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Citizen Scientist: Frank von Hippel's Adventures in Nuclear Arms Control PART 8. Nuclear-reactor Safety Again

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ABSTRACT
The Fukushima accident of 2011 pulled von Hippel back into the reactor-safety world. He was invited to join a Congressionally-mandated four-year study of the lessons that could be learned from the Fukushima accident to improve the safety of US nuclear plants. During that study he learned more about both a much worse accident that almost happened at Fukushima, and about how the US Nuclear Regulatory Commission had come to use "risk-informed regulation" as a way to avoid requiring costly safety upgrades opposed by US nuclear utilities. He campaigned unsuccessfully at both the national and state levels to move the nuclear utilities away from densely packed spent fuel pools by moving fuel that had cooled for more than five years to dry-cask storage. He also promoted on-site dry-cask storage in Japan and South Korea as an alternative to reprocessing. This last chapter ends with some stories of his father, also a physicist, who would not be intimidated and who was a leader in the development of the field of materials science and engineering.

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The Fukushima Accident and the Spent-fuel-pool Fire that Almost Happened There

Tomoko Kurokawa (***TK***): What did you do when the Fukushima accident happened?

Frank von Hippel (***FvH***): For background, I have to go back to the March 1979 Three Mile Island accident in the United States. When that accident happened, many journalists remembered my involvement in the 1974 American Physical Society study (see Part 1). So they called me.

Seven years later, when the Chernobyl accident happened in Ukraine, Bill Broad, a veteran science reporter with *The New York Times*, called me and then reported the preliminary cancer-death projections that Tom Cochran and I had made.

Fifteen years later, when the Fukushima accident began on 11 March 2011, Broad called me again and asked me what I thought was happening. His story quoting me appeared in the March 12 *New York Times*. Again, other journalists began to call me and

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I was also asked for television interviews. I did a couple of them with Rachel Maddow, who I admire.

For about two weeks after the tsunami flooded the electric power distribution systems in the basements of four of the six units of the Fukushima Daiichi (Fukushima I) nuclear power plant, most US reactor-safety experts, including those at the US Nuclear Regulatory Commission (NRC), believed there must a fire in the spent-fuel pool on the top floor of the building containing reactor 4. We all thought that because, on the fourth day after the tsunami, there was a hydrogen explosion in that building. There had been hydrogen explosions in units 1 and 3 in the previous days. In those units, the hydrogen had been generated by steam reacting with hot zirconium cladding in the reactor cores. But there was no fuel in reactor 4; it had all been removed to its spent storage pool to allow work inside the reactor pressure vessel.

Therefore, the only way hydrogen could have been produced in reactor building 4 was from steam-zirconium reactions in the pool. That would mean that the spent fuel in the pool was uncovered. It seemed that simple – except it wasn't.

It turned out that the earthquake had not cracked pool 4 and the spent fuel in it remained covered with water. The hydrogen that caused the explosion in reactor building 4 had leaked in through a vent system shared with the adjoining unit 3.

Tokyo Electric Power Company, which owned the Fukushima Daiichi plant, flew a helicopter around the plant to take photos and claimed – based on what they thought was a reflection from the pool in reactor building 4 – that the pool was still almost full.

At first, US analysts were skeptical because the picture was not clear and there was not yet an alternative explanation for where the hydrogen had come from. During this period, Gregory Jaczko, the Chairman of the US Nuclear Regulatory Commission, advised that Americans should evacuate to beyond 80 kilometers from the nuclear power plant while Japan's government had advised evacuation out to only 20 kilometers. The implications of the difference were huge: about 80,000 people lived within 20 kilometers of the plant versus about 2 million within 80 kilometers.

Some of us were concerned about this discrepancy. The Japanese would see their government as less interested in protecting them than the US government was in protecting Americans.

In 2003, I had been part of a group that had co-authored an article warning about the possibility of a spent-fuel-pool fire that could release a hundred times more cesium-137 than was released to the atmosphere from the core meltdowns in reactors 1, 2 and 3 at the Fukushima Daiichi plant (Alvarez et al. 2003). Thirty-year half-life Cs-137 is the gamma-emitting radioactive fission product that has contaminated large areas downwind from the Chernobyl and Fukushima accidents, causing the long-term relocation of about 100,000 people in each case.

The principal reason for the potentially huge size of the release from a spent-fuel-pool fire is because, unlike reactors, the pools are surrounded by flimsy walls and roofs.

Most reactors are enclosed in thick steel and reinforced-concrete containment structures (Figure 1). In the Fukushima accident, the containments of reactors 1, 2 and 3 were overpressured, the bolts holding down the tops of their steel containment vessels stretched and radioactive gases leaked out. But only one to three percent of the volatile

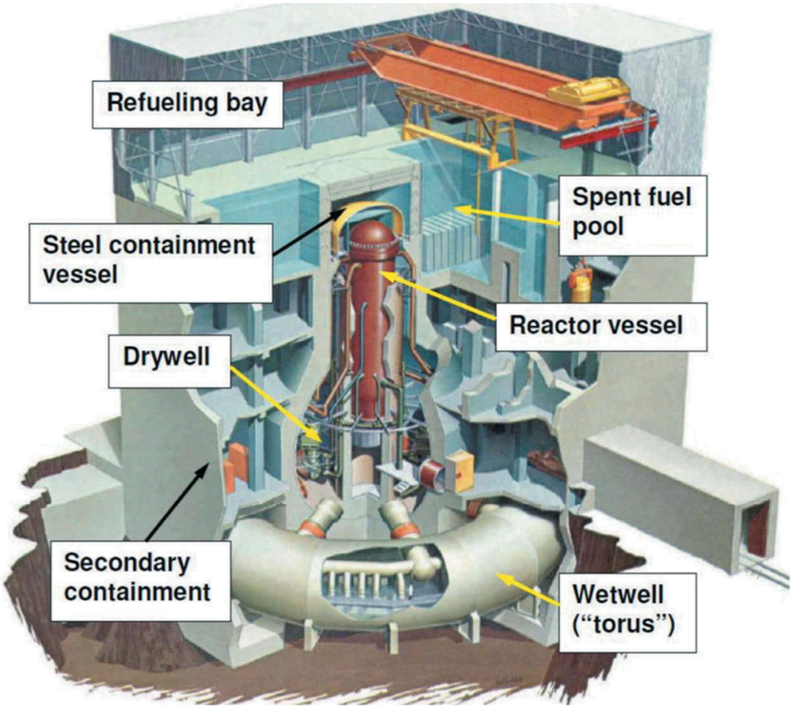

Figure 1. Shown here is a cutaway diagram of the Fukushima-type reactor building designed in the 1960s by the US company, General Electric. The spent fuel pool is on the top of the reinforced-concrete building surrounding the reactor. The walls and roof above the spent fuel pool are just sheet metal. In contrast, the reactor is surrounded by a steel and reinforced concrete containment vessel. Since that containment has a small volume, a water-filled torus was added to condense the steam that would be released if a pipe or the pressure vessel containing superheated water should fail inside the containment. At the time of the great earthquake and tsunami, the concrete blocks above the containment vessel of unit #4 had been removed, as had the top of the containment vessel and the top of the reactor vessel. The reactor well above the reactor vessel had been filled with water, and the fuel had been moved under water from the reactor vessel through a slot in the wall of the reactor well into the spent fuel pool.
https://allthingsnuclear.org/dlochbaum/containment-venting-is-cooling-but-needs-filters

cesium-137 that boiled out of the overheated reactor cores leaked out into the atmosphere. The rest plated out on the insides of the containment structures.

In contrast, the hydrogen explosion in reactor building #4 destroyed the flimsy walls and roof surrounding the spent fuel pool (Figure 2). Therefore, if there had been a fire in the spent fuel pool, the path for the Cs-137 into the atmosphere was wide open.

Even without the pool leaking, the water in pool 4 was evaporating, and its water level was dropping more quickly than the water levels in pools 1, 2 and 3 because of the radioactive decay heat of the recently discharged "hot" core that it contained. There was no power to operate the pumps ordinarily used to fill the pool, and workers could not be sent in with fire hoses because of the high radiation level in the pool area from radioactivity deposited from the core meltdowns in units 1, 2 and 3.

Emergency responders tried to add water by dumping it from helicopters and with streams of water arching up from fire hoses on the ground but both were ineffective. On

Figure 2. Fukushima Daiichi Reactor Building 4 after the hydrogen explosion on 15 March 2011. On the right is the "giraffe," a cement pump whose boom was used to deliver water to the pool through a hole in the roof (TEPCO).

the video clips that came with the evening news, one could see the wind blowing away the water dropped from the helicopters.

Finally, about 12 days after the tsunami, a cement pump with a long boom, designed for pumping cement up several stories at building construction sites, began to pump water into the area of the building where pool 4 was located (Figure 2).

For a month, no one thought of attaching a video camera to the end of the boom to see where the water was actually going. Instead, indirect evidence was used to establish that the pool had been filled. This evidence was provided by the flow of water into the pool overflow pipe. It was understood later that this indicator was unreliable because some of the water delivered by the cement pump was going directly into the overflow pipe.

As a result, the water additions were insufficient and, unbeknownst to the emergency responders, the water level in the pool was dropping. Finally, after a month, a camera was put on the boom of the cement pump, and TEPCO discovered that the water in the pool had sunk from its original level seven meters above to two meters above the top of the spent fuel. Then they finally filled the pool.

That was not the whole story, however, because, when TEPCO's experts reconstructed the history of the water level in pool 4, they realized that the spent fuel had remained covered only because of leakage of water from the adjacent reactor cavity, which was still full of water at the time of the accident because of delays in the work in the reactor pressure vessel (Figure 3).

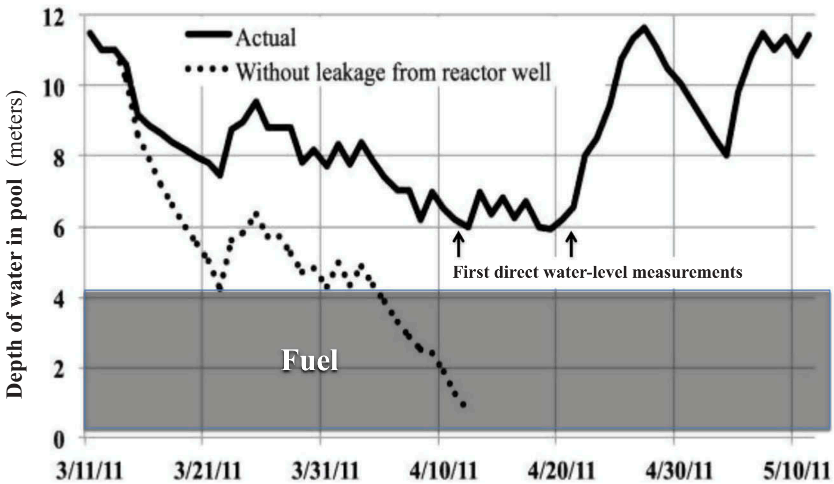

Figure 3. The solid line shows TEPCO's reconstruction of the water level in the spent fuel pool of Fukushima Daiichi unit #4. The sudden increases are due to water additions by the "giraffe" pump. After the first direct observations of the water level a month after the tsunami, the pool was refilled. The dotted line shows what the water level would have been had there been no leakage into the pool from the adjoining reactor well, which ordinarily is not water filled. (The decline during late April and early May was due to a temporary suspension of water addition. The purpose was to measure the rate of decline to see if it was consistent with a calculation of the evaporation rate in order to make sure that there was no significant rate of leakage) (adapted from National Research Council 2016, Fig. 2.15).

National Research Council "Lessons Learned" Study

During the accident, I didn't do much more than try to help journalists understand the possibilities. A year later, however, I was invited to join a Congressionally-requested National Research Council study of lessons that could be learned by the US from the Fukushima accident. Jan Beyea, another co-author of a 2003 paper a group of us (Alvarez et al. 2003) had written on spent fuel pool fires (see Part 6), was also invited and we both served on the committee for its full four years of existence.

TK: What was the purpose of the study?

FvH: The Nuclear Regulatory Commission (NRC) had already launched its own Fukushima-lessons-learned study. I think some in Congress wanted a second opinion.

The Nuclear Regulatory Commission decided that, to study the danger of spent-fuel-pool fires, we would need access to classified information. To get clearances would take time. During the first two years of our study, therefore, we looked at everything but the spent fuel pools.

The chairman of our committee had been the first science advisor for the U.S. State Department. He was interested in science diplomacy but did not get intellectually engaged sorting out the issues that we debated in the study. He left that to the vice chairman and the study director.

Unfortunately, the vice chairman was the high priest of the community that does the probabilistic-risk calculations the nuclear utilities use to show that the probability of accidents are too low for safety improvements to be cost justified.

Since the 1974 APS Reactor Safety Study, I have been among those who have argued that the methodology of probabilistic risk assessment is useful in identifying potential causes for serious accidents, but that the uncertainties in the probability calculations make their results an unreliable basis for regulatory decisions.

The problem was exemplified at our first briefing by a group of NRC staffers. I asked what probability they were assuming for a successful act of terrorism. The answer was that, since they did have an adequate basis for estimating that risk, they assumed it was zero.

The Vice Chairman and I went to war over probabilistic risk assessment. He would write a long draft chapter about how valuable this approach was. And then, I would write a long critique of its weaknesses. In the end, the rest of the committee did not know how to resolve our debate so it threw out most of what both of us had written.

As a result, the only one of my contributions that was included in the first report was Appendix L (National Research Council 2014). In that appendix, I analyzed the NRC's estimate of the average off-site economic damages from a Fukushima-scale release in the United States. The NRC staff calculated that it would be about 2 USD billion while, in Japan at the time, the estimated cost for cleanup, compensation of the relocated population, and replacement power for the shutdown nuclear power plants was about 200 USD billion.

Later, I dug into the NRC calculations and found several major errors.

TK: What kind of mistakes did they make?

Probability and Consequences of Spent-fuel-pool Fires

FvH: I will explain when we come to the spent fuel pool study because I got deeper into that and they made the same mistakes both times.

We published the first volume of our study on everything but spent fuel pool fires in 2014. It was a pretty frustrating experience for me. It was also pretty frustrating for both the chairman and the vice chairman and they both quit. The next stage, which focused on the danger of spent-fuel-pool fires, was with a new chairman and I was able to make a more substantial contribution.

First, we had to understand what had happened with the water level in pool 4. TEPCO had understood that the spent fuel in the pool had not become uncovered because of leakage into the pool from the reactor well. However, it took some time for us to understand that.

Meanwhile, the NRC was finally considering the proposal a group of us had made in the 2003 article (Alvarez et al. 2003) where we had argued that dense packing spent-fuel pools was dangerous and that spent fuel that had cooled for more than five years should be transferred to dry cask storage. The NRC staff found that there would be a hundred-fold reduction in the economic damage from a spent-fuel-pool fire if the fuel were moved out of the pool after five years. The reason was that, with less fuel in the pool, steam-zirconium reactions would not generate enough hydrogen to blow up the reactor building and most of the cesium-137 would not be released into the atmosphere but would rather plate out on the building's interior surfaces.

The NRC staff also estimated a very low probability for a fire, however. When they multiplied the reduction in damage due to the “expedited transfer” of spent fuel to dry casks by the probability of a spent fuel fire, they found an average probability-weighted benefit of only 7 USD million per pool while they estimated that the cost the utilities of moving the older spent fuel to dry cask storage after five years would be 50 USD million per pool.

I was skeptical of the probability calculation since it was so uncertain and left out terrorism. But that was just my opinion. So I decided that I had to understand the NRC staff’s estimate of economic damage. I was already suspicious of it because of the hundred-fold difference I had found between the NRC staff’s estimate of the economic cost of a Fukushima-scale release in the United States versus the actual cost in Japan.

As with my review of the consequence calculations in the Atomic Energy Commission’s *Reactor Safety Study* forty years earlier (see Part 1), reviewing the NRC staff’s consequence calculations turned out to be hard because many of the assumptions were buried inside a computer code that was not publicly available. The NRC staff report did say, however, that consequences were only calculated out to 50 miles (80 kilometers). That might be reasonable for an ordinary reactor accident but not for the huge release from a spent-fuel-pool fire.

In the meantime, however, consultants for the office of the New York State Attorney General were trying to understand the NRC’s estimate of the economic cost of a hypothetical accident at the Indian Point nuclear power plant up the Hudson River from New York City.

In the course of their investigation, they learned that the NRC staff was assuming that the radioactive contamination from an accident could be reduced by a factor of 15 in less than a year, and that therefore virtually all the relocated population could be returned home within a year. This would reduce the cost of supporting the relocated population and also the loss of value of their temporarily abandoned homes and places of work.

The NRC assumptions on the effectiveness and speed of decontamination were inconsistent, however, with the experience at Fukushima where, in built-up areas, a decontamination factor of only three was achieved after five years.

So the New York State team asked the NRC the basis for its assumptions about the speed and effectiveness of property decontamination.

The NRC finally came back and said: “The [NRC] Staff and Entergy [the operator of the Indian Point plant] could not explain the underlying technical basis for these values” (U.S. Nuclear Regulatory Commission 2016, 35).

I found a third major mistake in the NRC’s economic damage estimate after the NAS study was complete.

The New York State Attorney General had forced the NRC to post the computer code. I therefore was finally able to study it and tried to reproduce the numbers. Once again, as in 1974, I couldn’t reproduce the numbers and tried to understand why. Finally, I realized that the NRC staff had used in its computer calculations a higher threshold contamination level for population relocation than it had stated in its report.

The US Environmental Protection Agency had advised approximately the same contamination level for relocation in the US as had been adopted for Chernobyl and Fukushima. That level corresponds to a dose rate outdoors and away from buildings of about 2 rem (20 millisieverts) during the first year.

But the Nuclear Regulatory Commission staff had assumed in its program a threshold for relocation three times higher. Its rationale was that people spend most of their time indoors and the radiation levels inside are lower than outside. As a result, their threshold for population relocation was three times higher than mandated by the Soviet and Japanese authorities and recommended by the US EPA.

I asked the NRC staff whether my understanding of what they had done was correct. They did not respond until the Academy of Sciences' study had published its findings. Then I got the response that my understanding was correct.

One of our post-docs at the time, Michael Schoeppner,[1] knew how to do atmospheric dispersion calculations for historical weather conditions. He calculated what the relocation areas would have been in Japan for different historical weather conditions had there been a spent fuel fire in pool number 4 (Figure 4). We then redid the Nuclear Regulatory Commission's calculations for the consequences of a spent fuel pool fire at the Surry Nuclear Power Plant in Virginia (Figure 5) with the NRC staff's three errors corrected.

The result was to increase the NRC's estimate of the average economic damage from a fire in a US dense-packed spent-fuel pool by about a factor of 15 to about 2 USD trillion.

Adopting the NRC estimate for the probability of spent-fuel-pool fire – which was based on the probability of a super-earthquake cracking a spent-fuel pool – the increase by a factor of 15 in economic damage would increase the estimated benefits of removing spent fuel from the pools after five years from about 7 USD million to about 100

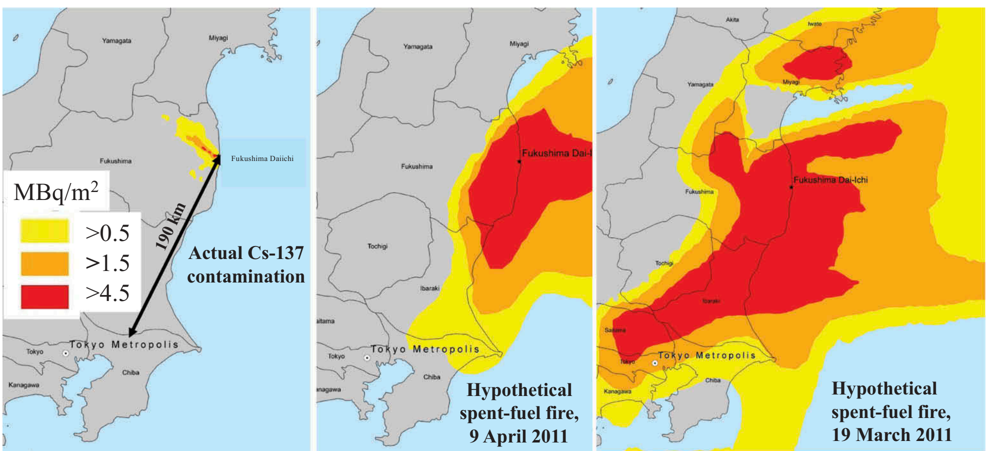

Figure 4. Left. Areas of cesium-137 contamination from the actual Fukushima releases during the week following the 11 March 2011 earthquake. The orange and red areas are those from which about 100,000 residents were ordered to relocate. A significant fraction of the population in the yellow area relocated voluntarily. Over the following years, decontamination made it possible for many of the evacuees from the orange area to return. The middle and right-hand maps show the corresponding areas for hypothetical spent fuel pool fires starting 9 April 2011, when the wind was blowing out to sea, and 19 March 2011, when the wind was blowing south toward Tokyo. In an analysis for the NRC, Sandia National Laboratory had found that a fire would release into the atmosphere almost all of the Cs-137 in the pool (Von Hippel and Schoeppner 2016).

[1]Michael Schoeppner subsequently moved to Vienna to work for the Comprehensive Test Ban Treaty Organization on "backcasting" to determine the sources of radioactivity in the atmosphere detected by the CTBTO's monitoring stations around the world.

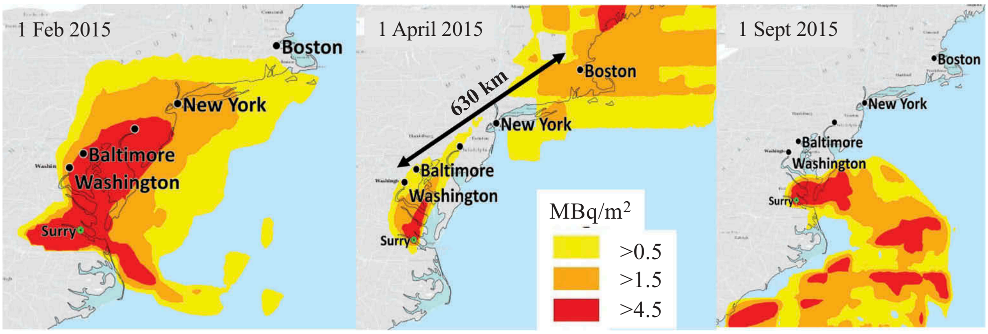

Figure 5. Sample contamination areas calculated for the average release estimated by the NRC from a fire in a densely packed US spent fuel pool at the Surry Nuclear Power Plant in Virginia, the NRC's average site in terms of surrounding population. The contamination areas were calculated for releases beginning on the first day of each month in 2015. From left to right, the population relocations are the largest, average, and smallest calculated out of the 12 months. The average was 8.2 million people, with a range of 1.2 to 41.5 million (Von Hippel and Schoeppner 2017).

USD million. This exceeds the NRC's estimated cost of 50 USD million per pool for "expedited removal" of spent fuel to dry casks after five years of cooling.

In reality, the consequences would vary by site and, because of uncertainties in both probability and benefits, there would be a wide probability distribution for the benefits. But the NRC ignored the uncertainties when it drew its policy conclusions.

Regulatory Capture

FvH: After Michael and I published our results, we joined with Ed Lyman to publish a commentary in *Science* magazine titled "Nuclear safety regulation in the post-Fukushima era: Flawed analyses underlie lax U.S. regulation of spent fuel" (Lyman, Schoeppner, and von Hippel 2017).

In the meantime, President Trump nominated two new NRC commissioners to replace commissioners whose five-year terms had expired, and nominated Kristine Sivinicki, the incumbent chairwoman, to serve another five-year term.

A few weeks after our *Science* article was published, the three nominees had their confirmation hearing before the Senate Committee on Environment and Public Works. Senator Markey was a member of that committee and asked each of the Trump nominees whether they had read our *Science* article. They answered that they had not and did not express any interest in doing so. At that time, the Republicans controlled both houses of Congress and the Commissioners-to-be knew that Senator Markey, a Democrat, could not hurt them.

TK: What did Markey say to them?

FvH: Here is the exchange:

Senator Markey: "Let me start with a major issue facing the Nuclear Regulatory Commission: how to ensure the safety of spent nuclear fuel. According to an article in *Science Magazine* by physicists from the Union of Concerned Scientists and Princeton

University, the NRC has drastically underestimated the risks from a fire at a spent fuel pond. The NRC's analysis has underestimated both the probability of a spent fuel fire and its consequences. As a result, the NRC has understated the benefit to the public of moving fuel from risky pools over to safer, dry cask …

> "The scientists … indicated that the cost of the fire could be upwards of 2 USD trillion nationally … By contrast, the Nuclear Regulatory Commission's estimate of the financial consequences was 20 times less. And the Commission used that estimate to dismiss the benefit of dry cask storage, which would only cost 50 USD million per reactor.
>
> "So, by dramatically reducing the cost that would occur if such a fire did hit a nuclear power plant, the NRC, in its cost-benefit analysis, is able to avoid forcing the utilities to move from the spent fuel pools over to dry casks.
>
> "Do any of you disagree that the NRC should apply state-of-the-art science when making decisions about safety?"

Chairwoman Svinicki: "Senator, of course I am in agreement that the correct science should be applied. The NRC staff has done a quick review of the article that you referenced. They have looked at whether it presents different scenarios that were unanalyzed by the NRC. They did not identify anything in this preliminary review, but their look is ongoing, so if I may respond for the record if there is additional comparative details that they can provide."

Senator Markey: "Well, it is a pretty blistering, scalding indictment … Have you had a chance to read that *Science Magazine* article?

Chairwoman Svinicki: "I have not, Senator." … (Senate Energy and Public Works Committee 2017).

Since that time, there have been two developments:

(1) Congressional investigations of two crashes of the Boeing 737 Max revealed that the Federal Aviation Agency knew of the control problem that caused both crashes but was so solicitous of Boeing that, even after the second crash, it did not ground the aircraft until after many other countries had done so. This may have sensitized Congress to the danger of regulatory capture, which was facilitated by Boeing's lobbying of Congress and the Executive Branch, and may raise concerns about the potential dangers from the nuclear utilities' capture of the Nuclear Regulatory Commission.

(2) The Democrats took the majority in the House of Representatives in the November 2018 election. The Democrats are less hostile to government regulation than the Republicans. Therefore, working with Ed Lyman and former NRC Chairman Greg Jaczko, I am trying to get the attention of the House subcommittee that oversees the NRC to the skewing of the results of the NRC's cost-benefit analyses.

TK: Who did the original calculation that you corrected?

FvH: It was the staff of the Nuclear Regulatory Commission.

The question is why did the NRC produce such skewed calculations? In part, this is because the calculations are so difficult to review that I doubt that even many of the NRC's staff understood the consequences of the seemingly plausible assumptions that had become standard in their cost-benefit calculations.

I remember that effect when I was doing physics. If a calculation came out the way you expected, you were less diligent looking for mistakes than when it came out in a way that you didn't expect.

Also, the formal process of cost-benefit calculations gives NRC decisions the appearance of objectivity and, when the results don't require costly fixes by the nuclear utilities, the NRC avoids pressure from Congresspeople concerned about the future in their districts of nuclear power plants with large workforces that are having a difficult time competing with natural gas, wind and solar power plants.

I wondered why the NRC had come to give such weight to such skewed cost-benefit analyses while ignoring their omissions and uncertainties forty years after it had accepted the critique of the methodology by its own Risk Assessment Review Group in 1979 (see Part 1).

I found part of the answer in a 2004 memoir by Senator Pete Domenici of New Mexico, *A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy*. In a section titled "The NRC's Day of Reckoning," the senator describes with relish a confrontation he had in 1998 with the chairman of the NRC. At the time, Domenici was the chairman of the Energy and Water Subcommittee of the Senate Appropriations Committee. That subcommittee, along with its House of Representatives counterpart, controlled the NRC's budget.

Senator Domenici recounted that he was receiving complaints from the nuclear utilities that the Nuclear Regulatory Commission was enforcing its safety rules too aggressively. So, "I announced my intentions to cut seven hundred jobs and consolidate departments at the NRC." The total number of NRC authorized staff was 3,000, with about 700 in the office of Nuclear Reactor Regulation.

At the time, the chair of the NRC was Shirley Jackson, who had been appointed in 1995. After Senator Domenici threatened to cut the NRC budget, she asked for a private meeting and, according to Domenici, "pleaded for time." He reports that, soon thereafter, she announced that, "I have made the theme of risk-informed regulation central to my tenure as the NRC Chairman. In fact, the Commission is committed to the goal of using risk information and risk analysis as part of a policy framework that applies to all phases of our nuclear regulatory oversight, including rulemaking, licensing, inspection, assessment, and enforcement."

Senator Domenici concluded with satisfaction, "Since that meeting with Chairman Jackson, I've been very impressed with the NRC. They are now a solid, predictable regulatory agency" (Domenici 2004, 71–78).

TK: Does the budget for NRC came from industry fees?

FvH: Almost ninety percent of the NRC's budget comes from nuclear utility fees. Currently, each nuclear power reactor pays about five million dollars per year, but Congress dictates how much the industry should pay, and industry lobbies the Congress to make that amount as low as possible.

Filtered Vents for Reactor Containments

FvH: Occasionally, the staff rebels. This happened with another of my issues: filtered vents. Jan Beyea and I wrote an article on the subject in 1982 after the Three Mile Island partial-core-meltdown accident (Beyea and von Hippel 1982). In that case, there was not a large release because the large-volume containment building held. But, as we pointed out, there were also many reactors with small-volume containments – like the reactors at Fukushima Daiichi where, three decades later, the containments of reactors 1, 2 and 3 were all over-pressured and leaked radioactivity. We urged that all reactor containments be equipped with filtered vents so that, if they were overpressured and some of the gas in the containment had to be released, most of the radioactivity could be removed in sand and activated-charcoal filters.

After the Three Mile Island accident, filtered vents were required on all reactor containments by the regulatory authorities in Western Europe and Canada but not in the United States or Japan.

After the Fukushima accident, Japan decided to require filtered vents, and the NRC decided to look at the issue again. Once again, however, the NRC staff did a skewed cost-benefit analysis and the costs of filtered vents were found to exceed the benefits.

But the staff urged that, nevertheless, filtered vents should be required because of "qualitative factors such as the importance of containment systems within the NRC's defense-in-depth philosophy" (NRC 2012, 2).

In 2012, Allison MacFarlane, who had been a co-author on our 2003 article on spent-fuel pool fires, had been appointed by President Obama to chair the Nuclear Regulatory Commission. At her invitation, I met with the staff doing the regulatory analysis on filtered vents three months before they made their recommendation. They told me that they had Jan Beyea's and my 1982 article pasted on their wall to show how old the issue was.

Republicans were in control of the House of Representatives, however, and 19 members of the House Energy and Commerce Committee, the NRC's oversight committee, wrote a furious letter to the Commission arguing,

> "When proposals fail a cost-benefit analysis, regulators should not abandon technical rigor in favor of subjective, qualitative factors to justify one-size-fits-all regulatory changes. Rigorous technical bases encourage regulatory stability and give the agency, the public, and licensees confidence that the NRC is pursuing justified, defensible safety improvements." (House Energy and Commerce Committee 2013).

When the NRC Commissioners voted, they voted 3 to 2 against the staff recommendation. MacFarlane was in the minority.

A Nuclear Safety Debate at the State Level

FvH: In the United States, the states have no regulatory authority over nuclear power safety but they can exert pressure in other ways. In New Jersey, for example, in 2018, the state forced the shutdown of the Oyster Creek reactor, then the oldest operating power reactor in the United States, with essentially the same design as Fukushima Daiichi units 1,2,3 and 4. The State did this by mandating that, if the reactor was to operate for ten more years, it would have to install cooling towers to reduce the impact of its cooling water on the aquatic life in Barnegat Bay. The utility did not want to make that investment and shut down the reactor.

Another opportunity for the state to influence a nuclear utility's thinking arose when the operators of the three other nuclear power reactors in New Jersey threatened to shut them down in favor of less costly natural-gas-fired power plants if they did not get additional payments from their New Jersey customers of about 100 USD million per reactor per year. The utilities argued that such extra payments could be justified by the fact that nuclear fission does not emit carbon dioxide.

I heard about this proposal and went to my Assemblyman, Andrew Zwicker, with an idea: The NRC had estimated that it would cost about 50 USD million per reactor to move fuel that had cooled more than 5 years from pools into dry casks. Perhaps New Jersey could require that half of the first year's 100 USD million subsidy for each reactor be spent on moving the older spent fuel out of their pools to dry-cask storage. Zwicker took me to meet Bob Smith, Chairman of the New Jersey Senate Environment Committee.

I explained my idea to Senator Smith but he was reluctant, "Why doesn't the federal government do this? I have something else I want to get out of the utility: a commitment to generate more renewable energy. That's my priority."

In December 2017, I went to the joint hearing of the New Jersey Senate and Assembly Environment Committees on the proposed subsidy. There must have been 50 lobbyists in black suits, including a former New Jersey governor, hired to support the utility's case for a nuclear subsidy. There were also a small number of environmentalists who wanted to slow the process down. Many wanted to speak. We were each given about 5 minutes. There were very few questions from the committee. My sense was that this was a token hearing.

TK: Is there a transcript?

FvH: Yes (New Jersey Legislature 2017). It includes a transcript and the written statements including an update of the PowerPoint presentation I had given to Senator Smith (Von Hippel 2017). Afterwards, one of the lobbyists came up to me and said that my statement that an average spent fuel fire would force the relocation of the population from an area twice the size of New Jersey was "scary." But the utility got its subsidy without my proposed condition.

The Future of Nuclear Power

TK: Why are we so stuck on nuclear energy?

FvH: You mean, why don't they just phase it out?

The Germans are doing that. On the other side, the UK government is paying a huge subsidy to France's Électricité de France (EDF) to build a new nuclear power plant in the UK despite the fact that EDF projects to build the same reactors in Finland and France have suffered long delays and huge cost overruns. In the US, the construction of four nuclear power reactors was launched in 2013 with loan guarantees from the US Department of Energy. The costs have skyrocketed and Westinghouse, the company responsible for their design, declared bankruptcy. The two reactors under construction in South Carolina have been abandoned and the future of the other two under construction in Georgia is uncertain.

But a few countries continue to build new nuclear power reactors, notably China and Russia. Russia is also financing the construction of its reactors exports to a number of developing countries.

In the United States, major environmental groups have come to regard climate change as *the* priority and feel that we cannot yet put all of our eggs in the renewable-energy basket. They believe that, eventually, with long-distance transmission and low-cost electricity storage, it will be possible to do without nuclear power, but that we need it during the transition.

Even though nuclear-energy enthusiasts are promoting the idea of "small modular reactors," it appears unlikely to me that more than a few government-subsidized nuclear power reactors will be built in the United States.

But, there is a lot of support for keeping in operation the plants we already have. New York and other states in addition to New Jersey are subsidizing the continued operation of most of their nuclear power plants. The NRC has extended the licenses of most US nuclear power plants to 60 years, and has just licensed the first extension to 80 years.

TK: These license extensions are occurring despite what happened at Fukushima, and your explanation of how the Nuclear Regulatory Commission has skewed its cost-benefit calculations.

FvH: It is strange that I found errors in the Nuclear Regulatory Commission's nuclear accident consequence calculations at both the beginning and end of my career. But I am not irreplaceable. Ed Lyman, who is a generation younger, understands these issues as well as I do. At the moment, however, Congress is not listening to Ed either.

As I explained above, what has happened is called "regulatory capture." It is a well-known phenomenon. Jack Gibbons, President Clinton's science advisor for whom I worked, was asked when he was the director of Congress's Office of Technology Assessment, how he maintained his ability to tell truth to power. He responded, "Archimedes' law: pressure from all sides."

In the case of nuclear power, in the 1970's there was a powerful anti-nuclear movement – powerful enough to achieve the dismantlement of the Atomic Energy Commission. So, during that period, we did have pressure from the public side on the NRC that balanced out the pressure from the industry side.

That may be the situation in Japan today where, after the Fukushima accident, a new tough Nuclear Regulation Authority was established. The average nuclear power reactor that is coming back on line in Japan has had to make about 600 USD million in safety upgrades. The accident also had major impacts on public attitudes toward nuclear power in Europe, China and South Korea.

Surprisingly, however, the Fukushima accident had very little impact on the US public's concerns about nuclear safety. The NRC and industry both said Fukushima could not happen in the US: we don't have tsunamis and earthquakes – at least not recently. And most people accepted that. As a result, there have been only about 40 USD million in post-Fukushima safety upgrades per power reactor in the United States.

TK: But what about terrorism?

FvH: After the Al Qaeda attacks on New York and Washington, DC on 11 September 2001 (9/11), the Nuclear Regulatory Commission developed a secret “design-basis threat” specifying the number of attackers and the types of weapons that the nuclear utilities would have to defend against. To make the response affordable, however, NRC assumed fewer attackers than the 19 people who were on the four airplanes on 9/11. The NRC also left out attacks with aircraft. It declared that the government would have to fill such gaps.

TK: For example, if drones fly in the night to a nuclear facility with explosives from all directions, nobody can stop them, right?

Did you see the Chinese drone lightshow last summer? Hundreds of them dancing. It is amazing. You can find many versions if you look for “China drone show.”[2]

FvH: For a while, after the use of passenger aircraft in the 9/11attacks in the US, France temporarily deployed anti-aircraft missiles around the reprocessing plant at La Hague.

In January 2019, Greenpeace flew two small drones over the huge spent-fuel pools at La Hague. One drone dropped a flare on the sheet-metal roof covering the pools while the second drone filmed what the first drone was doing (Daly 2019). Of course, it would require a much larger drone to do damage to one of the pools.

Arthur R. von Hippel

TK: We asked you questions mostly about your grandfather, James Franck, in Part 1. I am also interested in your father. Was he also a physicist?

FvH: He was a physicist. Before that, as a teenager, he was a German artillery officer in World War I. He lived 105 years from 1898 to 2003.

He married James Franck’s daughter, Dagmar. Early on, he studied the physics of electrical discharges and made images of beautiful multi-branched sparks in different types of gases that he later published as art under the title of “Lightning Strokes in Other Worlds” (von Hippel, 1988a). In 1963, he wanted to go to Iceland because there was a volcano coming out of the ocean and the cloud above it was generating a continuous thunderstorm (Figure 6).

He came as a refugee from Nazi Germany to MIT in 1937. MIT’s president appointed him in the electrical engineering department in the hope that he would introduce modern physics into that department.

In fact, he developed a new field, material science and engineering. His idea was to understand the basic physics of atoms and molecules well enough so that you could design materials with particular properties. Some of his students formed the Materials Research Society, which now has 14,500 members in more than 90 countries. It’s highest award is the Von Hippel Award[3].

Obviously, I am very proud of him.

[2]See e.g. “Drone Show in China,” https://www.youtube.com/watch?v=U9T3Dj1IRHY.
[3]https://www.mrs.org/vonhippel.

Figure 6. Lightning strokes created by the cloud over Surtsey volcano, 1963.
https://volcanocafe.wordpress.com/2013/11/13/surtsey-the-birth-of-the-modern-world/

During World War II, his Laboratory for Insulation Research worked on materials for radar. It grew to about 80 researchers and graduate students. He was not able to get additional space in the neo-classical building where the lab was located, but the rooms were quite high so he had platforms built so that people could work above each other.

He loved Karl Taylor Compton, the president of MIT who brought him there, and who was the older brother of Arthur Compton who ran the portion of the US World War II nuclear program based in Chicago where my grandfather, James Franck, worked.

After Karl Compton died, my father wasn't happy with any of the administrations that followed. He said, "There are so many vice presidents, some day, they're going to come all the way down the corridor and take over our space." Recently I visited MIT and there was indeed a vice president sitting in his office.

At one point, my father resigned from MIT. One of his students had started a company that did so well that the student offered to build an institute for my father. My father said, "I'm going to equip it with sensors so that, if an administrator crosses the threshold, it will blow up!" But the company's fortunes changed and he had to swallow his pride and went back to MIT.

The compulsory retirement age in those days was 65. When that happened, my father divided his lab into several independent laboratories and kept one where he worked without salary for another 15 years or so. After my mother died, he wanted to do research relevant to medicine. He said, "Well, the body is 98% water. I'll try to understand how water creates a medium for the biochemistry of life." This was similar to James Franck's earlier decision, after his involvement in the US World War II nuclear-weapons project, to devote the remainder of his career to understanding how photosynthesis uses solar energy to build plants.

My father wrote a memoir for the family, *Life in Times of Turbulent Transitions*. My wife, Pat, and I edited it and had about 200 copies printed. The Materials Research Society has a pdf of the memoir on its website (Von Hippel, A.R. 1988b). It includes humorous stories that his students and grandchildren enjoyed reading about his adventures during his youth in Europe and during 1927–28 when he spent a year in the United States as a Rockefeller Fellow.

He lived to be 105. At one point, when his memory was no longer good, I told him he had written a wonderful memoir for his grandchildren and showed it to him. He read the back cover and, when he got to where it said, "This book was published on the occasion of von Hippel's 90th birthday," he looked up and asked, "It says I was 90 when this was published – and I'm not dead yet?!"

On his 100th birthday, our former post-doc, Zhang Hui and his wife, who lived outside Boston near my father's house, invited my wife and me for lunch. I told them, "We are going to celebrate my father's 100th birthday tonight. I think he has lived so long because he takes walks every day after breakfast and after lunch."

Zhang responded, "Indeed! We have a saying in China, 'If you walk 100 paces after dinner, you'll live to be 100.'"

That evening, I told my father of the Chinese saying. He thought for a moment and then asked, "What if I walk 200 paces?" *[Laughter]*

When I was a post-doc at Cornell, someone told me that one type of personality is "kiss up and kick down." You kiss the people above you and you kick the people below you. My father had more of a "kick up and kiss down" personality. He would take students who were failing, would figure out what their talents were, and then would help them become successful.

And he was not afraid of anyone. For example, when a student of the president of MIT came to him complaining that he was being mistreated, my father went and told the president off. He didn't know whether the student's story was true or not but he identified with the underdog. His motto was "we shall not be intimidated."

In Germany, before World War I, there was something called the Youth Movement in which students went camping together and tried to live a pure and democratic life as a rebellion against the social stratification of the Victorian era. They called themselves "Wanderfögel" (wandering birds). My father was convinced that, if so many of them had not died in World War I, they could have stopped Hitler.

He was a good model. A person with backbone. He wouldn't bow to anybody, including Hitler, who he refused to salute, when he once met him.

TK: You could be him.

FvH: I try.

My son recently said he was grateful to me for the values I passed on to him. I responded that I'm just passing it on from my grandfather and my father. But it's a great inheritance (Figure 7).

TK: What does the name von Hippel mean?

FvH: "Von" means "of " or "from" so, in principle, there should be some place called "Hippel;" but there is not. It was an honorific in Prussia.

During World War II in the United States, it was not a popular thing to have a German name and a lot of people got rid of their "vons." My father was proud of his family and kept the "von."

Figure 7. My Jewish grandfather, James Franck, and my Prussian father, Arthur von Hippel, enjoy a view together on a mountain above the von Hippel family log cabin in New Hampshire (Dagmar von Hippel, mother of FvH, circa 1955).

TK: You said that, when you were young, you had a kind of inner conflict because you were half German and half Jewish.

FvH: Yes, I wondered whether, if I had been born in Germany as a pure German, I would have stood up for the Jews. And that question has been with me in different forms for my whole life. I remember when I was eighteen in 1956, during the Hungarian uprising against the Soviet occupation, the Hungarians called out for help and I agonized over whether I should go over and fight with them.

In the end, I was not a Joan of Arc type person. I didn't lead any uprisings. I have just tried to help people figure out what the nuclear dangers are and what to do about them.

At Princeton, the first course I taught was "Science, Technology and Public Policy" and I included two lectures on "whistle blowing." I gave one and invited Dan Ellsberg to give the other. In 1971, Ellsberg had become famous for his release to the newspapers of the secret history of the Vietnam War, *The Pentagon Papers*, for which he was tried under the Espionage Act of 1917. Twenty years later, the students had not heard of him.

The first time Ellsberg gave the lecture, he did not take into account the fact that the class period was only 50 minutes long. As a result, when the bell rang, he had not gotten to his main point. By pure force of personality, however, he kept the students in their seats until he was able to give them his message, "If you work in the government, you have to be ready to blow the whistle if you see it doing something terrible."

Ellsberg would have had no problem answering the question I kept asking myself, "would you have stood up to the Nazis?" After decades of writer's block, he finally wrote two extraordinary memoirs about what he had learned during his relatively short career in government (1958–71):

- *Secrets: A Memoir of Vietnam and the Pentagon Papers* (Ellsberg 2002) and
- *The Doomsday Machine: Confessions of a Nuclear War Planner* (Ellsberg 2017).

TK: Do you use social media?

FvH: I have decided to leave Facebook, Twitter, and so on to the next generation. I publish in the same types of journals I have always published in. I don't look at popular websites, but my friends usually let me know when I should read something – or I find it through Google when I need to know something.

Mostly, I write articles and send them out into the world. A real weakness of academics, however, is that they think that their job is done when they've published the article. In terms of having an impact on public policy, that's just the beginning.

My outreach is mostly the old-fashioned way: one-on-one education of government officials and to citizens' groups. In recent years, in addition to Washington, DC, many of my trips have been to Tokyo and Seoul. In Tokyo, since 1993, I have mostly been explaining why Japan should abandon its plutonium program and, in Seoul, I have been explaining why South Korea should not make the same mistake as Japan in this regard.

People like Trump are on Twitter all the time trying to change the subject from the damage that they are doing. It makes you despair. With all that noise, how can people hear what Leo Szilard called "the sweet voice of reason"?

TK: It's tough.

FvH: But there is hope. The world is beautiful and interesting and I am grateful to have known so many wonderful people.

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No potential conflict of interest was reported by the authors.

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