Nuclear Winter: *The Environmental Consequences of a Nuclear Exchange*

Transcript from the April 7th, 2023 Samuel Lawrence Foundation's First Friday Series

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In this informative First Fridays webinar we discussed the environmental risks and global impacts of a nuclear exchange with renowned atmospheric scientist, Professor Brian Toon and Dr . Paul Dorfman

00:59 Bart Ziegler, President: Good morning and welcome, everyone. I'm Bart Ziegler, president of the Samuel Lawrence Foundation. And I'm honored to have you join us today for this very important conversation on the potential consequences of nuclear conflict. We're privileged to be joined by two distinguished experts in the field, Professor Brian Toon and Dr. Paul Dorfman. Dr. Paul Dorfman is chair of the Nuclear Consulting Group, visiting fellow at the Science Policy Research Institute at University of Sussex, a member of the Irish Government Radiation Protection Advisory Committee and also has served as the Secretary Government Scientific advisory committee examining radiation risks from internal emitters. We are grateful to have their time, their expertise, and we're here today because we believe it's crucial to inform the public about the dangers of a nuclear winter and to emphasize that there are dedicated professionals like our guests who have spent their lives working tirelessly to fight for your safety through their research and outreach efforts. And I'd like to introduce Dr. Paul Dorfman (Moderator).

1:29 Dr. Dr. Paul Dorfman (Moderator): Hello and I in turn of course would like to introduce the key reason why we're here, Professor Brian Toon. Professor Toon is a Professor in the Department of Atmospheric and Oceanic Studies and Research Scientist's Laboratory for Atmospheric and Space Physics University of Colorado. It's very important to note that his research on asteroid impact that killed the dinosaurs led to the groundbreaking discovery of nuclear winter. He's developed key work on how aerosols behave in the atmosphere and impact climate and how the use of nuclear weapons threatens global civilization amongst many other accolades and awards. Professor Toon is elected fellow of the American Association for the Advancement of Science, has been given Future Life Award from The Future of Life Institute, and the award for Global Peace and Health by International Physics for the Prevention of

Nuclear War in recognition of his landmark research on nuclear winter and nuclear famine. Without more ado I give you ladies and gentlemen, Profession Professor Brian Toon.

3:00 Professor Brian Toon: Thank you. I'm sure that our audience is familiar with the recent threats to use nuclear weapons. This is a topic familiar that faded away from people's attention largely following the end of the Cold War. But unfortunately, we're back having to confront this possibility. I'd like to take about 20 minutes in this meeting here to give you a little background information so that we can have a nice conversation about this problem after that. I'm going to share my screen here. Hopefully this will work. Okay, so I'm going to talk to you about the environmental risks of nuclear war. There's the risk of having an explosion in a city that you're living in, which is a different issue as we'll talk about in a few minutes. This graph is a history of nuclear warheads on the planet and so this axis, vertical axis, here is a number of weapons and this is a time since the Second World War going up to a few years ago. What I wanted to talk about here is this peak value here.

In about 1986 there were more than 60 thousand nuclear warheads on the planet. Sixty thousand. They are only 500 cities in Russia and the United States, total, with more than a hundred thousand people in them. Sixty thousand weapons, that's more than a hundred nuclear weapons for every city and town, with more than a hundred thousand people in it. This was obviously absurd. It only takes one nuclear weapon to blow up a small city, which we already know because of Nagasaki and Hiroshima. Having a bloated arsenal of 60,000 nuclear weapons was obviously out of control. And at the time the populace of the world was aware of this. They knew how many nuclear weapons were there.

And in the early 1980s there were all kinds of demonstrations against having so many nuclear weapons and at that time a nuclear winter, which I'm going to be talking to you about today, was discovered. And something happened here in 1986 that led to the build down of these weapons, and it was not the disintegration of the Soviet Union which happened in about 1992, over here somewhere. What did happen?

5:59 Professor Brian Toon: Which we can learn from comments made by Ronald Reagan and Mikhail Gorbachev, who were the ones who solved the problem, is that they heard about this nuclear winter. And Ronald Reagan gave talks to the press and said, well I know about the year without a Summer or in 1816 where a volcano put a lot of stuff in the stratosphere and people had trouble growing their crops and that could happen after a nuclear war. And Mikhail Gorbachev said Russian and American scientists are telling us that all these nuclear weapons could end civilization as we know it and this is a people of morality and have to act in this situation.

Reagan and Gorbachev did act, and they started to remove nuclear weapons from Europe and you can see that every American president since then and every Russian leader since then has reduced nuclear weapons. This has continued up until the last few years when the Trump Administration and the Putin Administration decided to aggregate the treaty that led to the decline of these weapons and we have one treaty that's sort of left in place that Putin has said he's going to walk away from. I think an important point from this graph is, we can reduce nuclear weapons and politicians will respond to the public and to the science community if people tell them that there's a problem they should deal with. Let's talk about what's here now.

7:36 Professor Brian Toon: This graph shows you the number of warheads on this axis here and the various countries that have nuclear weapons. You can see there are a number of states over here with small numbers of nuclear weapons. Well, this is not really a small number of nuclear weapons. As I mentioned, there’s really only 200 cities in Russia with more than 100,000 people. France and the United Kingdom could basically bomb every city in Russia if they wanted to. The United States has 300 cities. China they can bomb every city in the United States. It doesn't have the systems to deploy the weapons there, but it could build them. And then you have India and Pakistan. Pakistan has like 60 cities, many more than India. India has many more weapons than are needed to bomb all the cities in Pakistan. These are not inconsequential arsenals over here. There's about a thousand weapons altogether in these countries, but more than 90% of the weapons are in Russia and the United States. And these bars represent how the weapons are controlled by treaties.

8:46 Professor Brian Toon: Down here are these red bars which represent about 2,000 weapons in Russia and the United States each, are the Deployed Strategic Warheads. They're on ICBMs or submarines or bombers. And they're deployed, which can easily be used quickly. Then there's another 2,000 weapons in each country. Now we're up to about 4,000 each that are in storage or stockpiled. These could be brought out in case of a war, although it would probably be difficult to do that without making the other country very worried. And then there are quite a few weapons here that are stockpiled to be dismantled. The basic point here is that there are about 4,000 weapons that are sitting here ready to be deployed instantaneously. There are only 500 cities to attack. That means there are eight weapons still left to attack every city with more than a hundred thousand people. In addition to that, Russia has about 2,000 tactical weapons. There's a lot of confusion about tactical weapons in the press.

9:57 Professor Brian Toon: Tactical weapons merely means that the weapon is used for fighting in a battlefield. It's not on an ICBM or a submarine or something like that. But it means nothing about the yield of the tactical weapon. It could be just as big as a strategic weapon. The average strategic weapon has a yield of about 250 kilotons. The United States tested tactical weapons as artillery shells that had yields of about 15 kilotons, which is the size of the Hiroshima bomb. You can imagine an artillery cannon with a bunch of nuclear weapons sitting next to it, each capable of destroying a city, being fired right on Europe. That's what these weapons are for. It was mostly used to be used against Europe. And they're on cruise missiles that are on short range normal missiles, they’re on ships, they're on aircraft. They're not controlled by treaty. We know very little about them, so this is very concerning that there are so many of these weapons still around. What are the targets? This is a controversial thing as to whether or not the military targets cities or it only targets military bases.

11:14 Professor Brian Toon: It's of course illegal to target cities, but that's how the Second World War was won in Japan. For example, at the end of the war more than 60 Japanese cities were burned to the ground by carpet bombing then with incendiary weapons. Then, of course there was Hiroshima and Nagasaki. It's unclear whether either country would attack cities just because they're cities. There are also military targets. but military targets are often located next to cities. Plus, a lot of military targets are things like large commercial airfields, oil refineries,

power plants, universities, and government laboratories that are doing essential research and things like that. The military targets are co-located with cities anyway so cities will certainly be bombed. In this map of the United States there's about 1200 military targets that I have found using military bases and the other targets I just mentioned. Nobody knows what the real targets are. They're highly classified, but in this map, there are at least two nuclear weapons targeted at every state in the United States. Some of them are things like state capitals in the U.S. capital, because those would be seen as places where the military might take orders from. Likewise, here, just an example, where we actually look at the size of the destruction area. I chose San Diego here to look at. You can see the harbor area here and on the left are circles that represent the damage that would be done from blast waves. And this little interior circle here is where concrete reinforced buildings could be destroyed and the outer circle is where brick buildings and houses like people often live in would be destroyed.

13:22 Professor Brian Toon: The military only pays attention to what's called assured destruction from blast waves because they know that's going to happen. You can see San Diego has a lot of military targets in it, so the whole area is pretty much covered. But this is actually tremendously under-estimates the damage that's likely to occur. This area over here is the fire ignition area so these are the same targets. But you can see they're much larger because when the nuclear weapon explodes it puts out a bright burst of light which can ignite easily ignitable things like newspapers and tree leaves and limbs of trees and things like that. And we know that these fires will occur. Hiroshima and Nagasaki both had firestorms or intense fires because of those nuclear weapons blowing up. But the military wants to ignore that because it isn't sure if it's blowing something up or there's fuel. There were more than 500 above ground nuclear weapons tests. They didn't start big fires because they were in deserts or on islands because they didn't want to start fires they couldn't control.

And you know the areas of these are quite substantial if you have a weapon that's like 200 kilotons, the area that's burned in these fires is going to be approaching 200 square kilometers. Very large area. Here's some European targets you can see. There are many European military targets for the tactical weapons and there's also these Russian military targets that I've identified here. There are a lot of targets over the world. What do we see when a nuclear weapon goes off?

We know this from Hiroshima and Nagasaki. This building was a part of an international exposition before the war. The bomb fell almost on top of this building. This was a small weapon like an artillery shell, as I mentioned, has been tested. You see this all this rubble-ized area out here and some concrete buildings standing in the distance. You might think that this is the area that blew down from the blast wave, but it isn't. This is the area that burned.

15:32 Professor Brian Toon: This is all a region that's been burned by a firestorm and destroyed by the fire. You get intense virus started by these nuclear weapons going off and this is an example taken a few hours after the Hiroshima explosion of the smoke from the firestorm. A lot of people have confused this with the fireball from the bomb, but that's not what this is. This is smoke from the fire in this big cloud which is called the Pyro-cumulus. We sometimes see these now after big natural fires in forested areas. This Pyro-cumulus or colored picture you see was full of smoke and the top of this cloud is about 16 kilometers. It's far above the ground.

The reason this matters is if you have a fire in a forest or something like that, which we're used to, they're not very big fires and the smoke is put into the region within a few kilometers of the ground where it rains a lot. And the smoke, it rains out within a few days and it doesn't persist. But if you start to put smoke up here into the stratosphere which is where this cloud is topping out, it never rains in the stratosphere. That smoke will stay there for years. This is a big problem. If you put smoke into the stratosphere, it absorbs sunlight, which I don't have time to really discuss here. But it gets so hot in the stratosphere that it basically destroys the ozone layer. Which would threaten us at the surface because of ultraviolet light. The other thing though that happens is if you stop the sunlight in the stratosphere, it doesn't get to the ground anymore. And this is a calculation of how much light on a global average would get to the surface for various wars.

These wars in here are all based on India and Pakistan. India and Pakistan are rapidly increasing their arsenals which is why we have gone up from this blue curve in the last decade. These are the possible levels of smoke now. This thing tera-grams is a million times. That's the amount of smoke being put into the stratosphere by this war. The uncertainty here with Indian and Pakistan if you don't know what the yield of their weapons is, if they're like the Hiroshima bomb then you

end up with this light blue color. But if they're more like the average weapons 100 kilotons or something like that the smallest weapons that Russia and the US use, they'd probably be more like this orange curve here. And we might have 37 million tons of smoke. What does this mean? If we take the in this example here from this orange curve, you'd lose about 30% of the sunlight at the surface. This is years down here; you'd lose 30% of the sunlight of the surface for like three years. If you had a war between the United States and NATO and Russia, you would probably lose more than 60% of your sunlight at the surface for more than three years. This is not something that's difficult to understand in a climate model. This happens every night. The sun goes down, it gets dark, it starts to get cold. It happens every year in the winter. In the winter there's less sunlight in the winter hemisphere, it gets cold and it gets snowy. There's nothing mysterious about the physics going on here. This is what happens at the global temperature when you have these kinds of conflicts. This on the right is a temperature change globally over time, scale of years. This is a U.S. Russia War. The temperature drops by 10 degrees centigrade on a global average. This is a war between India and Pakistan.

19:46 Professor Brian Toon: With modern weapons it's 5 degrees centigrade. This is a typical temperature in the last Ice Age. We're talking about creating Ice Age temperatures on the planet that you know, persist for periods of time, like 6 years. You know, it takes fully a decade for you to begin to recover and you're not even fully recovered after a decade. And of course, not only the temperature change, less sunlight, there's less evaporation of water, and precipitation falls. You've lost 30% of the precipitation for this war between India and Pakistan and here you've lost about 60% of the precipitation. Let us take an example in a specific place.
This is the temperature difference from normal, over a couple year time frame. We can do this for Iowa, which is a big grain producing area in the United States. And the Ukraine which is a huge grain growing area in Europe and in Russia. In that area. You can see the Ukrainian grain is so important to the world that even in their war the Russians are allowing it to be exported so people don't starve. In North Africa, in a normal year the temperature is cold in the winter in the summer it gets warm. You know, we're up to 20 degrees centigrade or so in here and 60- or 70-degrees Fahrenheit. It's cold again in the winter, warm again in the summer, cold again in the winter. In this imaginary war here which is marked by the black dashed curve, the temperature immediately starts dropping and by the end of the summer it's reached the freezing point for the

daily minimum temperature. Warmer in the daytime maybe but the daily minimum temperature is hitting freezing and it stays below freezing all the way to the next summer. And it stays below freezing all through the next winter and barely starts to get about freezing two years after the start of this war. You're not going to grow anything if the temperatures are freezing every day. It will kill all the crops. This is what this is going to look like. This is what a nuclear winter is going to look like a year or two after the war. You're going to have solitary individuals here wandering through a snow-covered landscape approaching abandoned buildings that people have left. We also had in addition to using climate models to understand this we've had to use agricultural models. What we've done is to evaluate the agricultural response in every country in the world, with a few exceptions, to a war between India and Pakistan and to a war between the United States, Russia, and NATO. This is an example for an India-Pakistan war, involving 100 kiloton weapons with a number of weapons that they currently possess. They currently have enough weapons to do this. We don't know their yield for sure. There's a bunch of assumptions you should have to make here so we assume that people are only going to keep half their livestock and they'll eat the other half of the food they would have previously fed to the livestock.

23:02 Professor Brian Toon: We assume that countries are not going to send food to anybody else, they’re going to hoard it for themselves. The most extreme assumption that we're making here is that we're only going to give food to the people, to enough people, so they could barely survive. And everybody else gets no food. That's not going to happen, those people that are getting no food are going to attack the people that have food. This is a conservative case in some respects. At any rate what you see here is that in Canada 95% of the population starves to death by the second year. In Russia more than 75% of the population starves to death by the second year. In the United States 25 to 50% of the population starve to death. Here in Northern Europe 95% of the population will starve to death. There are places which are not so bad. In South America mostly we're only a few percent of people may have starved. All together though, we think a war between India and Pakistan would kill between one and three billion people. One in three billion people. This is Indian and Pakistani generals deciding they're mad at each other, fighting their war, using their arsenals, killing one to three billion people over the planet. We calculate that the direct fatalities in India and Pakistan have between 50 and 150 million people

from just the explosions. But10 times that many people would die worldwide who had nothing to do with this war. Of course, it's even worse in a war between United States, NATO, and Russia. Here you see that Russia, China, most of Europe, United States, and Canada they're all losing 95% or more of their population. There are only a few percent of the population left in China and Russia in the second year. As I showed you before that's not when the climate change ends, it still goes on for another couple years before there's any hope of any agriculture going on. This is basically the entire northern hemisphere population is eliminated. There are still places in the southern hemisphere where it isn't quite so bad, you know down here in Argentina for example, there aren't too many deaths. In here, Australia and New Zealand. The reason is that these countries survive are complicated. For example, in New Zealand, most of the product of New Zealand is sheep which eat grass and they export a lot of the sheep. And after a war instead of exporting the sheep, they could just eat the sheep and so they would have enough food from the sheep to survive.

25:57 Professor Brian Toon: Iceland is somewhat similar. It grows up a lot of food that it exports but it also eats a lot of fish which probably, they wouldn't survive there because there's actually a big ice buildup on the coast of Iceland. They wouldn't be able to get out to catch the fish. This is probably not actually a good place to go to Iceland. Okay, so what should we do about this? In the late 1970s, Congress required the Department of Defense to report to the American people what would happen if there were a nuclear war. The Department of Defense is not reported to you about this in 40 something years. They have told you nothing about what would happen to you in a nuclear war, you have no information about this. Either they don't want you to know or they're not thinking about it. One or the other. This is not acceptable in the current war, in the current world. The population deserves to know what would happen if we did have a nuclear war. You should ask your Congressional representatives to require the military to make a report to the people and what would happen if there were a nuclear war. You deserve to know this. I should point out that probably having a military report to this in the 1980s is one reason that people objected to it and control the number of weapons that are being made. You know, 70,000 weapons is obscene. 4,000 weapons, eight in each city with a hundred thousand people in it is still obscene. The second thing you can do is to learn about the rapid buildup of new nuclear weapons and delivery systems. And even more horrible systems that are being built.

Right now, there are 50 nuclear missiles armed missiles sitting 50 miles to the north of me in Northern Colorado. There's about 450 scattered over Colorado, Wyoming, and Montana. And a little bit in Nebraska. Those things would be lost if they were a first strike and they weren't launched within 20 minutes of an attack by Russia. The American president has 20 minutes to decide what to do. I know some political people like to think of sleepy Joe Biden. Let's imagine it's the middle of a night here, it's the middle of the day in Russia, they launched their missiles. Jill Biden has to run down the hallway, wake up Joe, you have 20 minutes to decide whether you should end Western Civilization or you should assume that it's a false report that there's a missile attack. That's what we're facing right now. The president can launch our missiles on his own without anyone else stopping him. Or Russia in particular but also the United States are building new weapon systems designed to reduce the warning time. Hypersonic missiles which Russia has used against Ukraine already, recently.

29:09 Professor Brian Toon: Which the Ukrainians couldn't even shoot down. They fly so fast are being developed in both countries. Russia now has Torpedoes it can float into cities wherever it wishes with huge bombs on them and you know, destroy these cities probably with no warning. What are we going to do if we have all these systems floating around with no warning? Some military planner is going to turn this over to artificial intelligence. I don't know about you but I have an Apple computer. Millions of people use this computer and software. Mine messes up all the time. I can hardly even give you a talk on Zoom without wondering if the things gonna' break or not. Do I want to trust artificial intelligence to decide if it's going to be the end of Western Civilization or that we're going to launch our nuclear weapons? I don't think, but if you don't do something about this, that's what's going to happen in the next decade. Things are not good and they're getting worse. I should point out here that I spent a decade or more working on the ozone hole problem with NASA. It was a big important problem. You know, we could at this point in time actually have severe problems that we hadn't solved that problem. That took thousands of scientists around the world working on that problem to solve it. This nuclear war problem is even more complicated. These are the people that are working on this. This is not thousands of people. This is a small group of people.

Where is a scientific group working to solve this problem? Is it buried in the Department of Defense? Probably not. This is an issue that small numbers of people that know about this. There is a National Academy of Sciences' study being done in this problem at the current time, this may give us a little bit better impression of what is the status of this problem. Thank you I've stopped sharing this screen now and we could talk about it, this. Whoops, I did the wrong thing.

30:23 Dr. Dr. Paul Dorfman (Moderator): Okay, I guess that everyone is as stunned as I am, given the reality of the situation. But then again, I have to say that it's for me personally, it's hugely encouraging to understand that somebody like you Professor Toon has taken this weight on our behalf for so many years in the context of this potentially cataclysmic, cataclysmic issue. And to a certain extent when we're faced with these kinds of issues there's a sort of a kind of an idea of you know what can one do? And to throw one's head up and put one's head in the sand which is exactly what shouldn't happen. And one of the things that interested me about what you were saying is the as it were the cultural difference between what happened in the 1980s and what's happening now. And you pointed out for people like you and I, to a certain extent generational, that we remember what it was like when significant nuclear threats were on the horizon. And in that sense is there a sort of a cultural change now in terms of policy that policy doesn't quite get really what this is about?

33:02 Professor Brian Toon: Yeah, I think there's a huge cultural shift from the 1980s in many ways. I mean you know when I was young, I was born right after the end of the Second World War and there were nuclear weapons around. And you were, had to do drills when you were in school, get under your desk to prevent yourself from being killed by a nuclear explosion. Which of course was futile. And my mother by the early 1960s said, you can't drink milk anymore because the nuclear weapons tests. They're putting so much radiation in the atmosphere that's it's getting in the children's teeth and bones. And you know there were demonstrations led by Linus Pauling and other people that put a ban on testing nuclear weapons in the atmosphere. You know, those kinds of memories lead people to worry about this. But you know at the end of the Soviet Union in 1992 or, we became very hopeful. Everybody thought, my thank God. We're finished with this Cold War and we're threatening each other all the time with things. Or a peace has broken out and we're going to solve our differences by negotiations and talking to each other

and we're going to stop fighting these wars all over the place. For a while it looked like that was true and that would be a hopeful spring so to speak where we didn't have to keep worrying about this. And the number of weapons did go down and down and down. But for various reasons now we've reached a turning point where various dictators around the world have decided that they should invade their neighbors. That you know they should prevent their own citizens from expressing their views and you know of course the average person feels overwhelmed partly because of the information overflow now. There's so many problems going on in the world, so many things to think about you. When I was young you couldn't even go to China you know unless you had a lot of money and a lot of time and things like that and now on the news I hear every time there's a big flood in China, you know I hear about people getting killed in Africa, or something like that. Our expansive understanding of problems is so much greater now that it seems overwhelming, but there are times when people have to do something about these problems and this is one of those times.

35:29 Dr. Paul Dorfman (Moderator): Okay, I've been remiss in my job as a moderator given the fact that there's no sort of live vis-a-vis interaction. I would ask people to put their questions into the chat into the Q and A. That way I can then put these questions to Professor Toon. In turn you know to help with the discussion let's do this. Let’s talk. Let’s talk it through. Okay, so from Linda Gunther. Linda says what was your impression of that recent National Academy of Science committee meeting at which you and Alan Roebuck spoke? It was full of people representing the labs that make these weapons and the NSA. This didn't feel encouraging. What do you think that the NAS will do? Will the NAS do anything useful on this?

36:36 Professor Brian Toon: I think they will do something useful on it. I know several of the people that are on that committee and you know they're well-known science people and even some of them in the weapons labs. In the 1980s, the University if you want to say, science community and non-military scientists like a NASA for example, worked with scientists from the Department of Energy. They were the bomb makers and we had open conversations. We had meetings everybody went. They'll tell everybody what they had learned. There was even money to do research for a short period of time on this problem which we trained you know many tens

perhaps even 100 people in the university community. There was a lot of conversation at that time. And actually, a lot of, some people have written articles in magazines saying this is a birth of climate modeling that came from these nuclear weapons things. And I think there was less, I'm not like going on other than that, but nevertheless it did improve climate modeling and so those are very important conversations. But now we've reached a point now where the Department of Energy is silent on this topic. It hasn't been communicating to people and I hope this academy study is the beginning of the conversation that will engage. We have to involve the Department of Energy and the Department of Defense in these kinds of studies. Those are the people that are going to decide what to do. If we don't have these conversations, they'll pretty much decide by themselves and which is what's happened in nuclear winter. It's kind of like everything else like tobacco smoking, the ozone hole, global warming, there's a whole group of people that come up with false goods about every one of these things. And they're even the same group of people of course if some of them have died. Over the decades from banning cigarette smoking and to being against solving the problem of the ozone hole to like global warming and nuclear winter. But you know there's opposition to that and so it's very easy for the people in the Department of Defense to say that just a bunch of university people you know trying to make problems. It's very important that we have conversations about this with the people in the Department of Energy and Defense. Likewise, it's very important that we engage the world science community. When Gorbachev decided to work with Reagan to get rid of the weapons, he said Russian and American scientists are telling me this is a problem and part of this is about Carl Sagan.

39:30 Professor Brian Toon: At the time in the early 1980s, Carl was a very famous scientist and people paid attention to what he had to say. I worked for NASA at the time and we tried to give a talk about this when NASA shut us down and said you can’t talk about it. And said you have to have it reviewed. Well, this was a political mistake on their part because Carl said, okay let's have a review. If it had been me, I said okay, well let's let five people come and talk about it, he said no. Carl invited people from all over the world to come to Boston a hundred, more than 100 people to come to Boston from Russia and Britain and everybody else who had a stake in this and debate about whether what we were saying made sense. And of course, that encouraged them to go back to their countries and have their scientists talk about it. You're not going to get

anywhere in the world with me an American telling somebody in Iran about nuclear weapons. Somebody in Iran has to tell the leaders of Iran about that and we need a large number of people around the world to get involved in studying this problem.

40:42 Dr. Paul Dorfman (Moderator): Just one from me. I mean, do you think that China fully understands that if there were even to be a strategic, even a strategic exchange, between Russia and the US, that China would starve? And hence what might that imply?

41:07 Professor Brian Toon: Well, this is an interesting kind of question. There's plenty of intelligent people in China. There's a huge scientific community there. In fact, they're dominating publications now, not just in sheer number but in quality of publications in the world and science problems. I have no doubt that the people in China, some of whom are my former graduate students, know about this kind of issue. The question then is whether they can actually talk to their political leaders about it and then you know this is an issue here that even in the United States. We have politicians. It just happened yesterday where politicians in Tennessee told, got rid of a bunch of politicians that were talking about gun control. That doesn't make any sense to me. Where somehow the political system is so charged that you can't even have a debate with the opposition from the government. That’s the kind of thing that’s going on in places like China and Russia, where the government is suppressing the press and they're suppressing their own people. There's a lack of communication there that's very dangerous.

42:28 Dr. Paul Dorfman (Moderator): From, this is from Ace Hoffman. In Aparicio, all 6 reactors are destroyed with a nuclear weapon. What would the consequences be?

42:40 Professor Brian Toon: Okay, well this is a very complex question. Radiation in a nuclear war, it has a couple of different facets to it so there are some places, those missiles are buried under the ground in concrete silos and they would be attacked by what are called a ground burst where the explosion occurs right at the ground and makes a big crater in the ground. Which could be.

43:27 Bart Ziegler, President: At a certain point, your audio is not working very well. Professor Toon your audio goes in and out a little bit now. I didn't get that.

43:55 Professor Brian Toon: (Inaudible)

44:00 Dr. Paul Dorfman (Moderator): Whilst Professor tune is battling with audio and one wonders why all of a sudden, his audio has gone a bit awry.

44:09 Bart Ziegler, President: I thought the same thing.

44:14 Dr. Paul Dorfman (Moderator): Yeah, do you think his audio is back or should I sort of fill in as it were?

44:19 Bart Ziegler, President: Well, you can fill in and then perhaps I'll have someone in the office call see if they can call him and see what happened on audio.

44:26 Dr. Paul Dorfman (Moderator): Okay, okay. I'll try to do that, but clearly, I'm you know, he's absolutely the expat.

44:37 Bart Ziegler, President: But it is odd Dr. Dorfman. It's odd that just when he starts talking about the specifics.

44:44 Dr. Paul Dorfman (Moderator): Yes, it is odd actually.

44:45 Bart Ziegler, President: We'll try and bring him on the phone.

44:46 Dr. Paul Dorfman (Moderator): Yes, yes. It is odd actually. Yes, it is odd. In terms of what struck me by Professor Toon's discussion, is that one understands that if exchanges really get hot it's a horrendous situation. But the argument is that, yes, we've already had the nuclear cataclysm during the weapons test. When there had been a huge amount of bombs set off and we haven't seen nuclear winter. But actually, what Professor Toon tells us is that these weapons

were set off in a desert or island locations where you don't see the burn. Where you don't see the atmospheric dispersion burn that you would see if there was a strategic nuclear exchange. There's a key distinction between what happened in the, during the weapons testing era, when a significant amount of weapons were set off and the very real risk of a nuclear winter. In other words, I'm sorry to say but it's mass starvation, post a strategic nuclear exchange. Also, the other issue that Professor Toon really discussed was a kind of a cultural one. Which is also really very interesting because science risk is both a kind of, it's both a cultural and a scientific phenomenon. Both of these things work in tandem and what we saw in the 1980s was that there was a percolation into the, policy. That yes, we all basically, yes, we were all facing this, let's face it, this this form of Armageddon. That unfortunately that we're seeing less and less now. The issue seems to be the percolation of the science to policy and the question is how that can be achieved. Whether that's through the media or whether that's through direct meetings or otherwise. This is something that it seemed to be incredibly important to kind of emphasize. I'm just wondering how far we've got with Professor Toon?

47:21 Bart Ziegler, President: Let me retrieve my phone here. Is he on the line?

47:27 Madeline Molina, Project Manager: Yes.

47:28 Bart Ziegler, President: Fantastic.

47:29 Paul Toon: Yes. I'm sorry I don't know what the problem is here.

47:30 Bart Ziegler, President: Coincidental, but just when you started describing how the craters around the targets will happen, you disappeared off the face and then Dr. Dorfman just spoke about how the important, the importance of what you're saying needs to be shared with government policy officials etc. Do you want to maybe speak to the specifics of the sequence of events that would happen in an exchange?

48:08 Professor Brian Toon: Sure, let's just return to the question that was asked about the radioactivity. There is a danger from ground bursts which is important but then most of the

weapons that would be used to attack cities are what's called airbursts. A lot of the radiation then goes into the atmosphere. This is an important thing to know in case you're ever near a weapons attack. The radiation decays very rapidly. If the radiation within three days goes down to a few percent of what it was originally. Which is why you want to stay in your house and not go out if they're near an explosion like that. We think that most of the radiation would just blow away into the atmosphere but the big danger here really is attacking nuclear weapon or attaching nuclear reactors. The amount of radiation in a nuclear reactor core and then the waste around the nuclear reactor is very large. It can be much; it can be comparable to what's in all of the nuclear weapons. You don't want to have a nuclear reactor fail or be blown up. That would produce a huge amount of radiation.

49:35 Dr. Paul Dorfman (Moderator): Okay, there's a question from an anonymous attendee. Professor Toon, what kind of reasoning do you think would lead policy makers in DOD, Congress, DOE, and elsewhere to reopen the debate on the effects of nuclear war?

49:55 Professor Brian Toon: I think that in the 1980s Congress people were worried about this and they were pressing the Department of Defense to respond, but you know at the moment politicians are not concerned with this problem. They're paying very little attention to it and I think that's because they don't see their constituents being concerned about it. I think that to solve this problem we really need people to show politicians that they're worried about a nuclear conflict. If the government in the United States is spending somewhere between 300 billion and a trillion dollars to upgrade the nuclear arsenal, is that where you want your tax money to go? Is building up more nuclear weapons or would you rather spend it on health care and education and things like that? These are important political issues. In the United States at least I think it has to come from the ground up.

51:09 Bart Ziegler, President: Well, let me interrupt you for a second professor. And the one reason that we're so grateful to have you and Dr Dorfman in on this call today is because we have San Onofre nuclear waste piled on the beach, 100 feet from the ocean, rising seas. But we haven't really yet until this call and your magnificent diagrams seen how much of a target. I'm looking at the military targets in San Diego with 100 kiloton weapons It just strikes me as

something that has yet to be considered until the recent Ukraine events with Putin. And it just strikes me as more important is this than the vast 3.5 million pounds of nuclear waste sitting as a target. I had no idea that the waste storage and the nuclear power plants are a magnificent target for an enemy. Can you, is there any way you can speak to that?

52:15 Professor Brian Toon: Sure, well this is a complicated issue. It's against the laws of war to attack a dam for example because if you break the dam, it will flood everybody downstream and it will cut off their power. It's also not legal to attack nuclear power plants. However, in the laws of war there is an exception which says if the military is using that power or making use of something about the facility, then you can attack it. There's, so it's unclear about the rules of war and of course it's also unclear whether any combatant in the nuclear war would care about the rules of war. We have to think, nuclear war has got to be nothing like the wars we're familiar with. Like the Second World War went on for something like seven years. People were able to change strategies, develop new weapons, and build up industries, all those sorts of things. Because at that time a nuclear war is going to be over probably in a week.

You launch all the weapons you have and there's gonna be nobody left on the other end to do very much. It will be a very sudden attack which makes it more uncertain as to how will the attack be conducted. What targets will be used things like that? But the problem with these nuclear reactors of course, is some of them are in close to cities or in cities. They might, even if they weren't attacked directly, they might be attacked by accident. That may be in the footprint of the explosion but also, we already can see from the experience that Fukushima that the nuclear power plants need to have external power to keep their generators running. If they shut down their cores there's not going to be a bunch of generators running to support these nuclear power plants in a nuclear war. Even if they're not directly attacked, they may very well melt down in the same way it happened at Chernobyl and Fukushima because they lose power. That is a serious threat and it's one that as far as I know of, is several people have suggested it's a problem but I haven't seen very many analyzes of what the real scope of the problem is.

55:00 Bart Ziegler, President: There's a follow-up to that question from Gordon Edwards. Our friends in Canada, my understanding is that if a nuclear weapon were to vaporize a nuclear

reactor including the spent fuel pool that the amount of radioactive fallout would be increased by a factor of several thousand. Is this your understanding as well?

55:25 Professor Brian Toon: Yes, I think that there is a very large amount of radiation in these reactors and it's a lot more than there is and a modest number of nuclear weapons. I don't recall right this minute exactly what the factor is but you start blowing up a bunch of nuclear reactors and you're almost certainly going release a lot of radiation and much more than in the bombs. Now, you can ask you know that Russia is not likely to attack nuclear reactors in Europe because it would probably blow the radiation down in Russia. The United States might set reactors in Russia but certainly, Russia might consider attacking reactors in the United States because this stuff is far away from them. But who knows what they're what, we don't know what the targeting plans for any of these countries are. But yeah, the opening reactors is an important problem that is an example of something that we don't know if the military's ever even thought about this, very few people, there are a couple papers out there that would happen but I don't think anybody has given it very much consideration so it's an open issue.

56:51 Bart Ziegler, President: I mean they're just some, a number of questions about health effects on the plumes of radiation. One here from Norma Field asking for clarification regarding the photo of Hiroshima and the Pyro-cumulus cloud. You said that once a cloud reaches the stratosphere it doesn't rain out and the Hiroshima Nagasaki clouds did produce what's called black rain in Japan with important and contested by the government and scientists of the health effects. In the case of Hiroshima and Nagasaki did the highest level of the clouds linger on in the stratosphere while the lower strata rained out?

57:41 Professor Brian Toon: Well, we don't know very much about that. It was in the middle of a war and people had very little understanding of these problems. We do know a lot about Pyro-cumulus now because we've seen a number of them develop over large forest fires. For example, they've been a prediction of nuclear winter that its smoke got near the tropopause which is around 16 kilometers in the tropics and 12 kilometers latitudes. They spoke out to those altitudes that heating by the sun would drive it into the stratosphere to high levels. We predicted this in 1980s and finally in 2017 there was a big enough fire in Canada that smoke actually did get to the tropopause. And then it floated upward to about 20 kilometers. This is a very small amount

of smoke compared to what was nuclear war. And again in 2020 they said we saw the same thing happen from the big fires in Australia in the December January time frame around 2020. Those fires likewise put a huge amount of smoke into the stratosphere which could be seen by satellites for more than a year and it rose to high levels just as was predicted. Pyro-cumulus don't rain very much but they do rain. There was a black rain at Hiroshima and some of the smoke from Hiroshima did rain out on the city of Hiroshima. In our models, excuse me, we assume about 20% of the smoke will be rained out in the troposphere near where the fire was. Where the city was. But this is something that we don't know much about and there are a couple people on the National Academy Panel who know about our cumulus clouds and are studying them with advanced models. I should say the same thing is true in fires in general is that people know a lot about forest fires. There are huge numbers of people in Boulder where I live who know and are studying forest fires and how they're spreading and how they're blowing in the wind because they want to protect firefighters. And also tell the firefighters where to fight the fire and how to run if this fire is coming towards them but we know almost nothing about urban fires There are no models that are capable of predicting how a city will burn. We just had this happen in Boulder. We had a fire 100 mile an hour winds, December time frame that blew a fire across a city here in Boulder and burned a thousand houses in a day and we know nothing about how that spread. There's a lot of issues about urban fires and how high their smoke gets and how much of it rains out. Thes are all important issues that need work.

1:00:51 Dr. Paul Dorfman (Moderator): Can I say that that for me personally I find it hugely, I know it sounds paradoxical, but I find it hugely encouraging that someone like you has devoted a significant work to, as it were holding this key, issue. Which is hugely worrying, hugely traumatic. And in that sense, there's a sort of a debt that we owe you for this. Also, for others hearing that are hearing this, perhaps for the first time. There's probably a sense of if not revulsion then deep concern and deep worry which of course is true, is relevant. Because this is the reality. This is absolutely the way things are. And I was just wondering and I'm terribly sorry about this but at a personal you've engaged with this on a deep scientific level. I was just wondering how you've done this?

1:00:11 Professor Brian Toon: Well, this is not the only thing I do. I also work on Planetary Exploration and further issues. Right now, I've got students working on building climate model charts and things like that so it's not the only thing I do but nevertheless it is very difficult to work on this problem. The reason that I and the other people I showed pictures of like Alan Roebuck have been working on it is because it's an important problem and it's being ignored. Why do universities keep a bunch of faculty around where they pay them? I get paid 40% of my time to do research and the university lets me do research whatever I want. The taxpayers of Colorado who pay my salary want something there. They don't want me wasting my time and their time and their money you know they want me to solve their problems and tell them when there's an important issue and try to prevent something bad from happening to them. That's one of the roles of people who do research that are supported by the public. I feel an obligation. I didn't expect to work on this problem I was working on the dinosaur extinction problem which led us to think about the parallels between it and a nuclear war. The dinosaurs went extinct and they went extinct for a lot of the same physical reasons that would have physical phenomena that would occur in a nuclear war. Namely all this smoke. We know that everything in the surface of the earth burned at the time of the extinction of the dinosaurs and the smoke helped cause a lot of the extinctions.

You see a parallel like that. You think, well I better do something about this. I wouldn't say it's a fun project to work on it's very depressing and frustrating to see people ignoring it. It used to be five years ago if I tried to talk about nuclear weapons no one would come to hear my talk. I would talk about the death of the dinosaurs and the parallels with nuclear weapons and people would come to hear about the death of the dinosaur's episode. It's interesting you know. You give a talk about the dinosaurs; the audience is very engaged they're interested they're talking to each other. They're laughing about things. You switch to nuclear wars; the audience goes silent because it's them that might be affected.

I think it's come back because of Putin is an issue and it's something we have to deal with in the near future. Hopefully there won't be a nuclear war. I don't think there will be a nuclear war of Ukraine. I think that's just a bluff and people shouldn't become too worried about this. You know you have to maintain some level of calm and realize that things are often not what they've seen

but nevertheless, this is a problem we have to deal with and when the war in Ukraine is over, we have to have treaties back in place to control this problem.

1:05:41 Bart Ziegler, President: Professor, let me interrupt for one second Dr. Dorfman. I'm getting a lot of people texting me about the nuclear waste because in San Diego we have some nine million people within 50 miles of a nuclear waste storage dump site and that's of concern as a target or just as a, yeah. What can you, and I happen to have a background in Community Environmental Health, so that makes me more worried about the effects of radiation. I had not known before you that as a target, nuclear waste site, or nuclear power plant is considerably more dangerous than atom bombs blowing up in the air. I guess what's my question, help me out professor?

1:06:33 Professor Brian Toon: Well, you obviously don't want the local power plant to fail and nuclear power in the United States has a long history of being extremely risk-free. There have been very few incidents of much concern. It's generally very safe. But you can't guarantee safety forever. The power plant there in San Diego, I understand it. I've driven by it before. It is right in the coastline it's not on like Fukushima in terms of location. I have no idea you know how well is protected against a big tidal wave. Seems to me like up on a cliff so it probably isn't. People certainly know in California that there are earthquakes and so I assume that they would be protected from that, but I don't know that much about that power plant and this is not a field in which I'm an expert. All I can tell you is for sure there's a lot of radiation in there, in the waist and in the core and you don't want that to break open and be distributed. And we really have to solve this problem of where to store nuclear waste. It's not only a hazard from being broken open, it's a terrorist hazard. You could have somebody get in there and steal some of this nuclear waste and spread it around somewhere. Probably wouldn't actually be that dangerous but it would almost certainly create panic in the city so that's another aspect of this is just a terrorist getting access to all this stored nuclear waste and stirred all over the world in pretty much the same way. It's around the power plants or connected to them in some way. This is a widespread unsolved problem in nuclear power which is another problem that society needs to solve. It can’t just keep going this way. It needs to solve the problem of getting rid of this waste.

1:08:54 Bart Ziegler, President: Dr. Dorfman, how does the production of nuclear power relate to nuclear weapons production? If you want to speak to that, you may as well.

1:09:03 Dr. Paul Dorfman (Moderator): Okay, my colleagues at Sussex University at Spruce Science Policy Research Unit, Professor Andy Sterling and Dr. Phil Johnston, have made a clear argument that they go hand in hand on both the practical and sort of economic level to a certain extent. It's very difficult to have one without the other because in terms of R and D, research and development budgets and also the development of the capacity in terms of the intellectual capacity and the manufacturing capacity these two things sort of go hand in hand. Macron also has used this as a sort of significant plus from his perspective. Now, I personally I don't believe in unilateral disarmament. I believe in multilateral disarmament.
That is my position. However, it has to be said that if you were to put to one side the armaments, nuclear armaments budget from the Civil Nuclear Budget, then we could all see exactly how much this cost. And of course, the cost is truly astronomical. I remember back in the day; my PhD was on the health effects of a nuclear plant in the UK. That's Aldermaston, Green, and Common, and to a certain extent Halwell. And what occurred to me then was that it's a sort of a kind of a mad self-harming almost. What you're doing is that you're putting right near to your centers of population, this is in Reading which is right next to London, facilities that combine explosives with nuclear radiation. Therefore, you're creating a target and an exposed population. It's an incredibly complex issue that that has no real answers, no real solutions, but it has to be said that we're all to a certain extent really feeling these risks one way or another.

1:11:46 Bart Ziegler, President: My question to each of you, what do you do to keep life light? Let me start with you Dr. Dorfman.
1:11:56 Dr. Paul Dorfman (Moderator): Okay. I mean you know we've been around the block. I mean the point about life is it's not really a sort of a, it's not all about pleasure. There are certain things that are important but engaging with these important things allows one to, in one's life keep things light. There seems to be something important about trying to as it were, help. Now if one does this, there are honestly and truly very real paybacks. And one feels this very clearly in one's personal life.

1:12:40 Bart Ziegler, President: Professor may I ask you the same question?

1:12:45 Professor Brian Toon: Well, I'm not sure what the question was I couldn't quite hear it.

1:12:46 Bart Ziegler, President: Well, how do you keep life light? How do you keep your life with joy? And I mean you know so much that's so gloomy and you know imminent, so how do you, and what would Carl Sagan have said?

1:13:04 Professor Brian Toon: Well Carl was very worried about this because he, this is a famous question among astronomers, which was the basic question is where are they? You know, there's so many civilizations that should be out there in our galaxy. I mean the nearest planet that's inhabited could be only a few light years from us. Why aren't they communicating with us? Why aren't we detecting them? You know it's a big issue of why that's not happening? And Carl used what's called the Drake Equation to calculate the number of civilizations in the galaxy. And he concluded that civilizations must destroy themselves within a few decades of amending nuclear weapons. He thought 50 years was about the destruction time which we've passed. So yeah, he was he was quite concerned about that from the astronomical point of view, of the development of nuclear weapons and losing control of them. And I mean it's hard to imagine that the world 100 years from now is going to be having all these little countries having wars with each other and dictators babbling up all over the place. You just can't have an advanced civilization that's allowing itself to be so destructive an so I'm optimistic about the future that we will solve these problems. When I was a kid, I got interested in all kinds of the problems and discoveries in the world like, some of these are dumb. Like are there, yetis? When I was a kid, magazines had articles about the existence of yetis because people were wandering around Himalayas stuff, they had found evidence of giant ape people. It turned out this was something that some monks are making money on by selling monkey skulls together but that's how things still persists and people will think, there's Bigfoot around somewhere. You know, this is kind of a joke thing, but you know there are real television shows telling children that Bigfoot exists. I know a famous one.

I'm getting off the track here but I'll come back to my point. There's a famous one, there was a black panther on the TV show wandering around the U.S supposedly and someone had a movie of this black panther. And, yeah, it sure looked like a big black cat wandering around the yard and so they called in some photographer he said no this is just a house cat that's black and because of the way the picture's taken it makes it look like it's a mountain lion. You would think they would end this subject and that this TV program for children and say we solved the problem scientifically we know the answer is it's a house cat. No, they go right back to maybe it's a black panther. You know this is very bad for society to have these kinds of TV shows at any rate, when I was a kid there were all kinds of things. The Yetis got answered to me when I was about 10 years old, they don't exist. Lots of other problems you know like what caused the ice age, when did life arise, is there life on Mars, how did the dinosaurs die? I had kind of a list of these as a kid and I've been working on all of them ever since then and so that's very engaging and I enjoy working on understanding nature and trying to understand the answers to these problems. And they're not all answered by any means and then of course I had children of my own and a family and so I have a lot of pride in my children and happiness with my family. And I enjoy being at a university and teaching students and seeing my students grow up and become scientists themselves. All that is very rewarding and I'm optimistic about the future and studying this nuclear problem does not make me worry about it. It makes me want to do something about it. We have to do something about it not worry about it.

1:17:22 Dr. Paul Dorfman (Moderator): And I can add also that in terms of nuclear, when one really considers the facts here, something like 84% of all new power worldwide last year put down in terms of power capacity globally was renewables. There is no question but the renewable evolution is here. It's not an issue that one needs to discuss. It's like climate there is a, The International Energy agency says the same thing, The International Panel on Climate Change says that renewals are 10 times better at climate mitigation than nuclear. The debate is over. The renewable evolution is here and it will change all our lives in a practical and also in an emotional sense. When we know that we can switch on light or go on that Voyage on a train we know that the power that we use will be sustainable and, in that sense, there is also great hope within that, In the context of all of the kinds of things that we've been discussing which is potential cataclysm and all of the worries that surround us all. Within all of this there is very real

reason to hope and that's not a kind of a rosy toad for you. This is a pragmatic view from the information that we now have.

1:19:04 Bart Ziegler, President: Yeah, this has been absolutely brilliant. I want to thank Dr. Dorfman and Professor Toon for their exquisite enlightenment to us and the audience. Their expertise is invaluable. We're fortunate to be having the best people to share with their, to share their knowledge. I hope this conversation is provided everyone in the audience a better understanding of potential dangers of a nuclear winter, the need for continued research in the advocacy, to keep efforts on everyone in the call to keep us safe. I encourage you to stay in touch with the Samuel Lawrence Foundation by following up. The transcript will be provided shortly as well as the video. Subscribe to our newsletter, stay up to date on our work. Tune in for additional talks here. We advocate for environmental and social justice through spreading awareness and knowledge to progressive organizations and projects in need of support. Thank you very much Professor Toon and Dr. Dorfman and all the people behind the scenes, including Pilialoha, Madeline, Jill, and everyone else that made this possible. Thank you very much.

1:20:23 Professor Brian Toon: Thank you.

1:20:24 Dr. Paul Dorfman (Moderator): Thank you.