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, this 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 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 the most useful way to study professionals, 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 acquired 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.)

Three Nuclear Disasters and a Hurricane

Why Compare These Four Disasters?

The nuclear disaster that Japan suffered at Fukushima has been compared with other major nuclear disasters, especially the Three Mile Island disaster (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 injured perhaps a 100,000 square km of farmland. Over 300,000 people 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 accessible and regularly updated.)

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 radiation exposure in the population living near Fukushima have ranged from none to a non-peer-reviewed “guesstimate” of a thousand. No one died in the explosions at the plant or from subsequent radiation exposure (though some resident workers filtered out radiation from 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 valve failed to open, water in the secondary coolant loop was not replaced. Two workers, one reactor staff and workers, to have caused between 1,000,000 premature deaths worldwide, one reactor worker. For details, see Wiki, “Fukushima Daiichi”.

The discussion of Fukushima below relies not on this source but also on Wiki, “Fukushima I.” Though I shall hereafter refer to “Fukushima”, it is in fact Fukushima I (Fukushima Dai-iichi) that I shall be referring to. There is also a Fukushima II (Fukushima Dai-ii). For details, see Wiki, “Fukushima II”.

Three Mile Island

Three Mile Island was an “normal accident”, that is, it began with ordinary failures of equipment and practice within a plant itself operating normally. Perrow 1984 also describes Three Mile Island as a “normal accident”. While I agree that it was a “normal accident” in his sense, my use of that term is somewhat different. I mean simply that the accident was a product of what engineers normally do rather than a product of incompetence, negligence, corruption, or other unusual conduct (such as experimentation).

During the night of March 27-28, 1979, workers were engaged in routine cleaning of a blockage in one of Reactor 2's steam condensers. A bypass valve, which prevented steam from being released, was not closed, allowing steam to vent through the containment building's sump to fill and sound an alarm at 4:11 am. (For details, see Wiki, “Fukushima Daiichi”)

The secondary’s feed-water pumps stopped, three auxiliary pumps started up automatically, but because some condensers were not in use at the time, the system could not pump water. So the secondary loop was no longer working. Without the secondary loop removing heat, pressure in the primary loop began to increase, automatically triggering a relief valve. The relief valve should have closed again when the excess pressure had been released; instead, it stayed open. That open valve permitted coolant water to escape from the pressure regulator. Despite the plant being shut down, some time between 9 am and 7 am (almost three hours after the incident began) did contaminated water reach radiation-activated alarms. 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) may have over-reacted to the threat of the disaster, a typical engineering response. Its report ended with recommendations for changes in controls, quality assurance, maintenance, operator training, management,
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 down.

If conditions had been as planned, the experiment would almost certainly have been carried out safely. The Chernobyl disaster resulted from steps taken to avoid exactly this situation. For example, the operators conducting the experiment mistakenly inserted the control rods too far, nearly shutting down the reactor. Control-room personnel soon decided to restore the power and extract water from the reactor core, but the rapid 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 increase 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 accumulated graphite, leading to an increase in the temperature of the graphite moderator. This in turn increased neutron absorption, slowing the rate of the nuclear reaction. The power output dropped to zero, and the reactor 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 diesel generators continued to supply power to operate the emergency diesel generators. These would otherwise have provided enough power to operate the reactors’ control and cooling systems until the lost 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 flood-debris natural oil. 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 control-rod mechanism of Reactor 1’s building was damaged, and the building collapsed. 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).

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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 instead of allowing it to escape at high concentrations. These systems seem to have failed when the electrical power did.

Reactor 1’s containment survived the explosion. The explosion at Reactor 2 injured four workers. But this was only the beginning. Hydrogen gas was also collecting in 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 overheat 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 over the next few years because of 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 partially under control. One thousand workers at Reactor 6 were 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 evacuations—could not be restarted for several months. Only Reactor 2’s core was not too hot; it did 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 one would 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 low waves. The buildings on stilts could 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. But all of these changes would have been more or less expensive, raising the price of the fuel the plant produced. Typically, engineers, though consulted, do not make such decisions. Government regulators, senior management, or public opinion typically decide, for example, whether to protect against a 500-year, 1,000-year, or 10,000-year quake.

**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 hurricane season is 5.7; it was 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 worse at Task Force Never (PET) issued its (draft) Final Report. PET was an independent team of more than one-hundred-fifty international and national experts from more than fifty different government organizations, universities, and private companies. The U.S. Army Corps of Engineers commissioned PET a few weeks after Katrina hit New Orleans. It was to analyze how the levee system performed. Though many questions of detail remain unsettled, this nine-volume report, is (more or less) the last word on both the causes of the Katrina disaster and means of preventing similar disasters.

PET reports a “system” that grew up piecemeal, only in part under the control of the Corps of Engineers, the government agency officially in charge of waterways. In some places, the system failed because a levee or other barrier to water was not high enough, often because of unanticipated subsidence rather than original design error. In other places, the system failed because, though high enough, the barriers were not designed for the forces to which they were in fact subject (an unusually slow-moving storm). Design of floodwalls along three canals was “particularly inadequate”. A series of incremental decisions between the original plan and the final design structures actually constructed “systematically increased the inherent risk in the system without recognition or acknowledgment” (PET 2006, I-2). Many of the failures in the system would not have occurred had implementation of plans for reconstruction not been delayed for almost twenty-five years by inadequate funding, new laws governing the environment, and, sometimes, inefficiencies well beyond the control of government. For some important “decisions”, there was no decision-maker at all. The decisions were a mere byproduct of poor communication, poor information, poor coordination, or some combination of these.

The most important lesson IPET drew from its analysis is unsurprising: The way to avoid similar disasters is to use larger safety factors (“conservative design” and good materials (“higher quality, less erodible”). (PET 2006, I-3). The flood control system now replacing the one Katrina overwhelmed is considerably more expensive than the old one. For example, the Corps has been replacing the five-meter pilings holding canal walls in place with pilings that would go down fifteen and a half meters (three times as deep). The Corps agreed that the use of i-walls along the canals (i.e., walls even with the support of a simple earthen levee) was a mistake. It is replacing the canals’ i-walls with heavily-braced T-walls locked down by twenty-one-meter high piles angled out in two dimensions. The use of simple levees was also judged a mistake. The Corps is now “armorizing” all levees where they seem vulnerable to overtopping, that is, covering them with something water will not so easily flow over or quickly wash away. Yet even with the changes in design that government was unwilling to pay for without a major disaster and may yet lose interest in paying for before the work is complete.

**Conclusions**

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 at all and 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 where 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 involved, at least, in the so-called “solving” of the problem. One important function they have is helping to define problems—or redefine them when it becomes clear that the client or employer has not asked the right questions.

But, for any large undertaking such as a nuclear plant or flood control system, engineers are generally only one party 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. Flood control engineers on necessity 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

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a nuclear plant that will fail slowly rather than quickly or cool rather than heat up if left alone. Only when a planning limit is too strict do engineers have a reason to overrule the engineers on a matter of safety only — the situations engineers are in at the time. But over many years (rather than a chance concurrence of events — a hypothesis) is that most were engineers. I hope someone will find out.

The engineers at Fukushima were not as successful as the engineers at Three Mile Island and Chernobyl. Both those disaster were limited to one reactor. At Fukushima, the disaster spread to four of the six reactors — and might have spread to the other two as well but for the restarting of a diesel generator at Reactor 6 to provide power for cooling the fuel in the holding pools of Reactors 5 and 6. Workers also removed roofs from Reactors 5 and 6 to allow hydrogen to escape. The decision was made because, unlike New Orleans, there is no major nuclear plant that will fail slowly rather than quickly or not very. Perhaps only 10 interference, or the like. Even so, it is an empirical reminder that 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 backup. For its coolants, for example, it 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 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 “safely 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 million (Six Sigma)). No product of engineering is (strictly speaking) “failure proof” (all things considered).

Most, perhaps all, nuclear power plants now in operation have been built in violation of the planning principle suggested above (at least when the calculation of probability takes into account that human beings will operate the plant). The analogy with gamblers betting in games of chance is altogether for. For we always have the option of doing something much safer, such as going to the theater or buying government bonds. For nuclear energy, our choices today are more difficult. Fossil-fuel plants together (though not individually) threaten us with a world too hot to live in. Hydro-electric dams flood lowlands when they fail and are often not available as a alternative to nuclear power. Failing nuclear-electric dams may have killed many more people than nuclear power-plant accidents have (depending on how deaths are calculated). Just one dam failure, that of the dam at Banqiao, China, in 1975, seems to have killed at least 250,000 people directly. Another, the failure of the Howard W. Mt. St. John Flood”, which killed more than 2,000 people, the result of a dam failing in 1889 (Wiki, “Johnston Flood”). In contrast, no one died at Three Mile Island and statistical deaths worldwide to be expected from the radiation that escaped is much smaller.

Nowhere has wind and geothermal met the demand for electricity in an industrial country. And so on. Even wind and geothermal, like the alternative 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 adopt the view of some like the view of the general public. For the time being at least, a world too hot to live in, a world of disease and famine (Wiki, “Banqiao”). Three Mile Island itself is only a handful of miles or so from the site of the “Johnston Flood”, which killed more than 2,000 people, the result of a dam failing in 1889 (Wiki, “Johnston Flood”). In contrast, no one died at Three Mile Island and statistical deaths worldwide to be expected from the radiation that escaped is much smaller.

How likely is a catastrophic failure at any moment? Not very. Perhaps only 10 at any time. But over many years and many reactors even such small risks add up. One author recently calculated that there are: 450 nuclear power plants in the world. There have been 4 meltdowns in history, one each at Chernobyl and Three Mile Island and two so far at Fukushima, as partial meltdowns count as meltdowns. That is a 1% failure rate. (Lindsay, 2011)
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, 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” 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.

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References


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 convergent the supposed variety of verdicts. This pluralist testing process, made by moral experts, is only a fraction of a more complex procedure intended to deliver social sanction for a new moral policy. This longer procedure also shows that the adoption of a new moral policy, rule or law is not only a question of passing a strict ethical test, but also a political (i.e. multi-criteria) decision. In general, 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

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

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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 convergent the supposed variety of verdicts. This pluralist testing process, made by moral experts, is only a fraction of a more complex procedure intended to deliver social sanction for a new moral policy. This longer procedure also shows that the adoption of a new moral policy, rule or law is not only a question of passing a strict ethical test, but also a political (i.e. multi-criteria) decision. In general, 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.

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