[SQUEAKING]

[RUSTLING]

[CLICKING]

LECTURER: So let's get started. So far, we have focused exclusively on market dynamics of energy systems. But of course, there are a lot of non-market issues that we have to also consider in our hypothetical cost-benefit calculation, which we largely call externalities. So coal pollutes with sulfur and PM10, and wind farms make noise and kill birds. And nuclear reactors very, very rarely have accidents and release radiation to the environment.

So to do our assessment strictly on an economic basis isn't entirely fair. So we're going to look in part two of the course at these issues, not only does it factor in, at least theoretically into the calculation, but it also is an issue for the social debate around nuclear energy. So we need to know these things no matter what. So let's just start at the abstract level because I know you guys love economics.

So what is an externality? I think you probably all know it's a cost can actually also be a benefit. Any kind of value that is incurred by someone who did not choose to incur it, and by which they mean is not exchanged in the marketplace. So this is an externality. So I may be happy with a few kilowatts of nuclear power, but I really didn't plan, when I was buying that nuclear power to also be forced to live next to a nuclear reactor that was unsafe. So that would be the externality.

So we talked a lot about social welfare and the idea of why we're doing this cost benefit calculation is to maximize what we call consumer surplus-- essentially a measure of how resources are allocated so that the society benefits the most. And what externalities do is they make that calculation incorrect. So there's always, of course, a trade off between cost and benefits. Things like pollution and safety risks are just more costs.

But the issue is that they should be factored into the cost of the supply curve. So that supply curve is, in theory, too low down. It should be higher per unit. So we could raise it, and that would be the value of the externality that we raised it by. And what we see here is that leaves us with this interesting little triangle. So this is the quantity.

Let me just maybe go back a second. This was the equilibrium condition between the supply and demand, right. So the first person to buy the first unit of electricity had enormous value because they're engaged in some activity that absolutely must have electricity. So the demand is high regardless of the price.

And then as the price comes down, the demand begins to fall. And so the quantity demanded goes up and up and up as the price comes down. And the opposite is true of supply. So there's some equilibrium condition. And the first theory of welfare economics says that equilibrium condition, this is where we will achieve Pareto optimality, which is this idea that you cannot improve any person's lot without also harming somebody else's lot. It doesn't mean that resources are optimally distributed between individuals. It just means that, on the whole, there will be a 0 sum game of moving around resources. So this is what we call the equilibrium quantity that is purchased in the market.

And if we now put the externality in we see what happens. The true equilibrium-- the socially optimum quantity that should have been consumed is actually less. And so all of these units were produced, but they shouldn't have been. And the value of them was lower than the supply cost. So the height of this little bar here, dq, is the wasted social value, if you will, that got misappropriated because the market did not include the correct price.

And so if we integrate that up to the value that is actually produced, we get the total value lost to society, the total loss of social welfare. And this has a special term. This is called the deadweight loss. So this is the first problem that externalities have. They create this deadweight loss in the market.

But there's a second problem also. So if we just look at this yellow rectangle and think about it for a second, what is this? This is the total quantity produced times the value of the externality that was not included in the market. So this is the total value of the harm that was being done by that externality that was paid by someone who didn't buy the electricity. It was paid by someone else.

And this is what the person who bought-- or the people who bought the electricity actually paid. And so this value here is only a fraction of the total cost. And so what you have is the second problem, which is that you have this involuntary wealth transfer, where the yellow people are being forced to pay for some cost that really should be attributed to the green people. And so this is a kind of an ethics problem. So these are the two issues that we have to deal with.

So this is the general case. But in fact, the electricity market is slightly modified because these supply and demand curves aren't realistic. They're just pictorial. So here is closer to what the electricity market looks like. So we have what's called inelastic demand, which is to say that the demand-- the quantity demanded is relatively insensitive to the price. People come home and they turn on their lights, and they need electricity. And they don't really think, oh, is this really worth $0.65 a kilowatt hour to run my microwave to heat up this old cup of coffee?

That calculation is not being done. They just use electricity. And as a result, it's fairly insensitive to the price. You can argue that this is only true in the short run, and then in the long run that people will slowly accommodate. And all of that is true, but we generally look at it in this sense.

So let's just redo that calculation. We'll put in that externality. Boom. There it is. And now look what happened. The deadweight loss actually gets very small. So the suboptimal distribution of resources because of externalities associated with electricity production, whether it's nuclear, or wind, or anything else, is actually typically very small. It's important to make that electricity no matter what. But this problem is the same. So this is the primary thing that we are trying to deal with when we think about externalities.

So how do we deal with this problem? Well, people have had all sorts of ideas. This first one is that there are certain winners and losers. People getting the cheap electricity benefit. People who live next to the polluting coal plant get harmed. We should just have the winners transfer some value to the losers. And that's the Caldor-Hicks approach.

But this is very, very problematic. So first of all, what is the dollar value that you're going to transfer? Remember, value-- sorry, the price of something is something that really reflects scarcity, not utility. And what is being lost is some utility. Some health impact will be some loss of utility. But as we pointed out earlier in this class, water has tremendous utility to you. Diamonds do not, yet water is cheap and diamonds are expensive.

So there's no necessary relationship between the price of something and its utility. And that makes the valuation of those damages very, very difficult. Price really just reflects scarcity. The second thing is that even if you could figure out dollar value that was equivalent to the utility lost, that's not generalizable.

If I have to compensate you-- let's say I do something that makes you sick for a day, and you miss all your classes. And you say, well, I need compensation. And I say, would you accept $1,000? I coughed in your face, and you missed a day of classes. Would you accept $1,000 and feel it was fair?

STUDENT: Yeah.

LECTURER: Do you think if I said that to Bill Gates, he would accept $1,000? No, he would say get lost. I'm charging you $1,000 for having this conversation with me. So this is the problem-- that actually, because of different wealth, money has differing utilities for different individuals.

So if you're trying to compensate someone with money, you can't do it. If you can say, well, look, I had to use someone-- I had to bulldoze somebody's house to put in a gas pipeline to deliver some natural gas to some power plant, and you buy them another house in essentially the same neighborhood, in the same town, and it's functionally equivalent, or maybe a little better, have you compensated? Arguably, yes, apart from their emotional attachment to that particular house. But as soon as you start to try to do it with dollars, it breaks down.

And then finally, some losses are really non-marketable. There's no way to really put a price tag on them. Like, I asked about your health, and I could do what we just did is called a contingent value survey. I could go around and ask people, but if statistically I'm going to kill you. And I said, well, but if I kill you, I will compensate you for that. I don't really care because money has no value to me once I'm dead. So how do I deal with these types of losses? How do I do this compensation?

So that's the naive way. And we try and basically never do this. This is what courts do if you sue. And this is why court settlements are all crazy and all over the place. But this is not how we deal with it, as a matter of routine.

The second approach is kind of an intermediate step. This is the economist solution. They say, oh, yes, we remember those. We were interested in social optimization. And we want to get rid of that triangle the deadweight loss. And what we could do is we could put a tax such that we could fix the quantities and get the correct number and, therefore, there would be no deadweight loss. And I'll show you how that works in a second. And that is fine for dealing with social welfare, but it doesn't fix the reallocation problem.

And the third is that we could just try to ban or limit the existence of that externality in the first place. And that's where regulation comes in. I'm going to spend the rest of the class talking about that. So very quickly, what is number two of how do you fix the quantities? This is called a Pigouvian tax. It's the same idea, except now, what we're going to do is we're going to apply a tax so that the supply cost, which is the cost at which you can buy the good, is the cost charged by the company making it plus the tax, which happens to be just the right amount so that this moves back down to here. And then that deadweight loss goes away.

That sounds great. But you, of course, still have a problem in that you are now collecting a tax equal-- does this is have the yellow? No, it does not. You are now collecting a tax equal to that yellow box that used to be here. And what you do with it? Did this get a lot louder? If it's too loud, raise your hand.

So one of the things-- this is the basic problem with Pigouvian tax is that you don't really know how to do the redistribution. It's very difficult to identify who paid the externality when you're talking about something like pollution or distributed harm to the environment. And then even if you could identify who bore the burden, we still have all those other problems associated with utility in dollars, not being equal, and so on and so forth. So the general view is that you take the revenues from this tax, and you use it for political ends, which are generally consistent with offsetting other regressive taxes associated with wealth inequalities or phenomena associated in this market. So maybe if you taxed electricity, you would take the revenues and do something that helped the poorest people who suffered, maybe lived next to the coal plant or something like that. But you're not going to be able to compensate each individual correctly, but you try to do something in that vein.

I just also want to point out that the calculation of the tax is not necessarily equal. It looks in this plot like it would be equal to the value of the externality. But that's only because here, the externality has the same value for every unit. And if that's not true, then actually, the tax does not necessarily equal the value of the externality. Also, you have to remember that the demand curve in the presence of a tax may also shift. So don't think of it as the value of the externality. It's just some value that is adjusting the quantity.

So we still have the distributional issue. But that issue is avoided if we can somehow prevent the externality from happening in the first place. And that's where we get to regulation. So before we get to regulation, let's talk about one of the most difficult issues in measuring the cost of damages. Earlier I gave this example of this contingent value survey but said, what do you do when you're killing someone? Well, you need an answer to that no matter what, because ultimately, you like to do a cost benefit analysis for any kind of regulatory policy. And that still requires that you have some way to estimate the harm.

So we have this idea of a value of a statistical life. So these are the values of a statistical life over different years. And for different regulatory agencies-- the Environmental Protection Agency, the Food and Drug Administration, Department of Transportation, Consumer Product Safety Commission, Federal Aviation Commission, and the Nuclear Regulatory Commission. And you can see how they have changed.

And if you ever wanted a cold and heartless calculation that showed the world is getting better, this is it. This is in constant 2020 dollars. And so this is all inflation adjusted. You can compare dollars in different years. And what you see is that, over time, in general, regulatory agencies think that human life is worth more.

And that arises because of a number of issues. One is that society has become more affluent, so we are literally worth more. But also the view that we can, as an affluent society, take measures to protect people. During the construction of Hoover Dam, lots and lots of people died building that dam, and no one blinked an eye because that was just how it was. And we could not do that today. Society socially is not in that position.

So all of that is true for everyone except for the NRC. And the reason why that is the NRC doesn't do it like everyone else does it. They don't say they put a certain value per life. What they do is put a value per unit REM, which is a measure of radiation exposure-- value of $2,000 per unit REM avoided.

And from that, you can then calculate the statistical probability of a unit REM killing you, and then you can back out this. But they never actually talk about it in these terms. And so when there's public discourse about how to increase the vessels. They kind of fly under the radar screen.

There has been during the Obama administration-- the NRC did propose to rectify this problem. So currently, the NRC says you're worth about $3.2 million versus other entities, saying that you're worth $15 to $20 million. But NRC during the Obama administration wanted to revise that upwards to $8.5 million.

It doesn't really affect the price of building reactors, but it does affect the price of these changes after the fact, because those changes are enforced according to the back fit rule, for which they do this calculation that we just did an example. So the kind of story that I like to talk about is during after Fukushima.

So Fukushima was a boiling water reactor, and it has a small volume containment. And when the reactor overheats, it-- all sorts of steam is vented into this containment. In the case of those reactors, there's also a torus and some other things. And this concrete containment can't take all the steam pressure after a couple of days.

So what they have to do is they have to vent some of the gases to the atmosphere, which contain radionuclides. And that's where all of the radiation released from Fukushima basically came from. And so someone had this idea, well, why are we venting it to the atmosphere? Why don't we put a pipe and then have a big trench full of sand and water, and you bubble the gases through here, and then the radionuclides will adsorb onto the surfaces of the sand or dissolve into the water, and then clean gas or much cleaner gas will come out of this big pit.

How expensive is it to take a big pit and fill it with sand and water? I mean, it's going to be millions of dollars because there's going to be some kind of control system and so on, but it's a relatively cheap upgrade. And all the European BWRs decided, absolutely, we need to do this to minimize damages to humans.

And RC did a calculation, and they adopted their very low value of statistical life. And they said, ah, it turns out that according to our calculations, it's not worth a pit of sand. And so in the United States, we don't have this upgrade because of this calculation. So that's how it affects-- how the industry saves money with this.

So if we want to do something, regulation-- if we want to prevent these things from occurring, regulation is the way to do it. And it doesn't usually eliminate them. What it really tries to do is just minimize them to what we deem through policy to be an acceptable level. So what is it exactly? It's a set of administrative rules that governments or standards that governments can put into place and have essentially the force of law. They aren't passed by Congress. They're written by agencies, but they go through this special process, and then they basically have the force of law.

So in total, in the United States have about 165,000 pages of regulations. We have over 330,000 full-time federal employees who enforce the regulations. Arguably, depending on how you do the math, it costs roughly 50% of the US budget to maintain and enforce regulations-- the US Federal budget. And the average household pays about $15,500 for this pleasure in taxes for regulation to basically keep our standard of life where it is today, which is a lot of money.

So it's easy to see why there's a lot of critique about regulations, and especially from businesses where it directly increases their costs. In the abstract, it sounds like a lot. And keeping regulation going is a challenge. But it's also hard to remember how important regulation is. If you woke up this morning because your cell phone alarm went off, let's just walk through what happened.

That cell phone received its signal because of a regulation that required certain standards with the communication infrastructure. The radios didn't get zapped because of regulations that limit the RF output of other electronic noise. You didn't get a rash when you woke up because Consumer Product Safety Commission had regulations about what kind of stuff went into your mattress.

You went and brushed your teeth. There are regulations of what goes in your toothpaste. It can't be ground glass. And the number of regulations that you incur, that you benefit from the moment you wake up to the time you get to class would take me hours to go through. It just affects-- it is what creates the modern standard of living. So it is expensive, but it is also really important.

So historically, for the nuclear industry, this meant paying a lot of money. And typically, to get a brand new reactor design license can cost as much as $1 billion before the first plant ever gets built. And that's a big deal. And there are huge sums of money at stake.

So cost of a nuclear power plant in the US might be around $10 billion. A site where they typically build two at a time, $20 billion. And that means they have a lot to lose if the regulation gets in the way. And when you have that much money involved, $10 or $20 billion, well, now, you can do something. That kind of money speaks.

Maybe you can buy a political campaign, get some law changed. This stuff is actually happening for a small fraction of what it costs to build the plant. So you have, for nuclear, this problem that the regulator is subject to industry influence, because the cost of the industry to change the regulation is basically small compared to the numbers that they're dealing with.

Nuclear regulations are also complicated by the fact that, in principle, we want to do these cost-benefit calculations. But who's to say what the harms will be? We don't really know how safe these reactors are. We don't really know if we make this change what the effect will be on people. We don't really know what the effect of radiation is on people. All of these problems make the calculation of a convincing cost-benefit subject to interpretation, and that makes the regulations easily influenced by different political perspectives. So all of that means-- it's just a way to say that nuclear regulation is particularly challenging subject area.

So let's talk about how our current system came about. We began the nuclear age with the Atomic Energy Commission. This is the bad old days of nuclear. AEC was mother, father, judge, jury, and executioner of all things nuclear. They determine what information was secret, what information was not, et cetera.

And at the top of the AEC were these commissioners. I showed you a picture of them in the first lecture. And they really had this idea that they were going to give birth to this transformative industry, and that would set the world free from its energy burdens. And so they didn't want things getting in the way. And there was no regulator per se, but there was something called the Advisory Committee on reactor safeguards. And they didn't have legal authority to enforce standards like a regulator, but they were supposed to help direct the design of reactors to be safer. So they came up with some really good ideas. They came up with the idea of the containment. What else did they do? Nothing else comes to mind, but they did like the baseline ideas of reactor safety.

Then, in the 1960s, the US government started doing a bunch of crazy experiments where they would actually melt down reactors. And they learned a lot. So for example, prior to 1966, it was believed that if the fuel melted because of some kind of reactivity excursion got too hot, it would melt and just sit on the bottom of the pressure vessel.

And then we discovered, thanks to our experiments, that, oh, no, it's actually hot enough that it just melts right through the pressure vessel and keeps going. And this became known as the China syndrome. And people had these visions of it melting all the way through the center of the Earth and coming out in China, such nonsense.

But we learned that the pressure vessel was not a sufficient barrier. And so this discovery led to attempts to find ways to prevent this from happening. And so Westinghouse came up with the idea of basically putting a giant-- it's a ceramic concrete underneath the reactor pressure vessel called the core catcher. And it's a refractory material for which this, what we call corium-- melted core-- lava-- will not easily penetrate, and it spreads out, and then it cools off to the point where it solidifies and the problem is solved.

So that was the original idea. But General Electric, who invented the boiling water reactor, was always looking for ways to save money. And they said these ginormous ceramic dishes are going to be very expensive to manufacture and install. Why don't we just have a sprinkler system instead? And we'll just spray water. This is called the emergency core cooling system.

Now of course, the issue with the ECCS-- Emergency Core Cooling System-- was that now it was an active system. You had to have pipes, and sprinkler heads, and you had to have pumps, and electricity to run it, and you'd have to turn it on, and all that has to be done as opposed to this passive, always-present safety thing. But that was all a lot cheaper than trying to build this core catcher.

And so a debate ensued and many nasty accusations going back and forth about which was more functional and which was more expensive. And ultimately, the AEC commissioners, who cared about the viability of nuclear power said-- it turns out they didn't really believe that this was an issue. This guy who's, I think, head of reactor design-- I think that was his title-- Milton Shaw, he was like, safety guys are nuts. They're coming up with all these scenarios that will just not happen, in his opinion. And so let's just do whatever's the cheapest. And so they endorsed the General Electric sprinkler system.

And then the labs-- Idaho National Laboratory-- said, fine, we'll do some experiments because that's what we do. And they did this experiment where they sprayed hot water on something, and look what happened. It was-- or water on something hot, and this is-- they got the Leidenfrost effect right. So the water forms a vapor layer instantly on contact, and basically, the cooling power of the water goes away, and the water just sheets off the hot fuel and doesn't do a very good job cooling it.

And then they discovered, oh, actually, if you spray a lot of hot water on the core with sufficient force that you actually-- a lot of cold water on the core with sufficient force that you can actually cool it, then the fuel cracks, and now more radionuclides are released into the environment, and this is even worse. So this whole idea was problematic.

And so this led to something of a scandal. And the AEC kind of got its hand slapped by Congress, and said you need to work this out before-- you can't just go and install these things. You need to make sure that they're going to work. And so they did, and these things still exist, and they have been worked out. The EPR in Europe has a core catcher, and I think the American designs still have Emergency Core Cooling Systems.

Shortly after that, the AEC began to double down on their bad behavior, and they refused to comply with other regulatory laws that they saw were getting in the way of their vision of this nuclear future. So one of those laws is the National Environmental Protection Act that says you have to do Environmental Protection, assessment of the implications of building anything, basically, including a nuclear reactor.

And they said, eh, we don't have to do that. And then they got sued-- the US District Court. And the court ruled, quote, "the AEC is making a mockery of the law." They were just very high and mighty. And in 1972, Congress said, enough is enough. You guys cannot be maintaining the safety of these reactors and also clearly promoting them in this unbridled fashion. This is a conflict of interest. And so the AEC was dissolved and split into what became the Department of Energy and an independent-- the first independent regulator, the Nuclear Regulatory Commission, 1974. And that's how the NRC was born, as an independent entity.

And so what are the requirements for a strong regulator? So this is what the academic literature says. You need to have independent operations. You can't depend on-- you can't have Boeing inspecting their own airplanes and then telling you that they're safe. Now, there is a proposal right now in the nuclear industry to do this. But for now, we have independent inspectors-- the NRC employees who inspect nuclear sites.

They're supposed to have independent finances, so they're not dependent on the company for their operations. They're supposed to have independent sources of information, meaning they can run their own codes. They have their own competency to figure out what the truth of the matter is, and they should have legal authority. These are the metrics for a good regulator.

Unfortunately, not all of these hold true to the maximum extent for the NRC. So by its very mission, of course, the NRC will increase the cost of nuclear power. So for example, every nuclear power plant has-- large nuclear power plant has two inspectors assigned to it on a full-time basis. And for that privilege, the NRC invoices the power-- that reactor $4.5 million every year for their inspectorial services.

If a reactor owner decides they need to make some change to their plant, they can submit a request to the NRC. And the NRC will happily review that request for $272 an hour. So you can see how it feels to the industry positively masochistic that these people are both telling you what you can and cannot do, and you have to pay them for the privilege. They don't like this.

So does it make sense to charge-- for the NRC to charge the private industry for what is going on? Well, it's unfortunately written into the law. The law says that the NRC must recover 100% of its operating expenses-- yeah, of its operating expenses with the exception of a few exclusions from the industry through these fees.

But in an attempt to prevent these fees from becoming a mechanism that causes them to just keep charging like lawyers do more than they should, they don't get the money directly. That money goes into the US Treasury, and then the Congress allocates the NRC's budget the following year. So in principle, that break is supposed to get, basically, the budget as they need. And the money just goes back into the Treasury. So it can't charge a little more and make a little more. In principle, they can't do that.

Is there good otherwise philosophical idea for this? Well, yeah, there is actually. Safety is an externality. And the basic problem with externalities is that they are external. They're not incorporated into the cost. And if you make the industry pay for the process of making their reactors safe, you are internalizing that externality, which is fundamentally what you want to be doing.

So arguably, this is the ideal, but you do have this issue of the conflict of interest that the budgetary thing is supposed to solve. But there's one more problem that emerges, and that is this fee-for-service attitude. So you now have this idea that the industry looks at the NRC partly as their adversaries, but partly as people who are working for them.

Because look, we paid you to do this review. Do it the way we want you to do it. And the NRC says that's not our job. And they say, but you can see how it still changes the perception of the relationship because the NRC is paying-- sorry, the industry is paying. And that problem becomes worse if the NRC staff come out of industry, because now you have people with that mindset inside the NRC saying, oh, yeah, you're right-- well, we should do this in a favorable way. And you paid for it, after all. And that has happened, basically.

A lot of the staff level people can be independent, but the commissioner's more and more so do seem to be ex industry people. Despite this, the NRC has really done a very good job over the years. American reactors are the most robustly operated reactors in the world. And the NRC approval process, by which new reactors are licensed is still considered the gold standard by all countries in the world. There are many countries who don't want to build a reactor unless the US NRC has approved that design. They don't really care what the French regulator says. US NRC approval is what they want. So it has issues, as usual, but it is also considered to be the best there is.

And you know you're doing a good job when the other side is kind of pissed off. So here is a quote from the 1990s from the Nuclear Energy Institute. We talked about NEI before. They're the lobbying arm of the nuclear industry. And they said the NRC is "a serious threat to American nuclear energy resources by distracting plant managers, undermining public trust in nuclear power, and pricing nuclear power out of the competitive energy marketplace." They really love to blame the NRC for the fact that nuclear is expensive. And maybe it is the reason why nuclear is expensive.

Does it matter? That's up to you. If the NRC is doing its job in a fair and efficient way, and these are the true social costs of making a reactor safe, then it's just internalizing the externality and it's fine. On the other hand, if it's not a fair process or not an efficient process, then yeah, it should be improved.

So that has been the tension forever. And there's constant lobbying efforts to try to do things to change how the NRC does business. And they have had their effect, and we'll talk about some of them a little bit later. But most recently, there have been some pretty big changes brought on by the Trump administration.

The NRC is supposed to be an independent agency. It is not supposed to be subject to political manipulations by who is elected into the White House. It's supposed to be a technical entity with technical experts making technical judgments. That began to change in July of this year when Trump first removed the NRC commissioner and replaced him-- Chris Hansen-- replaced him with someone who was more in line with the White House's views.

And then another commissioner, Annie Caputo, resigned. And it's not like these commissioners were anti-nuclear people. So Hansen, the guy Trump fired, was endorsed by the NEI, the lobbying arm. And they publicly congratulated him. And he was all for reforms in the NRC and risk based licensing approaches, big advocate of advanced reactors and promoting those reactors, but it was not enough for Trump.

After that, Trump then appointed a new NRC commissioner, a person named-- what was his name? I'm blanking on his name. He was the head of Regulatory Affairs for Southern Company, the company that runs the new Vogtle reactors. So basically took the person whose principal job was arguing with the regulator from the largest, from the newest nuclear utility, and put him on the commission.

Then, Trump issued Executive Order 14300, and that mandates that the NRC not just be concerned with the technical health and safety of our nuclear infrastructure, but also consider the promotion of nuclear power, which was exactly what happened-- exactly why the AEC was dissolved in 1974, because this was a conflict of interest. And Trump is trying to create that conflict once again.

He then directed the NRC to fire technical experts from the Advisory Committee on reactor safeguards, which are where you get all your material scientists, and neutronics experts, and so on to the statutory minimum. By law, there's a certain number of people they have to have, but he wanted it reduced to the minimum. And also they reduced the overall workforce of the NRC thanks to DOGE.

So of course, this is a problem for the industry because they now need to get their licenses approved. But there's no one to do it, or fewer people to do it. And so why don't they oppose this? Because it's yet another provision. So the executive order caps the time that the NRC can spend reviewing to 18 months and also caps the fees.

And you can say, well, maybe 18 months is enough time. Maybe it is, maybe it isn't. I don't really know. But basically, that ensures that you have smaller staff and less time to review things. And of course, that means those reviews are not going to be as independent and complete as they used to be.

So the NRC in the United States is no longer an independent body. It is now operating according to the dictates of the White House. And given these capped timelines, the NRC is going to have to increasingly just take the things that the industry gives them and trust them on faith. And that is a problem.

But this is not new. These kinds of changes, manipulations have been happening maybe less dramatically than the executive order, but they have been happening for the last 40 years. So the reactor licensing process is probably the place where these changes have been most dramatic.

So let me just tell you a little bit about some of these changes. Originally, nuclear power plants were licensed in a two-part process, which we call part 50, which refers to the part of the federal-- what's the word--

STUDENT: CoTa regulations.

LECTURER: CoTa federal regulations. Thank you. Their part of the CoTa Federal Regulations. And part 50-- first, the utility would submit an application for the construction of a plant. And if it was approved, it could then build the plant. And it actually had a lot of flexibility in how it built the plant.

And then once the plant was nearing completion, that company would apply for a second license to operate the plant. And they would review the plant build. And then if it passed safety inspection, they would begin power uprates, and testing, and proceed all the way to full operation. It was a 2-step process.

It seems like a very perfectly reasonable way to proceed, but it had something that the industry turned out not to and that is it left something to chance. So you see, after the Three Mile Island accident in Pennsylvania, the NRC determined that many of the plants that were then being constructed had inadequate safety. And so they changed the rules while these plants were being built.

And that caused cost overruns and delays, and nobody liked that. So this was an issue because now this presented significant financial risk to the investors. You go get a bank to invest in your plant, and you can't promise them that this plant is going to go online and make money. So now, they're like, oh, well, we have to charge you more interest because you can't guarantee us that you're going to be able to finish this plant for the price that you say you are.

And so this was a big problem. And so this began a long process to limit the NRC's ability to demand changes. And here's how it happened. So after Three Mile Island, the NRC-- I'll quote an internal document here-- said that the process, quote, "vividly demonstrated the deficiencies in existing procedures for coping with an offsite nuclear emergency."

There was confusion and uncertainty among the decision makers and local authorities, who were trying to cope with the prospect of a radiation release from the plant. That was the principal kind of issue, if there will be a radiation release, how do you deal with this problem? If you don't deal with it in a timely manner, people will begin to inhale radiation, so you need to have a good plan.

So Congress requested that the NRC work to improve this emergency planning process. And in response, NRC required evacuation plans for the population within a 10-mile radius of every plant before granting an operating license, which sounds like a sensible move. And they also required that there be plans going out to 50 Miles for evaluating the effect of fallout on food production in those areas.

So this is what it would look like in Pennsylvania, where Three Mile Island accident. The red zones are the evacuation zones, and the blue zones are the larger 50 mile zones for dealing with food ingestion and so on. And you can see it covers roughly like a third of the state of Pennsylvania. It covers 90% of the state of New Jersey. And so you need to have a lot of local government officials and a lot of assessment going on to actually do this.

The problem was that the NRC nor-- neither the NRC nor any private utility had the power to compel any state or local government to do the things it wanted to do in an emergency. The 10th Amendment basically says that these-- unless it's in the Constitution, these rights are reserved for states and the individuals.

And so this, in effect, gave tremendous power to the local municipalities around the plant, who had to agree on how these evacuations were going to occur. And so you had this problem. This is the problem of Shoreham. This is Long Island, New York. This is where the Shoreham plant was.

And it was finished in 1983, a few years after the Three Mile Island accident. And there had been strong public opposition. And the Suffolk County government determined that the population of the red circle cannot be realistically evacuated if there was a major accident. Now, I'm not sure if that is true or not true.

It's a relatively unpopulated corner of Long Island. It's true that there were atypical hazards. There was a particular hurricane risk hazard. It was in the flight paths of two commercial airports. There was also five miles away a Naval weapons testing facility, and they continuously had military aircraft flying around running test drills.

And because it was on the edge of the island where there's a lot of weather, there was a lot of power outages there. In fact, during Hurricane Sandy, they lost power for two weeks, which would have been a real problem if there were a nuclear plant. So there were a lot of reasons not to put a nuclear plant there, but I have no idea if the evacuation story is the whole story.

So they couldn't get an emergency planning agreement with the Suffolk County government. And as a result, the Shoreham-- as a result of standoff, the NRC actually changed the rules for them. They passed something in 1988. The plant was finished in '83 and just sitting there waiting for his license. So in 1988, they passed something called the Realism Rule. The Realism Rule said, OK, they don't have to agree. We'll assume that if there is an accident that they will cooperate.

And that seems realistic. But it also meant that you could now write emergency plans for which the government had no capacity to execute, no review of whether that plan was a realistic plan at all. You just say whatever you want because they didn't actually have to sign off on it. And so it made the problem worse in a different way.

The NRC proceeded to issue a license to operate at 25% power on that basis. But by the time all of this occurred, it was too late. The utility was basically filing for bankruptcy. It had been 15 years since the plant had received its construction permit. Costs had skyrocketed to 100 times the original predicted price for this plant, and they just decided to cut their losses and sell the plant to the state of New York, and plant was never opened.

So the industry said, you know what? Never again is this going to happen. So what they decided to do was to eliminate this operating license that could prevent them from starting their plant by doing something called the combined operating license, which is part 52 of the regulations. And what that does is basically say, you apply for a license to build the plant and operate the plant at the beginning.

And once that license is granted, you're guaranteed the right to operate it as long as you build what you say you're going to build. And that's the key thing. It has to be functionally equivalent. So the key benefit is once this COL, as we call it-- Combined Operating License-- is issued, it can't be withdrawn. It can't be modified if the NRC decides to change the safety standards. And that was a key objective of industry.

And more importantly, it all happens when there's just a green field before anything happens. Once you start building the cooling towers and people in the neighborhood are like, oh, there's a nuclear plant going up there, and they might have public opposition. Well, guess what? Too late. You should have gone to the hearing when that was just a green field. And so that was a way to disenfranchise local voices, which of course, the industry really liked because it meant that you were not going to have public opposition.

So they implemented this rule, and then it went untested because no one ordered any new plants for 16 years. And finally, after the nuclear renaissance in 2005, that changed. We had federal loan guarantee program, and we had a bunch of new plants signing up to-- a bunch of utilities signing up to build new plants.

And we saw that with the building of the virtual summer generating station-- two AP1000S, just like Vogtle, but in South Carolina, not in Georgia. They filed for their COL in 2008, was issued in 2012. And the problem was that in the first five years of construction, as they were starting to build this plant, they kept discovering that they needed to make little changes, which meant they weren't building exactly the plant that they said they were going to build, which meant every time they wanted to move the road over here because it turns out the soil isn't strong enough, and that meant they had to move this other thing, every one of these required a modification to the license.

And of course, that had to go back to the NRC. And it was reviewed at $272 an hour and so on and so forth. And so between 2012 and 2017, 75 license amendments were made which, of course, slowed everything way down. They're paying the interest on the loan during construction. This is pushing up the budget, right. This is causing problems.

And so needless to say, costs skyrocketed out of control. And after spending $9 billion starting the construction of a nuclear plant, which should have been more than the total cost of the plant when they originally predicted, they decided it was still cheaper to just give up and walk away than to spend the rest of the money. And that's because of all the costs associated with these license changes and delays.

And so the industry blamed many things, but most of all, they blame the regulator. They said the COL is problematic. It's like, well, this is what you wanted. They now say it's not flexible enough, and they want further changes. One of the current things that is being proposed is that instead of having a 10-mile evacuation zone and a 50-mile emergency planning zone region, they now say that the emergency planning zone should be shrunk to the fence line of the plant, and that anything beyond doesn't apply. The NRC was fairly resistant to that for a long time, but this idea seems to have taken root.

And so how is this possible? Do they really think if there's a radiation release, it's not going to cross the fence of the plant? And the answer is no, they don't think that. They're using the magic of statistics. They say that these plants are so safe that the in expectation value, the probability of irradiation release going beyond the fence line is small.

Now, if there is a release, it will go beyond the fence line. Not a question. But because we get to multiply by very low probability of that safety event happening, then in expectation value, this plant is super safe. And the real beauty of this is that we don't have to deal with any of these public entities, and therefore, we can just do whatever we want.

Now, this gets us into the question of probabilistic risk assessment, which is how these calculations are done. So historically, the way safety was done in the United States was that we were humble. We knew we didn't have all the answers. And so what we had is this idea, which we still teach, called defense in depth. Defense in depth is like, this should be safe enough, but just in case, we're going to have some totally independent way of also keeping you safe. And just in case that fails, we'll have a third independent way of keeping people safe. And then hopefully these things don't interact. And that accommodates for the fact that it's impossible for us to predict everything that will happen. That's the idea of defense in depth.

And that idea is being slowly dismantled and replaced with something called the risk-informed approach, which sounds great because who is opposed to being risk-informed? I don't want the risk-uninformed approach. But this is what's really going on is that we are getting rid of redundancy that is there because of model uncertainty.

So PRA is the mechanism by which this happens, which stands for Probabilistic Risk Assessment. And maybe I can tell you a little bit about what you do. Instead of having all these safety layers, what you do is you have this big model of how the reactor operates. You have what we call fault trees. And you assign probabilities to all kinds of events that might happen. And then you multiply a bunch of small numbers less than 1, and you get a very, very, very small number, much, much less than 1. And that's basically the idea.

Where does this come from? It came from MIT. In 1975, after some safety incidents, there was a lot of public concern that nuclear reactors might not be safe enough. And George Rasmussen, who was a professor here, did this study where he built a model of the safety of a nuclear power plant, which was called WASH-- the name of the report was called WASH-1400, which was how report titles were given by the AEC at the time.

And it reported that the probability of a core damage event-- this is like the fuel melting was once every 20,000 years per reactor. And you can think to yourself as engineers, the more experience you'll have, the more maybe this number will sound just a little crazy to you-- that everything will just continually operate, and statistically, it will fail only once every 20,000 years.

After the report was issued, it was roundly criticized. Berkeley nuclear engineering department took it apart and said this is-- they called it inscrutable. The problem with this is that you have all of these numbers that you have to multiply together. And we didn't have data for the real probabilities of all of these things. So most of this stuff was just pulled out of thin air, and it was a garbage in, garbage out kind of phenomenon.

But it was very appealing to the industry because now you could have this quantitative thing. We all like math, and it provided proof that reactors were safe. And who could resist that? The NRC was not convinced. They're like, you guys are crazy.

But during the 1980s-- and they didn't adopt it. But then in 1980s, the defense in depth approach was discovered to have a problem. The defense in depth is perfectly fine for when you want to talk about designing a new reactor, but how do you make changes to reactor? How do I decide whether a particular change is worth it, if I should make this change or that change? If I have two changes, how do I make these trade-offs? The defense in depth approach doesn't give me any framework for that kind of thinking.

And so PRA's presented itself as a way of making these small changes in evaluating what was the right way to do things. And in fact, it worked pretty well. So you a lot of changes that came about because of PRA assessments have actually improved the operational reliability of these plants. And so the US plants have some of the highest capacity factors, in part, because of changes that we've made to operating behavior revealed by PRA-type assessments.

So it's not that PRA is useless. It's just that at the end of the day, the number that you get out doesn't actually mean anything in cardinality terms. It will help you with ordinality, which is to say, this is better than that. But you can't take the final number and say, oh, and this is the safety.

And maybe the best way to convince you of that-- we can look at the output numbers-- or as to point out that, when we look at most of the major nuclear reactor accidents, those accidents occurred along pathways that were not in the PRA model at the time that that accident occurred. And then they go, oh, yeah, that could also happen-- we should add that.

The problem is that the fault tree isn't a complete fault tree. It has to be hand-pruned and curated by humans. And these numbers about what happens are human estimates, and it will never be necessarily complete. And that is the basic challenge. 1985, the US government accounting office, which is the actuarial watchdog for US government entities, praised the NRC for not using PRA when it was trying to license reactors. But this is exactly what the industry is trying to do now, and they call it the risk-informed approach.

So let's just maybe look at how some of these numbers stack up. Here are the actual historical rates of a large early release-- radiation release from BWRs and reactors worldwide-- 10 to the minus 3 and 3 times 10 to the minus 4. You just count up reactor years, count up accidents, and this is your best estimate for the safety of those plants. Here's what the PRA model says. It should be 10 to the minus 5. So, you have somewhere between a factor of 10 to a factor of 100 difference between what is predicted and what is observed.

These latest reactors have PRA numbers of like two releases every 100 million years. And these numbers are starting to look less and less believable. So it's kind of like-- PRA, I think of it as like looking for your keys under the streetlight. These are the things you know about, and you solve those problems really well, and you can drive those things down to 10 to the minus 8. But there's all this other stuff happening that you haven't thought about.

And if you assume that the streetlight-- what is under streetlight is the entire universe of problems, well, you're wrong. So don't be fooled. It's not more scientific. It is not more accurate. It's just more quantitative. It has the appearance of being scientific, but it's still fundamentally revealing human biases and human preferences. And we have to remember that when we look at these numbers.

Nevertheless, industry has been working hard to get PRA into the licensing process. And some of the numbers for small reactors are crazy. So here's NuScale Power. They say the likelihood of a core damage event to a NuScale reactor from equipment failure at full power condition is one event per module every three billion years. This is older than the life of planet Earth. I really don't believe that number is accurate, and you should not either. But this is how you get your evacuation zone to 0. You multiply times 10 to the minus 9, and now it doesn't really matter.

So I mentioned PRA has found some uses. Let's see if I can go through some. So in 1985, NRC determined that more than 35% of, quote, "abnormal occurrences were directly attributed to maintenance deficiencies." And many of those problems arose from human errors, such as failing to follow procedure and installing equipment correctly. And so they pass what was called the Maintenance Rule in 1991.

And this required the NRC to identify deficiencies in how maintenance of reactors was being done, not just the overall operation of-- the overall design of the reactor. And it collected a whole bunch of data on all these maintenance deficiencies, and then it built PRA models that they were then able to target the inspection process to the types of maintenance defects that were common-- that commonly occurred.

And as a result, they were more likely to discover problems and prevent-- not only prevent accident precursors, but also prevent the reactor from just shutting down for an unplanned maintenance event. And so as a result, here's what happened to US uptime. In the '80s, we were kind of like the rest of the world. 65%, 70% operational uptime. And now, we are way up here-- 90-plus percent because of this PRA-focused approach on how we do maintenance.

And that not only is safer. It actually brings down the cost of nuclear power. And so that's a good thing. So this has all been enabled by PRA. It's a really good tool. You just have to use it in the right way. That brings us to how the NRC does Enforcement.

So the NRC actually has officers with badges and handcuffs, and they have the power to arrest people who fail to do their jobs. They really do. There is an office of the Inspector General, and its function is to keep the NRC independent. Of course, OIGs from across the government have been fired by Trump. And the problem is that everything would be fine if it weren't for the fact that people are basically lazy.

They will lie, and cheat, and generally fail to do what they're supposed to do, like do their homework, and this leads to safety problems. So you might think, well, how often does this really happen? And so just in case you're curious, here are the data. The OIG catches about 1 to 200 instances of this stuff happening in the United States per year. So that's one plant every six-- one incident per plant every 6 to 12 months gets caught by the regulator.

And there are all kinds of different materially false statements, violations of requirements, non-independent inspection, and retaliation against employees for safety concerns. I'll just read some of these from a 2013 report. A chemistry manager at Indian Point deliberately falsified test results from samples of the diesel fuel in the emergency backup generators. And diesel fuel can turn into gel, and then the diesel generators won't work, and he just didn't test.

Fire protection coordinator at Kewaunee Plant failed to conduct fire drills for five years in a row and submitted falsified fire drill evaluation and critique forms. Engineering supervisor at Wolf Creek falsified records indicate that they inspected the spent fuel on a monthly basis, and no inspections of the spent fuel pool had actually occurred. Condenser replacement project superintendent at Columbia was using drugs and submitted-- fake urine went to his drug test.

Electric supervisor at Watts Bar conspired to falsify paperwork which indicated that they had checked the installation of electrical cables when, in fact, they never checked to make sure those cables were installed correctly. So this is the kind of small stuff. It's small and generally doesn't have an issue, but sometimes there is an issue. That's why these things are there in the first place. And sometimes these things do lead to cascading problems.

And I think this is really the biggest one here. The corporation retaliating against employees when they bring up a safety issue. That kind of stuff means that more and more people are going to bury safety issues. The more of this that happens, the more likely you are going to have big problems that are not being reported because people are afraid of losing their jobs. So this is another reason why PRA can't ever really be right. Their calculations assume this ideal plant that is following the procedures. And if you're not following the procedures, and it's happening every six months, yeah, things are going to go wrong.

This is an important closing message. It's in the NRC's mission statement. Nuclear regulation is the public's business, and it must be transacted publicly and candidly. And there are all kinds of laws that prevent, for example, the commissioners from meeting with each other unless there is a public forum where people can hear what they're saying.

They're legally not allowed to get together in a room and conspire about what to do. For the most part, the regulatory process in the United States is an open process. And you can go to the NRC's website, and you can look at tons of documents that are being submitted, and letters submitted by industry about what they want to do. But they do protect proprietary information.

And what gets counted as proprietary can be debatable. So for example, plants have transient events where there's a power excursion, and sometimes there may be a scram to shut down the power. And who knows why these things happen? And the reason is investigated, but these events are never reported to the public. They are kept away from the public so that they can't be reviewed by independent people.

And you can understand why the industry likes that, because they don't want the public knowing that these plants are having these problems. But this is not a good way to do regulation. So there's kind of a constant battle going back and forth. And a few years ago, there's an organization called the Union of Concerned Scientists, which is based in Harvard Square. It was actually founded by professors in the physics department here at MIT. And they're kind of like the gadfly that constantly annoys the NRC and the industry and follows what is going on here.

And they found that some documents that were-- a lot of documents that were supposed to be released by the NRC were being withheld. Starting in 2004, the NRC just kind of stopped sharing public information. And this included a bunch of non-sensitive stuff that the operators of the plant actually did not make requests to withhold from public view. The NRC was just doing it for their benefit.

And that is evidence that the NRC is, in a way, becoming captured by the industry when they start hiding things on the industry's behalf. And that really, I think, is a worrisome kind of thing. What kind of documents were these? Request for an exemption for complying with fire safety regulations, for example which was at, I think the Oconee plant, Turkey Point, Browns Ferry, Fort Calhoun, and Sharon. Things like this. It's not the end of the world, but they're hiding stuff that doesn't look good. So this underlines the idea that even the regulator now treats itself as a problem.

So here are some final closing observations. Regulation does impose a major cost on industry. They are imperfect and slow to change, but they are subject to influence. And interest groups have really changed how regulation is done. And there's some bits of evidence that this is kind of getting out of control when the regulator is hiding things on their behalf.

The regulation is not all bad. It has improved, in fact, the safety and profitability of the industry. The battlefront is now hiding things in statistics with this, quote, risk-informed approach. Despite all this, it still kind of works, and we ought to keep it going. We'll talk about other industries in the future.