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EPILOGUE

Socrates talks about Nuclear Energy

The public has been told so many things about nuclear energy that are confusing or just plain wrong, that some of the basic physical facts should be clarified. The best way to do this was invented over 2000 years ago by the philosopher Socrates. So I've put this discussion into the form of questions by Socrates, and I'll have his questions answered by a metaphorical Dr. Proh, who sees no serious problems with nuclear technology, and Dr. Kahn, who feels the problems outweigh the advantages. [This Epilogue is based on a piece I wrote for Cosmos 2002, *the Cosmos Club journal.]*

Socrates: Why is nuclear waste a problem?
Kahn: Because we don't know what to do with it.

S: Why do we have to do something to it?
K: Because it's dangerous.

S: Bicycles and stairs kill people. Does nuclear waste kill or injure people?
K: No, but it can.

S: How can nuclear waste kill?
K: If it leaks into water that may be used for drinking.

S: Is nuclear waste liquid?
K: Sure. There are those huge tanks at Hanford, Washington.

S: Does Hanford store waste from civilian facilities?
Proh: No, virtually none; just weapons wastes.

S: So if we never built any nuclear power plants, it wouldn't change the situation at Hanford.
P: Correct.

S: What form is the waste from power plants?
P: Either spent fuel or miscellaneous waste products. We really shouldn't call spent fuel waste. Only three percent of the fuel has been used; the rest is available for recycle. You wouldn't call a used car waste, if it had been driven, say, 3,000 miles.

S: Are any of these materials liquid?
P: No, the fuel is hard ceramic pellets in metal tubes. The waste is consolidated into a solid—glass, concrete or bitumen. There may be some noble gases, but they are biologically inert and thus no real problem. Even if water were to wash over it, it could not leach out much from glass or metal-clad ceramic.

S: Why then is civilian nuclear waste dangerous?
K: It's radioactive. It gives off dangerous radiation.

S: So we should put it in casks with radiation shielding, right?
P: Well, they do, of course.

S: Can you get dangerous radiation from a nuclear waste cask?
P: No, you'd have to eat the waste.

S: How is that different from a non-radioactive poison?
K: Nuclear waste stays toxic for so long.

S: Doesn't nuclear waste continually *decrease* in toxicity?
K: Yes

S: Stable elements maintain their toxicity undiminished forever. Why is nuclear waste more dangerous?
K: Well, if all U.S. electricity were made from nuclear, the nuclear waste could kill 10 billion people!

S: What does that really mean? Is nuclear waste actually killing 10 billion people?
P: No. It's a hypothetical figure, meaning that the total production is 10 billion times the individual lethal dose. It's like saying that a community swimming pool has enough water to drown a million people. It has no real meaning.

S: How does production of nuclear waste compare with the annual U.S. production of other toxic materials?
P: We produce many common substances with thousands of times greater toxicity. For example, we produce enough chlorine gas each year to kill 400,000 billion people. Then we purify drinking water with it.

S: We don't seem threatened by these, do we?
K: But we keep increasing world's radioactivity, no?
S: Let's see. Where does nuclear waste originate?
P: From the fissionable isotope of uranium.
S: Isn't that naturally radioactive? What is its half-life?
P: Nearly a billion years.
S: So we take a billion-year material and convert it to fission products with mostly shorter half-lives. What's the ultimate effect of that on the earth?
P: In the long run, we make earth less radioactive.

S: Any other problems?
K: Well, there's so much of this waste—thousands of tons of it!

S: How does that volume compare with coal-fired plants, the major competitor to nuclear?
P: A 1000 megawatt coal-fired power plant, supplying all the electricity used by a million people produces 8 million tons of carbon dioxide, which can contribute to global warming; 100 thousand tons of sulfur dioxide, which can cause acid rain and respiratory problems; Nitrogen oxides equivalent to 200,000 automobiles; benzpyrene and other carcinogens; and a quarter million tons of ash containing enough uranium to make several a-bombs. This does not include the mountain tops pushed into valleys to get at Appalachian coal seams

By contrast, a nuclear reactor generating the same amount of electricity produces two cubic meters of waste, which can all be sealed in containers and controlled, not dispersed into the environment. All waste from 40 years operation is stored at the plant. They could store another 40 years worth.

S: If all your electricity were produced by nuclear power, how much waste would that represent?
P: You could store your life's share in a corner of your basement.

S: Why don't we put the nuclear waste into the sea? Would it would despoil the whole ocean?
P: No. The ocean's natural radioactivity would completely overshadow it. You could detect it only with special instrumentation that discriminates one isotope from another. Rivers continuously dump more radioactivity into the ocean than we create with all our nuclear power plants. We could put it in drums and drop them into the deep ocean clay, where they'd be isolated for millennia.

S: What if we did nothing about this problem for several years?
P: Even anti-nuclear activists agree there's no safety problem. The few sites shutting down would need the fuel casks sent elsewhere. Some other sites might need to increase their storage capacity, but that's not difficult. Some states have laws limiting fuel storage, but that is a man-made problem; it could be fixed.

S: Is that a multi-billion dollar task?
P: No. There are many government or private sites nearby that could store the casks for a few decades.

K: But then what would we do?
P: Nuclear waste contains many valuable products. We will ultimately want to recover those, as well as the unspent fuel. If this source of energy were in the form of oil, we'd be ready to sacrifice a generation to protect it. As coal, we'd destroy pristine mountains to get it. But here we have it, already refined, within our borders, ready to use. Right now it's cheaper to use uranium ore, but the spent fuel is there for the future.

K: But radiation is carcinogenic, right? It's always a danger.
P: No. In fact, radiation in small doses is beneficial. It's like selenium or other trace elements in your vitamin pills. In large doses they're deadly poisons. In small doses they're actually nutrients.

S: How can that be? Isn't nutrient the exact opposite of poison? Can the same substance be both?
P: Paracelsus said in 1540 that nothing is poison, but the dose makes it so. That's how vaccination works. Radiation acts the same way. Large amounts are poisonous, small amounts are beneficial. In fact, there are experiments demonstrating that reducing the natural radiation background causes organisms to get sick and die. And people who live where natural radiation is high generally live longer and have less cancer.

K: Why is that? Doesn't each cell damaged by radiation create a potential cancer? Twice as much radiation causes twice as many damaged cells. That's got to double your risk of cancer, no?

S: Doesn't each flu germ entering your body create a potential disease?
K: Yes, but…

S: Then do you conclude that the best way to fight disease is to keep washing your hands, wipe off doorknobs, avoid shaking hands—to minimize contact with germs, as some germophobes do?
P: That's not what doctors recommend.

S: What do doctors recommend? And why?
P: They say keep warm, eat nutritious food, exercise, to keep your body healthy. So the number of germs in our bodies is less relevant than the state of our immune systems and other defenses. If you keep healthy, your body will take care of the germs.

S: Does radiation work that way?
K: I don't think so. Radiation damages cells, and that's how cancers start.

S: Are cells in your body ever damaged by events other than radiation exposure?
P: Oh, yes. Normal metabolism damages hundreds of millions of cells for each one damaged by background radiation.

S: Is it the same kind of damage?
P: Not exactly. Radiation damage is harder to repair. But we know how much harder, and the net result is that even after repair, metabolism still leaves several million more damaged cells than radiation does. The number of damaged cells is not the critical factor, despite how some people argue. High dose radiation kills, not by damaging more cells, but by degrading the defense system.

S: Then how does low-dose radiation affect the body beneficially?
P: When it stimulates the defense system, it enhances repair and replacement of not only the few radiation-damaged cells, but also the very much larger number of metabolically-damaged cells.

S: One fact that complicates discussions of radioactivity is the presence of natural radioactivity. We've had congressmen urging that we "get it down to zero." How do the natural radioactivities compare with some regulatory limits?

P: To answer this, I have to explain what the numbers mean. Radioactivity measures how intense a radiation source is (just as luminosity measures how bright a light source is). The amount of radiation one gets depends on the strength of the source, its distance from the receiver, and whether any shielding is present.

We measure radioactivity in curies (named after Marie Curie, the discoverer of radium). One curie is the amount of radioactivity possessed by one gram of pure radium (1/28 of an ounce). We usually encounter much less than one curie, so we measure lesser amounts in picocuries (millionths of a millionth of a curie). In one picocurie, only about 2 atoms per minute are decaying and giving off radiation. The radioactivity of a liquid is measured in picocuries per liter (a liter is a little more than a quart). (Some years ago, equivalent metric units were defined, but U.S. regulations are still set in curies.)

So let me give you some examples in picocuries per liter. The proposed EPA radium limit on tap water is 5. The natural level of river water is from 10 to 100. Natural seawater is 300. Whiskey is 1,200, milk is 1,400 and salad oil is 5,000. And natural radon in much of the world's drinking water is 30,000, and some health spa waters are as high as 300,000. There is considerable evidence that these natural levels of radioactivity are not harmful and are probably beneficial.

S: So it appears we are protecting people against a truly non-existent hazard! How about terrorism? We read some really frightening possibilities. Plutonium, we're told, is the deadliest poison known? Is this true?
P: No. You can hold it in your bare hands. Spoonful for spoonful, it is about as toxic as caffeine. When physicist Bernard Cohen was told that he and other scientists were not interesting interview subjects, he offered to eat on-camera as much plutonium as Ralph Nader would eat caffeine. But the interviewer said that would be cheap exhibitionism.

S: So where does plutonium get this reputation?
K: It is considerably more lethal if inhaled.

S: Then the scenario of putting plutonium into a public ventilator would create a real disaster?
P: No, plutonium is very heavy and is extremely hard to keep suspended in air. It wouldn't work well. During all the decades we have been handling plutonium in tonnage lots there has never been a death from plutonium toxicity. Even after dispersing some 5 to 7 tons of it into the air during 1,000 weapons tests.

S: What about terrorist airplanes? Can an airliner fly through several feet of steel-lined reinforced concrete?

P: No. The plane would either slide off the curved surface or crush like an egg-shell outside. Any jet fuel would burn harmlessly outside. The size of the plane is relatively unimportant, since the plane structure collapses on itself, absorbing most of the impact energy, and only the engines pose a penetration potential. In 1988, a full-sized (unmanned) Phantom F-4 fighter plane was driven by rockets at 480 miles per hour into a simulated containment wall section. These instrumented tests confirmed analysis: the body of the plane crushed against the outside, penetrating less than a inch. The engine shaft penetrated less than two inches. It is clear that an airplane cannot fly through such a wall. It is true but largely irrelevant that the idea that a suicide pilot might undertake such an attack was not considered prior to September 11.

K: But If terrorists got inside the plant with explosives, couldn't they, as speculated in the papers, create a disaster like that burning reactor accident in Chernobyl in 1986, with tens of thousands of deaths?

S: What is the worst that could happen?

P: No credible sequence of events involving a U.S. reactor could lead to tens of thousands of deaths. Even Chernobyl caused no deaths to the public, even without containment and without evacuation for the critical first days. The U.N. scientific report (UNSCEAR 2000) reports no other deaths than the 30 workers and firefighters in the plant. The 2,000 thyroid cancers were said to be 97% curable and probably due to intensive screening, since they do not correlate with radiation dose. An American reactor meltdown, at worst, would be more like Three Mile Island where there were no significant health or environmental effects whatsoever, even to plant workers.

K: But wasn't that due primarily to the intact containment structure that held in the fission products? What if the containment was breached?

P: Studies after the accident showed that nearly all of the harmful fission products dissolved in the water and condensed out on the inside containment surfaces. Even if containment had been severely breached, little radioactivity would have escaped. Few, if any, persons would have been harmed. Tons of molten reactor sitting on the 5-inch-thick reactor vessel bottom did not even penetrate the 5/16 inch cladding. So much for the dreaded China Syndrome!

K: What if terrorists got hold of a spent-fuel shipping cask?
S: What is the worst that could lead to?

P: There is nothing one can do to a spent fuel shipping cask that could lead to a significant public hazard. Despite frightening claims about the hazards of what fear-mongers call "Mobile Chernobyls," spent fuel casks pose no significant public hazard. They cannot "go critical" like a reactor or detonate like a bomb. None of the radioactivity is in liquid form. It is solid ceramic pellets, metal clad. For more than 30 years over 5,000 fuel assemblies have already been shipped. Despite a few serious traffic accidents, not a single radiation release has occurred. The fuel in these casks is always cooled for several years prior to shipment, so the short-lived activity and the decay heat production have died down. The shipping casks themselves are virtually indestructible. To be certified for shipping, a cask must be able to withstand a 30-foot drop onto its edge, a 40-inch drop onto a puncture bar, a 1475^{o}F fire for 30 minutes, immersion under 50 feet of water for 8 hours. Further crash tests have involved a tractor trailer carrying the cask hitting a concrete wall at 84mph, a locomotive hitting the cask broadside at 80mph, crash at 80mph followed by 125 minutes completely engulfing jet fuel fire, and a drop test from a helicopter so that the cask buried itself more than 4 feet in the hard-packed ground. In addition, casks have been tested with high-tech anti-tank explosive charges. Only in this last case was the cask breached, but even then the result of scattering a few chunks of spent fuel on the ground could not create a serious public hazard. There is no mechanism to disperse the radioactivity in an ingestible or respirable form, over a significant distance. At the worst, only a very few people would get some radiation doses and these would not be life-threatening.

K: But there's still the "dirty bomb." A terrorist wraps radioactive material around an ordinary explosive and supposedly spreads death and destruction.

S: Is this a real threat?
P: No. It is completely ineffective. Many tons of shielding would be required to permit handling by deliverers. The radioactive ceramic scatters only a short distance. The noble gases are biologically inert. Little air, water or land contamination results. There would be few if any casualties beyond the reach of the explosion. This is not a credible weapon.

S: So are you saying we need not be careful in dealing with nuclear technologies?
P: No, of course not. We have taken extraordinary precautions, and consequently no one has been killed or even seriously injured by American-type nuclear power plants or their waste products. But this has had the perverse effect of scaring people into thinking we must have an unimaginably dangerous beast, to justify such extreme precautions. That's why it is good we talked about how the laws of nature and the physical properties of materials prevent any major public hazard, in any credible circumstance we can think of.

K: Wait a minute! I've read many times about some guy, usually a kid, getting burned by some radiation source. What about that?
P: Radiation now has thousands of industrial and commercial uses, some of which used to be done by x-ray tubes. Just as people are occasionally hurt by inexcusably careless use of x-ray tubes, so one can steal a radiographic source, take it out of its shield and carry it in his pocket, or play unknowingly with radioactive power and make a mess. But these injuries result from illicit use of industrial equipment and generally affect only the miscreants and sometimes their families or associates. While unfortunate, they are in the same category as accidents involving stolen tractors, police cars, or medicinal narcotics. We don't condemn the legitimate use of such things; we just tighten up on security. Such incidents are no more frequent or more damaging with radiation devices than with many other types of equipment.

S: Well, I think we've covered about as much information as one can comfortably absorb in one session. Let's get together again soon, shall we?