TAFT BROOME: Do you or your parents know any of the Norwegian language? OK. Do you or any friends or relatives you know have any interest in Norwegian mythology?

AUDIENCE: I do not even know. I don't really know much about it.

TAFT BROOME: OK. Well, I have an interest in all mythologies, but I've had to write about not only Western mythology, but recently in the past two months I've had to do some writing about Teutonic mythology and Gothic mythology, all right?

Well, there are-- it's really an anthropological term, and I could be more specific if I was ready. But you have groups of people who came into Western Europe in two great waves-- at least two great waves. And I'm not talking about after the migration out of Africa. I'm talking about in 330 AD-- around that time-- and in the time that England was populated with the Celts and all. And they came in in the last one because of a great drought.

And when they came in, they settled in what's now Germany, and then I began to learn that they were the Franks. I always thought the French were unique-- people who had been in France all along. But no, they came in. And so the thing I found out-- was able to do-- was to say that when Christianity came to the Goths, who they say is part of the Teutonic peoples-- I don't think I've got that right. If I don't I'll have it corrected by two. But it really didn't take at first, and it really never took in some ways because paganism was so strong.

And paganism was kept alive, because as I mentioned to you before, there is this big emphasis on the will. And the German scholars of 18th, 19th, and 20th century have kept that alive. You'll see more of an emphasis on the will there than you will most other places, because Christianity wants to talk about God's will and support and say that you are a good person if you submit to God's will. So Christianity really doesn't want to talk a whole lot about individual will.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Of course. Now--

AUDIENCE: [INAUDIBLE] Germany--

TAFT BROOME: Yes.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Yeah. So you also have-- sorry, go ahead. You also have, as I covered in class, Aryan. I think I covered a little bit Aryanism. OK, well I will later.

But anyway that has been-- I'm just finishing-- I'm thinking of finishing. I'm sorting that out, and so that's why I was interested in that. So OK, let's talk a little bit more about Three Mile Island. Let's do Chernobyl.

Oh sorry, I have another housekeeping issue for you. Then I think we're getting just about at the time when we need to start reflecting over the first part of the semester and start looking towards the second part with time that's left.

Remember Roland Schinzinger? This is his book, and this is his chapter on engineering as a social experiment, OK? And I don't-- I think it would be OK for me to say without revealing too much that I've just received a paper to review which begins with this theory, so it's still alive.

I would connect this theory to Henry Petroski's theory about engineering being-- engineers learning from their mistakes as being the substance of what engineering is. It's not just that they do it, but that's the substance of what engineering is. He says-- and he's become very-- yeah, we talked about him at length last time-- talked about the spin, how he put the spin on that thing. Yes.

OK let me leave that to you to decide about. Now there is one other housekeeping issue that I want to touch upon a little bit at least once a week, and that's what possibilities there are for you to do this final research paper. Now, Ms. Ratliff has gotten ahead of us already. You just mentioned that you want to sort of do something with environmental. OK, and I gave you a name already.

AUDIENCE: You did.

TAFT BROOME: You need to-- I suggest you send him some email or call him up, make it work. Tell him-- and I would suggest that--

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Yeah, not that that would make a whole lot of difference with him. No, he is a real-- I was invited-- when I met him, he was chair of the Civil Engineering Department at Duke, and he had invited me to come down to give a talk. And after the talk he was sort of-- motivated is not the word-- lifted to a level where he wanted to think about some of the stuff I said.

And we went to his office, and we sat in there for about two hours and had not realized that the sun had gone down and it got dark in there, and we were just talking. So he is a-- when I say a true scholar, I don't mean that a true scholar is better than any other scholar. What I mean-- a true scholar is a scholar 24 hours a day. So he's a scholar 24 hours a day.

So this man would enjoy talking to you. Say hello to him for me for collegial reasons. He's going to be your colleague anyway, and he does environmental and environmental ethics. He might be able to suggest some possible topics that would be interesting-- some things that I wouldn't think of or that you might not just find by scanning through the literature.

I had a little chat with David yesterday. We meet each other once a week at the ESD Brown Bag Seminar. And she was emphasizing your interest in education. And one third of my book is on education.

AUDIENCE: Yeah, [INAUDIBLE]. I've been thinking for the project, I'm also really interested in engineering [INAUDIBLE] some project that I've been working on in Honduras that's been really thought provoking. And I don't know what I think about American engineers or Western engineers working in Latin America and Africa, trying to solve human problems with sort of Western-based engineering. It seems like there's a lot of ethical issues there, and I'd be interested in exploring that.

TAFT BROOME: Do you want to take a minute or two and tell us about your Honduras experience-- project?

AUDIENCE: Sure, sure. So I got involved with a student group here at MIT that started in the D lab class.

TAFT BROOME: I don't know that class.

AUDIENCE: So it's run out of the Edgerton Center, which is sort of a hubbub of activity at MIT for education and hands-on related work. And they have a professor who is really interested in appropriate technology for international-- for developing communities. And so she started this class to help MIT students apply the engineering and science they're learning at MIT to developing communities.

And every year, they pick five communities and five different countries and split up into five groups and sort of research the needs of that community and come up with an initial problem statement in design. And they travel to that country.

So one group in 2003 traveled to Honduras and worked with a non-governmental organization in Honduras-- a local organization run by scientists there and with local employees-- and discover that the most overwhelming issue in the region is devastation from flooding. It happens yearly on a small scale-- destruction of homes and crops and things, and then devastating floods on like a 15 to 20-year scale with huge hurricanes. So people have settled in this river basin just in the past 20 years and settled there without realizing the dangers of the flooding.

So this student group started working on automatic flood warning systems. The problem is that people aren't warned about the floods in time to save their lives. And they started working on that, and at the same time they started working on a water chlorination project to help a village improve its water chlorination and stuff. And so I've been helping out with those projects.

And they're very different. The flood warning system is a huge engineering systems project that if you were saying would hire a firm to do that had electrical engineers, mechanical engineers, and hydrologists-- social education people-- but students are working on it, and they're smart students, and they have a lot of interest, but it's hard.

And then the water chlorination project is a very small project. There's a simple, cheap solution involving a toilet valve to regulate chlorine flow. But we can't get the villages to implement it, and they agree that the problems are mostly educational and social and political as far as getting people to pay their water tax. So it's been hard, too, but in a very different way.

Yeah, that's basically what the project is, and it's just been very-- it's been rewarding. The people are amazing. I've learned so much.

TAFT BROOME: Are you continuing with it?

AUDIENCE: I'm transitioning out of it because of my interest in education. I'll be stopping in the summer. But there's a student group that exists that will be continuing to work with this organization.

TAFT BROOME: Any questions or comments?

AUDIENCE: [INAUDIBLE] fascinating [INAUDIBLE].

TAFT BROOME: Yes.

AUDIENCE: What language do they speak?

AUDIENCE: Spanish.

AUDIENCE: So everybody is bilingual?

AUDIENCE: [INAUDIBLE] that's a good question. A couple of people are fluent, and some of us are proficient, meaning we can have a-- can successfully communicate with one person at a time. And some people don't know any Spanish except what they picked up from the phrase books and tapes.

TAFT BROOME: Are you bilingual? Do you speak Spanish?

AUDIENCE: Just-- I stopped speaking Spanish [INAUDIBLE].

TAFT BROOME: Oh. When you went to [INAUDIBLE]?

[LAUGHTER]

AUDIENCE: [INAUDIBLE]

AUDIENCE: So would you say they are more [INAUDIBLE] flood warning system than this chlorination project?

AUDIENCE: The students on the team or--

AUDIENCE: The people in the community. Do they embrace that project?

AUDIENCE: They embrace both. The chlorination project-- we've just been working with one town of like 20,000 people, but we've only interacted with about 30 people. So that's sort of their focus, because of their water committee people and plumbers. And then the flood warning system-- I mean, that's supposed to influence the 100,000 people that live in this river basin. And everyone we talked to says, oh yes, it was really important that we have better warning. Definitely [INAUDIBLE].

TAFT BROOME: There's an ethical issue that's been raised about early warning with respect to Katrina.

AUDIENCE: Yeah.

TAFT BROOME: And it comes up-- apparently you're looking into this?

AUDIENCE: Well yeah, we did some studying of Katrina because of its similarity to the issues in Honduras. But I haven't done a thorough study of it.

TAFT BROOME: Well, neither have I. But what raised the ethical issue was that some years ago this gigantic computer program was used to model of the consequences of a category three storm down there in Louisiana. And what it-- and they published it, and what they predicted would happen is almost exactly what did happen.

And it was given to-- it was given either to the government through the Corps of Engineers or to somebody that was in the Corps. And so the ethical issue was well, we knew that this was going to happen. Why didn't we do something about it? The answer gets ground up in political decision making.

But I think it would be a good project to uncouple all of that. So I want to leave that wide open for a little while. And if it looks like it's not going to settle in with anybody's particular interests, then I'll do a little bit on my own. Actually, there is a organization. There are several organizations here on campus about Katrina.

AUDIENCE: Right.

TAFT BROOME: One of them has to do with what I just brought up-- adding on one of the faculty members so I can get some stuff in case we need to do that. OK.

AUDIENCE: I didn't mean to cut you off about education-related ideas for term projects. Is there something specific?

TAFT BROOME: Well, we got a few more minutes.

AUDIENCE: No, I mean I didn't-- I haven't been thinking about education-related ideas for a term project for this class, but I'm just asking if there's something you were going to say.

TAFT BROOME: Well, I have-- yeah, I do have something to say about all that. My pet interest with respect to ethics and education in engineering ethics is public education.

AUDIENCE: Yeah, like public understanding.

TAFT BROOME: That's right-- like public understanding.

AUDIENCE: I'm really interested in that.

TAFT BROOME: And so I think that public understanding is not just a good thing. I think that public understanding is not just an issue for democracy. I think that it's a question of obligation, and that falls under Kant's theory that we have duties and obligations. And I think that experts-- I think that experts have an obligation to explain things in plain language, if they can, to the general public. So on that account, I think that fits into this class very well.

AUDIENCE: OK.

TAFT BROOME: I'm not the only one, but that's [INAUDIBLE].

AUDIENCE: No, I'm also very interested in that. My specific interest in engineering education is with K-12 students and their teachers, because I think that I'm not necessarily interested in creating more engineers, but just more understanding of engineering.

TAFT BROOME: Right.

AUDIENCE: Just like said.

AUDIENCE: Yeah. So--

TAFT BROOME: Incidentally, a student came to see me one day. This is before your tenure. And it was right before graduation. And she came in, and there's this phenomenon that occurs about once every four years or so, where usually there's a group of students come in. And usually they make an appointment. They're very serious. They come in, they close the door, sit down-- it's very private. I sit and wait. Somebody says something, OK?

On this particular occasion, she came in, but she had made an appointment. She came in closed the door, sat down, and was very disturbed. She said I'm going to graduate from engineering in a month. I said, right. She said, I don't want to be an engineer.

So I said, what do you want to be? She said something. I used to Plato's method. She finished. I said, what do you want to be? She said something different. I said, what do you want to be? And it kept coming down.

At the end, she said what she really wants to do in her life is to teach first graders. That's what she really wants to do. She came in engineering for all of these other reasons-- had to do with being able to prove to herself that she could do it, all sorts of other reasons. But now that she's done it, she didn't really want to throw it away, but she asked-- so that's the beginning of the story.

The end of the story is that five or six years later, she sent me an invitation to her PhD graduation at the University of Texas at Austin, where she got a degree in educational media, and she designed software for first graders. So she was able to put the two together. Now, I don't know if there's a strong moral issue in all of that, but it has more to do with destiny. And I did give a synopsis of her career in a paper once and had a picture up there.

But I say all that to say that sometimes you'll have to find these ethical issues. But I also say it because engineering and education-- and not just engineering education for engineers-- is becoming a pretty big thing. Someone was telling me just a few days ago that there-- I think Massachusetts is one. There are about five states that require-- oh, it was [INAUDIBLE]--

AUDIENCE: Yep.

TAFT BROOME: That require engineering be taught in high schools or--

AUDIENCE: Starting in kindergarten.

TAFT BROOME: Starting in kindergarten.

AUDIENCE: They were saying those frameworks that they get tested on in public schools include engineering. And this is an ethical-- or I don't if it's ethical, but it's an interesting issue, because these standards are put in place in 2001, and they got pushed through by engineers and experts on the outside of the school system.

And now the school system has the responsibility to teach engineering or the choice of making this the decision just to not teach it and therefore not prepare their students for the test. Anyway, without any resources to teach it, these outside people put these standards in place, and the teachers who teach kindergarten through eighth grade have never been exposed to engineering. So that's sort of another problem I'm interested in.

TAFT BROOME: Some of the professional societies got together-- not all of them, but American Society of Civil Engineers was one. And they published these what they call board resolutions.

AUDIENCE: OK, yeah.

TAFT BROOME: They're not passed through the general body as policy for the organization, but the board resolves. And one of them was that they resolved-- and this is interesting, because they resolved something they could not enforce. They resolved that there should be an engineer on the faculty of every high school in the United States. They weren't doing it just to be--

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Yeah, politicking for engineering, but because they thought everybody-- that they should be teachers.

AUDIENCE: Yeah, [INAUDIBLE] great teachers, because they understand where the math and science goes.

TAFT BROOME: OK, TMI.

AUDIENCE: Yes.

TAFT BROOME: All right. I think-- go ahead. Ms. Ratfliff, you were leading the discussion. Why don't you continue.

AUDIENCE: I think where we left off, we were talking about some of-- that there were two kinds of problems [INAUDIBLE] as well as [INAUDIBLE] facility itself. One of the issues that was brought up in our inquiry about it was the identification of human performance as a critical part of the design, and engineers doing that [INAUDIBLE] have to take that into account.

I was trying to frame it [INAUDIBLE] that we were talking about. I was not successful, but there was obviously a problem with people on duty. Their training [INAUDIBLE] it's a human being who is capable of making errors and misreading something, not understand, maybe is a little tired [INAUDIBLE] human errors that go on. So that was one interesting [INAUDIBLE].

AUDIENCE: Yeah, I'm struggling to figure out if committing a human error in an engineering system means that you've acted unethically. Are there ethical decisions or questions in that part of the Three Mile Island experience? And see, [INAUDIBLE] caused the accident--

TAFT BROOME: Right.

AUDIENCE: [INAUDIBLE] what to do once this happened.

AUDIENCE: Right, because I don't know why, but I didn't blame the people who [INAUDIBLE] And again, that's the thing with the engineers, that I don't know exactly what their background was. I'm just saying they weren't properly trained. I don't know.

TAFT BROOME: Well, at that time, who in the world was properly trained?

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Well, let's-- can I interrupt you? OK. As I told you before, that no matter what Aristotle said, I'm going to argue, and I will not be alone in arguing that an ethical decision is not entirely a rational or a decision based on reason-- that your emotions inevitably will get involved, and that's good, because feelings come from the effect, not from the cognition as I understand it. And you just have to do it. So you have to find some way to make a rational decision that agrees with what Abraham Lincoln called the better angels of your nature, OK?

And this is a good case where I think that on two accounts things happened that we really can't assign to individuals. And therefore, we have problems with Greek ethics or the classical approach. But they do not agree with the better angels of our nature.

And one of them is that engineers have problems with, and I can prove that engineers have problems with it. And that is engineers just find it difficult to rationalize ethical responsibility with competency. They mix the two together.

And I cannot find anywhere in any substantial ethical theory that we get from Greece or that we've built up from Greece that says that you are unethical if you're incompetent. But engineering sensibilities don't allow for that. Engineers, the older they get-- and I'm not just talking about age. I'm talking about experience. The older they get, the more they find it difficult.

And I'll prove it. Just look at the codes of ethics for their engineering professional societies. Competency will be in there somewhere, all right? OK, so that's first.

And I'll tell you one of the things that complicates the matter, and that was back when I was chairing this ethics committee that I told you about in the AAES. Some engineers that had-- and remember what I meant when I said responsible engineers-- engineers who had not only had the experience and the success in their lives, but who were pretty much authorized to speak for a large body of people, OK?

These people really had problems with this question of competency, because they said a small engineering company cannot survive if everybody has got to be an expert on everything they do. So you may have been graduated as an environmental engineer, and today you got a problem with whether or not this beam is deep enough to carry that load of that ceiling, and if you don't have the answer within a couple of days, you can lose the project. And they look at somebody and say, well, you just got out of college. You go do it.

Well, that's not an over dramatization. I can tell you some things that I've had to do that-- well, when I was in the army-- let's get this straight. When I was in the army, my first professional job in the army was to design the electrician's manual for the Department of the Army.

And when I got my orders, I got it from-- let's see if y'all know anything about the army. I got it from my-- I walked into my commander. I'm going to use some military terms. He was a bird colonel-- infantry officer. He told me to design that manual.

And I said, sir, I'm an engineer, but I'm a civil engineer, not an electrical engineer, OK? Most electrical engineers can't design the electrician's manual, OK?

And he looked at me, and his face and body language told me to do exactly what I did. I saluted, and said yes sir, and went out and designed that manual.

AUDIENCE: Wow.

TAFT BROOME: The good news is I got a nice little citation for it at the end, right? But if I had to stand before any ethical body that wanted to ask me about-- you knew you were not-- knew you were not competent to do that. And the Nuremberg Principle kicks in. That man with his rank-- and if you don't know what an infantry officer is, that's the one that's trained with hand-to-hand combat, OK? That's infantry. The foot soldier-- hand-to-hand combat-- the creed is follow me, right?

When that engineer-- when that officer said do it, he was coming from his basic instincts as an infantry officer. The enemy's coming over the hill. There's no time to be talking about "I don't do window."

[LAUGHTER]

OK? You do the job, all right? And engineering comes out of that tradition. So you learn a lot of engineering from that.

So no, a small company cannot compete if everybody has to be-- has to be competent in everything that they do. The ethical question then is, all right, if that's true, should we have small companies? Well, now you get into a lot of big issues now.

So he was very distraught about this whole business about competency-- that if you enforce that thing, then you'll only have the big companies. And a small company that can't even afford-- time notwithstanding to afford an expert in everything they do as a consultant, let alone as a regular person.

So you ask that question. Then you ask the question back with TMI, which is really important-- competency. And now you're talking about the kind of question that you ask at NASA, because they're cutting edge. All right, they're cutting edge.

Now there was a dramatization of all of this, and I made an assignment called *The China Syndrome.* And I did not say watch the movie, but did you find anything out about it? What does it say? What about it? When did it come out?

AUDIENCE: It came out--

TAFT BROOME: This is very significant.

AUDIENCE: --to the premiere, it was two or three weeks before the Three Mile Island--

TAFT BROOME: Right.

AUDIENCE: It's fascinating. It's fascinating.

TAFT BROOME: Right. Go ahead.

AUDIENCE: And the plot line is--

TAFT BROOME: Was almost exactly TMI.

AUDIENCE: --at a Chinese nuclear plant, there was an accident-- a near meltdown, I guess. And an engineer at the plant looked into the cover-up of the accident and found that sort of greed and corruption were motivating factors-- wanted to reveal it to the public, and found [INAUDIBLE].

TAFT BROOME: OK. Did they explain what the China Syndrome really is?

AUDIENCE: No [INAUDIBLE].

TAFT BROOME: I can tell you what it is. I'm not a physicist, but I can tell you what it is.

OK, when you think of a power-- when you think of a picture of a power plant, you probably think of these big chimneys that take out the excess heat. And they look pretty much like that. You've seen them from the air. Have you seen them from an airplane if you're flying?

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Pardon?

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Yeah, they have those big stacks everywhere that I know of, at least in this country. But if you're in a plane, you can fly over, and you can see them. They're always right next to a river.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: She's an environmental engineer. Well, that's a big issue, too-- dumping the waste in the river. But the actual radioactive process is being taken care of in another building, all right?

Now, this is the main distinction between the TMI case and the Chernobyl case-- Chernobyl case. Took Russian, so I had to get my pronunciation. And that is in the US, this particular building is required to be housed by a big concrete structure called the containment structure. So over it is this big containment structure. In Russia, they don't build it, and when Chernobyl went off, they did not have the containment structure. So that is an ethical issue.

Now a simple but not simplistic idea of what a nuclear power plant is, or at least the nuclear part of it is, is to liken it to an atomic bomb that's not exploding all at once. It's getting hot, but it's not getting hot in a short period of time-- a catastrophe. And they're keeping it down by putting in these control rods-- these carbon control rods. And that's what happened at TMI. They couldn't get them in there, right?

Now what they said about *The China Syndrome,* Hollywood got some physicists to do some calculations. And that was that if you have an explosion in here, and this containment structure is strong enough to keep a lot of-- to force a lot of the energy to come out the bottom-- there was a bullet. If a lot of it comes out of the bottom, then they say that there will be this hot bullet-like material that will be hot enough and move fast enough to actually penetrate all the way through the Earth's core and come out on the other side. And what's on the other side, if this is the USA?

AUDIENCE: China.

TAFT BROOME: So that's the China Syndrome-- that you're getting ready to make an atomic bullet. This is Hollywood talking.

AUDIENCE: Yeah.

TAFT BROOME: But they were not talking science fiction. And so two or three-- this movie comes out, and people are watching this movie. Jack Lemmon is starring in it, all of this. And people are watching this movie, and then two weeks later, you get almost the same thing playing out. And people are beginning-- and it really-- I can't overemphasize the effect that the two of them together had on the American public, let alone the world-- rest of the world. And I am not so sure that I fully appreciate it, even though I was there at the time.

And I went to work for the Nuclear Regulatory Commission that June-- June 1, as I mentioned to you before. And so there was-- I came into a situation that was very obviously not the everyday norm-- very obviously. Nobody could operate with that much energy-- human energy.

And there was a big issue at the time, because the United States wanted to gear up its energy production from nuclear power plants, and gear down fossil fuels, and all of this other thing that had been the subject a lot of controversy in the early '70s and the '60s-- the late 60s.

The other thing was competition with Europe, because France had decided to do the same thing. And even after this, the people in France were not as panicky about the whole thing as we were, and they went ahead with their program. This program was cut.

So there were a lot of people who stood to make trillions and trillions and trillions of dollars if this whole energy thing had turned over. There was a lot of people who would lose a lot. There were a lot of people who would not lose anything, because they would simply just change their market-- I mean their product. They had the money, the infrastructure. They've got a name for it in business now. They call it-- what is it? Not multidimensional.

AUDIENCE: Flexibility.

TAFT BROOME: Not flexibility. There's a common term that's used technically. But anyway, where you could be in the business of selling diamond rings if your business is big enough. And if nobody wants to buy diamond rings anymore, you can go into the business of automobile repairs. So just change over. There's a lot of discussion about that.

But anyway, so you had all of these issues impacting this TMI event at the same time. And very few people in the United States could keep a cool head over it. So what we're saying here is that, at least in the United States, the better angels of most peoples' natures was-- I mean, sorry-- resonated with this problem here, even though they could not find an individual that they could hold responsible, all right?

AUDIENCE: I-- go ahead [INAUDIBLE].

AUDIENCE: Well, do you think-- I mean, obviously the person watching [INAUDIBLE] we can't say he's ethically responsible for what happened. But do you think there's some responsibility on the part of the engineer who designed it-- who puts the design together to factor that in-- that you're going to have someone sitting there who may or may not know exactly what he's doing [INAUDIBLE]

TAFT BROOME: Ah.

AUDIENCE: And so that's kind of-- that was kind of my take on it, that [INAUDIBLE] support for engineers.

TAFT BROOME: I hadn't thought about that.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: They typically don't.

AUDIENCE: Like human factors in engineering isn't always considered.

TAFT BROOME: Well, I shouldn't say they typically don't. What they typically do is-- well, let's put it this way. If a design engineer was in here today-- not a professor, but one who does it every day-- we'd say, oh, we include all of that stuff in the safety factor. Well, once you include it in the safety factor, then you continue to include it when you want to reduce the safety factor to improve profit.

AUDIENCE: I would think that would be one of the first things to go actually when you're trying to--

TAFT BROOME: Well, you wound up down at the legal limit.

AUDIENCE: Yeah.

TAFT BROOME: And so I even had an experience with that on that first job I had a couple of weeks later. We were put putting steel down for the concrete, and steel bars had rusted. So I came into work the next day. This is a construction job. I came into the construction job the next day with one of my textbooks from school and said, see? We're not supposed to be putting anything in here that was rusted, because the notion--

How many people have ever taken any concrete? OK, let me give you a little background on concrete, because this structure here is concrete and steel-- steel reinforced concrete. Basically, let me just say this too before I forget it. My job was to review what's called a finite element program and to correct an error in it and to recommend it to NRC that, among other things, analyzed the ability of a containment structure to withstand a direct impact with an airplane.

AUDIENCE: Oh wow.

TAFT BROOME: And that's interesting after 9/11. And this was back in 1979.

AUDIENCE: Interesting.

TAFT BROOME: So what do they say, there's nothing new under the sun? OK. So that was my job, and that's a whole story in itself. And I'll tell you that story sometime when we have nothing else to do. That's a good story. So what was I saying?

AUDIENCE: The rusted steel.

TAFT BROOME: Oh, the steel had rusted. Let me give you a little background on concrete. First of all, concrete-- the Romans were the ones who more or less perfected the use of concrete, but they did not have steel reinforcement. Concrete is very plentiful, or the materials of concrete are very plentiful, and so therefore they're very cheap. And they can be molded into a lot of shapes, so architects love it.

The good news about concrete is that it is very strong in compression-- very strong in compression. And that's the reason that the arch is so significant. It's the second most important reason that the arch is so significant. The main reason that the arch is so significant is that it's beautiful. There is no human being-- excuse me.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Hi, excuse me.

AUDIENCE: Oh.

TAFT BROOME: We're going to have to close this door. We've got a class, but we'll be out at 5 minutes of 12:00. OK.

Yeah, I'm going to make a statement here that I'll stand by, even though I've never seen a proof of it. I don't think that there's a human being living or who has ever lived it doesn't find the arch naturally beautiful. The reason that engineers love the arch so much is that if you make it out of concrete, almost all of the loads are compressive loads. It's carrying a vertical load, but they come out at the edge, and the whole thing is in compression. So therefore, you can build an arch out of brick without cement in between if you do it right.

Concrete is also reasonably strong in shear. The bad news is that concrete is very, very weak in tension. So if you have a beam that's going to bend and have compression at the top and tension in the bottom, you've got problems in the bottom.

Now, how do you solve that problem? Well, if you still want a beam that's made out of concrete to carry tension, well the answer to that is that concrete is also an adhesive with metal steel. So it's not just steel when you put steel in there. It's not just in there. It bonds and becomes part of the structure.

So if you are building a structure like Stonehenge, and you want the whole thing to be concrete, and this particular beam is going to sag under its own weight, and you've got tension over here and compression down here, then what you do is you come along and you put steel in the bottom. Now, that adhesion is enhanced by putting ribs on the bar. So when if you pass by a construction site and see the bars, they're not just smooth bars.

Also, the adhesion is weakened by rust. So I asked this old engineer. I said we can't be-- what are we going to do about all that rust down there? And his answer was straightforward. The safety factor takes care of all that.

AUDIENCE: Meaning it's overdesigned enough that--

TAFT BROOME: Yes. Well now, the more we cut costs, the more that becomes a real factor. But back in-- this was in 1966. Overdesign was something people did just as a matter of norm to cover for all of these field problems. So the issue comes out now with all of this competition and design right up to the edge as to whether or not they're taking into account these field conditions.

But in the old days, they had liberal safety factors. They would look at the law, and if the law said 1.6, they would do 1.8.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: I don't know what it is now. They probably do 1.6 right down to--

AUDIENCE: [INAUDIBLE]

TAFT BROOME: Well, what they'll say nowadays is that the technology is so high that you can design right down to the safety factor, and that there's not a whole lot of field conditions, so to speak, because everything is controlled so much better now than then, OK? And I say that in sort of a snide way of saying it, but I don't mean it entirely, because a lot of that's true.

I say it in a snide way, because you're supposed to listen to that. You'll find that a lot of it is true, but you should not take anybody on their word for that. If you ever have to look into this kind of matter, don't say that that's not a place that I will not look. That's the place to look.

But yes, they are right. A whole lot of these field conditions are much better controlled now than they used to be. But there's always this thing in engineering when you're going beyond the envelope. And when you get beyond the envelope, what do you do? Get back to the same old problem.

OK, so let's put TMI down for a moment, or for a while, and say that what really happens with TMI is that, so far as engineering ethics is concerned, we have a problem rationalizing Western ethics with what our sensibilities tell us is a group or a cultural problem. And when we get to the narrative approach, I'll have something to offer on that. What I have to do is get outside of the Greek paradigm.

OK, how about it, Ms. [? Beth, ?] do you want to bring us up to Chernobyl?

AUDIENCE: Sure. So in 1986, there was-- at a nuclear plant in Russia, the nuclear reactor overheated in a more severe way than at TMI, because their plant isn't water cooled. They used graphite, I think, to cool the nuclear reactor.

TAFT BROOME: Rods-- graphite rods they're putting in.

AUDIENCE: I think.

TAFT BROOME: Carbon graphite. They used graphite to trap the neutrons rather than water. So in the American system, the nuclear core is covered with water to take away the heat. And to my understanding, in this Russian design it's covered with graphite to cool the core. So this just means that it's harder to react when the nuclear core starts to overheat.

But the more important thing-- so this reactor started-- the core started to have a meltdown because the operators shut off the-- so it says the--

AUDIENCE: [INAUDIBLE] shut down the reactor, and then I think there was a power surge of some kind.

AUDIENCE: Well they didn't-- it says they didn't shut-- so they wanted to see how long the turbine could run without getting steam from the nuclear reactor. And what they should have done is not just shut down like the steam supply system, but shut down the reactor, too. But they were unwilling to do that, because in the Russian design, if they shut down the reactor, then it would take days to power it back up because they had to let some [INAUDIBLE] dissipate.

So anyway-- so they like shut off the steam supply system to see how long the turbine could run, but they didn't shut down the reactor totally. And they also shut down the emergency systems, because they knew the emergency system would go off because if the action they were taking. They thought they could keep it under control and do this test of how long the turbine would run. But they couldn't keep it under control. So that's sort of my understanding of it.

TAFT BROOME: All right, let me mention a few things, and then let's go back to the discussion. Number one, this was in 1986, which is only seven years after TMI. So people said, oh no, not another one.

Secondly, it did not have a containment structure on it, so therefore now you have to worry about fallout. So you're--

AUDIENCE: No, and like 30 people were killed by the explosion.

TAFT BROOME: Yes. So people were--

AUDIENCE: [INAUDIBLE]

TAFT BROOME: People were killed on site.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: And the rest of us were worried that the fallout would come in the atmosphere all around the world. So therefore, the affected parties now would not just be us and China, but that you would get something going all around the globe.

There is another report that there were some heroes involved in all this, and that some of the plant operators, after it occurred, went back in there to try to bring the system under better control. And they lied about the amount of radiation that their suits were programmed to take. In other words, they were taking a lot more radiation, and they did it anyway. So some people say that was sort of foolish, but a lot of people say that sort of heroic. And there are a lot of people who-- a lot of cancer cases broke out right after that from people within about a 20 mile radius.

Now, is there an ethical issue in all of this? Was there any person, or was it something more like the system or groups of persons?

AUDIENCE: It seems easier to assign individual blame in the cause of this accident, because the operators consciously made decisions to turn off emergency systems and run this test that was not really regulated.

AUDIENCE: But then we go back to the competency, because I think they honestly thought they were doing the right thing. I mean--

AUDIENCE: Yeah, I don't. I read one article that said they just wanted to-- they wanted to test the limits of the system-- in that article. But they knew they weren't doing the right thing. So yeah, I don't know. But it's possible that they thought they were doing an important test, and--

AUDIENCE: Yeah, I think they thought everything was going to be OK, [INAUDIBLE] I think they thought they were.

AUDIENCE: So there wasn't any malicious intent, right?

TAFT BROOME: Well now, I'm going to use a word here that is not out of line, I think, for this case, but might be a little bit strong. There's a tendency for engineers to be a little bit arrogant about what we do. Ah, I got this under control.

Now, I'm worried about something you said, and that was it goes back to this problem of well if they shut the whole system down, it would take days to bring back up. Is that a good reason?

AUDIENCE: Not to shut it--

TAFT BROOME: Not to shut it down.

AUDIENCE: Hmm. Not if you significantly increase the risk of an explosion at the core by not shutting it down. So I guess the debate is if you shut it down for a few days, then you're not producing any electricity. You're not generating profit during those days when it's shut down.

AUDIENCE: [INAUDIBLE]

AUDIENCE: No, they could have done the experiment.

AUDIENCE: They probably [INAUDIBLE] shut down [INAUDIBLE].

AUDIENCE: Right.

AUDIENCE: [INAUDIBLE]

AUDIENCE: Right, but I couldn't find any reason why the experiment was necessary. Like the facts they wanted to get was how long would the turbine run without being powered by the reactor. Like why is that worth risking [INAUDIBLE]?

AUDIENCE: [INAUDIBLE] They would have to put [INAUDIBLE] have an inherent risk of [INAUDIBLE]

AUDIENCE: But if you know you're getting away with something, shouldn't you stop and think about the ethical--

AUDIENCE: Well, that's like [INAUDIBLE]

AUDIENCE: Yeah, that's your view [INAUDIBLE]

TAFT BROOME: Well, I think what I think-- I think it is possible to get so overwhelmed with the engineering questions that you can forget the human questions, as if any human is different from [INAUDIBLE]. You can forget the human questions, even if they involve your own life, because that's what they were. These people were the affected parties.

AUDIENCE: Yeah.

TAFT BROOME: Well, the question of--

AUDIENCE: And they really wanted to know engineering.

TAFT BROOME: And they might have had their families living within 20 miles. They did it. I mean, they did it without going-- you see, that's what this whole thing is about. When I came into this class the first couple of days and put those pictures-- those Raphael pictures in there, getting into the right mindset-- if you get into a mindset where you are bringing the people out of the picture, then the moral questions don't come up.

Let me give you two real quick experiences that I think bear on this, then I think we can make an assignment.

AUDIENCE: Can I ask a quick question?

TAFT BROOME: Yeah.

AUDIENCE: Do you think [INAUDIBLE]?

AUDIENCE: This kind of goes back to one of the things I was looking to do. I've [INAUDIBLE] for a few years [INAUDIBLE]. And they attribute this to the Cold War, because this was a direct consequence of the isolation that had occurred and then not being aware of the superior designs that were available.

And so I thought that was an interesting take on it, too-- that there is some kind of ethical responsibility. You have to have some kind of agreement with the scientific community, open, aware of what's going on. You can't [INAUDIBLE] and let other people [INAUDIBLE].

TAFT BROOME: That's an interesting twist.

AUDIENCE: Yeah.

TAFT BROOME: Yeah. There was a lot of secrecy going on in those days, but there was a lot of-- there was a lot of information being passed, too. Because to know that a nuclear facility exists is easy to determine. To know that one exists without a containment structure is easy to determine. For them to know that all of our nuclear facilities have containment structures is easy to determine.

AUDIENCE: So they knew that.

TAFT BROOME: They had to know. They had to know. They might not have wanted to spend the money, because you're talking about, I don't know-- I would say the word billion is about right-- billions of tons of concrete. But you're talking about a lot of concrete and a lot of steel, and you save a lot of-- you save because that's armament. You're really building a bunker, so one could argue that the Soviets really didn't want to spend the money.

AUDIENCE: Yeah, and maybe part of the isolation is also in not adapting the same [INAUDIBLE] the rest of the world. had maybe jumped [INAUDIBLE] other implications. And, I mean, I think he attributed it to some of the flaws in the design also, but maybe even just that way of thinking about it when you have to [INAUDIBLE].

TAFT BROOME: Well, there's another thing, too. When you get out of the United States, it's easy to go someplace where a lot of people don't think about the individual as being so important as we do. Some people say that the state is more important. Others say that, well, the state is not more important, but you are a better person if you can get out of this individualized, individualistic mindset and start thinking about the whole. And we'll talk about that when it comes to mythology, because mythology deals with both mindsets.

Let me give you two experiences, and then-- how about-- y'all are ready for this. Can you do an analysis of-- we went through TMI more thoroughly than we did Chernobyl [INAUDIBLE]. You all do a paper on Chernobyl-- analysis on Chernobyl.

AUDIENCE: So like we did for the [INAUDIBLE].

TAFT BROOME: If you go outside--

AUDIENCE: Did people take right actions?

TAFT BROOME: Yeah, you're going to have to, on this one, talk about somebody who made the decisions not to bring in that safety or the emergency system.

AUDIENCE: OK.

TAFT BROOME: Unless you think of something else you want to deal with, but at least that one. And do both the archeological analysis and a utilitarian analysis.

At this point, if you don't want to do Mill as a consequentialist view, and you've got another one you want to use, that'll be cool. That'll be OK, too. See what you can do with this one.

Here are some things to take into account. Now back when I was an assistant professor, as Henry said, when the dinosaurs still running around at that--

[LAUGHTER]

Well, let's put it this way. There were people who reported having seen them.

I had a master's student. This is a long story. I'm going to bring it down to a short story, but I'd like to tell the long version of this story sometime. I had a master's student who was interested in the problem of having a concrete wall with a load on the top of it supported at the bottom. And the question was if you continue to put the load on this thing, how much load can you put on it before it buckles out?

Everybody got a picture of what the problem is? You've got this load. You put the load, and it gets more and more, and after a while the thing buckles out. But like concrete, this load-- this material does not have tensile strength. And we're talking about putting it in an underdeveloped country that can't afford the steel or the steel workers-- the steel workers being expert workers that charge a whole lot of money per hour.

So we want to see what this critical load is-- the buckling load, this critical load-- for a concrete-- or any other kind of structure that does not have tensile strength. And you're just building up. Actually, you'll find this problem turns out to be an interesting problem even today-- even to this day in Italy with the restoration projects, when you have all of these concrete blocks that were put on top of each other with no cement, and they don't have any tensile strength.

And the leader of all of that is a woman by the name of [? Anna ?] Sinople-- S-I-N-O-P-L-E. She has been for many years. I guess she still is.

And what we found out was that if this is the height and this is the width, that-- I'm sorry-- put the width over height, and put P, critical-- that you get-- this turns out to be a nice nonlinear problem. This is a master's student. We got a differential equation-- highly nonlinear. And we used a technique called finite differences, and we got a curve like this.

So I said, this is a good paper. So I submitted it to the *Journal of Structural Division* of the American Society of Civil Engineers. And that was bold, because that journal and the journal of the mechanic's division were turning down 67% of the articles coming in from PhDs. This was a massive [INAUDIBLE].

And they wrote back, said they want to publish this paper, but this curve is so complicated. How can we give it to a designer in the field? Can we simplify it? How can we simplify it in such a way that we can code it as a legal formula? This thing has no formula.

So we went back, and what we said was that for any width over height ratio, as long as the critical load is below the curve, you're safe. So what we did was we plotted a straight line under here and got a nice straight line formula. They said beautiful. They published.

Suppose you're an engineer on a job. Your ratio is right here. The straight line curve, which is now law, says that you have to be under this amount. But you get another a situation like Chernobyl. Ah, it's still safe. I know what the law is.

We'll be out-- we'll be out at 5 of.

AUDIENCE: 5 of?

TAFT BROOME: Yeah, according to my watch we got about three-- about four or five minuted.

AUDIENCE: Oh yeah, I'm sorry [INAUDIBLE].

TAFT BROOME: But you do have a meeting. But we'll be out at 5 of 12:00.

AUDIENCE: [INAUDIBLE]

TAFT BROOME: OK. All right, I know what the law says, but I read this paper. And we can go up to around here and still be just as safe. We agree it's illegal. Is it immoral?

So I think that those engineers in Chernobyl were thinking like this. They knew what the law is. They know what the theory is. They can break the law. Should they have broken the law?

If you do not include this in your paper, that's fine. I'd like to see [INAUDIBLE]

AUDIENCE: This case of [INAUDIBLE].

TAFT BROOME: No, the case of Chernobyl-- this kind of thinking of [INAUDIBLE].

AUDIENCE: OK.

TAFT BROOME: OK, anything else? All right, then I'll see you on Tuesday. And with your permission, then I'll let these other people in. Yeah, thanks.