MICHAEL SHORT: We've actually got a special guest today. It's Jake Hecla, one of the seniors at NSE who's gone on to Chernobyl for the second time, just returned from there two weeks ago. So if you remember on Tuesday, we went through all of the physics and intuition about why Chernobyl happened. And we left off on what does it look like today. So Jake is going to tell you what does it look like today.

JAKE HECLA: All right, so first off I'm actually going to go over a bit of the reactor physics involved with the Chernobyl accident. I realize you guys have already covered this to some extent. But I didn't plan for that. So it's in my presentation.

MICHAEL SHORT: It'll be a good review.

JAKE HECLA: Yes, also I am a little sick. So I'm probably going to start coughing, apologies. I'm not dying. It's just a cold.

AUDIENCE: Radiation poisoning.

JAKE HECLA: I have heard that joke about eight times in the last two days. And I'm so done with it. But yes, it's not radiation poisoning.

AUDIENCE: [INAUDIBLE].

JAKE HECLA: Yeah, all right, where is Chernobyl? Ah, dang it. Come on, no, go the other way, the other way, yep. OK, there. OK, so one of the first questions I got when I said I'm going to go and visit Chernobyl is wait, isn't that a war zone? Not quite.

So the Ukrainian, the war in Ukraine is mostly in this portion over here. It's not entirely under Rebel control in that area. And I say "rebel" in quotation marks because rebel means Russian. However, if you notice those arrows, Russian forces are built up all along that border. So while it's not an active war zone, it's certainly not a place to be spending a large amount of time.

That said, Chernobyl is north of Kiev by about, I don't know, let's see, 200, 250 kilometers. So it's not completely out in the sticks, right. Hopefully this gives you good sense of roughly where it is.

All right, so what is the Chernobyl nuclear power plant look like? It consists of four finished reactors. There are two unfinished reactors, unit 5 and 6, that are not shown in this image. Units 1 and 2 are located at the right. Those were constructed in the 1970s and early 1980s. All of these reactors or the RBMK type.

Units 1 and 2 operated with some success-- I'll go into that later-- for a number of years before the accident that happened in 1986. We also had some call outs up here that show the, some of the incidents that I'll talk about here a little bit later in the presentation. But this just gives you a general idea of the layout.

So it's two separate buildings for units 1 and 2. And then units 3 and 4 are in one building, all connected by this turbo generator hall. So this is where the generators that turn the steam from the RBMK into power, r. This is one giant-- well, before the accident, this was one giant, not separated hallway, basically. So you could walk from one end to the other, theoretically.

All right, so what is an RBMK? An RBMK is a light water-cooled, graphite-moderated, channel-type reactor. This means that it does not have a giant pressure vessel like you would see in a VVER or an equivalent American light water reactor.

Why does that mean anything? Well, building giant pressure vessels is very difficult. If any of you've done research on manufacturing of nuclear reactors, you'll find out that the equipment necessary to construct a reactor pressure vessel is not actually something we even have in the US anymore. Is it Korea that does it for us now?

MICHAEL SHORT: Japan Steel Works.

JAKE HECLA: Japan that does it now. In the Soviet times, it was very, very difficult for the Soviet Union to produce such pressure vessels at any kind of reasonable rate. So the RBMK got around this by using individual channels that were their own pressure vessel, so to speak.

So the way this works is, let's just start on the cold side. You take in cold water, goes here through these things. These are main circulating pumps-- MCPs, as you'll see them referred to later in the presentation-- goes up through the bottom up the core. These are the hot fuel rods. The water goes from liquid to steam phase as it's flowing through the channels, comes out the top, goes to the steam water separators. Steam goes to the turbines, turns the turbines, makes electricity.

The important thing to remember here is that we've got a giant graphite core. The graphite is what is doing the moderating in this circumstance. It is not the water. This allows you to run very low-enriched uranium. So you could theoretically run an RBMK on I believe it was 1.2 percent was as low as they could go. But regardless, extremely low-enriched uranium, which is convenient if you don't want to waste a lot of time enriching uranium.

The problem with this is that you have a giant core. If you recall the scattering cross-section for graphite, it's pretty small. And the amount of energy lost per collision is likewise also fairly small. So the core on this thing is, let's see, 11, yeah, 11.5 meters across. The core for an equivalent American reactor-- so well, there is no real equivalent to this-- but for, let's say, an AP 1000 reactor of equivalent electrical output, is about four meters across.

So the core is huge. As I already discussed, this is what the individual pressure channels look like. So cool water comes in the bottom, goes by the fuel rods, pops out the top.

The RBMK had some serious design flaws. So as I said, the core is huge. This allows local power anomalies to form really, really easily. If you look at the core, one portion can be kind of neutronically separated from the others because neutrons just don't make it all that far when diffusing across the core. So you can have very, very high power in one corner and very low power in the other, which is not something that can develop in a physically smaller core, which has a characteristic scale equivalent to that of the neutron being free path.

Further, the encore flux monitoring on the RBMK is seriously deficient. So there are a variety of neutron detectors that exist around the periphery of the core. But they're wholly insufficient to catch these local power anomalies.

Chernobyl actually found out the hard way on this one. In 1982, unit 1 suffered a quote "localized core melt," not really something that can happen in LWR, really any other type of reactor. But a couple of the fuel channels actually experienced one of these local power anomalies and ended up melting.

So if you go into the control room of unit 1, you can see that on the fuel channel cartogram on the wall, there are two of them that are just Sharpied out. And those are the ones that melted.

Further, it has a positive void reactivity coefficient. What does that mean? Well, when the water boils in the core, the density of the water there goes down. And the power of the reactor ends up going up because the water is primarily acting not as moderator but as a neutron absorber. This is bad for a whole variety of reasons. And they found out quite catastrophically in 1986 exactly why. Further, the system is extremely unstable at low power.

So how did the 1986 accident happen? It was part of this thing called a turbo generator rundown test. The general idea is that if you have an off-site power failure, and your main circulating pumps are no longer have off-site power, you somehow need to keep water flowing through the core, such that the fuel does not melt.

The problem is that the backup, large diesel generators, are just that. They're large. They're diesel. And therefore they're very, very slow to come online and come up to full power.

The way that you can bridge this gap is by using the energy that you've stored in the turbines to effectively power the main circulating pumps until the diesel generators can come up online.

When unit 4 was fully constructed in 1983 and turned on for the first time, they had never actually done this test where they did a turbo generator rundown, despite the fact that it was required by law in the Soviet Union that all new power stations should have this test performed. It was delayed until 1986. And yeah, it was delayed until 1986 is the long story short.

The test procedure-- sorry for all the text on this slide-- is basically as follows. So you would ramp the reactor down. So you would bring it from a normal thermal output of up to 2,400 megawatts thermal, down to 600 or 700 megawatts. You'd bring the turbo generators up to full speed. So you'd store as much energy in them as you possibly could, then cut off the steam supply such that now you are just extracting energy from the spinning turbo generator.

This would then be used to power the main circulating pumps, each of which took about 40 megawatts. There are eight of them total. I believe six could be used for normal operation.

The rundown would take somewhere in the range of 60 to 70 seconds. And hopefully by this time your diesel generators would be turned on, pumping water, and everything would be fine.

What happened in the test was decidedly quite different from that. So on April 26, 1986, they attempted to begin this test about six hours behind schedule because there was an incident in another part of Ukraine, in which a coal power plant went offline.

So what happened was the authority for the grid in the area ordered that Chernobyl should stay online at full power for an additional six hours. They began the test by bringing power down. But as a result of running for an extra six hours, they'd built up a significant amount of xenon precursors in the core. So when they started turning the power down, the power started going down, and down, and down. And they were unable to arrest its drop.

What ended up happening was that the power dropped all the way down to 30 megawatts thermal. And the reactor operators kind of panicked. Their response to this, instead of canceling the test, was to pull out as many control rods as they could get their hands on. They did so. And this managed to rescue the thermal output of the reactor. And it bumped up to around 200 megawatts thermal.

At this point, the reactor was in an extremely unstable state. Mind you, almost all of the rods that they could get their hands on were out of the reactor. The only thing keeping reactivity at a reasonable level was all the xenon that was built up in the core.

At this point, they began the turbo generator run down test. They shut off steam to the main turbine, or one of the turbines after it was run up to full power, and then attempted to run the main circulating pump.

The main circulating pump started drawing down the energy from the spinning turbine. And as a result, it ran slower and slower, meaning that the flow through the core was less and less, more water boiled, going into steam, which increased the reactivity.

As a result, the power output of the court went up. It burned out more xenon. And the cycle continued. They noticed a power excursion, about 40 seconds after they began the test and at this point recognize they were in bad territory and hit the scram button. This would jam pretty much all of the available control rods into the core, including some emergency extras, and shut everything down. In most circumstances, this would be a fairly safe move. But in the case of the RBMK it was most certainly not.

RBMK control rods have a graphite tip on them. When jammed into the core, they caused a localized power increase because the graphite is a great moderator. And it is displacing water, which is a great absorber. And as a result, after they made it a couple meters into the core, the increased pressure in the core from the power output, which was localized around the tips the control rods, ended up shattering the control rod drive mechanisms.

And instead of turning off, the cycle basically just continued, power continued to ramp up over the next couple of seconds. It eventually reached somewhere around 10 to 20 times the maximum rated thermal output of the system. And a massive steam explosion ended up ripping through the facility.

It tossed the 2000 ton biological shield on top of the reactor through the roof of the facility. It injected a significant portion of the fuel, as well as the moderator in the core. And it started a massive fire around the facility.

Just to give you a good sense of scale, let's see, if I've got the virtual laser pointer. That's a person right here, this little guy. This is the top of the biological shield, Elena shield. And then this is a model, a cutaway model of the Chernobyl reactor facility with the shield, and with the flipped shield that went up through the roof and came back down. So as you can see, it was an utterly massive explosion.

So the damage to the reactor was immediately quite catastrophic. Moderator blocks, fuel was spread all around the immediate area. If you look in this photo, it's rather difficult to see. But at the bottom of that column of smoke you can actually see the bottom up the biological shield. Kind of gives you a sense of the scale of the damage to the reactor.

After the explosion happened, actually none of the operators believe the reactor breached confinement in any way. They didn't really have an immediate way of seeing what had happened. So they open the door and went to the main turbo generator building to investigate the damage. They believed it was perhaps one or two ruptured fuel channels. As it happened at, I believe the Leningrad, I think it was the Leningrad power station a few years earlier.

In the few seconds that they were there, they received fatal doses and died in the hospital in May of 1986. This is a photo from control room of reactor 4, showing a jammed control rod drive at the 6 meter position. So this was probably a rod, let's see, this is probably a rod coming up from the bottom, in that it, seven meters would be all the way out. Zero meters would be all the way in.

The initial response to this, despite the fact that the reactor operators were not yet dead, did realize that it was a full breach of containment, was the response was to an accident that was non-nuclear in nature. So when the fire department got a call from the authority at Chernobyl, the message that they received was there's a fire at the reactor complex.

As a result, what they showed up with was not equipment suitable for a hazmat situation in any way. That said, there's pretty much nothing that could shield anyone from the extremely high radiation field that one would encounter around the reactor in the immediate aftermath of the accident. But nonetheless, they were extremely vulnerable.

It was night when this accident happened. As I mentioned, this happened at 1:23 in the morning. They actually couldn't see the extent of the accident. And they initially believed that it was just a fire on the roof of the turbo generator building. They attempted to fight the fire. And some of them actually succumb to acute radiation poisoning, or acute radiation syndrome, almost immediately. A number of firefighters went up on the roof and just didn't come back.

The aftermath of the accident, the cleanup was handled by the Soviet Army. The people that were involved in this were known as the liquidators. They would spend several minutes on the rooftop of the turbo generator building, or up near where the reactor was, the reactor containment building was. And they would receive a, effectively a lifetime dose, which I believe was, I believe their limit was 50 REM. And that would be a couple of minutes up there.

Let's see, this photo doesn't show much evidence of it. But I suppose it shows a little bit of evidence of it. If you look around the bottom up the frame, you can actually see a little bit of hazing in kind of a periodic fashion. Let's see if I can get my pointer on it here, here, here, here, and here. That's the gear that moves the film is actually shielding the film from radiation exposure at those points.

The radiation dose rate was so high up there that most of the pictures that were taken just didn't turn out whatsoever. A few smarter photographers used a whole lot of lead and were able to capture photos like this. But nonetheless, the dose rates were tremendous.

The reactor structure itself was entombed in this thing that we call the sarcophagus. People in Ukraine call it the object shelter, or the shelter object. It was constructed in starting almost immediately after the accident, basically to keep radioactive graphite and fuel fragments from leaving the reactor structure and contaminating any more land.

This is a photo from when it was under construction. Basically what it consisted of were steel and concrete walls that were erected around the reactor, using a variety of technologies. They at first attempted to use robots, that were almost immediately rendered useless by the high radiation field. Later on, they ended up using quote "bio robots," people, to move things into place. As I've said before, a whole lot of people died in this accident both immediately and after, many during the construction of the sarcophagus.

Actually during the initial firefighting, or yeah, the initial firefighting measures, as the core remained burning for a number of weeks after the accident, they attempted to put it out with bags of sand dropped from helicopters. And during that effort, a helicopter actually ended up hitting one of the cranes that they were attempting to use for this and falling into the reactor, and a good portion of its remains remain entombed within the sarcophagus, from what I understand.

All right, so my visit to Chernobyl, why would anyone ever want to go there? The primary focus was to learn about radiological decontamination at the site, basically how is contamination control managed, how do workers stay safe. Mind you, there are 3,000 people that go to work there every day. And what are the strengths? And what are the shortcomings of their radiological program? It was seven days total, four of which were on site. Other days were spent in Pripyat as well as in some classroom training, which I've got great photos of.

So this is a slide stolen directly from the PowerPoint that I was sent on day one. But this was organized by three people, Carl Willis, Erik Kambarian, and Ed Geist. I've known Carl for a few years now. He lives in Albuquerque, New Mexico and is a radiation safety officer at a company that, I think they do advanced energy storage technologies. I'm not exactly sure.

Erik is a firefighter and specializes in radiation emergency response. And Edward works at the Rand Corporation and does nuclear history and nuclear security research.

This is the team this year. So we've got, let's start here. This is Lucas. He does environmental radiation monitoring. That's me after having no sleep because I did a 22.611 p-set the night before. I know. I looked so happy to be there.

This is Nathan. Nathan builds organs, as in the musical instrument. He was along because he's always been interested in Chernobyl but didn't really have any experience in the field. This is Stanislaus. Stanislaus was our guide from the Chernobyl authority. He's been working at the plant since 1991 and is a fantastic resource for information. This is Ed, who I believe I talked about earlier. And this is Ryan Pierce. I'm not really sure what he does. This is Iris, who is a friend of Carl's and works in, believe radiation oncology. And then Danell Hogan, who's an educator based in Phoenix, Arizona who works with the DOE.

By the way if you're wondering why we're all wearing those absurd robes before we were going to go in to another room and change into basically coveralls, which are easy to decontaminate.

One of the activities that we did was real decontamination training. So that is a truck from the Novarka work site, which, by the way, that is me with a Geiger counter. I'm surveying for contamination. We then pressure washed the truck. As it turns out, there's a very specific technique one needs to use for pressure washing when you're dealing with a contaminated object, so as to not blast contaminated dirt up back onto the truck.

This was a very interesting experience and also one that was very entertaining for the workers involved, because they don't actually wear that when they're doing decontamination because their respect for safety protocols are, shall we say, a bit different. So they got to see us where the absurd rubber ducky suits while they stood by smoking and laughing at us. I believe you can actually see the corner of that guy's jacket back there. And he's just wearing everyday clothes.

We also went on the new safe confinement work site. So I haven't talked about it earlier in this presentation, but I suppose I should have. There is a object called the New Safe Confinement Arch that consists of basically a giant stainless steel structure on rails which is being slid over reactor 4 so as to prevent the spread of any sort of contamination from it.

This is known as the New Safe Confinement, or NSC, arch. It's been under construction since 2007. And it just moved for the first time, actually while I was there, so on the 12th of November. It's supposed to last for 100 years. And hopefully in that kind of time span they'll be able to take apart what remains of the reactor.

So actually what you see here is the corner of the sarcophagus. And then if you were to pan over this way a little bit, you'd see the right set of tracks for the New Safe Confinement Arch.

We also did some classroom training. Admittedly, the classroom training was the most disappointing part of this. The instructors were not particularly interested in showing us really anything other than YouTube videos and other things that would just waste our time. That was the one part of this trip that I did not enjoy. Regardless, we did get to learn a little bit about the various hazmat getups that folks would wear when working on site.

As I mentioned we also got to visit Pripyat, which I have more photos of later, as well as the reactor 4 control room, which is inside the sarcophagus, which is quite a treat to visit. The reactor 4 control room is not terribly contaminated as a result of the decontamination efforts. During the accident, the dose rate would have been somewhere in the range of 5 to 10 rem an hour. But today, it's in the range of 10 mrem an hour.

This is the New Safe Confinement Arch that I've been talking about. This is actually a photo from 2015 with a clip art Statue of Liberty on it, but to give you an idea of how huge it is, 5 meters taller than the Statue of Liberty. And it's on rails, which is interesting. It's actually too big for wheels. So it's not on rails like with wheels on them. It's on rails with giant Teflon scoots.

This is the inside of the turbo generator hallway. Remember that long building that I showed you that connected reactors 1 and 2 and 3 and 4? This is right outside the reactor 3 part of it. There are-- I think I'll show you these photos later. There are chunks of the turbine from reactor 4 that are down here in this area that are quite visibly radioactive and are very easy to detect if one swings a Geiger counter about.

Within Pripyat we also visited a hospital 126, which is where the firefighters went immediately after the accident, that is, the ones that made it off the roof. This garment here, we're not exactly sure what it was because none of us were going to really touch it. But we think it might have been part of a cover-- it would go under one's helmet-- was extremely radioactive. It was contaminated with alpha, beta, and gamma, which is fairly unusual. Alpha contamination is fairly rare around the Chernobyl site, and was somewhere around 50 to 75 mR an hour on contact.

I think I already showed you photos the control room. Yep, unit 4, that's the cartogram, so that would display various parameters of the reactor for each fuel channel, depending on how one configured it. That's an external photo of the sarcophagus.

And I think that's it for the PowerPoint slides. I do have a bunch of photos though that I think you will find interesting. I apologize if it's a little disorganized. This was put together relatively recently because, well, I just got back from Chernobyl. And then I went to a conference. And then I came back here and tried to get work done.

Right, so these are in chronological order roughly. I'll go through and hopefully tell you guys a little bit about what the site's like.

MICHAEL SHORT: [INAUDIBLE].

JAKE HECLA: OK, so this is on day one. We're driving to the Chernobyl nuclear power plant site. That blue and white bus is pretty much what everyone uses for transport around there. All right, so we're not really supposed to be taking photos in this area. So everything is tilted because it's taking them out the window with the camera like that.

That's the New Safe Confinement Arch. It's in considerably better shape than it was last year at this time. They have done a fantastic job of putting it together. It's actually almost a year ahead of schedule. There it is, again. You can see the sarcophagus with the new support wall, which is that right there.

All right, so this is our excursion into Pripyat on our second day. So this is the group led by Stanislaus. As you can see, there's not very much left. Just in comparison to what we saw last year, the number of buildings that had been taken apart for scrap metal, illegally, of course, was pretty huge. In, I don't know, 5 or 10 years, it's going to be very difficult to see much of Pripyat at all, frankly.

So this is a standard apartment block in Pripyat. As you can see, a lot of broken windows. A lot of bricks have fallen off. These things are pretty dangerous. A lot of tourists do go into them. If one decides to do a tourist expedition to Chernobyl-- which I don't particularly recommend-- don't go in the apartment blocks.

This is on the way to one of the schools. This is Lucas who has more detectors than anyone I've ever met. He was wearing 7 at the time. So I had to take a photo of him. This is Iris imitating some of the graffiti, which unfortunately has popped up all over the place.

Pripyat itself is really decaying quickly. As I've said, there's a huge problem with looting. In addition, there's a huge problem with graffiti and vandalism. It's really depressing, honestly, to go there and see how much has changed just in a year.

So despite my earlier warning, we did go in an apartment block. This is just a measurement showing that the background up there actually is not terribly high. Yeah, that's Iris, not particularly safety conscious at times.

This gives you a good idea of how far away Pripyat is from the reactor. That is not very far, about two kilometers. So you can see the New Safe Confinement Arch to the top left of the detector. Background there is about, in this particular apartment block, at this particular time, was about four to five times what you would see in downtown Cambridge.

There are wild animals in Pripyat and the rest of the exclusion zone. This is a huge problem. So despite the fact that the cats are very cute and the puppies are very cute, they also have rabies, not all of them, but a very large number of them. In 2009, five workers were injured by, I kid you not, a rabid wolf. There's a YouTube video of this you can look up on your own time if you so wish.

This is because Ukraine doesn't have a lot of money. So they have not been able to continue with their vaccination program. They actually use baits that have a rabies vaccine in them to normally suppress rabies in wild animal populations. But Ukraine doesn't have any money. They killed the program about five years ago. And as a result there's a huge, huge problem with, especially rabid foxes. Because everyone thinks foxes are cute, especially tourists. And foxes, when they get rabies, some of them go through a stage in which they appear to be very friendly.

As far as I know, no one has gotten rabies from a rabid animal at Chernobyl. But it's certainly a possibility. So Stanislaus was being a very bad example by feeding one of the wild cats. So that's why I took a picture of it.

This is one of the many memorials that you'll find in downtown Slavutych. We stayed in the city that was built, effectively, as a replacement for Pripyat. It's actually a fantastic town. I really enjoy Slavutych. And as one might expect, there are memorials everywhere because the entire population is basically the folks that were removed from the town of Pripyat.

This is the train we would take every day. Slavutych is separated from Pripyat by a little isthmus of Belarus that drops down. So that's bad, because you can't get a visa to Belarus. It's not really a thing you can do as an American. I mean, you can apply for one. You'll just never hear back. Belarus is Europe's last dictatorship. And it's not some place one wants to go for any reason.

So when we would get on this train, the doors would shut. We would go through Belarus and we would all pray that didn't break down because then we would have to spend some time to Belarus in prison. But yeah, this is the train yard, bright and early.

The various zones on the reactor site for cleanliness, so to speak, radiological cleanliness are separated by these benches effectively, that you have to step over, so that it reminds you that, hey, this is the clean area. You need to be wearing boot covers and at least these garments in order to go here.

Sideways, for some reason, this is part of the-- all right, I don't know why these are all sideways. But regardless, you get the picture. If you notice on the top of the screen, which should be the left of the screen, let's see if I can rotate it.

That's a giant puddle of water. This place is falling apart. Despite the fact that they have money from the European bank on reconstruction and development for the New Safe Confinement Arch, the Chernobyl site itself does not have a lot of money. And as a result things are falling apart. And the amount of contamination that is getting into places where it very much shouldn't be, like this quote "clean area," is fairly high. That puddle of water was pretty toasty, something like 5 to 8 mR an hour on contact. That's generally quite bad.

As I said, water is coming in everywhere. And in this case they were using leg covers to catch the water. Another one of the hallways that had water leak into it and therefore all the lights are out. That's the footwear which we were issued, which breaks after walking about a kilometer, which is not particularly encouraging if one wants to take their boots back.

Again, walking down the hallway, you notice this gold corrugated material that you see on the sides? It's aluminum that is anodized. And it's placed there because it covers up all of the sheets of lead that were affixed to the wall. What happened is in the aftermath of the accident, the entire facility was just hopelessly contaminated. And you can scrub all you want, but ultimately it's very difficult to get radioactive contamination off of things.

So what they ended up doing was getting it down to a somewhat acceptable level, and then fastening sheets of lead over it, and then fastening this stuff over the top of that.

This is unit 2's control room. So this is what a fully fleshed-out control room looks like. Unit 2 were shut down in 2000. The reactors actually continued operating after the 1986 Chernobyl accident because Ukraine was in such desperate need of power. As a result, the fuel is still fairly hot. It's producing a reasonable amount of decay heat. And there is a crew that sits in the control room at all times monitoring it. That's Nathan.

This is actually, I took a picture of this because it's a very good diagram of the Chernobyl reactor that's simplified. It shows the core and the relative locations of these steam, water separators.

OK, as I said, there is a team that stays in there. So there are people that work on site and work in the reactor control rooms, which I have to imagine has to be a bit of a surreal job.

This is inside the main, inside the turbo generator hall. Those chunks that you see here are from the turbo generator of reactor 4. So they're quite contaminated and quite easy to detect. Actually, there is a good story behind this.

So we were trying to figure out exactly what was making the dose rate so high in the area when we were up there. So we got a group of us to stand in a circle, minus one person. So there's a gap. We got a person in the center with a scintillator. And we all kind of rotated around until we found in which direction the scintillator reading was high enough, so basically made like a 2 pi meat shield. It worked fairly well. It thoroughly baffled all of the guides that were with us. They were like, what are you doing linking arms and spinning around. Regardless, that is a good way to find sources if you're in a pinch.

This is looking the other direction from that same vantage point as in the last photo. Behind those walls with a little radiation signs on them are chunks of the ventilation stack, which is fairly iconic. They've been fairly well decontaminated. At that fence area, the dose rate or more accurately exposure rate, was 10 mR an hour. And yeah, that's another close up photo of it. And I managed to sneak by phone over the top of it and get a good shot.

Unfortunately, none of the pieces are uncovered. I would really like to see the orange and white of the ventilation stack. But I did not. Again, same shot, slightly different shot of the turbo generator hallway looking in the unit 1 2 direction. More detritus, oh here's a slightly better close up of those components.

One of the interesting things I found out about the facility is way that access is controlled. So instead of having an RFID card or something like that, they've got cameras and operators. So what you see here is a camera.

So Stanislaus would scan a badge that would automatically call someone who is an operator. Stanislaus would say, hey, I'm at this door. I want to go into this location. Will you let me in? And then they would look at the camera, determine that yes, that is Stanislaus. He does want to go into this area. And then they would approve it and let him through.

Walking through the corridors of the sarcophagus. You can actually see up here those lead sheets I was talking about. I don't know how thick they are on there, or how close they are to falling off, for that matter. But I'm sure several thousand pounds of lead is right there alone.

These are main circulating pumps, about one-half of the main circulating pumps for reactor 2. And each one of these things takes something around, something around 40 megawatts to actually operate. These are aligned differently and are of a different type than the ones used in reactor 4 because reactors 1 and 2 were of an earlier design. Ironically enough, reactors 1 and 2 actually don't have all of the safety measures that reactor 4 does, which is a bit terrifying to think of.

Yet more photos, right, as I said, dog problem at Chernobyl. This is right outside the entrance to a clean facility. And occasionally these dogs would wander in. Unfortunately dogs are large furry piles of easily airborne contamination. So they would walk in. People would go to shoo them out. They would shake their coats or whatever. And then clean up on aisle three, because now there's contamination everywhere. More sad looking puppies.

New Safe Confinement, yet again, to give you an idea of scale, let's play find the workers. Those are workers right there. Can you guys see them?

AUDIENCE: Barely.

JAKE HECLA: Yeah, they're really, really small next to this facility.

AUDIENCE: [INAUDIBLE].

JAKE HECLA: Yeah, I think I've got a slightly better shot here. That's a guy right there. There's also another dude right here. Yeah, this place is, or this structure is absolutely enormous. It's really hard to wrap your head around exactly how large it is.

So this is in an area called the local zone. So it's the immediate several hundred meters surrounding the reactor. As you can see, the hazmat equipment that we're wearing there is significantly different from what we would wear inside the reactor or inside the sarcophagus, mostly because the threat from dust in this area is pretty huge.

As you can see, we're walking on fill. It's actually meters and meters of fill because the ground was so contaminated that they scraped it away, put fill in there, put fill on top of that because just the residual contamination was enough to make it hazardous to use as a work site.

Though they're not shown in this image, or I believe any images here, there are little concrete and lead structures that these workers take breaks behind because you have a dose limit that is enforced while you're working there. And if you're going to take a smoke break, as a huge fraction of the population of Ukraine smokes, or you're going to take a break of another sort, they don't want you racking up dose during that time. So you basically hide in a little concrete shack for a while with a few inches of lead between you and the reactor.

Yet another shot inside the sarcophagus, Ed explaining something about which I'm not sure.

As you can see these places are not exactly in the best condition on the inside. And one thing that did concern me a lot was the amount of dust that was very, very easy to kick up in the area. This is inside control room of reactor 4. Selfie, which I didn't mean to have in this album.

Control room 4 hasn't changed a whole lot since last year. But there is a dividing wall that actually separates reactors 3 and 4 that's being put together. And it cuts right through the edge of the fourth control room. And for a while, we actually didn't know whether or not we were going to be able to visit it at all because of ongoing construction. I'm very glad that we were able to.

Most of the instruments have been removed. It's unclear as to why. We've been told that some of it was because of contamination. But the pattern doesn't really make sense. This is the reactor control room cartogram, excuse me, reactor core cartogram, which, as I said was lit and could display various parameters regarding the various fuel channels.

There is only two control rod indicator, well, yeah. There are really only these control rod indicators left. And we believe that actually some of these might not be original. Someone might have stolen the real one and put another one back. I don't have any evidence to support it. But I suspect that there's significant looting that happens in here.

This is a rather entertaining photo. That means smoking area. That's in the control room. You shouldn't be smoking. You shouldn't take your mask off for any reason.

That's a high gamma radiation warning sign. It was in fact, not that high of a dose rate, somewhere in the range of 30 mR an hour.

We also explored a little bit outside of the more formal part of the reactor premises, namely we went to this place called Buriakivka 2, which is a burial facility for waste from the reactor, not waste as in nuclear waste but waste is in chunks of metal and other things that are contaminated and therefore removed when the New Safe Confinement Arch was being built, or when, let's say, they were building the separation wall between reactors 3 and 4.

And there were some incredibly hot spots. So I might, I think I have some more photos later. But just under that little triangle, the dose rate was 150 mR an hour, so 0.15 rem an hour. It's extremely high. And that was just in a field basically, not controlled, not patrolled, no warning signs.

Getting dressed up, lots of fun. That was the truck we were sent to decontaminate. Honestly it wasn't particularly contaminated in the first place. They weren't going to give us real fun things to play with.

That's all of us. And then as you notice, the real workers here are not wearing even a fraction of what we are. More decontamination, yeah, see, barely anything.

These are chunks of metal that have come out of the reactor. We're not exactly sure what part, what parts they are. No one was really able to answer our questions about them. But they were also rather contaminated, somewhere in the range of 50 to 75 mR an hour on contact in some spots.

More photos of Chernobyl, or of Chernobyl from Pripyat.

MICHAEL SHORT: Dr. Jake, I want to take a quick break and ask folks if they have any questions on what the experience was like [INAUDIBLE].

JAKE HECLA: Yes?

AUDIENCE: Did you suffer any adverse health effects or anything?

JAKE HECLA: Only the cold I picked up on the way back. The total dose that I received on this entire expedition, minus the flights there and back, was 0.6 millisieverts. So effectively, nothing.

MICHAEL SHORT: [INAUDIBLE].

JAKE HECLA: Well, all of the high radiation areas that we were in, we were encouraged to walk quickly, is basically what it comes down to. The time portion of time, distance, and shielding was emphasized. Further questions? Yeah.

AUDIENCE: Are there [INAUDIBLE] radiation area versus [INAUDIBLE]. Do they use the same levels

[INAUDIBLE]?

JAKE HECLA: No, radiological control in Ukraine is a totally different game than it is in the US. There are the same types of controls that exist in the US just don't exist at that site. For areas that are immediately dangerous to your health, you know, 10 rad an hour, something like that, from what I understand that there are locked doors that prevent one from accessing those accidentally. And there are warning signs in a variety of locations. But I don't think that there is a the same standardization of 5 mR an hours is a radiation area, et cetera, et cetera. Yeah. Further?

MICHAEL SHORT: And are folks still going to be running these tours pretty continuously?

JAKE HECLA: No. You won't be able to see the sarcophagus itself because it will be contained within the New Safe Confinement Arch pretty much now. It's 75, right, let's see. Last I checked, the New Safe Confinement Arch was 75 percent of the way over the reactor itself.

Regular tourist visits to Pripyat will continue to happen. This program that I went on is something very special. Carl, Ed, and Erik have done this type of thing once before. That was the trip I went on last year. And they intend on doing it once a year as long as they can. But that's pretty much your only opportunity to get that kind of access to the reactor. It takes a lot of work.

MICHAEL SHORT: Anyone else have questions for Jake? It's rare to meet someone that's actually gone to Chernobyl to [INAUDIBLE]. Yeah?

AUDIENCE: Do you think it's haunted?

JAKE HECLA: No. There's a rather haunting location, though, the Khodemchuk Memorial. So when the accident happened there was one guy who was-- depending on how you look at it, either lucky or unlucky-- in that he wasn't killed by radiation poisoning. He was killed by being flattened in the explosion. And his remains are within the reactor and within the sarcophagus, never really recovered him. Better than dying of radiation poisoning. But nonetheless, not a fantastic way to go.

The memorial that is within the sarcophagus is pretty interesting to visit, and rather somber. Makes you reflect a little bit on the enormous human toll that the accident had.