This paper began with an invitation from Japan a month after the disaster at Fukushima I Nuclear Power Plant began on March 11, 2011. The paper was to be presented six months later (October 30) — at a conference where I was already scheduled to present a paper on the use of imaginary cases in ethics (Davis, 2012). The disaster was still very much the province of journalism. Its outlines certainly lacked the stability of history. Of course, even history, though it generally seems stable, is not entirely so, being subject to dispute here and there and to radical revision every now and then. At first, Fukushima’s facts changed almost daily — if by “facts” we mean those descriptive propositions about which there is general agreement. After a while, the changes were less frequent and more a matter of addition than correction. Today, a year after I began work on the paper, the outline of the disaster seems settled. Dispute now concerns only details, such as how much land, if any, will have to be abandoned for some years, how many premature deaths are to be expected because of radiation released during the disaster, and so on. At some point, I had to stop worrying about the facts and report my reflections. I stopped worrying about the facts on October 15, 2011. Since then, I have changed “a fact” only when a reader or auditor pointed out that it was no longer fact.

I am an oddity in science and technology studies (STS) because I focus not on science and technology but on scientists and technologists. Indeed, I do not write about “scientists” in general or “technologists” in general but about specific professions, for example, chemists or engineers. While most STS scholars seem to have a better understanding of ethical issues by promoting research into various areas of applied ethics and philosophy, and by providing researchers, scholars, and students with a forum for dialogue and discussion on ethical issues raised in contemporary society. The journal welcomes papers from scholars and disciplines traditionally and newly associated with the study of applied ethics and philosophy, as well as papers from those in related disciplines or fields of inquiry.

Three Nuclear Disasters and a Hurricane: Some Reflections on Engineering Ethics

Michael Davis
Illinois Institute of Technology, USA

Abstract

The nuclear disaster that Japan suffered at Fukushima in the months following March 11, 2011 has been compared with other major nuclear disasters, especially, Three Mile Island (1979) and Chernobyl (1986). It is more like Chernobyl in severity, the only other 7 on the International Nuclear Event Scale; more like Three Mile Island in long-term effects. Yet Fukushima is not just another nuclear disaster. In ways important to engineering ethics, it is much more like Katrina’s destruction of New Orleans than like any nuclear disaster. It is (primarily) a consequence of a natural disaster, the enormous earthquake and tsunami that wrecked much of northeast Japan. One lesson of Chernobyl, one shared with Katrina, concerns the different roles engineers have at different stages in an engineering project (planning, designing, management, and operations). In the planning stage, engineers seem to have relatively little power to affect certain early large-scale trade-offs between public safety and public welfare. Another lesson may be the importance of not leaving complex technical systems untended. The events that made the disasters at Three Mile Island and Chernobyl inevitable lasted only a few minutes or hours; the events that made the disasters in New Orleans and Fukushima inevitable were spread over several days. Fukushima avoided a more serious disaster because the plants were not abandoned in the way New Orleans was. A third lesson concerns our ideas of heroism, especially our sense that heroism is sometimes one’s duty. An engineer’s duty sometimes includes protecting others from harm even at the risk of the engineer’s life.

Keywords: Chernobyl, Fukushima, Katrina, Three Mile Island, precautionary principle

Editorial Note

The Journal of Applied Ethics and Philosophy is an interdisciplinary periodical covering diverse areas of applied ethics. It is the official journal of the Center for Applied Ethics and Philosophy (CAEP), Hokkaido University. The aim of the Journal of Applied Ethics and Philosophy is to contribute to a better understanding of ethical issues by promoting research into various areas of applied ethics and philosophy, and by providing researchers, scholars, and students with a forum for dialogue and discussion on ethical issues raised in contemporary society. The journal welcomes papers from scholars and disciplines traditionally and newly associated with the study of applied ethics and philosophy, as well as papers from those in related disciplines or fields of inquiry.
to be interested in what scientists or technologists have in common, I have focused on what distinguishes one discipline from another, for example, what distinguishes chemists from engineers (Davis 2002). I have found that there is no single way to study professions, especially the profession of engineering. I am, in short, not a philosopher, historian, or sociologist of technology (though scholars in those fields sometimes find my work useful). I have edited the invitation from Japan—was a quarter-century of thinking (and writing) about engineering. (For those unfamiliar with my work on engineering, the place to start is Davis 1998.)

This paper’s title promises “reflections” on four disasters, not systematic or definitive understanding. There is not much that a philosopher can do about a problem. The newspapers, websites, and other sources available (at least in English) seldom identified anyone as an engineer. The stories focused on “workers,” “managers,” and machinery. I had to use what I knew about nuclear power plants in the United States to interpret the facts thus given. I had similar problems, though less severe, when interpreting the other disasters to which I chose to compare Fukushima.

Interpretations are, of course, open to objection but, without interpretation, facts merely pile up, becoming in time an unmanageable heap. There is no understanding without interpretation. But interpretation relying on changing facts is necessarily the sort of time-stampedengineers philosophical enterprises are inclined to avoid—and I would have avoided it if I had had an invitation from Japan. There is not much that a philosopher can do about a disaster such as that at Fukushima—except help those seeking to understand it and thereby help to prevent similar disasters. I felt I owed the Japanese that much.

Why Compare These Four Disasters?

The nuclear disaster that Japan suffered at Fukushima has been compared with other major nuclear disasters, especially Three Mile Island (1979) and Chernobyl (1986). It is more like Chernobyl in immediate destructiveness, the only other 7 on the International Nuclear Event Scale (the upper limit of which is 7). It is more like Three Mile Island in probable long-term effects (though Fukushima’s long-term effects are likely to be substantially worse than Three Mile Island’s). To date, Chernobyl seems to have directly killed thirty-one reactor site workers, to have caused the permanent abandonment of a city of about 200,000, and 1,000,000 premature deaths worldwide, to have forced the permanent abandonment of a city of about 50,000 (Pripyat), and to have ruined perhaps a 100,000 square kilometers of farmland. Over 100,000 lost their homes to contamination. (All information about Chernobyl here and below is drawn from Wiki, “Chernobyl,” a source valuable both because it is easily accessed and regularly updated, but also not reliable.

In contrast, the radiation released from the Fukushima plant, though significant, will, it seems, leave little long-term contamination, except at the plant itself and in a plume perhaps fifty km beyond. At least six workers have exceeded lifetime legal limits for radiation and more than three hundred have received significant radiation doses. Estimates of future cancer deaths due to accumulated radiation exposures in the population living near Fukushima have ranged from none to a non-peer-reviewed “guestimate” of a thousand. No one died in the explosions at the plant or from subsequent radiation exposure (there were no Plan B tsunami killers (filters for the secondary cooling loop). At 4 am, the pumps feeding the polisher stopped. We still do not know the cause of the stoppage. When a bypass was not opened, condensed water from primary loop’s main feed-water pumps. These also shut down. No longer receiving water, the steam-driven generators stopped and the reactor automatically carried out an emergency shutdown. Within eight seconds, control rods were inserted into the core to halt the nuclear chain reaction. The reactor nevertheless continued to generate heat (a byproduct of normal decay). Because steam was no longer being used by the turbine, heat was no longer being removed from the reactor’s primary water loop. (Except where otherwise indicated, the discussion of Three Mile Island held and below relies for its facts on Wiki, “Three Mile Island.”)

Once the secondary’s feed-water pumps stopped, three auxiliary pumps started up automatically; but because some 160,000 liters of coolant was lost, the system could not pump water. So, the secondary loop was no longer working. Without the secondary loop, heat builds up. Steam and other fluids in the reactor core create a pressure that forces coolant into the containment building. This coolant was pumped from the containment building up to an auxiliary building, outside the main containment, until the sump pumps were stopped at 4:39 am.

After almost eighty minutes of slow temperature rise, the primary loop’s four main pumps began to suffer damage as a mixture of steam and water passed through them. The operators then shut down the pumps, believing that natural circulation would cool the coolant. But the coolant was a mixture of steam and water; movement, but steam in the system (itself the product of rising temperature) prevented coolant flow through the core. As the coolant stopped circulating, it increasingly turned to steam. Just before 2 am, after almost a day of trouble, the coolant level fell so low that the top of the reactor core was exposed to the steam. Intense heat then caused a reaction between the steam in the reactor core and the nuclear fuel—cladding. That reaction burned off the cladding and damaged the fuel pellets. The pellets then released more radioactivity into the reactor coolant, producing more hydrogen gas. The gas fed full explosion in the containment building in the afternoon.

At 6 am (two hours after the incident began), there was a change of shift in the control room. A new arrival noticed that temperature gauges and holding tanks were too high and used a backup valve to shut off the coolant venting through the relief valve. But, by then, about 120,000 liters of coolant had already leaked from the plant. Most of it flowed out at 7 am (almost three hours after the incident began) did contaminate water reach radiation-activated alarms. But, by then, the radiation in the primary coolant water was around three-hundred times higher than usual. The plant was seriously contaminated and the reactor’s core had suffered a partial meltdown.

The Nuclear Regulatory Commission (NRC) made an extensive investigation of the disaster, a typical engineering response. Its report ended with recommendations for changes in controls, quality assurance, maintenance, operator training, management,
and communication of important safety information. There was no finding of negligence or more serious wrongdoing having caused the disaster, no suggestion that major redesign of nuclear plants was needed, and no proposal to rethink the place of nuclear energy in the generation of electricity. (Rogovin 1980, pp. 89-93, focused mainly on changes in emphasis and procedures at the NRC; Kemeny 1979, pp. 61-73, focused on "attitudinal changes" reports do, however, contain much criticism of other aspects of how Three Mile Island operated.

Chernobyl

Chernobyl was not a normal accident. Its cause was an engineering experiment which, though successful, lacked proper approval. That is not to say that the experiment was unjustified, fundamentally improper, or indeed abnormal. Even when not actively generating power, nuclear reactors require cooling to remove heat produced by the natural decay of nuclear fuel. Chernobyl's pressurized water reactors (different in design from Three Mile Island's) used water flowing at high pressure to remove waste heat (about 28,000 liters of water an hour). After an emergency shutdown, the core could still generate a significant amount of residual heat. If not removed, the heat could cause a core meltdown (as it did at Three Mile Island). If the power grid failed, power to run the plant's cooling system might be unavailable from outside for far too long.

Chernobyl's reactors had three backup diesel generators. Each generator required fifteen seconds to start up but took over a minute to attain the speed required to run one of the main coolant pumps. Chernobyl's engineers judged this one-minute power gap unacceptable. Too much can happen in a nuclear reactor in a minute when the cooling system is not working. Analysis indicated one way to bridge the one-minute gap was to use the mechanical energy of the steam turbine and residual steam pressure to generate electricity to run the main coolant pumps while the generators were down (135 RPM, frequency, and voltage. But, of course, the analysis had to be confirmed experimentally. The engineers had to work out and then prove a specific procedure for effectively employing residual momentum and steam pressure.

Previous experiments—in 1982, 1984, and 1985—had ended in failure. The 1986 experiment was scheduled to take place at Reactor 4 during a planned maintenance shutdown. The experiment focused on refinements in the switching sequences of the electrical supplies for the reactor. The experiment was begun with an automatic emergency shutdown. Because no danger to the reactor was anticipated, the engineers did not formally coordinate the experiment with either the reactor's chief designer or scientific manager. Indeed, the experiment did not even have the approval of the onsite representative as the Soviet nuclear authorities. Only the director of the plant approved it (and even his approval did not follow standard procedures).

The experiment began just after 1:23 am on April 26, 1986. At 1:26, the displaced control rods were picked up loads. The turbine generator supplied the power for the four main circulating pumps as it coasted down. The experiment was all but complete forty seconds later. But, as the connections to the core were made, the generator that powered the water pumps decreased, the water flow decreased, producing more and more steam bubbles in the core. The reactor was now ready to begin a destructive feedback loop: The production of steam would reduce the ability of the coolant to absorb neutrons, increasing the reactor's output of heat. The increased heat would cause yet more water to become steam, further increasing heat. During almost the entire period of the experiment, the automatic control system successfully counteracted this destructive feedback, inserting control rods into the reactor core to keep the temperature from rising.

If conditions had been as planned, the experiment would almost certainly have been carried out safely. The Chernobyl disaster resulted from attempts to boost the reactor power to a level never intended, therefore, it was not an emergency—once the experiment had started (something inconsistent with approved procedure). The approved procedure called for Reactor 4's power output to be gradually reduced to 700–1000 MW. The minimum level established in the procedure (700 MW) was achieved at an hour before the experiment began. However, because of the natural damping effect of the core's neutron absorber, reactor power continued to decrease, even without further operator action.

As the power dropped to approximately 300 MW during the experiment, one of the engineers conducting the experiment mistakenly inserted the control rods too far, nearly shutting down the reactor. Control-room personnel soon decided to restoring the power and extracted the control rod columns, but several minutes elapsed between the extraction and the time that the power output began to increase and stabilize at 160–200 MW. The extraction withdrew the majority of control rods to the rods' upper limit, but the rapid reduction in the power during the initial shutdown and subsequent operation at less than 200 MW led to increased dampening of the reactor core by the natural surface of the core that absorbs neutrons at a high rate. To counteract this unwanted high-absorption, the operators withdrew additional control rods from the reactor core.

Then, about the time the experiment ended, there was an emergency shutdown of the reactor. The shutdown started when someone pressed the button of the reactor's emergency protection system. (We do not know whether the button was pressed as an emergency measure, by mistake, or simply as a routine method of shutting down the reactor upon completion of the experiment.) Because of a flaw in the design of the graphite-tip control rods, the core was already overheating when the control rods were withdrawn. The few rods remaining in the core and the graphite-tip control rods absorbed neutron-absorbing material to slow the reaction. The emergency shutdown therefore briefly increased the reaction rate in the lower half of the core. A second few seconds later, the core was massive power increase, the core overheated, and seconds later this overheating produced the first explosion. Some of the fuel rods fractured, blocking the control-rod columns and causing the control rods to become stuck at one-third insertion. Several more explosions followed, exposing the reactor's graphite moderator to air, causing it to ignite. Since the reactor lacked a containment (a thick concrete shell), the fire in the reactor sent a plume of highly radioactive smoke into the atmosphere, causing dangerous fallout over a huge area (as much as five-hundred km away)—and, eventually, less dangerous fallout over much of the world.

The effort to halt the nuclear contamination and avert a much greater disaster soon involved over 500,000 workers and an estimated eighteen billion roubles, crippling the Soviet economy.

Because most of those directly involved in the Chernobyl disaster died of radiation poisoning, there are many uncertainties about the exact sequence of events. Nonetheless, we can be sure that the actual accident would not have occurred had the experiment been carried out as expected. Chernobyl was as much an engineering disaster as Three Mile Island: both the immediate and underlying causes were ordinary engineering decisions, whether in operation or design.

Fukushima

The disaster at Fukushima fits neither of these patterns. The accident was not normal or the result of an engineering experiment. It was also not the result of operator negligence, incompetence, or misconduct. The post-accident investigation (begun in 2011 and still ongoing as of early 2023) revealed that the Fukushima disaster was caused by a combination of factors: a large earth attack, the failure of a tsunami-resistant facility, and human error.

At the time of the quake, 2:46 pm, Reactor 4 had been de-fueled while 5 and 6 were in cold shutdown for planned maintenance. The remaining three reactors shut down automatically as part of the normal emergency protection system. The reactors shut down, the plant's own generation of electricity ceased, eliminating one source of electricity used to run cooling and control systems. One of two connections to the national electrical grid also failed. That loss of power started up thirteen on-site emergency diesel generators. These would ordinarily have provided enough power to operate the reactors' control and cooling systems until the loss connection to the national grid could be restored. Had the earthquake been the only disaster to hit the Fukushima plant on March 11, there would have been little to discuss here. The tsunami changed that.

The plant was protected by a seawall designed to withstand any tsunami up to 5.7 meters, but the great wave that struck forty-one minutes after the quake was fifteen-meters high. It flooded the entire plant, including generators and electrical switchgear in reactor basements. It also broke the remaining connection with the national electrical grid. All conventional power for cooling was lost. Only one backup remained: emergency batteries, able to run some of the monitoring and control systems for up to eight hours. Replacement batteries and mobile generators were soon dispatched to Fukushima, but collapsed bridges, debris-strewn roads, and similar obstacles delayed them. The first replacements did not arrive until 9:00 pm (six hours after the first call went in).

The arrival of the replacement batteries and mobile generators did not end the crisis, however. They had to be installed. The normal connection points were in flooded concrete. There was also difficulty finding suitable cables. Work to connect batteries and generators was still continuing twenty-four hours after the quake when there was an explosion in Reactor 1's building. The side walls of the reactor building roof collapsed, and debris covered much of the floor and machinery.

The roof of the building was designed to provide ordinary weather protection, not to withstand an explosion or to act as containment for the reactor. In the Fukushima reactors, the primary containment surrounded the reactor's pressure vessel. The top floor had no roof. The only water filled pools for storing new fuel ready to be craned into the reactor and used fuel ready for disposal. This first explosion was probably caused when
hydrogen collected under the roof. Exposed fuel rods became very hot and reacted with steam, oxidizing the cladding and releasing hydrogen. The hydrogen would have leaked upward. Safety devices normally burn such hydrogen but not the explosive concentrations. These systems seem to have failed when the electrical power did.

Reactor 1’s containment survived the explosion. There was no loss of radioactive material, although there was an increase in radiation following the explosion. The explosion at Reactor 1 injured four workers. But this was only the beginning. Hydrogen gas was also leaking at the other five reactors. Over the next few days, hydrogen explosions destroyed the upper cladding of the buildings for Reactor 3 and 4 and the containment inside Reactor 2. Several fires broke out at Reactor 4. In addition, spent-fuel rods stored in the spent-fuel pools of Reactors 1–4 began to heat over as the water level dropped. Fear of radiation leaks led to evacuation of all non-essential persons within a twenty-kilometer radius of the plant.

In short, the Fukushima plant was overwhelmed by forces from outside well beyond what it was designed for. Without heroic efforts by plant staff, some of whom may die from exposure to radiation, the Fukushima disaster might have become at least as devastating as Chernobyl. Even with those heroic efforts, several weeks passed before the plant could be said to be more than merely “controlled.” One generation after Reactor 6 was restarted on March 17 (six days after the quake) allowing some cooling at Reactor 5 and 6, the least damaged. Connection to the power grid was restored to parts of the plant on March 20, but machinery for Reactors 1–4—damaged by flooding, fires, and explosions—could not be restored for several months. Only Reactor 3’s core survived the quake. It did not cool in all the reactors reach safe temperatures.

The Fukushima plant could have been designed to withstand the natural disaster that occurred. A breakwater three times higher than the actual breakwater could have protected the plant against the tsunami (assuming it survived the quake); the plant might have been located far enough away from the ocean to be safe from even such tsunamis. Building basements might have been made waterproof; and so on. Even some less expensive arrangements might have improved what happened considerably. For example, storing more batteries on site would have allowed the cooling and control systems to function longer without repair or resupply, weeks instead of hours. All of these changes in design that government was unwilling to pay for might have prevented the Fukushima disaster.

Katrina

When it struck New Orleans on August 29, 2005, Katrina was a category 3 hurricane, a large storm but no larger than storms that strike the Gulf Coast almost every year. The top of the hurricane scale is 5. Ike left much of the levee system nonetheless unusually destructive because it moved so slowly that anything in its path was subject to heavy rains and high winds for many hours. The rain and high winds were what Task Force IPET (IPET) assigned much destruction in New Orleans. (Except as otherwise indicated, all information in this section comes from Davis 2007.)

Even on an ordinary day, New Orleans is a city that must work to prevent flooding. One of the world’s largest rivers, the Mississippi, flows through it. From Jackson Park, the jewel of the tourist-drawing French Quarter, one of the highest points in the city, one can see the mighty river rushing by about two meters above the street. On any day of the year, the Mississippi would flood the city were it not for the levees that hold it back. Nor is the Mississippi the only water threat. Though the oldest parts of the city are as much as ten meters above sea level, a majority of the city is below, and the Gulf of Mexico, reaches New Orleans at its back, through Lake Pontchartrain, and underground, through the water table. (While the water under New Orleans is fresh, it is as high as it is in part because the Gulf’s salt water is not lower.)

Mostly developed since 1900, the newer parts of the city are, like much of the Netherlands, dry only because water is constantly pumped out. Every year, there is more land below the level of the original rice paddies. Only a third of a meter a century; some parts of the city have subsided by half a meter or so because the weight of buildings is compressing the soil or because pumping water from the ground allows the soil to compress. Were the levee system not for suggesting alternatives, for example, conservation or safe construction too expensive. They are also important for designing the location of a nuclear power plant. For example, a location because the risk of earthquake makes safe construction too expensive. They are also important for suggesting alternatives, for example, conservation or a gas-fired plant rather than a nuclear plant. Engineers are not free to work within those limits, for example, to design a technology in question.

We can, I think, distinguish four sorts of engineering decision in these four case studies: planning, designing, management, and operations. (In a different context, I would include “disposal” in this list. I do not include it here only because none of these disasters concerns disposal as such, though Fukushima’s problems were due, in part, to fuel rods waiting disposal.)

By planning, I mean such decisions as whether to build an airport in a place where to put it, and the upper limit of its budget. For such decisions, engineers are most important for vetting certain options, for example, a location because the risk of earthquake makes safe construction too expensive. They are also important for suggesting alternatives, for example, conservation or a gas-fired plant rather than a nuclear plant. Engineers are not free to work within those limits, for example, to design a technology in question.

But, for any large undertaking such as a nuclear plant or flood control system, engineers are generally only one part in a complex social decision in which the other parties include employer, government officials, experts of various sorts (such as geologists), bankers, and civil society (or “the public”). Perhaps the most important contribution engineers can make to planning is developing minimum standards for evaluating and responding to specific risks and benefits of the technology in question.

By designing, I mean the actual drafting of specifications. Floor plans on a nuclear power plant are often even necessary to construct or modify the technological artifact in question. Once planning has set limits, engineers are generally free to work within those limits, for example, to design

Conclusions

The Fukushima plant could have been designed to withstand the natural disaster that occurred. A breakwater three times higher than the actual breakwater could have protected the plant against the tsunami (assuming it survived the quake); the plant might have been located far enough away from the ocean to be safe from even such tsunamis. Building basements might have been made waterproof; and so on. Even some less expensive arrangements might have improved what happened considerably. For example, storing more batteries on site would have allowed the cooling and control systems to function longer without repair or resupply, weeks instead of hours. All of these changes in design that government was unwilling to pay for might have prevented the Fukushima disaster.
This calculation means nothing unless the four meltdowns are statistically significant, that is, a good predictor of what will happen over, say, the next hundred years (rather than a chance concurrence of events—like winning the lottery three days in a row). No, it is an empirical reminder that even a low-probability event will, given a large enough population, become highly probable.

If we look at our four disasters, two—Three Mile Island and Chernobyl—seem unrelated to any ordinary planning or design failure. Of course, with a higher budget, the Three Mile Island plant might have had more working backups for its cooling system. But Chernobyl might have had a concrete containment for its reactor or a better way of controlling core temperature. But that will always, or at least almost always, be true. Engineering is about making things "safe enough" rather than "absolutely safe".

How safe is "safe enough" is at least as much a social decision as an engineering decision. But it is an engineering decision in part. For small risks, engineers may well make the final decision. Even concerning the largest risks, engineers will be consulted and their opinion given considerable weight. No decision-maker was going to say, "Better order a new reactor on the 0.00005% chance to have the decision (more or less figuratively) blow up in her face.

Engineers generally evaluate risk by multiplying the harm's (net) divisible by the harm's probability. This method of risk analysis works reasonably well for small harms. The method does not, I think, work at all well for the largest harms—that those, even if highly improbable, would be intolerable if realized—such as destruction of the earth or even the sort of devastation Chernobyl produced. For such intolerable harms, engineers should, I do, and most engineers agree, avoid even the basic mistake of prudence in planning: if we (society at its rational best) would reject any plausible benefit in exchange for suffering that harm, we (that part of society making the decision) should, all else equal, rule out any design that risks that harm (however small the probability—so long as it is finite). Since this principle applies when we know both the harm in question and its probability, it is (technically) a precautionary principle (though its spirit is much the same). It is, in this respect, more like advice frequently given to gamblers betting in games of chance with known odds ("Don't bet more than you can afford to lose"). Precautionary principles are about dealing with uncertainty. (See, for example, Andorno, 2004.)

The principle I am proposing is only about dealing with known probabilities. Yet it is, or at least should be, an important principle in engineering. Failure is part of engineering. While engineers have a very low tolerance for failure of any kind, even in subsystems that are not "safety sensitive", I have yet to hear of any complicated system (even one as simple as a mechanical pencil) for which engineers have not calculated a failure rate (often, to be sure, a tiny failure rate, such as 3.4 defects per billion, or six-sigma). No product of engineering is (strictly speaking) "failure proof" (all things considered).

Most, perhaps all, nuclear power plants now operate with a failure rate of 0.00005% per year. Such a planning principle suggested above (at least when the calculation of probability takes into account that human beings will operate the plant). The analogy with gambling games is apt: if you are given the odds of winning at, say, 1% and you are allowed to play for any length of time, you would have an expected return of playing, you would clearly refuse such an offer. But, given the laws of statistics, and the fact that people do not play games for which the expected return is negative, you can afford to lose. Precautionary principles are about giving up things that can afford to lose. Precautionary principles are about giving up things that "bet less than you can afford to lose". Precautionary principles are about avoiding foolish failures.

And, of course, after these disasters, engineers designing made— or, in the case of Fukushima—will make—such improvements. Engineers generally learn from their failure, and we do not expect that every disaster will be a foretaste of a worse disaster, such as sight lines. And, of course, after these disasters, the engineers designing made— or, in the case of Fukushima—will make—such improvements.
other engineers may not be able to make the necessary changes immediately because of budget or schedule, or at all because changes that they have already made bar the improvement in question. Engineers may also find an alternative way to achieve the same end. For these reasons (and perhaps others), nuclear plants, however alike at birth, tend to grow into noticeably different individuals, much as biological plants do.

Some people, especially philosophers, seem to think of those who stayed on at Fukushima—those who, for example, worked in the dark in cold waist-high radioactive water to restart the generators—as engaged in "supererogatory" conduct, that is, as engaged in conduct above and beyond what morality requires. The engineers I have discussed this with seem to view the conduct as heroic but required (supposing the "workers" in question to be engineers). An engineer who left when needed would have acted unprofessionally; he would have failed as an engineer even if he left to save his life or look after his family. Engineering sometimes requires heroism (a significantly higher standard than proposed in Alpern 1983)—or so the engineers I have talked with about this seem to think.

Acknowledgments

This article has benefited from discussion of it at: a workshop for philosophy graduate students at the Technical University-Delft, The Netherlands, May 11, 2011 ("The engineer, public safety, and economic constraints"); a seminar for the Department of Philosophy and Ethics, the Technical University-Eindhoven, The Netherlands, May 13, 2011 ("The Fukushima Nuclear Disaster: Reflections"); a talk for the University-Eindhoven, The Netherlands, May 11, 2011 ("The engineer, public safety, and economic constraints"); a seminar for the department of Philosophy and Religion, University of North Texas, Denton, October 13, 2011 ("The Fukushima Nuclear Disaster: Some Issues of Engineering Ethics"); a plenary session of Sixth International Conference on Applied Ethics, Hokkaido University, Sapporo, Japan, October 30, 2011; and the Annual Meeting of the Association for Practical and Professional Ethics, Cincinnati, Ohio, March 3, 2012, as well as from comments of several reviewers for this journal.

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Decisions about the moral value of an action, rule or public policy cannot be reduced to a verdict resulting from the application of traditional tests based on the major ethical theories, despite the fact that handbooks still unanimously support this view. The history of ethical test results is more one of surprises than one of predictability. You would expect, for instance, that people who adopt the same moral doctrine do this in order to approach issues in the same way, including the moral assessment of actions. We all believe that this is the main reason it is useful to embrace the same moral creed. Therefore it seems strange to find that several members of the Romanian Parliament, all active supporters of Christian morality, assessed the legalization of prostitution in opposing ways. On the other hand, it is also strange that two people who adopt different ethical theories precisely because they offer distinct explanations of moral phenomena can frequently assess actions in the same manner. When a utilitarian and a Kantian—or a follower of Christian ethics and one of Muslim ethics—debate issues, it is somehow surprising to see them judging situations in the same way in most cases, despite the fact they declare themselves to be supporters of opposing ethical beliefs. Are these beliefs really opposing? In general, it appears that use of tests based on distinct or even opposing theories, such as utilitarianism and Kantianism, can result in different verdicts, but in most cases it results in convergent ones (Kantian and utilitarian moral duties are, ultimately, the same). On the other hand, if we dogmatically adopt a single theory and apply the same test repeatedly to the same action we usually get similar results, but some divergent ones also appear (see the cases of divergent utilitarian assessments of the same case given as examples in the textbooks).

A Pluralist Ethical Decision-making Procedure

Valentin Muresan
University of Bucharest, Romania

Abstract

This paper claims that the use of several moral tests to assess the ethics of a new policy is unavoidable. All the efforts to make credible a methodological monism by critical or reductionist strategies have been unsuccessful; moreover, it must be acknowledged that even if there were a single test, when applied successively or by different people it would usually give divergent results. The main aim of the paper is to propose a pluralist procedure of ethical decision-making, using a set of proper ethical tests (such as utilitarian, Kantian, Christian, principlist and casuist) in the frame of an ethical Delphi procedure intended to make the adoption of a new moral rule does not rely solely on an ethical test, but is essentially the outcome of a complicated social agreement. That is why in academic applications of the usual moral tests we do not take a moral decision on a new case, but merely simulate it.

Key words: ethical decision-making, ethical pluralism, ethical Delphi, pluralist model