"New" Nuclear Reactors, Same Old Story

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The dominant type of new nuclear power plant, light-water reactors (LWRs), proved unfinanceable in the robust 2005–08 capital market, despite new U.S. subsidies approaching or exceeding their total construction cost. New LWRs are now so costly and slow that they save 2–20× less carbon, 20–40× slower, than micropower and efficient end-use.[1] As this becomes evident, other kinds of reactors are being proposed instead—novel designs claimed to solve LWRs' problems of economics, proliferation, and waste.[2] Even climate-protection pioneer Jim Hansen says these "Gen IV" reactors merit rapid R&D.[3] But on closer examination, the two kinds most often promoted—Integral Fast Reactors (IFRs) and thorium reactors[4]—reveal no economic, environmental, or security rationale, and the thesis is unsound for any nuclear reactor.

Integral Fast Reactors (IFRs)

The IFR—a pool-type, liquid-sodium-cooled fast-neutron[5] reactor plus an ambitious new nuclear fuel cycle—was abandoned in 1994,[6] and General Electric's S-PRISM design in ~2003, due to both proliferation concerns and dismal economics. Federal funding for fast breeder reactors[7] halted in 1983, but in the past few years, enthusiasts got renewed Bush Administration support by portraying IFRs as a solution to proliferation and nuclear waste. It's neither.

Fast reactors were first offered as a way to make more plutonium to augment and ultimately replace scarce uranium. Now that uranium and enrichment are known to get cheaper while reprocessing, cleanup, and nonproliferation get costlier—destroying the economic rationale— IFRs have been rebranded as a way to destroy the plutonium (and similar transuranic elements) in long-lived radioactive waste. Two or three redesigned IFRs could in principle fission the plutonium produced by each four LWRs without making more net plutonium. However, most LWRs will have retired before even one commercial-size IFR could be built; LWRs won't be replaced with more LWRs because they're grossly uncompetitive; and IFRs with their fuel cycle would cost even more and probably be less reliable. It's feasible today to "burn" plutonium in LWRs, but this isn't done much because it's very costly, makes each kg of spent fuel 7× hotter, enhances risks, and makes certain transuranic isotopes that complicate operation. IFRs could do the same thing with similar or greater problems, offering no advantage over LWRs in proliferation resistance, cost, or environment.

IFRs' reprocessing plant, lately rebranded a "recycling center," would be built at or near the reactors, coupling them so neither works without the other. Its novel technology, replacing solvents and aqueous chemistry with high-temperature pyrometallurgy and electrorefining, would incur different but major challenges, greater technical risks and repair problems, and speculative but probably worse economics. (Argonne National Laboratory, the world's experts on it, contracted to pyroprocess spent fuel from EBR-II—

a small IFR-like test reactor shut down in 1994—by 2035, at a cost DOE estimated in 2006 at ~50× today's cost of fresh LWR fuel.)

Reprocessing of any kind makes waste management more difficult and complex, increases the volume and diversity of waste streams, increases by several- to manyfold the cost of nuclear fueling, and separates bomb-usable material that can't be adequately measured or protected. Mainly for this last reason, all Presidents since Gerald Ford in 1976 (except G.W. Bush in 2006–08) discouraged it. An IFR/pyroprocessing system would give any country immediate access to over a thousand bombs' worth of plutonium to fuel it, facilities to recover that plutonium, and experts to separate and fabricate it into bomb cores—hardly a path to a safer world.

IFRs might in principle offer some safety advantages over today's light-water reactors, but create different safety concerns, including the sodium coolant's chemical reactivity and radioactivity. Over the past half-century, the world's leading nuclear technologists have built about three dozen sodium-cooled fast reactors, 11 of them Naval. Of the 22 whose histories are mostly reported, over half had sodium leaks, four suffered fuel damage (including two partial meltdowns), several others had serious accidents, most were prematurely closed, and only six succeeded. Admiral Rickover canceled sodium-cooled propulsion for USS Seawolf in 1956 as "expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair." Little has changed. As Dr. Tom Cochran of NRDC notes, fast reactor programs were tried in the US, UK, France, Germany, Italy, Japan, the USSR, and the US and Soviet Navies. All failed. After a half-century and tens of billions of dollars, the world has one operational commercial-sized fast reactor (Russia's BN600) out of 438 commercial power reactors, and it's not fueled with plutonium.

IFRs are often claimed to "burn up nuclear waste" and make its "time of concern…less than 500 years" rather than 10,000–100,000 years or more. That's wrong: most of the radioactivity comes from fission products, including very long-lived isotopes like iodine-129 and technetium-99, and their mix is broadly similar in any nuclear fuel cycle. IFRs' wastes may contain less transuranics, but at prohibitive cost and with worse occupational exposures, routine releases, accident and terrorism risks, proliferation, and disposal needs for intermediate- and low-level wastes. It's simply a dishonest fantasy to claim, as a Wall Street Journal op-ed just did,[8] that such hypothetical and uneconomic ways to recover energy or other value from spent LWR fuel mean "There is no such thing as nuclear waste." Of course, the nuclear industry wishes this were true.

No new kind of reactor is likely to be much, if at all, cheaper than today's LWRs, which remain grossly uncompetitive and are getting more so despite five decades of maturation. "New reactors" are precisely the "paper reactors" Admiral Rickover described in 1953:

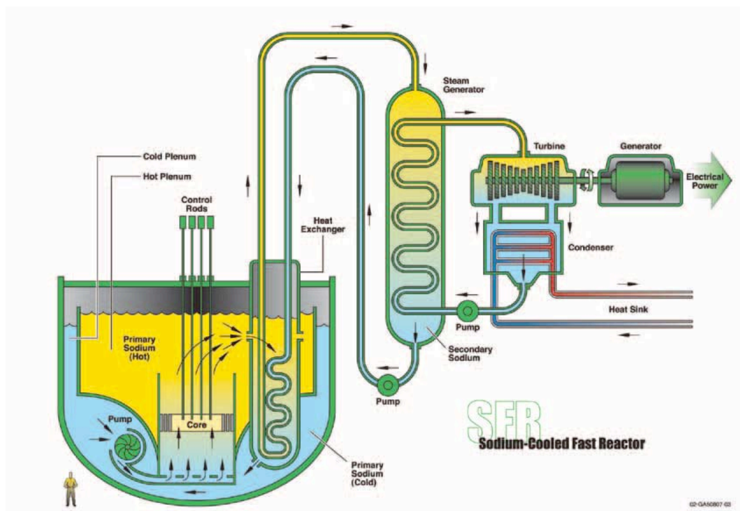
> An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap. (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose. (7) Very little

development will be required. It will use off the shelf components. (8) The reactor is in the study phase. It is not being built now.

On the other hand a practical reactor can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It requires an immense amount of development on apparently trivial items. (4) It is very expensive. (5) It takes a long time to build because of its engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated.

Every new type of reactor in history has been costlier, slower, and harder than projected. IFRs' low pressure, different safety profile, high temperature, and potentially higher thermal efficiency (if its helium turbines didn't misbehave as they have in all previous reactor projects) come with countervailing disadvantages and costs that advocates assume away, contrary to all experience.

Thorium reactors



A Technology Roadmap for Generation IV Nuclear Energy Systems

Some enthusiasts prefer fueling reactors with thorium—an element 3× as abundant as uranium but even more uneconomic to use. India has for decades failed to commercialize breeder reactors to exploit its thorium deposits. But thorium can't fuel a reactor by itself: rather, a uranium- or plutonium-fueled reactor can convert thorium-232 into fissionable (and plutonium-like, highly bomb-usable) uranium-233. Thorium's proliferation,[9] waste, safety, and cost problems differ only in detail from uranium's: e.g., thorium ore makes less mill waste, but highly radioactive U-232 makes fabricating or reprocessing U-233 fuel hard and costly. And with uranium-based nuclear power continuing its decades-long economic collapse, it's awfully late to be thinking of developing a whole new fuel cycle whose problems differ only in detail from current versions.

Spent LWR fuel "burned" in IFRs, it's claimed, could meet all humanity's energy needs for centuries. But renewables and efficiency can do that forever at far lower cost, with no proliferation, nuclear wastes, or major risks.[10] Moreover, any new type of reactor would probably cost even more than today's models: even if the nuclear part of a new plant were free, the rest—two-thirds of its capital cost—would still be grossly uncompetitive with any efficiency and most renewables, sending out a kilowatt-hour for

~9–13¢/kWh instead of new LWRs' ~12–18+¢. In contrast, the average U.S. windfarm completed in 2007 sold its power (net of a 1¢/kWh subsidy that's a small fraction of nuclear subsidies) for 4.5¢/kWh. Add ~0.4¢ to make it dispatchable whether the wind is blowing or not and you're still under a nickel delivered to the grid.

Most other renewables also beat new thermal power plants too, cogeneration is often comparable or cheaper, and efficiency is cheaper than just running any nuclear- or fossil-fueled plant. Obviously these options would also easily beat proposed fusion reactors that are sometimes claimed to be comparable to today's fission reactors in size and cost. And unlike any kind of hypothetical fusion or new fission reactor—or LWRs, which have a market share below 2%—efficiency and micropower now provide at least half the world's new electrical services, adding tens of times more capacity each year than nuclear power does. It's a far bigger gamble to assume that the nuclear market loser will become a winner than that these winners will turn into losers.

Small reactors

Toshiba claims to be about to market a 200-kWe nuclear plant (~5000× smaller than today's norm); a few startup firms like Hyperion Power Generation aim to make 10¢/kWh electricity from miniature reactors for which it claims over 100 firm orders. Unfortunately, 10¢ is the wrong target to beat: the real competitor is not other big and costly thermal power plants, but micropower and negawatts, whose delivered retail cost is often ~1–6¢/kWh.[11] Can one imagine in principle that mass-production, passive operation, automation (perhaps with zero operating and security staff), and supposedly failsafe design might enable hypothetical small reactors to approach such low costs? No, for two basic reasons:

- Nuclear reactors derive their claimed advantages from highly concentrated sources of heat, and hence also of radiation. But the shielding and thermal protection needed to contain that concentrated energy and exploit it (via turbine cycles) are inherently unable to scale down as well as technologies whose different principles avoid these issues.

- By the time the new reactors could be proven, accepted by regulators and the public, financed, built, and convincingly tested, they couldn't undercut the then prices of negawatts and micropower that are beating them by 2–20× today—and would have gained decades of further head start on their own economies of mass production.

In short, the notion that different or smaller reactors plus wholly new fuel cycles (and, usually, new competitive conditions and political systems) could overcome nuclear energy's inherent problems is not just decades too late, but fundamentally a fantasy. Fantasies are all right, but people should pay for their own. Investors in and advocates of small-reactor innovations will be disappointed. But in due course, the aging advocates of the half-century-old reactor concepts that never made it to market will retire and die, their credulous young devotees will relearn painful lessons lately forgotten, and the whole nuclear business will complete its slow death of an incurable attack of market forces. Meanwhile, the rest of us shouldn't be distracted from getting on with the winning investments that make sense, make money, and really do solve the energy, climate, and proliferation problems, led by business for profit.

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1 A.B. Lovins et al., "Nuclear Power: Climate Fix or Folly?," RMI, 31 Dec. 2008, www.rmi.org/images/PDFs/Energy/E09-01_NuclPwrClimFixFolly1i09.pdf.
2 E.g., Tom Blees's Prescription for the Planet, skirsch.com/politics/globalwarming/ifr.htm, and three retired Argonne National Laboratory physicists' 2005 Scientific American summary article at www.nationalcenter.org/NuclearFastReactorsSA1205.pdf.
3 See www.columbia.edu/%7Ejeh1/mailings/20081229_Obama_revised.pdf.
4 For a third type often proposed, see J. Harding, "Pebble Bed Modular Reactors—Status and Prospects," 2005, RMI Publication #E05-10, www.rmi.org/images/PDFs/Energy/E05-10_PebbleBedReactors.pdf; S. Thomas, "The Economic Impact of the Proposed Demonstration Plant for the Pebble Bed Modular Reactor Design," Aug 2005, www.psiru.org/reports/2005-09-E-PBMR.pdf; www.neimagazine.com/story.asp?storyCode=2030985, 6 Sep 2005.
5 Such reactors, called "fast reactors" for short, do not slow down their neutrons with a "moderator" like water or graphite. They therefore don't depend on a small fraction of "delayed" neutrons to keep the chain reaction going, so they require different means of control and safety.
6 See www.nationalcenter.org/NPA378.html.
7 See http://en.wikipedia.org/wiki/Breeder_reactor.
8 W. Tucker, 13 March 2009, online.wsj.com/article/SB123690627522614525.html.
9 Most proposed thorium cycles need reprocessing to separate U-233 for use in fresh fuel. Some also use 20%-enriched uranium-235, which needs very little further enrichment to become bomb-usable. Diluting U-233 with U-238 also makes more separable plutonium. See A.B. Lovins, "Thorium Cycles and Proliferation," Bull. atom. Scient. 35(2):16–22 (1979), 35(5):50–54 (1979), 35(9):57–59 (1979), all at books.google.com/books?id=GgsAAAAAMBAJ&source=gbs_summary_s&cad=0#all_issues_anchor.
10 See ref. 1.
11 Id.