

Von Hippel, F. 1982b. "Potassium Iodide Policy." 6.

Von Hippel, F. 1982c. "Potassium Iodide for Thyroid Protection," 1174.

Von Hippel, F. 1983a. "Thyroid Protection," 906.

Von Hippel, F. 1983b. "The Myths of Edward Teller." *Bulletin of the Atomic Scientists* 6–7. doi:10.1080/00963402.1983.11458958.

Von Hippel, F. 1991. *Citizen Scientist*. American Institute of Physics, College Park, Maryland.

Von Hippel, F., D. H. Albright, and B. G. Levi. 1985. "Stopping the Production of Fissile Material for Weapons." *Scientific American* 40–47. doi:10.1038/scientificamerican0985-40.

Von Hippel, F., B. Levi, T. Postol, and W. Daugherty. 1988. "Civilian Casualties from Counterforce Attacks." *Scientific American* 36–42. doi:10.1038/scientificamerican0988-36.

Von Hippel, F., and B. G. Levi. 1983. "Automobile Fuel Efficiency: The Opportunity and the Weakness of Existing Market Incentives." *Resources and Conservation* 10: 103–124. doi:10.1016/0166-3097(83)90072-X.

Yalow, R. 1982a. "Potassium Iodide Distribution." *Science* 295. doi:10.1126/science.217.4557.295.

Yalow, R. 1982b. "Potassium Iodide: Effectiveness after Nuclear Accidents." 742