Episode 2

The Untold History of Nuclear Energy

Emmet Penney

So my hobby is arm wrestling. I go out to Evanston and have guys who actually do this for a living rinse me for about an hour and a half. I actually started it to overcome my fears of doing advocacy for nuclear. It was very not fun to be pro-nuclear just a few years ago, and I thought, "I gotta fix that".

I figured the only way I'm gonna fix that is if I can learn how to lose, because competition is about learning how to lose.

Packy

That was Emmett Penny, a nuclear advocate, arm wrestler, and author who goes by @nukebarbarian on Twitter.

Julia

Being a nuclear advocate over the past few decades has only been for contrarian thinkers brave enough to believe in something counter to the mainstream narrative. However, we're now seeing hype for nuclear ramping up again. In the 1950s and '60s, people were hyped about nuclear, too. We've been here before, but then things turned.

Before we get too excited about what's happening now, let's examine what happened and how we avoid making the same mistakes again.

Packy

I'm Packy McCormick.

Julia

And I'm Julia DeWahl. And this is Age of Miracles.

Packy

If you're just tuning in, Age of Miracles is about exploring what needs to happen to turn innovation into impact. All the hard, nitty-gritty details that go into creating the age of miracles we think is possible in our lifetimes.

This season, we're starting with nuclear energy, because energy is the foundation of progress, and because nuclear is the prime example of the fact that even the most miraculous innovations don't work without the hard work of implementation. Fission is a miracle technology, and we've had it for 80 years.

But we don't live in an energy abundant world because progress takes more than miracles.

Julia

Today, we're going deep into the history of nuclear energy and why the industry went from thriving to stagnating.

What lessons can we take away from its near demise?

Packy

As we've done our research, there are these overarching narratives that, at least coming in from the outside, I had in my head. But the reality is so much more detailed and messy than that.

Let's start by talking about the two narratives. Julia, what's the first narrative that you hear when you even hear the word 'nuclear' in the first place?

Julia

The overarching narrative people have probably heard is that nuclear energy comes right out of nuclear weapons - they're practically the same thing. We built a bunch of reactors for a while, then we had these huge disasters: Three Mile Island, Chernobyl, Fukushima. Those prove that nuclear energy was not safe.

And of course, there's the impossible to solve issue of nuclear waste. Finally, thank goodness, the environmentalists put an end to all that nuclear stuff. Now we have wind and solar, the true renewables, and those costs are coming down precipitously, so we just don't need nuclear anymore.

Packy

Yeah, and then there's the second narrative. I think this is the one I encountered as we started doing research and having conversations for this podcast. This one comes from nuclear supporters. If you've started to look into the industry a little bit to get "nuke pilled," as we called it in episode one, you've probably heard this too. In this telling, everything you've heard about nuclear energy from environmentalists is wrong.

Nuclear is safe. It's the safest and cleanest form of energy we have. Nuclear is the greatest thing since sliced bread. We should build reactors, large reactors and small modular reactors, by the hundreds. Everything in nuclear land would be great if it weren't for those damned environmentalists and all of the Nuclear Regulatory Commission's regulations.

Julia

While I definitely fall more in that second camp, and I think, Packy, you do too, what we've discovered together is that there's a lot more nuance to it. It's not just "It's perfect. Build tons of it, no problem." We've figured out how to solve waste. We know it's carbon-free, which is great. We know it has really high capacity factors. There's a lot to love about nuclear, but at the same time, the regulation is there for a reason, and it's tricky to navigate.

The costs are hard. We've gotten worse at building large construction projects. There are a lot of complications and nuances to get through here. I'm really excited to use this episode to take a look back at where we've been with nuclear, what kind of baggage we've accumulated along the way, and then look ahead to where we want to go from here.

Packy

Totally. Nuclear power did start with the development of nuclear weapons, though maybe not quite how you might think. Renewable energy sources that aren't nuclear are growing very quickly and getting cheaper, and we're going to talk about that later in the season. But we think all of that is great.

What I really want to get out of this episode is an understanding of where things went wrong so that we can avoid making the same mistakes again. The topic is complex, and understanding how nuclear's momentum in

the '60s and '70s ground to a halt will help us prevent that from happening a second time.

Julia

Quick preview for this episode: we're going to zoom through the early history of nuclear energy and how we actually started with small-scale nuclear reactors before abandoning them for large-scale reactors and plants in the mid-'60s. We'll then go deeper into the history and what factors led to nuclear's decline.

We'll finish by looking at where nuclear is today and peek into what it might take to build more nuclear energy large-scale power plants. We'll be talking to people who have worked in the nuclear industry or have studied it closely, the people who know nuclear the best.

You might think these would just be all rah-rah pro-nuclear people. But I've found that nuclear people tend to be some of the most self-critical about the challenges their industry faces.

Packy

Let's go back to the beginning to tell the true history of nuclear as best as we understand it. The first thing most people get wrong is the fact that we didn't build the bomb first, like you might have seen in Oppenheimer. Here's Rod Adams to explain.

Rod is a managing partner at Nucleation Capital, a former US Navy submarine officer trained on nuclear subs, and a historian of and advocate for the industry. Note, when Rod says Irene Curie, he means the daughter of her more famous mother, Marie.

Rod Adams

Conventional wisdom says we went to the bomb first, but there were people in 1939 who were already thinking that nuclear was going to be a replacement for coal. Leo Szilard patented a nuclear reactor power source even before fission had been proven. When he heard of what Enrico Fermi had done in 1934 with neutrons splitting isotopes of uranium, he applied for a patent in 1935 or '36 for a power-producing system using nuclear reactions.

By 1939, just after fission had been proven, the New York Times had several articles featuring Frédéric Joliot-Curie, Irene Curie's husband. He and Irene had discovered artificial radioactivity. Once he heard that fission was working, he started trying to figure out ways to use uranium as a coal replacement. He talked about how $2 worth of uranium could replace over $1,000 worth of coal. It wasn't the bomb first. Even if you look at the Manhattan Project, way before we got the bomb, we built several reactors.

Julia

What's surprising is just how small those first nuclear power reactors were. That's an idea we're actually back to today, if you've heard about small modular reactors, or SMRs.

We talked to Nick Touran, a nuclear engineer at TerraPower and writer of the excellent website whatisnuclear.com, about the early experimentation in nuclear.

Nick Touran

There was a time back in the '40s, '50s, '60s, where around 100,000 people worldwide, the smartest people in the world, were all focused on nuclear reactor technology. It was the thing. There's so much interesting information and history about things that people did back then. It just blows my mind. Every time I look, I find something new.

We had lots of small reactors, dozens of them, some of which pretty much check all the boxes of the things we're excited about now. We actually built them.

Julia

Nick takes us back to 1942. That's the year Enrico Fermi's team was at the University of Chicago, and they achieved the first self sustaining nuclear chain reaction, which was part of the Manhattan project to develop the atomic bomb.

Nick Touran

That was sort of a big reactor. I mean, it was the size it had to be. It wasn't a power reactor. Then we started saying, "Let's make plutonium for weapons." So they made big reactors at Hanford designed just for plutonium.

The next application was submarines, which needed much, much smaller reactors. So this thing called the pressurized water reactor was invented, which is a small, compact, simple, reliable reactor. We built a prototype of that in Idaho. That was really the first application of actual nuclear power that comes out of the chain reaction.

Then we started saying, "Okay, we need to come up with ways to make power plants." So we built a bunch of little test reactors that were just for research. The cores are roughly this big. There was a little reactor called Clementine in the '50s. The core was this big.

Packy

The core for the Clementine reactor was contained in a metal cylinder that had an inside diameter of 15.2 cm with a length of 117 cm. So imagine that: a reactor that has a diameter less than the length of a dollar bill and the height shorter than that of a seven year old child. That's the whole core.

Nick Touran

They were just small experimental reactors. But then things got really interesting when the Air Force wanted nuclear-powered airplanes. There was this huge ten-year, $10 billion program to make nuclear-powered airplanes. The idea was for strategic bombers that could stay in the air forever. We built little tiny reactors that were super high-power that could propel aircraft. We flew them - we put one on an airplane, operated it and flew the airplane - but we never actually had one of these things power an airplane.

That program eventually got canned when ICBMs, the long-range missiles, came out. The Navy had their reactors, Air Force had them. So when the Army came along, that's when we got really into the micro reactors, portable reactors. There's this thing called the Army Package Power Program where they built these amazing reactors, little tiny 1 megawatt and less...

Packy

This rhymes with the development of so many moonshot technologies. The military needs a certain capability, and the government teams up with researchers to develop solutions to address that need. In the beginning, they produce something that works, but that isn't economical by any stretch of the imagination for regular consumers.

And then they declassify it and hand it over to the private sector to let the free markets work their magic. This is a story that you see over and over again. It's one that we'll tell later in the season about the development of fusion. But for now, let's talk about space.

Julia

The space race laid the groundwork for the modern space economy, and even created the initial demand for solar panels used to power satellites, and semiconductors. Space missions required lightweight, compact electronics, and semiconductors beat vacuum tubes. They helped bring those technologies down the cost curve so the commercial sector could grab the baton.

We followed almost the same process for nuclear energy in the 40s and 50s, except with a little more nuance. Here's Rod again.

Rod Adams

After the war was over, we took a nine-year break and didn't do anything with power reactors, except for one project started by the Manhattan Project. Groves and his folks, along with a financier, the guy who was in charge of the metallurgical laboratory at Chicago - his name was Farrington Daniels - started a project called the Daniels Pile. It had a lot of industrial cooperation from organizations big in the electrical power business. He brought these engineers down to Oak Ridge, and they were making good progress. They had a pretty solid design.

But the project got canceled and defunded by the Atomic Energy Commission as one of their first acts after they were created when the Atomic Energy Act of 1946 came out.

Packy

The Atomic Energy Commission, or AEC, are, by the way, the same guys featured in the last third of Oppenheimer. The commissioner, Lewis Strauss, was the villain played by Robert Downey Jr. in the film.

While the movie focuses on the personalities and geopolitical struggles of nuclear weapons, the effect that the AEC had on nuclear power's rise and fall is underreported and provides another lesson on what we can do in the future, which we'll touch more on later in the episode.

Rod Adams

By April of 1947, the Daniels Pile project was canceled, and the civilian Atomic Energy Commission decided that their main mission was to focus on building up the infrastructure for manufacturing bombs. It wasn't until '53 that President Eisenhower said we really need to build some peaceful uses of this stuff.

In December 1953, almost exactly 70 years ago, President Eisenhower said that we were going to produce power to supply "abundant electrical energy to the power-starved areas of the world."

Julia

With President Eisenhower's Atoms for Peace speech in 1953, the country pledged to use atomic power for good.

President Eisenhower

It is not enough to take this weapon out of the hands of the soldiers. It must be put into the hands of those who will know how to strip its military casing, and adapt it to the arts of peace.

The United States knows that if the fearful trend of atomic military buildup can be reversed, this greatest of destructive forces can be developed into a great boon for the benefit of all mankind.

Rod Adams

That started off a rather interesting boom in nuclear power plants.

Julia

And it worked. Nuclear power shifted from just a military initiative into something more broad and commercial for the benefit of all mankind.

Back to Nick to explain.

Nick Touran

When they started to build the commercial ones, they said, "If we make that ten times the size or more, it only takes three times the material and only 1.5 times the personnel." So the economy of scale really pressured

these reactors to get bigger and bigger. When they first made the early ones, PWRs and BWRs, they were pretty small, tens of megawatts, very much in the small modular reactor size. They weren't competing with coal at the time - coal was the major competitor for electricity - so they had huge pressure to get cheaper.

The way they got cheaper was by getting bigger, and they got bigger and bigger until about 1965, when they reached parity with coal. There were announcements throughout the industry: "We've done it. Economical nuclear power is here." Orders came in like crazy, and everybody started building relatively large light water reactors.

Packy

Hang with us. We're going to explain what light water reactors are and how nuclear power plants work in episode three. For now, just picture the big nuclear plants with the cooling towers that you're used to seeing. Because you can see them.

For a while there, we built a ton of light water reactors. James Krellenstein, a physicist and nuclear advocate, explains more.

James Krellenstein

We really start seeing the takeoff of light water reactors. Big companies like GE and Westinghouse start going to utilities and initially offer them turnkey deals, where you can basically buy a nuclear power plant for a guaranteed price. This coincided with skyrocketing electric power demand, coupled with a belief that we'd start seeing decreasing fossil fuel availability, particularly oil. Coal prices were increasing and natural gas was not nearly as cheap as it is today. Utilities in the 1960s, dealing with skyrocketing electric power demand, were trying to figure out how to meet this demand while also dealing with potentially scarcer fossil fuels. Coupled with atomic age optimism, this led to a huge amount of ordering of nuclear power plants.

These light water reactor designs seemed commercially viable and able to generate power to the grid somewhat economically. Westinghouse, Combustion Engineering, Babcock & Wilcox, and GE were iterating on their own product lines. Most critically, we started seeing the size of reactor plants really increase. We went from 50-70 megawatt plants up to 100, 180, then 200, 300, 400, 500, 600. Then we had Zion Unit 1 come online in the late '60s or early '70s at literally a gigawatt per reactor.

We saw this massive increase in just a decade, going from the small demo plant Shippingport in the late '50s at less than 100 MW, to scaling an order of magnitude in a single decade. This was driven by economics. We see profound cost capacity scaling in nuclear power plants. Reactor orders were increasing each year, peaking in 1973 with 100 new reactor plants ordered in that single year. In response to the 1973 OPEC oil embargo, President Nixon announced Project Independence: we're going to build 1000 nuclear reactors in the United States to get off foreign oil and achieve energy independence in the US.

Packy

From a standing start in the 1950s, nuclear was booming. By 1965, nuclear plants were generating 3.85 terawatt-hours. By 1978, just 13 years later, nuclear power generation had grown 75x, reaching 290 terawatt-hours, good for a 40% CAGR, or compound annual growth rate.

Had that growth rate continued for just another eight years, nuclear would have generated more electricity by 1986, the year before I was born, or 4,180 terawatt-hours, than the entire United States consumed in 2022.

Julia

From the perspective of 1973, it seemed like things were only going to get better for nuclear. It had government support, popular support, and geopolitical tailwinds. Calls for energy independence then echo the ones causing nuclear to surge today. But instead of an inflection point, the 1970s were a turning point. By the end of the decade, growth would plateau and we would never see this rate of building again. Heres Rod again to explain.

Rod Adams

We ordered gigawatt-scale reactors for about five years, say from 1969 to 1972-73. Then reactor orders pretty much trickled off and were down to zero by 1978.

Packy

The early history of nuclear energy ended in the 1970s. So that's where we'll pause to pull out the factors that led to nuclear's decline. We think there are five key ones:

1. The Atomic Energy Commission itself. 2. An economic death spiral. 3. Increasing regulation. 4. The environmental movement. 5. The disasters at Three Mile Island, Fukushima, and Chernobyl.

Remember Emmett Penny, the nuclear advocate who arm wrestles? He starts with the Atomic Energy Commission.

Emmet Penney

Yes, the Atomic Energy Commission was created after the success of the Manhattan Project and the bombings of Hiroshima and Nagasaki. It was a really tense political formation. The AEC has a dual mandate: both to promote nuclear power and nuclear weapons, and to regulate them. That's an immediate conflict of interest that's going to raise a lot of questions later on down the line.

But in the meantime, no one really knows a lot about nuclear, so a case has to be made to the public. It's made in a very limited way and actually kind of a disingenuous way. There were already accidents and problems, not as lethal as other industrial accidents. I think that should always be put in context: combustion, when it comes to power generation, is always going to be more lethal than fission. Historically, that's the case.

But that doesn't excuse these guys at the AEC who were saying there's a one in a billion chance that it's going to happen, when they already had on record some accidents they had tried to cover up that had hurt a handful of people.

Packy

Thanks for listening so far. Hang on, we'll be right back after a quick word from our sponsors.

Julia

The AEC, along with the private sector, started to overpromise on the safety of nuclear reactors. Instead of treating nuclear power plants like any other industrial plant or power plant, where mechanical failures and accidents do happen, the AEC got overly defensive on nuclear, essentially claiming it was impervious to the standard issues of industry.

It set expectations that no plant could live up to. When the inevitable mishaps occurred, it teed up detractors to falsely paint them as disastrous meltdowns.

Emmet Penney

As time goes on, they do so much boosterism and so much to help get reactors built that they sort of overstep and create this big bandwagon market where everybody wants a nuclear reactor, in the same way that everybody wants renewables now. The system might not be ready to onboard that because we have to think about how this is cutting-edge technology, highly complex engineering projects. There are human capital problems, there's difficulty in getting parts to build these things. So we start to get some delays there.

Over the course of that time, the Atomic Energy Commission adopts basically two fatal premises for radiation dosages in its final years. The first one is called linear no threshold, which is just "not safe at any dose." Mark Nelson, a good friend of mine who I hear you guys are interviewing, once explained it to me like this: if somebody added up every single time you'd been cut in your life and then looked at you and said, "You just bled out." It was an oversensitive mechanism.

Then they took it a step further and they said, "We're gonna try to make our exposure at our plants as low as reasonably achievable." But that's not an engineering metric you could ever design something to meet. So what does that mean? Well, that means fiat of the regulator. We see both labor costs and construction costs hit. I think labor costs were up by over 137% between the '60s and the mid-'70s, which is a lot. It's almost the same thing for construction costs. At some point, the NRC takes over for the AEC because the dual mandate is obviously a problem.

Packy

Already we're seeing what a tangled web this is. Emmett's point about the NRC's regulation is a big one. It deserves its own section, and we're going to give it one. But it's all tied together, because at least initially, regulation's biggest impact was on the economics. The second domino to fall against nuclear was actually the economics. Regulation was part of that, sure. But there was also good old fashioned supply and demand.

What happened to nuclear reactor demand in the seventies looks a lot like what happened to the demand for Internet fiber in the 2000s. A lot of excitement and rapid growth in demand for electricity led to utilities over ordering reactors to meet over optimistic projections. When demand for electricity slowed, so did orders. Many were even canceled.

Julia

Here's Rod again to explain how slowing demand slowed nuclear's growth.

Rod Adams

In 1973, we had this really important thing called the Arab oil embargo. The Arab oil embargo raised the price of gasoline by a factor of four from October '73 to March or April '74. Gas lines. All kinds of things were causing problems. But part of the impact of that oil embargo was for people to take a real hard look at their energy use. For the first time in decades, the US electricity demand actually shrunk, partly because of conservation, partly because of the recession caused by a quadrupling of the price of gasoline. People couldn't spend money while they were sitting in the gas line. When the electricity demand actually dropped, instead of growing at 7% a year, which it had been doing for a very long time, electric utility companies were really concerned because they had a lot of plants in progress, a lot of plans for expansion, and they didn't know where they were going to be able to sell the electricity that all these new plants could produce.

In particular, one utility, Public Service in New Jersey, had a big plan to build nuclear power plants offshore. Westinghouse had come up with this idea for the Offshore Power Systems (OPS). Public Service of New Jersey had ordered, I think, three or four of the reactors and had a place they were going to build them offshore. Westinghouse had been building a factory at Blount Island, just north of Jacksonville. One of the largest overhead cranes in the world was there. They were coming up with doing all this stuff. That was a very nice order. They were looking at building dozens of reactors in a factory. Does that sound familiar? Of course, the factory was called a shipyard, but it was all the same design.

But in '74, when Public Service New Jersey (PSNJ) had a drop in their demand, and their drop was even bigger than most because some of their biggest customers were oil refineries near I-95, they didn't have any oil to refine, so they shut down because of the Arab oil embargo. Public Service New Jersey canceled their order from Westinghouse and ended up paying Westinghouse $100 million or something like that for the cost of canceling the order. That was the very first cancellation of nuclear plant orders. And it sort of started a trend.

So I tell people, can you imagine the Arab oil embargo? This is a time when oil prices go up by a factor of four and actually slowed the growth of nuclear energy in the US, ultimately helping to stop it. So by '78, we stopped ordering nuclear plants. Again, a lot of it was part of the demand wasn't growing as fast as expected.

Julia

Basically, after rapidly achieving economies of scale over 20-30 years, it almost as suddenly became cost prohibitive to build a nuclear plant. This shift in cost dynamics emerged even before all of the disasters, environmental pushback, and regulation that have since impacted the industry.

Packy

So the second factor in nuclear's downfall is simple. It's the economy, stupid. That's one of the things that surprised me most in the research and our conversations, and why I said earlier that the narrative in which the nuclear industry would have been totally fine if it weren't for environmentalists and the NRC, falls apart a little bit.

Economic considerations were a real concern, and they weren't caused by anything other than typical market forces.

Julia

But regulation was certainly a bottleneck, if not the only one. Regulation has been a hot button topic as it relates to the nuclear industry for a long time.

A framework called linear no threshold, or LNT, has been around since the AEC was getting started. It says that there is no safe dose of radiation.

Packy

To understand why radiation became such a focus, Rod Adams argues that you need to go all the way back to the 1950s, the year before the first nuclear power station opened at Shippingport. And to the people who stood to lose the most from cheap, abundant nuclear energy: the oil industry. You almost have to be impressed by their foresight.

According to Rod, the Rockefeller Foundation, whose fortune gushed from Standard Oil's wells, was behind the bogus research that led to LNT.

Rod Adams

In '56, some very influential parts of the oil and gas industry helped to finance a study by the National Academy of Sciences, the most credible body of scientists available in the US. They paid the whole cost of the studies. They even supplied the chairman of one of the committees. They had six different committees, and almost everyone in the group had been financed, had grants, or educational things or whatever paid for by the Rockefeller foundations.

They produced a report that said that every dose of radiation, down to a single gamma ray, a single ionizing event, raised the risk of cancer, and there was no safe dose. That was published on June 13, 1956. The Rockefeller Foundation continued to support what was called the BEAR (Biological Effects of Atomic Radiation). BEAR worked through about 1963 or so, built a lot of foundation, produced educational materials. I mean, that was one of the things the Rockefeller Foundation was investing in: education. They had a lot of people in the medical field, they had money to spread all over.

By the early '60s, it was pretty solidly embedded in the scientific community: every dose of radiation caused the risk of cancer. So that was a background thing. And like anybody else who wants to influence the public, they kind of pulled their hands away. They wanted to make sure that nobody really made the association. It was all about protecting the oil business. They didn't hide the fact that they'd done it. They claimed that they were doing great things by helping the public understand about radiation.

Julia

Listener, they were not doing great things. A number of studies since have disproven the National Academy of Sciences findings, including a 2018 study in Genes and Environment that said of the 1956 LNT findings, "This spurious hypothesis was not based on solid data" and actually found that low dose radiation from atom bombs elongated lifespan and reduced cancer mortality relative to unirradiated individuals. Low doses of radiation cause radiation adaptive responses that actually strengthen the body. The paper's author concludes, "For many reasons, LNT must be revised or abolished, with changes based not on policy, but on science."]}]},

Packy

That is an insanely asymptotic standard to build towards. As low as you go, you can always go lower. Typically, LNT and ALARA are discussed as onerous standards imposed from outside the industry.

But Bret Kugelmass, the founder of Last Energy, has a different take. He thinks we're looking at a classic case of regulatory capture.

Bret Kugelmass

What I realized was that around the mid-1970s, the industry turned against itself. The companies that we thought of as selling nuclear power plants were in fact selling something very different. They were selling fear of nuclear power plants, safety systems, and radiation protection. So the industry turned on itself through rent-seeking behavior, a term economists use to describe extracting as much value out of what we already built instead of innovating and bringing new things to the fore.

Through this rent-seeking behavior and using a very effective tool of regulatory capture, Congress created the Nuclear Regulatory Commission with unprecedented powers. It's actually a branch of government that's independent of the executive. The president can't tell them what to do. That is an extremely powerful agency. So if you're going to capture an agency, boy, do you want it to be that one.

The incumbents captured the regulator to insist on ever more protection in order to sell their new product, which was ten times as lucrative as the old product: to sell fear of nuclear power. After being very successful at that for 50 years, this is how we can find ourselves in a circumstance where the facts say nobody gets hurt, even when all safety systems fail and three gigawatt-scale meltdowns occur simultaneously. Yet emotionally, we all feel very different.

Julia

Alex Epstein wrote an excellent book, "Fossil Future", in which he makes the case for fossil fuels. But more than anything, he's an energy realist.

He's also very pro-nuclear, and he agrees that LNT and ALARA are insane.

Alex Epstein

Then on top of that, nuclear also faces this totally irrational danger policy. This relates to things like linear no threshold (LNT) and as low as reasonably achievable (ALARA). You can think of it as our law saying that our goal with nuclear energy should be to minimize its risk as much as imaginable. The way they do this is with pseudoscience like LNT, treating any amount of radiation as deadly, which is just false. But the other thing is, it's patently illogical to say our energy policy is to minimize the risk of nuclear infinitely because if nuclear is the safest thing, and if you minimize infinitely the risk of the safest thing not minimizing the risk of the other things, then you just use more dangerous things. That's the story of nuclear.

So we have this anti-impact policy regime and then we have this uniquely irrational policy toward radiation-related danger that doesn't apply to, say, the danger of explosion or the danger of a dam bursting or these other things. That combination means you can't do anything.

Packy

We often lump regulation into one big bucket but there are really two main categories that slowed nuclear down and made it more expensive to build. The first one is specific to nuclear safety regulation related to radiation as Brett and Alex called out. That's LNT and ALARA.

Then there's a second one, environmental regulation or NEPA. This one applies to so many big projects from solar installations to SpaceX launches. The Institute for Progress has a great piece on how NEPA environmental reviews actually harm the environment by slowing down things like renewable energy and nuclear projects. We'll include it in the resources guide.

Certainly NEPA, passed in 1969, contributed to making nuclear build-outs slower and more expensive.

Julia

Here's James again to explain how the National Environmental Policy Act (NEPA) began to slow nuclear down back in the 1970s.

James Krellenstein

But what occurs starting in '73, '74, '75 is a dramatic increase in environmental regulation caused by a DC district court case called Calvert Cliffs' Coordinating Committee vs. the Atomic Energy Commission. This basically says that the AEC, the predecessor of the Nuclear Regulatory Commission, needs to take the National Environmental Policy Act much more seriously when it comes to nuclear power plants and do much more serious environmental impact statements, use cooling towers generally if you're using a river or a lake to cool with, and so on. That starts increasing the price.

But also we see inflation occurring in 1973, '74, '75, and major supply and labor shortages, which means that all of a sudden a nuclear power plant, which can have 5,000 or 6,000 workers on the job site, can be very expensive to do. And the productivity just starts really decreasing. So what we see is the costs skyrocket for new nuclear power plants during this time.

And then Three Mile Island occurs in 1979, which really causes a major increase in the regulatory burden for safety systems. That decreases the economic competitiveness of nuclear power plants, skyrockets the price, and makes them take years and years to finish.

Packy

I didn't realize the chronology here, but it seems like before we even get to the anti-nuclear movement or disasters, we have a witch's brew of economic and regulatory concerns that made building nuclear harder, slower, more expensive and riskier.

Emmett's not one of mince words, so let's ask him to divide up the blame.

Emmet Penney

I think the lion's share of the impact, because you have to, goes to the changing economic conditions and regulatory environment. Those actually happened first historically, which is really important. NEPA, for example, gets put in place around nuclear power plants. But it wasn't necessarily anti-nuclear. It was just a typical environmental concern: "Are these animals going to be hurt by our industrial thing?" It doesn't really become explicitly anti-nuclear for a while. So I'm going to put the lion's share there. I'd say that's about 60%.

Then I'd say the other 40% is the cultural element. No politician is going to risk their career to do something interesting, and neither is the utility industry because it's going to mess up their books and they don't want the headaches.

Julia

Typically, you hear about Three Mile Island as the turning point. But by 1979, a potent anti-nuclear mix was already at play. The AEC had overpromised on safety. Utilities had ordered too many reactors, expecting energy demand to continue to rise.

Then economic conditions changed, and environmental regulation made it much slower to build.

Packy

On top of all that, there was a cultural element that Emmett described. That's the fourth factor: the environmentalist anti-nuclear movement. They got started long before any major reactor issues. Their work actually helped color the public reaction when the first issue did occur. In fact, the movie "The China

Syndrome," starring vocal anti-nuclear activist and actress Jane Fonda - yes, that Jane Fonda - came out twelve days before Three Mile Island and worked to spark fear in a generation. First the anti-nuclear movement, then Three Mile Island.

We'll play you a clip to put you in the state of mind that people were in when the incident at Three Mile Island happened in 1979. "The China syndrome. It will start with a tremor in a nuclear power plant where it will end, will depend on three people. I would say you're probably lucky to be alive. The same for the rest of southern California. Jane Fonda. Let's face it, you didn't get this job because of your investigative abilities. Kimberly, don't fight it."

Julia

Jane Fonda wasn't working alone. Who was behind the anti-nuclear push and why? One of the biggest players was the same group celebrating Illinois's August decision not to overturn its moratorium on new nuclear: the Sierra Club.

This environmental group was initially very excited about nuclear energy because of its tiny land footprint. Mark Nelson, founder and managing director of Radiant Energy Group, explains how things turned.

Mark Nelson

You can say that Sierra Club got politicized in the direction of the anti-nuclear bombs and nuclear bomb testing movement. This clustered along with anti-population work or anti-human population growth. It also got clustered in with left-wing, anti-war, anti-industry work. Happening before carbon was a particular concern, it was really a vibes problem. In the end, it all seems to come back to the bomb. Why? Because the nuclear plants were seen as part of an industry, a supply chain, an industrial ecosystem that included nuclear weapons.

We have early evidence for Sierra Club members, the anti-nuclear ones, describing why and how they wanted to fight nuclear. Eventually they actually had to split off from the Sierra Club in part to fight nuclear. Eventually, the Sierra Club came back around and became anti-nuclear. But the older guard of Sierra Club, the ones who had fought in World War II, Ansel Adams and Will Siri for example - these were pro-nuclear people for exceptionally pragmatic reasons.

The anti-nuclear folks said, "Look, we've got to convince people nuclear plants are dangerous because it's part of the same effort as nuclear weapons. And nuclear weapons are a sign that humans have gotten dangerous toys. They've gotten beyond their moral capability to act. They've gotten too much power." That "too much power" argument very cleanly steps into "too much energy." Too much power, too much energy - it's all the same thing, too much growth. You can see how imperceptibly, being against nuclear weapons and nuclear weapons testing was to make an argument against nuclear energy.

Packy

Emmett was even more blunt in his assessment of the anti-nuclear camp's motivations. In his telling and the telling of others, including Robert Zubrin, this camp viewed nuclear energy as a bad thing, not because it was inherently unsafe or the bombs, but because nuclear power represented the greatest opportunity for humanity's practically limitless growth. Nuclear opponents were OG decels, like "The Population Bomb" author Paul Ehrlich, who argued for population control under the guise of environmentalism.

This is where it gets even weirder. I'm going to turn it over to Emmett to untangle the web for us.

Emmet Penney

I mentioned before that there's a connection between technological development, population growth, and running out of resources. That was explicitly in the calculations that the Club of Rome used in its famous "Limits to Growth" report. Hunter Lovins, who worked on that, was the wife of Amory Lovins, who heads the Rocky Mountain Institute. They were pulling on ideas that go back to the progressive eugenics movement. This theme has been enduring since the 16-1700s.

It's about the relationship between industry and nature, and whether we can continue to keep feeding, clothing, heating, and sheltering ourselves. They were trading on that, and there are some really dark roots to the progressive stuff.

The guys that founded the Sierra Club - and this isn't the current Sierra Club's fault; in fact, they've done good work trying to distance themselves from their founders' ideology - had deeply racist ideas about people who didn't have "Teutonic blood," like they couldn't steward the forest because they were "dirty garbage people." You see that kind of thinking all over history; that's not unique to them.

What is unique is that it donned the veneer of something closer to science when ecologists like Paul Ehrlich got involved. Ehrlich's whole thing is "I'm going to do population growth scares, but make it less racist."

Julia

The environmental movement at this time promoted degrowth over growth and popularized mantras like "small is beautiful." Renowned environmentalist Amory Lovins said in 1977, "If you ask me, it'd be little short of disastrous for us to discover a source of clean, cheap, abundant energy because of what we would do with it." Or even more bluntly, Paul Ehrlich, author of "The Population Bomb," said, "Giving society cheap, abundant energy would be the equivalent of giving an idiot child a machine gun. The environmentalists turned against nuclear energy because it was too good. It could make energy abundant and cheap, and they were scared of that. So they did everything they could to damage nuclear's reputation, conflating nuclear bombs with nuclear energy and leading a popular anti-nuke movement. Many figures, from politicians to musicians to celebrities, vocalized their support. They primed the public for incredible overreaction to the nuclear accidents that would follow.

Mark Nelson

The biggest misconception people have is that somehow the meltdowns came first, and then because there were meltdowns, people got an anti-nuclear movement. That's entirely backwards. We wouldn't even know about the meltdowns with the exception of maybe Chernobyl. Even that would be just a footnote for people who didn't live through it. Not that it was fun to live through, but most people on the street don't understand Bhopal and the Union Carbide plant that had a massive leak that killed and maimed thousands of people.

But it would be that sort of thing: a local curiosity and tragedy, an individual tragedy for those caught in it, instead of the world-defining global narrative that Chernobyl became. The existence of the anti-nuclear movement changed the meaning of the few meltdowns that have come to public attention.

Julia

So, to recap, at this point, the nuclear industry is already collapsing on itself. This is due to the over-promising of safety from the AEC, the economics of the time, increasing regulation like LNT and ALARA, and the whole environmental movement.

The final nail in the coffin were the disasters which we myth-busted in episode one, but wanted to touch on further here. Mark explains how Chernobyl - the worst disaster - had some unexpected elements.

Mark Nelson

When I talk to people who are against nuclear and they say Chernobyl, Three Mile Island, and Fukushima Daiichi prove we can't do it, I think of my most extreme experience with this. San Francisco is close to these big, beautiful redwood forests. We go up Mount Tam in the morning with various runners from around the bay. I had this long, brutal, uphill debate with this British lad, a nuclear physicist either with a PhD or getting one at Oxford and who was visiting the Bay Area.

He was adamant that nuclear is not good enough and not acceptable. Fusion's the future, he said, and nuclear fission is too dangerous. On the way down, I was fed up and said, "How can you possibly say nuclear meltdowns are so dangerous when they didn't even stop running the Chernobyl nuclear plant?" He paused and said, "Yes, they did." I replied, "No, they kept running it for 14 years." He said, "That's impossible. What's your

evidence?" I told him these are open records, no one's hiding it. The IAEA has the production data.

He was silent for about 10 seconds, then said, "So nuclear's not that dangerous." He hadn't realized that the worst nuclear blow-up ever didn't even stop production at the next reactor a few feet away.

Julia

It's fascinating that even with Chernobyl, arguably the only actual disaster in nuclear, the power plant itself - minus the reactor that blew up - continued to operate for years afterwards. People needed the power.

Packy

Brett, the founder of Last Energy, who we heard from earlier in the episode, came to nuclear in a similar way, but his turning point was Fukushima.

Bret Kugelmass

One of the early facts I learned about nuclear was that Fukushima, despite having three gigawatt-scale meltdowns and every single safety system failing, couldn't manage to hurt a fly. That's a fact, but it doesn't resonate well with us. Why it doesn't resonate well is part of the puzzle. How did we get here? How can we all be so emotionally resistant to the fact that nuclear was never a hazard to begin with?

Remember, zero safety systems worked, three full meltdowns, not a single injury. If there is no hazard, yet we all say that a meltdown is a catastrophe - the epitome of catastrophe - that's a clue to how we got to this point.

Packy

The nuclear accidents at Three Mile Island, Chernobyl, and Fukushima stand out in our collective memory because the idea of a nuclear explosion is terrifying and because Americans were primed to be afraid. But their role in nuclear's history is often overblown. They were more effect than cause. If anything, they've been catalysts that have helped nuclear become safer.

That's why we wanted to look at the history of nuclear, to talk to as many people as we could, to understand what actually happened, and to pull out the lessons. So let's recap those historical lessons, because I think they're going to be really important for the rest of the season, particularly in the next episode when we talk about what we can actually do to build more nuclear power in 2023.

Julia

Okay, quick history recap. We had the atomic bomb, which was the first awakening of nuclear fission in the public's understanding. There was a hiatus where people focused on weapon stuff as the Cold War started. Then Eisenhower said, "We have this great technology. Let's use it for the public good." He kicked off the atomic age with his famous "Atoms for Peace" speech, proposing to build nuclear energy. And we actually started doing that. In the late '50s, we built the first one. Into the '60s, we kept building.

As we got into the '70s, it looked like there would be a lot more electricity needed, so we were still building. But then a few things happened that slowed us down.

Packy

So first, there's the Atomic Energy Commission itself. As Emmett pointed out, by overpromising on the safety of nuclear power, saying there was a one-in-a-billion chance that anything bad would happen, they set the bar too high, lost public trust, and made nuclear an easier target for both environmentalists and regulators alike.

While simultaneously covering up incidents that disproved that claim.

Julia

Next, we have the environmental movement that kicks off in 1970 with Earth Day and grows from there. You see "The Population Bomb" come out and people start to rally around "Small is Beautiful."

They don't want to see nuclear energy built. The Sierra Club is changing their stance on nuclear energy. So there is this building momentum around the cultural aspect of being anti-nuclear.

Packy

Third, there's the economic reality of building nuclear power plants. This is one that I think hits close to home because it feels so non-obvious. Today, that is the big challenge with nuclear: it's expensive, and we'll get into why that is and how to fix it.

My perception of the past was always that this stuff made sense and it was just shut down. But large reactors are multi-billion dollar, decade-long projects that can pose an existential risk to the utility companies who order them. Often these utilities exist in deregulated markets where they can't just pass on the cost to consumers.

Nuclear has to compete on price with other electricity sources from day one. And if it doesn't win, the utility could go out of business. It's happened before. Nuclear has been called a utility killer for a reason.

Julia

I would say the last thing here is we do start to see regulation layered in. You have NEPA, you have various kinds of regulatory ratchets as the NRC is coming in with its mission just to regulate.

And they're just adding layers upon layers of regulation, which drives up the cost.

Packy

That web of cost, regulation, financing costs, and construction - we're going to unpack all of that. Last, and less important than I had thought, are the disasters. Although if you look at the history of nuclear installations, there are sometimes inflection points. For the overall narrative, the disasters at Three Mile Island, Fukushima, and Chernobyl certainly color people's minds. There's a lot of residue left over from these events that maybe got overhyped because of all these other factors we talked about. They're certainly a factor, but we put these last because without the other four factors, all but maybe Chernobyl would be non-stories - footnotes in history.

Even Chernobyl, I mean, there have been gas plant explosions and deaths from oil all around the globe for hundreds of years, and I can't name another one of those. So I think even Chernobyl, the worst of the nuclear disasters, would probably also be a footnote in history if there hadn't been this big movement against nuclear happening at the time and all these other factors that led to its demise.

Julia

This list isn't exhaustive, but it gives us a good hit list of issues we need to tackle if we want to make sure that the recent wave of enthusiasm for nuclear doesn't turn into another 1970s. If the nuclear industry is going to learn how to win, we need answers to all of these issues and more. Issues like: how to finance these projects, how to build up our construction expertise so we can come down the cost curve, and how to balance free market capitalism with the government muscle often required to get big things built.

We're going to spend the next episode going deep into the weeds with the people on the ground to understand how we move forward here.

Packy

Thank you for listening and watching to this episode of Age of Miracles. If you like what you hear, please rate, subscribe, and share. And if you're feeling really generous, tell us what you think in the comments.

Plus, we have a ton of resources and references in our resource hub if you want to go deeper. And we've linked them all in the show notes below. See you next week.