HOLTEC INTERNATIONAL

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Re: Response to Article: *If Radical Innovation Makes Nuclear Power Expensive, Why Do We Think It Will Make Nuclear Cheap*

Dear Sir:

In a well-sourced article entitled "If Radical Innovation Makes Nuclear Power Expensive, Why Do We Think It Will Make Nuclear Cheap," Mr. Michael Shellenberger posits the thesis that the nuclear industry's attempts to innovate are responsible for its present travails. I submit that his narrative of nuclear energy's ascent and decline, while based on factually accurate strands of logic, leads to a conclusion that does not do justice to the range of issues that afflict the industry. The underlying reasons for the industry's problems are far too complex.

The author cites the innovations introduced by Westinghouse in its AP-1000 reactor to be behind its spiraling cost. This is only partially true; the major cause is the new regulatory regimen known as 10CFR52 adopted by the government which, while well intentioned, has failed to streamline the nuclear plant regulation process in practice. Much of the delay in completing the AP-1000 plants can be attributed to the untested "Part 52" regulations. Imperfect innovations, to the extent they have played a part, can be traced to the erosion of practical know-how which occurred because of nearly three decades of hibernation that the industry suffered in the wake of TMI and Chernobyl.

On a more fundamental level, the safety regulation of nuclear power plants has been on national level with each country's regulator reigning as its uncontested sovereign. There is no global regulator like there is the International Court of Justice in The Hague. This is peculiar for an industry where a mishap in for instance, Chernobyl, affected millions of citizens in far-away countries in central and Western Europe. This fragmentation of regulatory control has led to uneven regulations and their enforcement. Thus, while the AP-1000s in China are smartly coming on line, the ones in the United States lumber along.

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A pernicious offshoot of the uncertainty in regulations is the "cost plus" culture for building nuclear power plants. It is not hard to deduce that "cost plus" contracts dampen the drive for, yes, innovations! Contrast the paucity of robots in the nuclear plant construction industry to the automotive manufacturing industry which is swimming in robots.

There are many drivers behind the nuclear industry's present difficulties but the quest to innovate is not one of them. Our company, unconstrained by the quarterly report pressure of Wall Street, has invested hundreds of millions of dollars in a new innovative 160 MW reactor we call SMR-160. Our reactor is brimming with innovations with unconditional safety as its core mission. Our belief in success through innovation is so firm that we are soldiering on without a dime of funding from any government. We are among the small coterie of entrepreneurial companies who believe that creative ideas and innovations tempered with lessons learned from seven decades of nuclear plant operations will deliver bounteous amounts of competitively priced carbon-free energy to a world desperately in need of it.

Very truly yours,

K P Singh

Dr. Kris P. Singh, President & CEO

If Radical Innovation Makes Nuclear Power Expensive, Why Do We Think It Will Make Nuclear Cheap?

Michael Shellenberger12:23 pm

You might have heard about a new kind of nuclear reactor that promises far greater safety at a much lower cost. How?

- It is much simpler and thus requires "half as many safety-related valves, 83 percent less safety-related pipe and one-third fewer pumps;"
- Its components can be manufactured in a factory and assembled on-site at lower cost rather than built from scratch;
- Its cooling and passive safety features rely on "natural forces, like gravity... rather than relying on mechanical pumps powered by electricity."

These features mean it will have a very low cost. How low? "Somewhere between $1.4 billion and $1.9 billion" per reactor.

Does such an advanced nuclear reactor actually exist? It does. It is the Westinghouse "Advanced Pressurized 1000", or AP1000. But instead of taking *four* years to build it will take *nine* — and instead of costing the mere $1.4 to $1.9 billion Westinghouse promised, it will cost *five to ten times more*.

What went wrong? The "source of the biggest delays can be traced to the AP1000's innovative design," concluded investigative reporters with the *St. Louis Dispatch*, "and the challenges created by the untested approach to manufacturing and building reactors." (Research I conducted last year, and by other journalists, came to the same conclusion.)

In the end, Westinghouse went bankrupt, and the building of two AP1000s in South Carolina was cancelled. It's not clear any more of the reactors will ever be built.

An eerily similar fate befell France's radically innovative European Pressurized Reactor (EPR). Like Westinghouse, its developer promised far higher levels of safety, greater efficiency, an improved control room, factory manufacturing of key components, and lower costs. Like the AP1000, the EPR ended up a decade behind schedule and three times the anticipated cost. And like Westinghouse, its developer, Areva, went bankrupt.

The nuclear industry was surprised by the construction delays and cost overruns, but they were entirely predictable. History shows that radical changes to reactor design increase costs while standardization of design and incremental innovations, like increasing the size of the reactor, lowers them. "Contrary to other energy technologies," two French economists concluded in the most rigorous econometric study to date, "innovation leads to construction cost increases."

Now, a new crop of companies are promoting designs that are even more radical, and which they say will deliver even more radical reductions in cost. How?

- By being "dead simple" and "smaller and simpler" which "will result in lower construction costs" because their "construction is simple;"
- Through "factory construction" where "each module is mass-manufactured in factory settings;"
- By "relying more on natural phenomena [that] eliminate expensive components like reactor coolant pumps" and by being "continuously cooled by natural air flow" making it a "very safe, passive nuclear reactor."

Sound familiar? Apparently, those things that made the AP1000 and EPR so expensive — an innovative new design and an untested approach to manufacturing — will, henceforth, make nuclear power cheap.

The Birth of an Industry

In the mid-1950s, the job of building the first U.S. nuclear plant for civilian purposes fell to Navy Admiral Hyman Rickover, who had created America's nuclear-powered (and armed) submarines and aircraft carriers. In his essential new book, *Energy: A Human History*, Richard Rhodes describes Rickover as hard-charging and cantankerous.

A hands-on director, Rickover would arrive at the site [in Shippingport, Pennsylvania] from Washington in the evening or late on a Friday afternoon, to keep his managers worrying nights and weekends. Not everyone loved the admiral, but he got the job done.

Every major component pushed the envelope. The pressure vessel "approached the technical limits of steel fabrication at that time," note historians Richard Hewlett and Jack Holl in *Atoms for Peace and War*. "Likewise, the required performance of the pumps, valves, and steam generators pushed design engineering and fabrication into unexplored realms of technology."

Although it hardly seemed possible, Rickover further increased the tempo of the project during spring and summer 1957.... Hundreds of valves and instruments already installed were found defective, ripped out, and rushed back to the manufacturers for repair or modification.

Many of the obstacles Rickover and his team encountered, and the solutions they devised, could not have been anticipated in advance. "Then there was the midget welder," writes Rhodes.

One day an X-ray revealed a defect inside a bend of fifteen-inch pipe. It was a hard place to get at. We considered dismantling the pipe, but that would have been costly as hell in time and money. Then we learned of a firm in Georgia that hires out midget welders for just such jobs. They sent us one who was just thirty-nine inches tall, and he crawled into the pipe and made a good, solid repair.

What Rickover achieved is on par with humankind's greatest technical achievements, from Thomas Edison's creation of the first commercial electricity grids to Henry Ford's mass manufacturing of automobiles. That's because Rickover hadn't just created the first nuclear power plant. *He created the entire nuclear power industry.*

"No private utility executive who complained about Rickover's insulting and outrageous behavior acknowledged or even understood that he was slowly and painfully building a national network of suppliers and fabricators capable of producing equipment that met nuclear standards," wrote Hewlett and Holl.

"Most readily evident," write Hewlett and Holl, "was the exceptional performance of the plant at power levels far above its design rating and virtually free of operational faults or failures from the day of its first operation."

Rickover knew that creating a whole new industry also required creating a whole new workforce. "Over the next six years, more than one hundred engineers and technicians from the United States and ten other countries learned the rudiments of reactor technology at Shippingport."

As Rickover and his team were achieving this remarkable feat, few in government or industry appreciated what was happening. "While the [Atomic Energy] Commission debated policy issues," note Hewlett and Holl, "Rickover and his staff forged the commercial infrastructure on which the future of the nuclear industry in the United States would depend."

Advocates of alternative designs sometimes claim that the U.S. rushed into water-cooled designs, but Hewlett and Holl's history describes a process closer to the opposite.

In 1957, experts on the U.S. government's reactor advisory board concluded there were *too many* designs being pursued. The U.S. government was supporting 12 projects — five of which involved creating real world reactors:

In fact, the group believed that a long campaign of patient and painstaking development, rather than a dramatic technical breakthrough, was the likely road to nuclear power. And even then, the only hope seemed to be in very large reactors plants that took advantage of economies of scale. The group concluded that the Commission was working on too many types of reactors and that there was "too much breadth and not enough depth" in the reactor program.

A half century of experience has proven the reactor advisory board right. Where standardization of design allows for builders to gain the experience they need to go faster and lower costs, design "innovation hampers the competitiveness of nuclear power through an increase in construction costs," noted the French economists in 2015.

In the 1950s, most experts understood that, with such a complex machine as a nuclear reactor, increased construction and operational experience allowed for through standardization was critical to bringing down costs. That's why both the Soviet Union and most of Europe scaled up water-cooled designs to take advantage of the "standardized, economical mass production that America's rapidly growing nuclear technology made possible."

Despite this history, in the popular media and among policymakers, there has remained a widespread faith that what will make nuclear power cheaper is not greater *experience* but rather greater *novelty.* How else to explain the excitement for reactor designs invented by teenagers in their garages and famous software developers with zero experience whatsoever building or operating a nuclear plant?

A Design Is Not A Power Plant

In 2008, *The New Yorker* profiled Nathan Myhrvold, a former Microsoft executive, on his plans to re-invent nuclear power with Bill Gates. Nuclear scientist Edward "Teller had this idea way back when that you could make a very safe, passive nuclear reactor," Myhrvold explained. "No moving parts. Proliferation-resistant. Dead simple."

Gates and Myhrvold started a company, Terrapower, that will break ground next year in China on a test reactor. "TerraPower's engineers," wrote a reporter recently, will "find out if their design really works."

And yet the history of nuclear power suggests we should have more modest expectations. While a nuclear reactor "experiment often produced valuable clues," Hewlett and Holl wrote, "it almost never revealed a clear pathway to success."

For example, some [members of Congress in the 1950s] thought that a small reactor experiment would tell the engineers most of what they needed to know to build a power reactor; however, although the experiment often produced valuable clues, it almost never revealed a clear pathway to success. The popular assumption... was that the progression from reactor experiment, to pilot plant, and then to full-scale power reactor was not only direct but automatic.

For example, in 1951, a reactor in Idaho used sodium rather than water to cool the uranium — like Terrapower's design proposes to do. "The facility verified scientific principles," Hewlett and Holl noted, but "did not address the host of extraordinary difficult engineering problems."

New designs often solve one problem while creating new ones. For example, a test reactor at Oak Ridge National Laboratory used chemical salts with uranium fuel dissolved within, instead of water surrounding solid uranium fuel. "The distinctive advantage of such a reactor was that it avoided the expensive process of fabricating fuel elements, moderator, control rods, and other high-precision core components," noted Hewlett and Holl.

In the eyes of many nuclear scientists and engineers these advantages made the homogeneous reactor potentially the most promising of all types under study, *but once again the experiment did not reveal how the tricky problems of handling a highly radioactive and corrosive fluid were to be resolved.*

In early 1957 before his plant went online, Rickover responded — testily — when asked by members of Congress about whether future reactor designs might be more efficient.

Any plant you haven't built yet is always more efficient than the one you have built. This is obvious. *They are all efficient when you haven't done anything on them, in the talking stage.* Then they are all efficient, they are all cheap. They are all easy to build, and none have any problems.

Why do so many entrepreneurs, journalists, and policy analysts get the basic economics of nuclear power so terribly wrong?

In part, everybody's confusing nuclear reactor *designs* with real world nuclear *plants*. Consider how frequently advocates of novel nuclear designs use the future or even present tense to describe qualities and behaviors of reactors when they should be using future conditional tense.

Terrapower's reactor, an *IEEE Spectrum* reporter noted "*will* be able to use depleted uranium...the heat *will* be absorbed by a looping stream of liquid sodium...Terrapower's reactor *stays* cool" [emphasis added].

Given that such "reactors" do not actually exist as real world machines, and only exist as computer-aided designs, it is misleading to claim that Terrapower's reactor "will" be able to do anything. The appropriate verbs for that sentence are "might," "may," and "could."

Another problem is that people impose mental models from other industries onto nuclear. "In the past," write Hewlett and Holl, — meaning before the invention of nuclear fission— "engineers had enjoyed notable success in translating the results of an experiment in a chemistry laboratory into an efficient industrial process."

In reactor technology, however… the number of nontechnical variables was much larger… [and] required a large measure of creative and imaginative engineering to make the transition from experimental reactor to proven reactor.

And if chemistry was an inappropriate model to impose upon nuclear, consider just how more inappropriate the model of software development is. Software entrepreneurs can, with little money, supplies, societal permission, or government oversight, build their products in a garage or dorm room.

By contrast, building a nuclear plant requires billions in capital, massive supply chains, public consent, and unmatched regulatory oversight. Many of the problems with the AP1000 were simple things, like creating a foundation, pouring cement, and installing rebar — but up to the Nuclear Regulatory Commission's (NRC) exacting standards.

Myhrvold expressed great confidence that he had proven that Terrapower's nuclear plant could run on nuclear waste at a low cost. How could he be so sure? *He had modeled it.*

"Lowell and I had a month-long, no-holds-barred nuclear-physics battle. He didn't believe waste would work. It turns out it does." Myhrvold grinned. "He concedes it now."

Rickover was unsparing in his judgement of this kind of thinking. "I believe this confusion stems from a failure to distinguish between the academic and the practical," he wrote.

The academic-reactor designer is a dilettante. He has not had to assume any real responsibility in connection with his projects. He is free to luxuriate in elegant ideas, the practical shortcomings of which can be relegated to the category of 'mere technical details.'

Designing Away the World

One difference between nuclear power and every other technology is that there is, and has been for 50 years, a well-financed, highly organized, and profoundly influential war on nuclear that has terrified a significant portion of the public. Nothing like it exists against any other technology — certainly not against software.

Ironically, the war on nuclear has never been more violent than when attacking sodium-cooled reactors like the kind Terrapower is designing. In 1982, a Swiss anti-nuclear terrorist, who later became a Green Party politician, fired a bomb at an experimental sodium-cooled plant in France. Why? He feared it would, if completed, blow up like a bomb.

Rather than address the public's fears, nuclear industry leaders, scientists, and engineers have for decades repeatedly retreated to their comfort zone: reactor design innovation.

Designers say the problem isn't that innovation has been too radical, but *that it hasn't been radical enough*. If only the coolant were different, the reactors smaller, and the building methods less conventional, they insist, nuclear plants would be easier and cheaper to build.

Unfortunately, the historical record is clear: the more radical the design, the higher the cost. This is true not only with the dominant water-cooled designs but also with the more exotic designs — and particularly sodium-cooled ones.

The more radical the reactor, the more expensive it is.EP

The radical innovation fantasy rests upon design essentialism and reactor reductionism. We conflate the 2-D design with a 3-D design which we conflate with actual building plans which we conflate with a test reactor which we conflate with a full-sized power plant.

These unconscious conflations blind us to the many, inevitable, and sometimes catastrophic "unknowns" that only become apparent through the building and operating of a real world plant. They can be small, like the need for a midget welder, or massive, like the manufacturing failures of the AP1000.

Some of the biggest unknowns have to do with radically altering the existing nuclear workforce, supply chain, and regulations. Such wholesale transformations of the actually existing nuclear industry are, literally and figuratively, outside the frame of alternative designs.

"Everyone has a plan until they get punched in the face," a wise man once said. The debacles with the AP1000 and EPR are just the latest episodes of nuclear reactor designers getting punched in the face by reality. Consider the following observation:

An academic reactor is simple... small... cheap... light... built very quickly... very flexible and... *not being built now...*

On the other hand, a practical reactor *being built now* is behind schedule... requires an immense amount of development on apparently trivial items... is very expensive... takes a long time to build because of its engineering development problems... is large.. is heavy... is complicated.

Will what happened with the AP1000 and EPR lead nuclear scientific, engineering, and industrial leaders to be more modest in their claims about future reactors? Perhaps. One reason to be skeptical is how long such technological immodesty has dominated. The sage observation above, for instance, wasn't offered by a newspaper reporter after the failures of the AP1000 in 2017. It was offered by Admiral Rickover in 1953.

Michael Shellenberger, President, Environmental Progress. Time Magazine "Hero of the Environment."

I am a Time Magazine "Hero of the Environment," Green Book Award Winner, and President of Environmental Progress, a research and policy organization.