[SQUEAKING] [RUSTLING] [CLICKING]

DAVID KAISER: So as I think you know, today, again, we're going to have just an informal optional discussion. You've all come. So I guess you've exercised your option. But we'll be talking today in 8225 SJS 042 about some of the themes raised by that second documentary film that hopefully you had a chance to watch, the film called *Containment,* the film made by Peter Galison and Robb Moss and their team, their whole team.

And like last time, like our discussion after the film*The Day After Trinity,* so the floor is open. So I'm just curious what people make of it. Let me ask you a more specific question. Was there anything in the film that surprised you, that you really didn't expect, or that you hadn't seen, or you knew something about, but this looked at it from a different angle, or something like that?

You might know, it might not have been so clear. I can't remember. Peter and Robb, the filmmakers, were working on this project before the Fukushima earthquake and reactor meltdown. They were already immersed in this project. And they were already actively filming. And then the earthquake in March 2011 occurred. So in some sense, the film took a turn, while they were already immersed in it.

Considering how squarely the film begins and ends with a lot of material about very fairly recent developments in Japan, I was just curious if that shows in your viewing because the film originally-- of course, they didn't know that was coming. They were starting the film, were working on the film before that even had occurred. Did the film hold together? Did that seem like it was tacked on? I'm just curious what people make of this body of material.

Thank you. Let's sit with that. Peter and Robb already were quite interested in areas that do show up a lot in the film, like the waste storage facilities in the continental United States. And as many of you might know, there've been long, long longstanding, decades-long debates, just within the US context, about how, where, or whether to develop a domestic storage facility.

Should it be at Yucca Mountain? Should it be some other site, the so-called WIPP facility was already then well under-- My apologies. The power went out in my house temporarily. So here I am. It's clearly just a little blip. Anyway, sorry about that. So I have to say, I might be repeating things that I missed when I was offline for a moment.

One of the parts of film that I do find most fascinating are these efforts to get a range of types of specialists to design some kind of symbol system or communication system that could plausibly and reliably be legible, be readable to people hundreds of thousands of years in the future.

Whether it's archeologists, and linguists, or other kinds of anthropologists, or experts in SETI, the Search for Extraterrestrial Intelligence, or sculptors, or all these kinds of range people to say, how do we make something that will tell people still, still, still don't dig here because some of these highly poisonous to humans at least-- highly poisonous radioactive isotopes have half lives in the tens of thousands-- multiple tens of thousands of years.

And so if you need activity levels to fall by many half lives worth, you're looking at 300,000 year time horizons into the future. And you think about we've had the printing press since approximately 1450, plus or minus, or 1350 anyway. We can measure that expanse in a couple thousand years, not a couple tens of thousands of years.

The latinate alphabet dates to, again, on the order of maybe-- I don't know-- 5,000 years, something like that. These are a drop in the bucket time scale-wise compared to a 300,000 year projection into the future. And I found that part of the film really just fascinating.

I think in part of the interview that was also on the readings for today, an interview that Peter Galison had done while he was working on the film, it's part science fiction. It's an interesting thought experiment just to imagine a communicative system for our vastly future selves.

So it's partly science fiction and also really, deadly serious. This stuff will still be harmful to humans and even humanlike creatures, plausibly, in n generations forward. So anyway, I found that part of the film-- that's something I didn't know much about before learning about it from Peter when he's working on the film. That really stuck with me quite hauntingly.

Any other thoughts on the material? It doesn't have to be limited to the film. Other things we talked about in class recently as well, it's totally fair game as well. Yes, I worked with a number of students and colleagues who thought very hard about SETI from an astronomical point of view, but also as historians or anthropologists of science studying these communities in present day.

And it does feel like that work is often a projection of our assumptions about ourselves. What will the others look like? Well, we have a range of experience to base that on, which is what we know about. And so it does have a similar kind of ambition and yet maybe limitation from just the horizon of our own imaginations.

And so I think it struck me as totally appropriate, once I learned of it from, say, Peter and Robb's film that these department of energy experts would call on SETI experts because the nature of the intellectual challenge does seem quite similar. And at the same time, it also feels exactly as, well, as big a remaining challenge as it is for anything else because the SETI folks have are also dealing with what they know about, what they've experienced, what they can even imagine, the horizons even of their imaginations.

So in that sense, it does feel like a remarkably similar exercise. I mean, I wrote a little piece about this some years ago, as many of you might know, as a bit of an aside. But SETI, a large part of the SETI work has focused on something called the Drake equation, named for astronomer Frank Drake back in 1961.

And there was an effort to try to quantify and estimate-- admittedly, very loose estimates-- how likely a signal might actually be expected to be from, say, an intelligent extraterrestrial civilization. And the last term in this equation is always the expected lifetime of the civilization that would have been sending the putative signals.

And in the Cold War, in exactly the period we have our heads in the middle of in this class, that last term in the Drake equation, capital L, always was a stand in for-- to those thinking about at the time, for all out nuclear Holocaust. So it wasn't that there was a biological lifespan. They thought it was, did the civilization blow itself to bits the way it seemed to many people at the time that maybe people on Earth were about to do or were poised to do?

So there's actually a high nuclear component even to SETI as well. The community had already been thinking about a kind of knife edge of survival in a nuclear age, at least what they consider to be a knife edge. At the same time, there have been all these kind of technological spinoffs for certain kinds of multichannel analyzers and other technological fancy electronics and code that was developed first for SETI.

How do you sift through millions of channels at once, millions of frequency bands, say? And some of those were brought back, so to speak, behind the fence into certain kinds of very sophisticated nuclear testing, especially after the ban on actual test blasts in this era of what's now called stockpile stewardship.

So SETI seems like it's always about the faraway, the distant, the literally extragalactic or certainly extraterrestrial. And yet, its own history has been grounded and intertwined with the Cold War nuclear age from its own beginning. So maybe all the more appropriate then that some SETI experts, as well as linguists, and philosophers, and sculptors would be working with the Department of Energy to think about symbol systems for 300,000 years hence.

Were there parts of the WIPP facility-- what was it called? I can't remember what WIPP stands for-- Waste Injection Pilot Project, something like that. That's a great question, Alex. I don't remember the specifics. Thank you for asking it. So I think, in general, it's smaller. I think the ideas for Yucca Mountain were ultimately much more grand. It would have had a much higher storage capacity, for example.

At least, it never got past kind of design specs. But that was the ambition for Yucca Mountain, was it really was supposed to be like a one-stop-shop and we solved it. That's it. We have enough capacity for the indefinite future. And I don't think anyone at WIPP ever thought that. I think WIPP was always seen as a proof of principle center. And Ilona helpfully reminds us what WIPP stands for-- thank you, Ilona-- Waste Isolation Pilot Plant. OK, good. Thank you.

So WIPP, I think, was built to be, as its name even implies, a kind of pilot project for something that could potentially later be scaled up. And then as it turns out, there are some real technical challenges even with the pilot design. That's why they build pilots, I guess. You find out what might not work the way you think it would just from the engineering specs.

But I think, in general, the plans for Yucca Mountain were to be forever, like we've solved it, was the ambition or the hope. There would be the one place with enough capacity, with presumed geological stability, that can be estimated-- again, in the hundreds of thousands of years frame-- I don't know how one could ever have that confidence. But that was at least something people were thinking about, and that it would be the one site needed at least for the domestic United-- continental United States, maybe even for worldwide. And I think that certainly has not yet come to be, to put it mildly.

And there's that, I think, really interesting footage in the film about some of the local town hall meetings in and around where the WIPP facility I think was ultimately made. Well, you can see there's a robust range of opinions. Is it good for the local economy in the short term? Does it make good, secure, well-paying jobs? Does it improve the local tax base? Those kinds of arguments and other concerns that are raised about is that a worthwhile trade-off.

And that's just for, again, this pilot facility in one area. It is a fascinating question if you get to-- participatory democracy for the here and now is already really hard. I think, again, we're getting reminded of it every day. Now, imagine this when you're trying to make decisions, I think as you're saying, they'll have implications for generations to come. Who has say on behalf of them? How do you even incorporate that, let alone the next five year or 10 year plan? Will this be better or worse for the local community?

Yeah. Yeah, and again, that's something much like with Fukushima. Obviously, the filmmakers were immersed in the project long before that had occurred. So the film was itself a kind of moving-- not a moving target, but the film evolved more over the course of its making than I think films otherwise often do. And again, it was a genuine surprise-- surprise to filmmakers, a surprise, of course, to many of the operators in the locals.

And again, one could say, well, that's why you do small scale engineering pilot projects. You want to learn from these and hopefully get better and better. And maybe it'll scale. It raises some extraordinarily difficult questions. If, as you say on a kind of decade-long , time scale let alone 10-- 10 to the power of 1-- 10 to the 1 years, as opposed to 10 to the 5 years. That's a big change. Can we get 10 to the 1 years done or even a century let alone 100,000 years? So yeah, I was surprised by that, too. Yeah.

What about some of the scenes-- some of this was new for me as well, some of the scenes within active reactors, just the scenes of the kind of machinery of what it's like for humans to be interacting with these very hot materials, hot in many ways. I don't think I'd ever seen moving picture of that myself, before seeing the film, just even in a reactor site that's operating perfectly appropriately, perfectly canonically.

Just how do you deal with these spent fuel rods and all these kinds of things? Just getting a visual of that and the scale of it, what it's like with all the benefits of our own present day high technology, let alone when people were doing this back in the '40s and '50s, I found that really actually pretty riveting too, just visually, viscerally, what's it like to be working in a site like that when things are going right, when things are going perfectly as the engineers and scientists had hoped.

I don't know, Alex. That's a great question. I don't know if anyone else on the conversation knows about that. I bet we could find out with some quick googling, but I don't know offhand. Yeah.

As you may know, there was a time in the-- starting in the late 1940s, the early years after the Second World War, really accelerating throughout the '50s, when many, many very small scale research reactors were built on university campuses across the country. MIT was, in that sense-- MIT's is unusual for having survived so long, not for having been built when it was.

And so I don't know what the longest-- what the larger original plan was for collection and containment of these unavoidable waste products. The Atomic Energy Commission, the successor to the wartime Manhattan Project really had a very, very-- at the time, it seemed a very generous program to build these facilities, small scale facilities, I mean, just by the dozens and dozens across liberal arts campuses, big research universities, and everything in between.

And so I don't know what the plans were for that larger collection of stuff, let alone what we've been doing very locally. Lucas, it looked like you were about to jump in as well. I cut you off, I think.

Yeah, especially-- I mean, by now, it fades into the background. We've all been used to-- the basic knowledge has been there seemingly forever, at least for generations by now. Many of the folks-- the GAs certainly won't remember this. One time when Cambridge residents did have a reason to recognize these things was not an accident at the MIT reactor thankfully, but what had been a particle accelerator closer to Harvard's campus, actually really contiguous with Harvard.

It was, at the time, called the Cambridge Electron Accelerator, or the CEA. And also, one of the things-- MIT also had one. The Atomic Energy Commission had also subsidized the construction of dozens and dozens of research accelerators, so particle accelerators, not just reactors. And the one in Cambridge and closer to Harvard was one of that set.

And in-- I think it was 1965 or '66, mid '60s, there was an explosion that actually killed a graduate student, did an enormous amount of damage, property damage, as well as a loss of life from the accelerator. So basically, at the time, a lot of the detectors required cryogenic cooling. You keep these things really cold. And that often required lots of volatile gases under pressure, these so-called bubble chambers.

And I believe it was a case of-- others on the call, Tiffany, or Julie, or others might remember better-- Peter Galison had written about this in one of his older books. So I think what happened with the CEA explosion was I think it was part of the cryogenic system that blew. It blew the roof off this factory-sized building. I think at least one graduate student was killed in the explosion. I think only one loss-- one person killed.

But that's a wake-up call to the neighborhood in a big way. Wait, what that little, quiet, sleepy, factory-looking, nondescript building practically contiguous with Harvard's campus, they're doing with what volatile materials? It could really do what? So there's certainly been moments in Cambridge's own-- in our own Cambridge History, going back not super long ago, going back 60, not quite 55 years or so, where things where accidents happen, right?

All these things are built-- designed and built by humans. None of us, it turns out, is perfect. And when you build lots and lots of these things sometimes in pretty dense, quasi-urban settings, that can be a bad recipe. That was nothing like the enormous accelerators that were built with much more careful shielding, and site selection, and all that kind of stuff. It wasn't like it was Fermilab or the Stanford Accelerator, which was pushed far away from campus.

This one was really right near highly populated parts of Cambridge. So things like that certainly have happened. Luckily, that did not-- I don't think there was a concern about radioactive waste being spread by that. I think that was a volatile set of chemicals that exploded. And the damage was immediate, but not showering immediate land with isotopes that would be here for another-- through the next Ice Age. So in that sense, it's not like a reactor meltdown. But still, dangerous stuff that really, every now and then unfortunately, doesn't operate as designed.

Yes. And is that a different kind of-- is the threat different today in a Google Earth, everything's in principle under some kind of camera surveillance, anyone can map anything anywhere in principle? Is that different than when it took work to identify where these things even were? No one had automatic GPS coordinates downloadable.

So I do think I think the nature of that challenge has changed in the last, let's say, 20 years as well. Tiffany, you mentioned in the chat about Lake Anna, Virginia. I actually don't know about that one. Do you want to tell us about it?

Yeah, I didn't realize-- I've never been to the WIPP facility. A number of colleagues from MIT have been because, again as you may know-- and maybe they mentioned it in the film-- that was a site for a bunch of underground fundamental physics experiments as well. You want to be shield it from cosmic rays. And lots and lots of physics experiments-- and this is Julia's mind very directly.

But for generations, lots of fundamental physics experiments have been in abandoned or no longer used mines because you want to get underground for various shielding reasons. So I have several colleagues who had been at WIPP regularly for neutrino experiments or other kinds of particle physics things. So they've been there. I've never been there, let alone driven past it going to or from Vegas.

But Tiffany, your comment also reminds me of something I didn't have a chance to really linger on in the class material. But for many years, when nuclear weapons tests were still above ground, before they went underground with the limited test ban treaty in the early '60s, these things were often pegged as tourist attractions.

So obviously not to get too close to them, but in Vegas in particular, it was within sight lines of one of the continental testing grounds. And so the casinos and the hotels would actually sell advertising. Come this weekend because you'll get to see an explosion off on the horizon. It won't be in your hotel room. But you could have a clear view of this temporary display out the window.

It was seen as not just something to be tolerated or otherwise based on what seemed like Cold War realities, but really-- I don't know if we'd say celebrated, but seen as a tourist attraction, something that would help you sell hotel rooms and come to Vegas this weekend kind of thing.

I just find that chilling. I mean, it's just astonishing, the way-- in this case, the weapons not even reactors, weapons, were seen in popular culture. So again, coming back maybe to Lucas's point, it's not only were they not trying to keep secret when the blast would be-- you think well, are you worried about any kind of bad actors messing around with these nukes? Not only did they worry about keeping the date and time secret, they were actually advertising it as if they could almost sell tickets. Again, just our attitudes toward these things over the last 50 or 60 years, I just find that stunning.

Yeah. I mean, maybe as you're saying, there is-- I don't if we call it flourishing. But there is an actual nuclear tourism-- oh, maybe we can call it industry. One of my colleagues wrote a book, a very interesting book a few years ago called *The Nuclear Family Vacation,* which is a pretty fun pun.

She and her husband went traveling. So it was like a nuclear family that also went to all these nuclear family vacation-- they went to visit nuclear sites actually around the world, including-- I can't remember they went to the Chernobyl site. But they certainly went to many places in the former Soviet Union, as well as, I think, Eastern Europe and throughout the United States. She wrote-- I can't remember if they co-wrote it together. They're both journalists, excellent writers.

Anyway, just saying, how many of these sites are accessible in general? And what's the appeal to go to them? You want to go see, collect them all. I've seen this one, and this one, and this one, this one, like other families might try to go to all the national parks and in some region of the country. They were going to tick off all of these kind of nuclear-related sites as a kind of tourism.

Yeah, thank you. I agree, Deborah. I find that very hard to watch myself. I'm not an expert at all in the present day biomedical hazards and what precautions are actually being taken. So I don't know. But I think I mentioned briefly in a previous discussion, I know that there was a very cavalier attitude toward these things during the Second World War and in the early years afterwards.

And often, the cavalierness was not telling workers enough to inform them of risks that actually were otherwise well-known by other experts, let alone the experts decided to take their own risks or to behave certain ways. And so I don't know what the current training is like and so on.

But 3.6 ranking is not great, not terrible. I don't remember what kind of exposure would amount to 3.6 rankings. I don't remember the scales, what to expect. Do you do you remember? We can look it up. Right, thank you. I'd missed the reference. Very good, yeah. Right.

I agree as well. While we're at it, let's hawk all of Kate's books. She's my colleague. Kate's most recent book-- oh, shoot, what's the title? And that just came out roughly a year ago. There was a collection of Chernobyl-related books came out around the same time, one of which was Kate Brown.

As you may know, Kate's a member of the MIT faculty. She moved here roughly a year ago. She's a real expert on-- both on the Hanford site and the longer term historical development of nuclear projects in the United States. She's also trained as a Russian and Soviet historian, an environmental historian.

She's done a lot of original work in Russia, Ukraine, and many, many non-English language sources, which I can't do. She does marvelously. So she's really a remarkable scholar of comparative views of a lot of these materials.

Yeah, I don't know. And this does raise the other questions. I mean, this came up a lot during the debates over Yucca Mountain, when it was still considered a live prospect. Let's say you have sufficient geological stability that you can somehow estimate for an unbelievably long time scale. Let's say you have enough sufficient storage and containment.

How do you get the stuff there? I mean, do you put this on commercial railway cars. Coming back to Lucas's point before, someone knows there's some bad stuff on that train, why don't you just knock out the train and have some horrible dirty bomb-type attack? So how do you move this stuff, let alone in what form is this stuff most stable and most easy to move?

And there are plenty of experts who study this full-time. I'm absolutely not one of them. I don't what the current best practices are. But I know these were the kinds of things that had to be thought through-- not just can you predict the geological stability and the groundwater flow over multiple millennia. I think the answer to that is not with sufficient confidence, right? That's already just incredibly hard, just as a narrow scientific question.

And then you start getting to practical terms like, well, this stuff has to travel you know 2,000, 3,000 miles-- 2,000 miles. How do you get it there? What happens along the way? And those were, let's just say-- again, in the physicist terminology-- nontrivial, which is code for I have no idea. It's really hard and prone to all kinds of additional worries and concerns.

Because even for the best intentioned humans, we're still human, let alone any kind of nefarious things that could interrupt it. So I know those kinds of considerations have been live issues since the '70s or '80s, let alone in more recent times. But to Tiffany's more direct question, I actually have no idea how that set of decisions were made. Is this format more stable to handle than others? That is well beyond anything I know about directly.

Some years ago, I mean, maybe 15 years ago by now-- I've lost track-- again, a little off-topic, but there was another historian of Cold War nuclear age stuff who put a petition together because-- speaking about Hanford, there was a move to-- let's see if I can get the story right.

The local department of energy administrators were going to basically incinerate a bunch of literally garbage, mostly from World War II era or early post World War II times. And this other historian colleague of mine started a petition to say, please don't burn that stuff. Historians can learn so much about what it was like to live on the site from the crumpled up cigarette wrappers.

It wasn't like the radioactive sludge. It was like signs of human encampments. It was like what did the workers there-- what was their life like? And you can learn a lot from going through someone else's garbage, right? So there's this effort to save the Hanford garbage, which sounds a little tongue in cheek. It was a robust effort to say, we need to learn about what it was like for all kinds of laborers and other staff on the site.

So please don't burn their, at that point, nearly 50-year-old or 60-year-old garbage. And actually, I don't know whatever happened. I don't remember the follow-up, whether that succeeded in saving the historical garbage or not. But I found that an interesting effort.

Think about the longest, earliest known, human stories that we still know anything about. And just to your point, they haven't been unchanging in interpreted meaning, imputed meaning, right? And that's over not even 10,000 years, maybe 5,000, on the order of 5,000.

I mean, we don't teach the ancient Greek stories, say this was their meaning. We teach them to say, look at the plethora of meanings that people might then or might still make of them. And think about Talmudic commentary. Any tradition, they're treated as living interpretive traditions, often at least, precisely because a single, unambiguous meaning is not what people seem to reach for or identify.

And now, multiply that by a factor of 30, right? Now, do that not for 10,000 years but for 300,00 years. I just find that just utterly mind-boggling. So anyway, I share I share your observation that it's interesting that that's what people-- I take that maybe as a sign of we might call it desperation that they'll even go for that as opposed to any other, like Tiffany's saying recognizably high tech, high modernist interventions.

I can't open documents that I wrote in college because of technological creep. I was actually using Microsoft Word, whereas my teachers weren't. So there was actually a level of continuity with my machines and my software. And yet, I can't open documents from like the early '90s. Think about that level kind of just getting a message to persist and be readable over, again, tens of years, not hundreds or hundreds of thousands.

Right, exactly. Yes, no, I think I totally agree. If not literally invitations to dig, they're at least not very good at stopping people from digging.

Maybe. Remember, our baseline since Chernobyl is approximately 30 years, 33 or 34. And again, I'm a little cautious of making the leap from 30 years to 300,000 years. So I guess I don't know.

Right. Right, right. But also, I mean, I've seen some of these terracotta warriors. So clearly, part of the site has been not just investigated, but actually parts removed, moved around the world. So I don't remember the full details of it. It wasn't like the entire site was left untouched and pristine.

Yeah, no. Again, I take that as a sign of the kind of desperation, the nature of the challenge, and the need to do out of the box thinking. But I'm not sure that they found compelling answers, even with these wild exercises. Yeah. And also, how many cults have survived for 300,000 years or 10,000 years, let alone-- just the mismatch in timescales I just find utterly mind-boggling.

And that's a good example, where I think it's safe to say that at each moment in those 2,000 years, there hasn't been a single unified interpretation of what that body of practices and beliefs seems to mean. And that's a mere 2,000 years, let alone longer.

Or how many of the interpretations even for people to take it seriously, how many of them line up with the original intentions or the hoped-for message back some generations ago? They're interpretive moving targets for people who make meanings. So that means the meanings will change.

You think would be the Pyramids all over again, in other words, right? So build some kind of fairground-type marker. That could draw people in, as opposed to tell them to stay away. Yeah.

That might buy you 1,000 years in round numbers-- Notre Dame, or the Durham-- there are, I'm sure, many structures in other parts of the world that I don't know about. 1,000 years, pyramids, 4,000 years. We're still missing some zeros on that. Yes. Unlike the Sphinx, of course, nearby, which lost a nose to overeager soldiers with machine guns. So Yeah.

Any other parts? I mean, we're focusing a lot on this 300,000 years time scale because I keep harping on it because I find it so mind-boggling. Any other parts of the film, other themes or questions that are raised are brought to mind, things that were unexpected?

So that's a really interesting question, Alex. I don't know what we mean by safest or what the metric would be. So I do know we have many colleagues at MIT who are very, very concerned about climate change. That's true broadly. And some subset of them are very concerned that if we're not trying to figure out safe and reliable nuclear power, then is there a longer term viability to address climate change to get off of such a dominance of fossil fuels?

I'm agnostic. Just personally, to share, I just don't consider myself an expert enough on that to really understand the layers of trade-offs. But I know that there are plenty of our neighbors at MIT, let alone in the wider world, who would answer your question in the affirmative. And I don't know enough to give a thoroughly independent answer. I can understand at least where they're coming from.

And I think the challenge then becomes, if that is the case-- and I say if, I don't know-- how do we learn from the past to not keep replicating the unintended consequences that have surrounded that body of work to date? And again, we're not talking about 1,000 years. We're talking about 50 to 70 years and the number of instances where safeguards weren't put in, where human error was nonetheless not sufficiently guarded against, where bad stuff happened even with the best of intentions.

Then I think that makes other of my friends and colleagues concerned about saying, well, there's the answer. Let's just put all our eggs in that basket. Let's go charge right ahead. So I guess I sit astride a lot of these discussions. And I'm personally, genuinely just stuck, just really stuck because I can really appreciate the impetus, especially in terms of climate change and sustainability, and yet also really share the worries that people who knew better in the past didn't always do better.

People didn't always know better. What don't we even know today to even worry about, let alone what do we do know and still haven't adequately really addressed in a systematic way? So I just feel paralyzed, I mean, personally, even though I there are strongly held arguments on a whole range. It's not like it's one side or the other, but a whole spectrum.

So I don't know. I mean, I don't know. If we had a flawless history for even a five year stretch, let alone 50, then maybe I'd have more reason for confidence. But personally, I see the flaws and the unintended consequences pretty sharply, just personally from where I sit, partly maybe because being a historian who focuses a lot on the Cold War, there are a lot of things that people did know better about back then and yet, nonetheless, citing national security, citing pressing demands and needs would cut corners or not tell people the full story. It'd come out only later. So I guess I come to some of these things with a bit of a jaundiced eye. That's just me, personally. So that's where I get I get stuck. I will just simply say I get stuck.

I mean, it's a great point, Lucas. And even stepping away from the nuclear side, I mean, again, you can find these very earnest debates about cost-benefit analyses and risk trade-offs about, let's say, ethanol or other efforts to focus on, say, fossil fuel use. Oh, well, you'd use bio-organic, this or that.

And then you try to cost in all of the fossil fuel-based fertilizer that's needed or all the other things beyond the product narrowly construed. And then you find that, at the very least, it becomes murky. The answer becomes pretty unclear, at least to me. And I think that is all the more so amidst these uncertainties like, what do you do with all this nuclear waste that's not going to go away any time soon?

Then we come back to the question about nuclear power. So that doesn't mean the answer can never ever be nuclear power. But I mean, the tendrils, the extent of this very extensive system, as opposed to the safety protocols of a given reactor design, I think the breadth of those-- of the range of questions makes me skeptical that we're going to find a clear answer, a clear metric that says, at the end of the day, yes, green light. The answer is plus 7. Go forward. That's where I get more skeptical.

What are the competing incentive structures structures? And I'm not saying there's one clearly the right answer. But we have to worry about what decisions are being made according, again, to what measures and what metrics. What are the incentives? Yeah.

Why can't it still be used? Oh, that's interesting. Again, others on the call might have a better answer. But I think the reactors that I'm familiar with are usually trying to do very specific kinds of reactions ultimately to extract excess energy. And not everything that's radioactive will contribute to that energy balance.

So things become radioactive as a consequence of these reactions from which one can extract energy. But I think the most well understood, and as far as I know the most efficient, reactions that will produce the excess energy ultimately involve very specific kinds of ingredients, let's say, very specific kinds of target nuclei to start from.

And so that's why I think it's called waste. The other things that become radioactive are not ones that one can nonetheless put back into the reactor and extract excess energy from in any scalable way. That was a very abstract answer. I'd have to learn more about the particular isotopes and particular reactions, which is not what I work on at all directly.

But I think the basic point is that, for these fission reactions, not everything that's radioactive is highly fissionable. And yet, it still could be dangerous because it's still emitting junk that could hurt people, and plants, and the environment. I think that's the upshot. So only a small set of these isotopes will actually fission upon being struck by neutrons of a certain characteristic, and then release the excess energy. The others are shooting out alpha particles, and beta rays, and gammas, but not splitting a nucleus from which there'll be this large excess energy per splitting, per fission event.

So these uranium-boosted armaments, these kinds of things? Yeah, yeah. I don't know Nixon's book. I remember reading at least some of the journalistic accounts about more recent concerns about uses of uranium-doped armaments, basically. Yeah, yeah.

Good. Well, we can pause there. We don't have to run down the clock. We covered a lot of ground already. Thanks for joining the discussion. I thought that was really interesting. We'll go back to the regular format on Wednesday and thereafter, of course. And then we'll go from there. If you have any other questions, of course, please don't hesitate to email me or any of the TAs. I'll have my regular office hours Wednesday morning at 11:00 and all that good stuff.