

WASHINGTON ROUNDTABLE
ON SCIENCE & PUBLIC POLICY

**Examining Risks
of Nuclear Waste
Disposal**

By

Dr. Bernard Cohen

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June 24, 2008

Jeff Kueter: I want to thank you for giving us a few minutes of your afternoon to talk about a critically important subject which provides context for considerations of national energy and environmental policy. As many of you are aware, the role that nuclear power will play in meeting our energy needs, as well as how it contributes to an environment where carbon dioxide emissions may or may not be part of our future, is a critical decision point for the nation and the world to grapple with. Underlying that context and that discussion, of course, are questions of what one does with the waste products from nuclear power. Many of you are familiar with the now-famous Pacala and Socolow wedges, where they try to define a set of policy options available to reduce carbon emissions at gigaton-level reductions. Each wedge therefore is a gigaton. In an analysis that I was privileged to sit through some time ago, persons were talking about how you would actually fulfill and implement the nuclear power wedge that Pacala and Socolow had laid out. One of the takeaways from this briefing was that it would require the world to invest in something like twenty or so Yucca Mountains. I came away from that surprised at the extent of the investment that would need to be made, but also concerned about how this nation or any other would begin to make that kind of investment, given our history of trying to build even one Yucca Mountain. Dr. Cohen approached us with the opportunity to talk about a different way of handling the radioactive waste problem and we thought it was important to bring his views to your attention as you consider the role that nuclear power will play in the future.

Dr. Cohen is a Professor-Emeritus of Physics and Astronomy and of Environmental and Occupational Health at University of Pittsburgh. He is the author of six books, over 300 papers in scientific journals, and more than seventy articles in non-technical journals. He has been awarded numerous prizes for his work in science and he was elected Chairman of the Division of Nuclear Physics of the American Physical Society and Chairman of the Division of Environmental Sciences of the American Nuclear Society. Dr. Cohen, thank you for being with us today.

Bernard Cohen: Thanks a lot for coming and please don't hesitate to interrupt if you have any questions. This talk is about what is called high-level radioactive waste, which I will refer to as radwaste. This is a radioactive material, the spent fuel after it has been removed from the reactor. It contains the vast majority of the radioactivity produced by the reactor. What are we going to do with it? Well, everybody pretty much agrees that the way to dispose of it is to bury it deep underground. A typical

depth discussed is 2,000 feet (600 meters) below the surface. What is there to worry about? Everyone seems to agree that what we have to worry about is radioactive material being dissolved in groundwater and transported with the groundwater. And of course it comes up to the surface and thereby gets into the food and water supplies, which means that it would get into people's stomachs. Once it gets into people's stomachs, there is radiation exposure to the various organs in the body and this can cause cancer. We will consider this danger with two different burial approaches, which I call Nature's Way and Government's Way.

Of course, to say much, you have to quantify the toxicity of this material. The way I like to quantify it is in terms of cancer doses (CD). This is a method for quantifying the toxicity of this radioactive material that gets into some people's stomachs. To give you an example, if a total of 50 CD of this radioactive waste is ingested by 1,000 people, there will be 50 extra cancer deaths among them. It doesn't have to be 1,000 people; it could be 100,000 people. If a total of 50 CD is ingested by 100,000 people, there will be 50 extra cancer deaths among them (since there are 100 times as many people, the average received by each must be 1/100 as much). Another way to apply it: if a man ingests 0.2 CD, this gives him a 20% chance of dying from cancer in addition to his normal risk. Now there are standard methods for calculating CD which are universally accepted; I don't think we have any questions about these. And these figures assume no toxicity is "wasted" by a single person ingesting more than 1 CD.

We begin by estimating how many CDs there will be in U.S. nuclear power waste. I am assuming here the continuous use of nuclear power at the current level for many thousands of years; the current level is 20 percent of all present U.S. electricity. If you think we will be using more or less, everything is proportional, so you can still use these results. There is a dependence on some variable details, such as if and when we do reprocessing but they have minor effects on results. The general conclusion is that if we have this continuous use of nuclear power at the present rate for many thousands of years, there will always be about 2 trillion CD of radioactive waste buried 2,000 ft. under the lower forty-eight states. If the idea of 2 trillion cancer doses, enough to cause 2 trillion cancers, scares you, we can get some perspective by recognizing that there is a lot of natural radioactivity in the ground, especially from uranium, thorium, radium, and other elements in the top 2,000 feet. The number of CDs of these in the top 2,000 feet is 30 trillion CD, fifteen times more harmful than the radioactive waste buried under the 2,000 feet level. This is naturally occurring. So the question is, how much harm is this uranium, thorium and radium doing?

This is fairly easy to determine. From measurements on corpses, we know the amounts of these elements – uranium, thorium, radium, polonium, lead and things like that – in our bodies and knowing the amounts in our bodies allows us to calculate the radiation dose and from that we can calculate the cancer risk. You have to assume it

And the dissolved material in groundwater is held up by chemical reactions with the rock, which extends the times to many thousands or millions of years. If you look at the curves in Figure 1, you will easily see that delays of thousands or millions of years, reduces the amount of radioactivity that gets near the surface by factors of hundreds or thousands.

Another point is that it is very easy to detect escaping radioactivity. All you have to do is measure the radioactivity in your drinking water supply. This is probably done now in most drinking water supplies. If radioactivity is detected, it would be very easy to prevent exposure to people. Another point is that the cancer cure rate improving at about 1 percent per year, so if we are talking about deaths that will occur thousands of years in the future, there ought to be a large decrease in the number of deaths that we calculated. And remember, we said that this stuff would be buried in selected sites, which would presumably be more secure than an average site. Without these things, we would be suffering two deaths per year in the United States from all this buried waste, so the conclusion is that we would expect much less than one death per year in United States from buried radioactive waste.

There are several independent ways of showing this without using the uranium and thorium and radium in the ground. As one example, the known average rate for groundwater dissolving rock at 2,000 feet is one atom per billion per year. In other words, one atom in a billion in a rock 2,000 feet underground is dissolved in the groundwater every year. Once it gets in the groundwater, what is the probability of it entering a human stomach? There are various pathways for it to do this: drinking water from wells (the main way), groundwater gets into rivers which are used for drinking water, eating fish from these rivers, and using river water and groundwater for irrigating food crops. The total probability of something that is in groundwater getting into a human stomach comes out as 0.0004, or four chances in 10,000. If you apply this calculation to radioactive waste (and this is a little complicated), it gives less than one death per year. There are other independent approaches which lead to results in agreement. So I think we can confidently say that all this radioactive waste buried 2,000 feet underground will cause much less than one death per year in the United States.

So here is what I call Nature's Way for handling radwaste:

1. Let geochemists decide on a form which is comparable to average rock. There are technologies to make it as similar to average rock as you want, although there is good evidence that there is no problem here and you don't have to do anything, really.

2. Have geologists pick favorable sites. For example, they might consider low-population areas, areas with low groundwater flow, and things like that. Presumably if geologists take this into account, they will pick a site that is better than an “average” site.
3. Simply bury the waste at a depth of 2,000 feet.

The licensing requirement should be that the site should be better than an average U.S. site, and the result, we can be confident, would be less than one death per year in the United States. In comparison with this one death per year in the United States, our present principal technology for generating electricity is by burning coal, which puts out a hell of a lot of waste which we call air pollution. Typical estimates are 10,000 deaths per year due to air pollution from coal burning for electricity, so surely less than one death per year is highly acceptable. So that is Nature’s Way.

Now we have to come to the Government’s Way. The bureaucracy is outlined in my Marshall Institute Policy Outlook *Radioactive Waste Disposal: Nature’s Way vs. Government’s Way*;¹ there are roles for the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Energy (DOE); then there is the government of the host state, the Secretary of Energy, the President, Congress. There are roles for critics, including financing their efforts, and stuff like that. To make a very long story short, the Department of Energy picks a site and must prove that it satisfies the requirements set up by EPA and NRC. An example of these requirements, the most important point, maybe, is that they have to show that there is less than a 15-millirem dose to any one person in any year over the next 10,000 years. Now how serious is a dose of 15 millirems to a person? This gives him a risk less than 2 percent of our present risk of being killed in an accident in any one year. It is only one-tenth or less of the extra radiation a person receives from living in Colorado or New Mexico, where natural background radiation is higher than average.

In order to satisfy these requirements, you have to go through what is called a “Probabilistic Risk Analysis” (PRA). To do a PRA, you list every potential sequence of events that can lead to radiation exposure, go through these sequences step by step, estimate the probability for each step, and then combine this information to determine the probability that one person over the next 10,000 years will get an exposure of 15 millirems in any one year. DOE has to do this analysis and satisfy the NRC and the EPA that it satisfies the requirements.

This process, site-specific PRA, presents problems like mad. First of all, you have to learn all about the geology of the site you have chosen, which is very difficult

¹ <http://www.marshall.org/pdf/materials/591.pdf>

and very expensive. We have spent something like \$8-10 billion already doing this for Yucca Mountain. And then you have to convince skeptics about the predictions for future geology. For example, what is the chance of an earthquake or volcano? The climate may change; ten thousand years ago the Arizona desert was a rainforest, for example. Land uplifts, which can cause rivers to change their courses. There are insect and animal activity and human use changes. It is just one hell of a job that DOE has to do and it is very open to skepticism.

What I am proposing here is to just do a probabilistic risk analysis for an average U.S. site, and that is what I have done above, which tells you that there will be less than one death per year in the United States. Now all these problems about earthquakes, changing climate, changing weather, rivers changing courses, and insect and animal activity occur somewhere in the United States, so they are taken into account in the average with a reasonable weighting. Also changes over time in the U.S. average will be much less than the possible changes over time at a specific site.

Now what do we mean by a PRA for an average site giving less than one death per year? If you did a PRA like we have been talking about, step by step for all the things that could lead to the effect, for a whole bunch of randomly-selected sites in the United States – randomly stick pins in a map and do a PRA for each of these sites – the average result from all those PRAs would be, we calculate, less than one death per year. You would think that spending billions of dollars on site selection should do at least as well as random selection. But the present law requires a site-specific probabilistic risk analysis.

Among the problems that I haven't mentioned yet is that we don't well understand the processes for dissolution of rock by groundwater. It depends on the granularity of the rock, the chemistry of the area, and things like that. Transport of dissolved material depends on things which we don't understand well, such as cracks in rock, which are very difficult getting a handle on, and so forth.

So the Department of Energy solution is to build an underground chamber with many features to prevent contact with groundwater. No expense is spared. But they can't guarantee that groundwater will never get in. There could be an earthquake or rock fall or who knows what. The problem then is, if water does enter, what happens? The DOE sponsored a bunch of engineering tests where they have water flowing over samples of the waste and see the ways in which it dissolves away. It turns out that it dissolves away at about one part in one thousand per year in those tests, which is one million times faster than for rocks submerged in groundwater. So they are starting off with a factor of one million which they have to make up. It is just a tremendous job convincing people that you can make up for the factor of a million.

The risk estimates they have come up with depend heavily on transport phenomena which are open to uncertainty about cracks in rock and uncertainty about future events. It is a big mess, as probably a lot of you know. So the evaluation that DOE has come up with has many uncertain elements, which makes it easy prey for critics. The law gives critics financial help and avenues for endless appeals in court and things like that. Politics favors critics and in the case of the Yucca Mountain repository, the rallying cry of critics isn't about technical problems; they say, "We don't want Nevada to be the nation's garbage dump." As a result, opposition to Yucca Mountain is requirement for a politician in Nevada. Unfortunately Sen. Harry Reid, the Senate Majority Leader, is a Nevada politician and he has vowed that they will not bury waste at Yucca Mountain on his watch. The result is many years of delay, many billions of dollars spent, and the outcome is still in serious doubt. And they are going to have to go through this process for every future repository! They will have to build another repository every thirty to fifty years or so; it has taken that long to get Yucca Mountain going. The cause of this mess is using Government's Way, rather than Nature's Way.

I will close with my analysis. The future of nuclear power is clouded by this problem. Many states, including California, have laws against starting a new nuclear power plant until the waste problem is "solved." That would mean having a repository available, and who knows when that will happen. Many utility executives are afraid to build new plants, because they are afraid of this unsolved problem. The result is that the future of nuclear power is clouded, which is a great shame because it is a major answer to climate change. It is the only technology we have that can produce vast amounts of electricity without contributing to global warming.

My solution then is to change the licensing requirement to show that an average U.S. site is adequately safe. As far as I am concerned, that has been done; as I said before there is much less than one death per year. If people want us to do a better analysis, that is fine, but it is very easy to do analyses like that for an average U.S. site. Then all you have to do to license a repository is show that the selected site is as safe as an average U.S. site. It seems to me that it would be very easy to sell this. Isn't it logical to show that an average site is a very safe site, and a selected site is safer than an average site? I think these are very rational and easily defended requirements and they are also very easy and inexpensive to satisfy.

So that is my solution and I welcome your questions.

Questions and answers.

Question: Dr. Cohen, you seem to be saying it is better to bury waste in a saturated zone than an unsaturated zone. My understanding is the American effort is the only one that is looking at the unsaturated zone. Why are we better off in a saturated zone?

Cohen: I didn't say we are better off in a saturated zone.

Question: But some say that the rate of dissolving would be lower.

Cohen: That is very probably correct, but I know how to do an analysis for a saturated zone, so that is the analysis I have done. I don't know how, and I am not sure DOE knows how, to do one for an unsaturated zone. The rate of dissolution has to be less than in a saturated zone. Some of the things I have said don't apply directly to Yucca Mountain. But for people who would think it is an insoluble problem or a very difficult problem, I really would like to change that impression.

Question: Dr. Cohen, you were talking about disposing of this material in Nature's Way. Is there any pretreatment before burying it underground? Is it encapsulated in some kind of container? They have talked about vitrifying it. Your paper talks about a rock-like substance.

Cohen: Yes, you would do things like that. You would do cheap and easy things. As I said, I would leave this up to the geochemists to decide what is enough like average rock. There is a technology to make it into something which is really like average rock in every way. The usual technology is to convert it into a glass. Many natural rocks are glass. There are a lot of good arguments that say that this glass would be as good as average rock, the same order of magnitude at least, or maybe one third as good as average rock. There is even an argument that you can make that just burying the spent fuel would be as good. But you do sensible things; you capsule it. Probably you surround it with bentonite clay, which has a lot of useful properties. If it gets wet, it swells up to keep water out. If any water does get in and dissolves the waste, it has a very high probability of absorbing radioactive material before it gets away.

I would recommend doing simple things like that. But this is much simpler than to build an underground chamber with such high confidence that water doesn't get in that you can assume that if water does get in, the waste is a million times more likely to dissolve than if were buried in groundwater.

Question: Let me follow up with a different question: you are assuming the burial depth at 2,000 feet, if I understood you correctly. The Yucca Mountain repository is half that. What would that do to the likely dose?

Cohen: As I said, this isn't directly applicable to Yucca Mountain.

Question: But if the depth where the material is buried is less than 2,000 feet, even hypothetically, regardless of the site, does that mean that there would be a tendency for the dose to increase?

Cohen: Yes, there is more water flow. Remember, the average for the top 2,000 feet is six times more water flow. So that means if you did it at 1,000 feet, it would probably be three times more. But these are all trivial. It is much less than one death per year, so you multiply that by three. And you are comparing it with coal burning, which is killing 10,000 people a year and nobody seems to worry about that. That is the thing that drives me crazy.

Question: You mentioned that you would need to build one of these repositories every thirty to fifty years if you go to a 2,000-foot level. Is there anything to preclude dropping down to 2,500 or 3,000 feet, putting the first load in, sealing that somehow and dropping another load in on top of it? That way you could reuse the same location. Because it is so difficult to get the first location approved, once it is approved, you could keep loading it in there.

Cohen: That is certainly a possibility. There is a heat-loading problem, of course. One problem is that you don't want to get it so hot that it cracks the rock and stuff like that. The waste is radioactive so it puts out some heat. In fact, that is what determines the design of the repository; you want to keep these pieces far enough apart so it doesn't get too hot. The details of the repository design are not something that a physicist should have a problem with. Once people understand what the problems are, you get them in proper perspective.

Question: I'd like to make a couple supplementary comments. I am a founding member of the EPA and I was a member of the panel that wrote the regulations concerning radioactive waste. Yucca Mountain was chosen primarily because there was a study at the time that suggested there were about 250-odd nuclear weapons tests conducted there, some above the groundwater, some below the groundwater, some at the groundwater, and some of them at the surface. We were wrong; the number was a thousand. When you blow up a thousand atomic bombs in a place, you already have a radioactive disposal facility. What do you think is in an atomic bomb, potato salad? So that was one reason, and if you ever go to Nevada, you will see that Yucca Mountain is just about north of the test site. That was a reason for doing that.

Second, if you take uranium from the mines and put it over there and then you put reactor waste or spent nuclear fuel next to it and leave it a thousand years, the risk to the public becomes about the same. My calculation was 950 years; other people estimated 600 years and some other people came to nearly 3,000 years. The reason for 10,000 years is that when the EPA composes regulations, we always use a ten-fold safety factor. So that is where 10,000 years came from. Now they will never put that into the regulations, but there was at least partially some logic in it. I subscribe to the statement of my friend here that we have forgotten to look at the alternatives of actions we do and the risk assessment process. With all of these uncertainties, it is not a bad

thing to evaluate, if I have three or four choices, which one of them I should take. It is very important to recognize that what we have developed is really a reasonable approach to evaluate what you are trying to do. I was a physical science advisor for radiation and hazardous materials and I left in 1985.

Cohen: I never did understand why you set the regulation for the exposure to one individual. Why not the total exposure to a population?

Question: The reasoning is simple. You have to listen to appointees, who have allegiance to their constituency, and federal employees. The way you handle these is the art of the possible. You are right.

Question: I wonder if you have had any contact with the Australian Synrock project?

Cohen: That is what I was referring to when I said there is a technology available for making it really like average rock. I think that it is more expensive than just glass and there is a lot of good evidence that glass would do just fine. In Japan, Russia, England and France, they convert their stuff into glass. That is what we have been doing with some of our defense waste

Question: So is the problem with Yucca that the effort is to keep it dry or that the standards that were established were wrong?

Cohen: Well, I would say the problem is that it is almost impossible to convince skeptics that your probabilistic risk analysis doesn't have problems with it.

Question: Especially the Department of Energy.

Cohen: Well, whoever you are. The Department of Energy hires all kinds of people; the U.S. Geological Survey is involved, for example.

Question: But a PRA will be part of the licensing basis, no matter where the site is placed.

Cohen: It seems to me that a PRA for an average site ought to be adequate and a PRA for an average site is a hell of a lot easier than a PRA for a specific site.

Question: Right, but the analysis presumes that the leeching rate from a very high concentration of both naturally occurring materials and materials that don't occur in nature is the same as the rate today for natural materials that have been in place for eons and they are at a low density.

Cohen: I don't see why concentration makes a difference. The number of CDs that are dissolved and get into people is all that matters. There are experiments; there is a Canadian glass block experiment, for example, where they actually put a glass block of radioactive waste in the ground and followed it for thirty years. We learned a lot from that. There are natural deposits, of course, which are very concentrated. Some of these uranium deposits are the same materials as spent fuel, uranium oxide.

Question: But we are only looking at natural deposits as we find them now. The question is, what was their leech rate when they were new, before they were washed by millions of years of groundwater? Are we confusing nature in the present with an extrapolation of what that would have been in the past? The uranium deposits are billions of years old. If I take a two-kilo block of uranium that is concentrated and bury it at 600 meters and I use as my analogy for how fast it is going to dissolve what a 2-kilo block of uranium that nature put there 3 billion years ago looks like, it is possible that what I am looking at now is not what was there originally, and that it had a very high leech rate earlier on. If the relevant period for us is 10,000 years or a million years, then confusing what it looks like after three billion years with what it looked like new could be a factor.

Cohen: These things have been considered and studied, of course. In the Canadian glass block experiment, they do find a higher leech rate for the first few years and it finally gets down to be more or less what you would expect. In thirty years or a hundred years, it ought to be down pretty much to what you would expect. The Oklo deposit in Africa has been there for millions of years. We know how much was there originally and it hasn't moved. If you say a lot moved at first, they know that didn't happen.

Question: Why? Over geologic time, why do we suppose that the material hasn't moved through underground water channels and dispersed into the general environment?

Cohen: Because it's not there. You can follow its movement; it has moved perhaps ten feet. We need a geologist or geochemist to discuss these things.

Question: When I was working on the EPA standards, the subject was addressed. Because of the way a crystal is structured, whether it is a million years old or a day old, a crystal is a crystal, and the solubility and the behavior of that crystal is determined by the crystal's structure of that material. In other words, it makes no difference if that crystal is whatever it is. It goes without saying that the crystal with time loses its crystal-line structure; that is true. But when a crystal is there, you know what that is. Therefore if you discover that there is uranium – I forget the name of the name for uranium that is mined – that material, when you look at it now or when you look at it a million

years ago, it looks identical. If it loses its crystal structure and dissolves, then of course, you know that. If the crystal structure has remained a million years ago and is still around, you can assume that if you create the same crystal structure and leave it in there, and the geological conditions are right, it will remain. It is the crystal structure that determines the ability of the water to remove materials from that crystal.

Cohen: There are surface effects which can be important. For example, in these glass block experiments, the radioactivity is dispersed through the glass. Some of it was originally on the surface and that would be dissolved away faster. But the glass itself is not dissolved away that fast and so after the surface is dissolved away, everything from inside has to get out through the lesion, which is a very slow process. In fact, it goes inversely as a square root of time in the Canadian glass block experiment. So there would be some minimal effects. You have to go through more detail than I have gone through here, but the main thing I am trying to make clear is perspective.

Question: If you are talking about public acceptance, why do you expect that a generic PRA would have better public acceptance than a site-specific one?

Cohen: Isn't it logical to say that if you can prove that an average site is 10,000 times safer than coal-burning waste and then say that all you have to do is show that to the best of the geologist's understanding, the selected site is better than an average site? Isn't that logic?

Question: Doesn't that move part of the public acceptance question to why people should accept the first analysis of the average site?

Cohen: There are several different ways to prove it, and those are very easy things to prove. I felt as though I had proved it two different ways here, in fact. The site-specific analysis is full of assumptions and the skeptics have so many easy targets to shoot at. They don't have any easy targets here. Maybe an easy target was brought up here: there would be an initial time when things might not settle down; that might be a target which would have to be considered in more detail than I have talked about here. I would let the geochemists and geologists work that out, which I am sure they could. But it is so much safer, to me at least. Don't you find it convincing?

Question: I don't see how it is different to do an analysis on an average site. How do you know the levels?

Cohen: An average analysis just consists of little things like I said: monitor the amount of uranium and thorium in corpses and go from there. But to do it for a specific site, you have to understand everything that is going on. You don't have to understand how it happens for the average site; all you know is the final result. And you can get this

final result in at least three different ways, maybe four different ways, which are easy to understand. Give me an hour with anybody and I think I can convince them by any one of these ways. Whereas for a specific site, I don't see how you can convince anybody. You just have to use all kinds of judgments and best guesses and things like that. Because we don't really understand how things are dissolved by groundwater and how things are transported by groundwater. We understand a lot of things about it, but not in the detail that we can say that in this particular site, where the rock has a certain composition and certain granularity and the groundwater has a certain composition, what is going to happen. Those things are as complicated as hell.

Question: So we are going to bury irretrievable wastes in material we don't understand?

Cohen: It doesn't have to be irretrievable, of course. But that is true; nature has done it. Nature has buried all this irretrievable waste.

Question: Nature doesn't have liability.

Cohen: Well, we are here. It has allowed us to survive and it is not doing any harm.

Question: I am also hung up on the issue of the site-specific characteristics, the geochemistry, the geology, things of that nature. How do you define an average site? Is it an average site per geological formation or what?

Cohen: An average site for the United States. We know that by knowing how much uranium and thorium and radium is in people all over the United States. That is all you have to know, from that approach. For the other approach, all you have to know is how much rock is being dissolved away over the United States. To do that, all you have to do is measure what goes out into the oceans from the Mississippi River, the Columbia River, the Hudson River and so forth. In other words, you know how much dissolved material is being dissolved out of the United States. A hydrologist estimates how much comes from groundwater, and we have pretty good estimates of that and how much from different depths in the ground, and things like that. These things are all rather well known without any big uncertainties. In other words, you don't have to understand the process; you understand the results.

Question: Was there ever, in the history of these naturally occurring large deposits, a case where, in looking at it now, these deposits presented a threat to the safety of the people in the environment when they were newer?

Cohen: Well, nothing is new 2,000 feet underground. New things occur at the surface.

Question: But even in terms of the amount of material that is dissolved and gets into the groundwater and is therefore accessible to the environment for uptake by the people and the plants and can get into the food chain. In areas where this has occurred, meaning the large deposits, have there ever been cases where natural occurring radioactive has been dissolving and dispersing? You are talking about large deposits and you are saying that these naturally occurring reactors have been safe. Well, it is safe now, but what about when they were younger? There is still a chance of the rainwater filtering down, dissolving the minerals and getting into the groundwater and water table. When the deposits were less old than they are now, what about the chance of that presenting a threat to the environment? I was just wondering if there have been cases of that in geological history.

Cohen: Well, certainly on the surface, things happen all the time. Things are eroded away on the surface. But at 2,000 feet underground, there is not much going on.

Question: Was there some cataclysmic event archaeologically evident in the prehistoric past where deposits of radioactive material killed living organisms? Is that what you are trying to say?

Question: The half-life of uranium is over a billion years, so in the history of mankind, we are not talking about changing amounts of emitted radiation.

Cohen: Well, if anything happens, it happens when these things are near the surface. You ask about what happens when the stuff is new. New things happen near the surface; new things don't happen 2,000 feet underground, as far as I know.

Question: I have a question about the security of radwaste underground. You are talking about some form of encapsulation and something less than what is done at Yucca Mountain. How does that affect the security for the waste?

Cohen: Do you mean security against somebody taking it out and using it? It is 2,000 feet underground. You could have live security, if you want to, if you are worried that somebody is going to go down and get that stuff. Of course, the way it is now, it is stored at the power plants, which are on the surface. If terrorists wanted to get at them, they would have a much better chance of getting it now than they would when it is buried 2,000 feet underground. I haven't thought about that much.

Kueter: Dr. Cohen, thank you so much for your comments.

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