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Fukushima, Flawed Epistemology, and Black-Swan Events

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The Black-Swan Claim

The black-swan claim (BSC) is that nuclear-core-melt accidents are rare. For instance, reporting on accidents like the 2011 Fukushima Daiichi disaster, many experts said it was a black-swan event, completely unpredictable (Bodansky, 1996, p. 391; Sommer, 2011, p. A6). The World Nuclear Association (WNA) likewise claims that core meltdown and containment failure are 'both extremely unlikely,' because 'the risks from ... nuclear power plants ... are minimal' (WNA, 2011). Relying almost completely on industry-supplied data, government representatives also repeatedly make the BSC, as when the Japanese Atomic Energy Commission said the Fukushima Daiichi disaster was 'unpredictable' (Broad and Jolly, 2011, p. A10).

One obvious problem with the BSC is political-economic. For years, well-documented nuclear-industry-government fraud and public relations (PR) have misled laypeople about reactor-risk probabilities. For 20 years the US government repeatedly alleged atomic energy was safe, yet covered up its own reports showing high nuclear-accident probabilities and warnings that an accident could destroy an area the size of Pennsylvania and kill 150,000 people (AEC, 1957; Mulvihill *et al.*, 1965; Shrader-Frechette, 2007, 2011). Repeated US Congressional hearings and government-oversight reports likewise say the nuclear industry and government regulators have underestimated reactor-accident probabilities, withheld safety data, falsified records, suppressed scientific information, and failed to do adequate testing (see GAO, 1999; OTA, 1991).

Similar government-nuclear-industry cover-ups occur globally, perhaps because of the nuclear-industry-military connection (Shrader-Frechette, 2011). In fact, two weeks before the March 11, 2011 Japanese disaster began, Tokyo Electric admitted 'it had failed to inspect 33 pieces of equipment' for cooling the six Fukushima Daiichi reactors. Japanese regulators warned that the 'quality of inspection was

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insufficient' and that Tokyo Electric continues to 'manipulate data,' to have 'uneven safety records, and a history of cover-ups.' Earlier, regulators forced Tokyo Electric to temporarily shut 17 plants because it 'falsified inspection records and hid flaws over 16 years—to save on repair costs.' For years, General Electric (GE) engineers who designed the 40-year-old Fukushima Daiichi reactors warned they were 'outdated,' and more susceptible to explosions, accidents and radiation releases than newer reactor designs (Tabuchi *et al.*, 2011, pp. A1, A6; see Makhijani, 2011).

The Data-Trimming Fallacy

Obviously such warnings, either unheeded or covered up, suggest BSC may be false, and core melts may be probable. In addition, three important epistemic reasons—focusing on data-trimming, relative frequency, and inconsistency—suggest BSC is false.

When atomic-energy proponents, including the US and Japanese governments, use BSC, they typically resort to one of two types of data-trimming fallacy, in order to allege that nuclear-core-melt probabilities are low. In the first sort of trimming, fission proponents report only 'major' core-meltdown accidents in utility-owned reactors. For instance, WNA says 'there have been three major reactor accidents in the history of civil nuclear power' (WNA, 2011). Yet the criteria for 'major' melts are never explained. Also, who owns a power-generating reactor—civilian corporations or a government agency, like the Tennessee Valley Authority—is largely irrelevant because all nuclear plants everywhere are heavily taxpayer subsidized, up to 80%, even in the US (Shrader-Frechette, 2011), and standardized reactor designs make core-melt probabilities comparable, regardless of reactor ownership.

In the second sort of trimming, fission proponents report only meltdowns of which the public is likely to be aware. For instance, well-known nuclear engineers say only 2–3 reactor core melts have occurred and that atomic-energy disasters are rare (Bodansky, 1996, p. 391; but see Lochbaum, 2011). Or, they cite the US government's prediction that: (i) a core-melt accident in the 104 US reactors will occur only once every 1000 years (NRC, 2003); suggesting (ii) a core-melt accident will occur only once every 250 years for 442 global reactors.

Yet, as explained below, (i) is doubtful because US reactors have had at least five core meltdowns in roughly 50 years—and not just one core melt in 1000 years; and (ii) is doubtful because global reactors have had at least 26 core melts in roughly 50 years—not four in 1000 years. How many meltdowns have occurred?

This is an interesting question, given the political-economic incentives for nuclear-accident cover-up. To provide a best-estimate answer, the list below excludes: (a) serious non-melt accidents; (b) intentional or deliberate melts; and (c) supposed melts not documented in reliable scientific literature. Regarding (a), the lists below exclude fuel-loss or criticality accidents, however serious, if they do not partially melt the core. Thus, many damaging US-reactor accidents—such as the criticality catastrophe in Charlestown, Rhode Island; the fire near Chicago; the loss of cooling in New York; or the Nebraska and Connecticut reactor explosions—are not included in the lists below (see Pollack, 2011). Regarding (b), the lists also exclude melts that have been intentional or experimental, not the result of apparent accidents or negligence—such as those at Borax-1, SPERT, and TREAT reactors in Idaho. Regarding (c), the lists below exclude meltdowns for which detailed accounts are not available in refereed scientific literature, such as at the WTR reactor in Pennsylvania. Given the previous three caveats, (a)–(c), at least five unintentional, nuclear-core melts—all resulting in radiation releases, death, and injury—appear to have occurred in the US:

- EBR-1 in Idaho, 1955.
- Santa Susana in Los Angeles, 1959.
- SL-1 in Idaho, 1960–1961.
- Fermi 1 in Michigan, 1966.
- Three Mile Island in Pennsylvania, 1979.

Given the same three caveats, at least 21 unintentional nuclear-core melts appear to have occurred outside the US—all resulting in radiation releases, death, and injury:

- Mulvihill Windscale in the UK, 1957.
- Chalk River in Canada, 1958.
- Lenin (ship) in Russia, 1966–67.
- Chapelcross in Scotland, 1967.
- Saint-Laurent in France, 1969.
- Lucens in Switzerland, 1969.
- Greifswald in Germany, 1975.
- Saint-Laurent in France, 1980.
- Eight in Soviet navy nuclear submarines K-19 (1961), K-11(1965), K-27 (1968), K-140 (1968), K-429(1970), K-222(1980), K-314 (1985), and K-431(1985).
- Chernobyl in Ukraine, 1986.
- Three, so far, in Fukushima, Japan 2011.

As the preceding list of 26 nuclear core melts reveals, scientists interested in epistemically legitimate probability claims ought not use highly stipulative definitions of 'core melt'—that prescribe using data only for 'major' core melts or only for civilian-owned reactors. If not, BSC is questionable insofar as it relies on such definitions (Broder *et al.*, 2011; Gonyeau, 2005; Johnston, 2011; Smith, 2006).

The Frequency Fallacy

A second illegitimate defense of BSC is through the frequency fallacy, confusing core-melt-relative-frequency data with subjective probabilities. Yet 'probability' can mean: (i) 'classical probability;' (ii) 'relative frequency;' or (iii) 'subjective probability,' not all of which are applicable to nuclear-core-melt assessment.

Classical probability (i) is illustrated by card games in which the deck contains a fixed number of cards, for example 52. The probability of an event (e) thus equals the number of possible favorable outcomes (f) divided by the total number of possible outcomes (n): $P(e) = f/n$. Provided the deck of cards is fair, each card has an equal chance of being picked, and the probability (i) of picking an ace $= 4/52$. Thus, (i) assumes that all possible outcomes are equally likely and that we know n—neither of which is the case regarding nuclear-accident outcomes.

Relative-frequency probability (ii) is often used for cases where the number of outcomes (n) is so great that all typically cannot be observed, as in the probability

(ii) that current 5-year-olds will contract cancer. We cannot observe all 5-year-olds throughout their lifetimes, but can reliably predict cancer probability for random, typical 5-year-olds, if we observe a large-enough, long-enough sample. Thus, if we observed 1000 5-year-olds over their lifetimes, if samples were representative and large enough, and if we observed 350 cancer deaths, we could say this cancer probability was roughly P(e) = 35.0% (350/1000). We cannot predict with certainty, however, unless we know the frequency of all relevant events—whether lifetime cancers or total nuclear-core melts. Given that preceding core-melt lists include all occurrences (consistent with the three caveats), those lists suggest an almost-certain, core-melt probability (ii) = core melts/total reactors = 26/442 = roughly a 6% probability (ii)—roughly a 1 in 16 chance of core melt—which is hardly a low probability.

Subjective probability (iii) relies only on what people think particular probabilities are. The odds people get when they bet at racetracks are subjective probabilities because if the probabilities were objective, smart players would always win. Obviously (iii) does not provide reliable nuclear-core-melt probabilities because it is based not on facts, but on what people think about facts. Nuclear proponents think the facts are one way, and opponents think they are another. Both cannot always be correct. Since (iii) is subjective and could be inconsistent, and because (i) would require knowing n and knowing a falsehood (that all reactor outcomes were equally likely), (ii) appears most relevant to nuclear-core-melt assessment.

As preceding sections revealed, however, typical atomic-energy advocates use (iii) not (ii) to assess core-melt probabilities, such as when the Nuclear Regulatory Commission (NRC) said core-melt accidents, for all 104 US reactors, would only occur once every 1000 years. Instead, the NRC should have made predictions based on government inspections, independent analyses, and accident-frequency data, not 'on [subjective-probability] data submitted by plant owners' (Broder *et al.*, 2011, p. D1). The NRC predecessor agency, the Atomic Energy Commission (AEC) also has a long history of making BSC based on (iii). AEC said the probability of a US nuclear core meltdown is 1 in 17,000 per reactor year (AEC, 1957; Mulvihill *et al.*, 1965).

Even universities erroneously use subjective probabilities (iii), not frequencies (ii), to assess nuclear-core-melt likelihood, particularly when pro-nuclear-government agencies fund their studies. For instance, although the classic, Massachusetts Institute of Technology (MIT)-authored, government-funded, reactor-safety study had frequency data for various nuclear accidents that already had occurred after decades of US-operating experience, it did not use them; instead the MIT authors used subjective, pro-nuclear assumptions and conjectures about these accident probabilities (Rasmussen, 1975). When independent, university mathematicians compared US nuclear-accident-frequency data, reported from operating experience, with MIT guesses (iii), they discovered that all 'guesses' were far too low, by several orders of magnitude. None of the nuclear-accident-frequency data, based on reactor-operating experience, was within the theoretical, 90% confidence interval of the MIT 'guesses.' Yet there is only a subjective probability of 10% that any of these true (frequency-based) probability values (for different types of reactor accidents) should fall outside this 90% interval. The conclusion? University mathematicians said that MIT assessors were guilty of a massive 'overconfidence' bias toward nuclear safety, a typical flaw in most industry-government-funded, nuclear-risk analyses (Cooke, 1982).

This fallacious substitution of subjective probabilities (iii)—for nuclear-core-melt frequencies (ii)—has at least two interesting parallels, namely, nuclear-industry preferences for subjective opinions, over empirical data, in reporting both nuclear costs and carbon-equivalent emissions. Since most nuclear-industry-performed studies employ purely subjective economic estimates, instead of empirical-cost data, they counterfactually assume that nuclear-load factors are 90–95%, that average reactor lifetimes are 50–60 years, and that nuclear-construction-loan-interest rates are 0%. Yet in reality, industry-collected empirical data show average nuclear-load factors are 71%, not 90–95%; average reactor lifetimes are 22, not 50–60 years; and nuclear-interest rates are at least 15%, not 0%. When one corrects only five subjective (counterfactual) nuclear-cost assumptions with actual empirical data, nuclear costs rise 700% above industry-reported costs, revealing that fission is far more expensive than wind or solar-photovoltaic. Similarly, most nuclear-industry-performed studies claim that atomic energy is carbon-emissions-free—a claim dependent on subjectively counting only emissions from reactor operation, not emissions from the entire, 14-stage nuclear-fuel cycle. Once one counts all fuel-cycle emissions, the ratios of carbon emissions are roughly 112 coal : 49 gas : 7 nuclear : 4 solar : 1 wind. For low-grade-uranium ores, the nuclear ratios are even worse: 112 coal : 49 gas : 49 nuclear : 4 solar : 1 wind (Shrader-Frechette, 2011).

Inconsistency in Black-Swan Arguments

A third way fission proponents often illegitimately defend BSC is by making inconsistent appeals to market/safety data about BSC. Most nuclear-industry-performed studies say fission is inexpensive, partly because core-melt probabilities are low (Shrader-Frechette, 2011). However, most such market assessments ignore government interventions and subsidies that reduce industry risks/costs, for example laws giving nuclear operators protection from full-liability claims. Given such protection, industry need not purchase full-nuclear-liability insurance, despite government-calculated, lifetime-core-melt probabilities of 20%. Thus, EC studies show that if nuclear utilities had to buy insurance at market rates, this alone would triple nuclear-generated-electricity prices (EC, 2003). Obviously such high market-based charges are inconsistent with BSC. Nuclear-utility demands for full-accident-liability protection (as a condition of electricity generation) also are inconsistent with BSC. The US nuclear-liability limit—1–2% of total possible, government-estimated losses—ensures that victims and taxpayers, not industry, bears most reactor-accident costs, even those resulting from utility negligence or illegal activities. Thus, while industry tells the public that reactor-accident probabilities are low, its market behavior reveals the opposite (Shrader-Frechette, 2007, 2011).

What keeps the public from recognizing that BSC is flawed? Harvard economist Robert Stavins says that because governments have massively subsidized fission and 'capped the liability of nuclear-power producers ... markets have never really had a chance to price nuclear power' (Sommer, 2011, p. A6). Massively subsidized markets, artificially 'propping up' reactor industries, thus help mislead people about BSC and nuclear safety. Bankers, however, are not misled. Virtually no bank anywhere will give nuclear loans. All credit-rating agencies downgrade utilities with reactor, and utilities admit they would never build reactors without massive taxpayer subsidies covering most costs (Shrader-Frechette, 2011). They are not misled by BSC. Neither should the public be.

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