Should we support new nuclear power?

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Civilian nuclear energy, developed as a spinoff of the nuclear bomb effort of the United States and Soviet Union, was seen among the technocracy of the 1950s and 1960s as the next improvement in energy provision, which will replace polluting and scarce fossil hydrocarbons sometime around the turn of the millennium. (For example, US Rear Admiral Hyman Rickover, speech to the Minnesota State Medical Association, May 14, 1957 [http://www.theoildrum.com/node/2724]: “Our present known reserves of fissionable materials are many times as large as our net economically recoverable reserves of coal. A point will be reached before this century is over when fossil fuel costs will have risen high enough to make nuclear fuels economically competitive.”) However, an initial build-up of nuclear power plants based on ^{235}U fission slowed beginning in the 1970s, dragged down by high (and, it seems, escalating) construction and maintenance costs, cheap coal and natural gas, plant meltdowns in Pennsylvania in 1979 and in Chernobyl in 1986, association with the unpopular military-industrial complex and its ideology of mutually assured destruction, and the intractable problem of accumulating dangerous radioactive byproducts. Some construction continues in industrializing countries, but according to BP’s *Statistical Review of World Energy* (http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622), the share of nuclear generation in world primary energy use peaked at 6.4% in 2001 and by 2008 fell to 5.5%, equal to its level in 1989. Over the last few years, with growing realization that fossil fuels, especially oil, are increasingly scarce and a greater sense of urgency to curtail fossil fuel burning to stop climate catastrophe, there have been numerous calls, and substantial government subsidies, to build more nuclear power plants as, at least, the lesser evil compared with coal. (Ecologist James Lovelock in the *Independent*, 24 May 2004 [http://www.ecolo.org/media/articles/articles.in.english/love-indep-24-05-04.htm]: “We have no time to experiment with visionary energy sources; civilisation is in imminent danger and has to use nuclear – the one safe, available energy source – now or suffer the pain soon to be inflicted by our outraged planet.”) Regardless, the massive unit capital cost of new plants and the current investment crunch has kept this enthusiasm from having noticeable impact on the ground, and it is unlikely that nuclear power will grow much at least for the next decade.

Ideas for new forms of nuclear generation

Uranium is found in the earth’s crust at a typical concentration of around one part per million. It cannot be economically extracted at this concentration, and is mined from a few deposits where its concentration is much higher; these seem to be only enough for less than a century at current rates of use. Only 0.7% of a sample of mined uranium is the fissionable ^{235}U, and separating this isotope from the dominant ^{238}U has been a major technical challenge first encountered in seeking to make nuclear bombs. However, bombarding ^{238}U with neutrons can transmute it to fissionable ^{239}Pu, which would allow on the order of a hundredfold more energy to be obtained from a given amount of uranium than in current reactor designs. Since plutonium is extremely toxic and is a common material for nuclear bombs, support by governments for this “breeding” process has been distinctly mixed. Several experimental reactors have been built over the last five decades, but with no immediate prospect of commercial application. Similarly, ^{232}Th, which is somewhat more abundant and cheaper than uranium, can be bombarded by neutrons to make fissionable ^{233}U. Experimental reactors using thorium have been built, with the most intensive development effort currently in India, which has large thorium deposits. Again, there is no immediate prospect of commercialization.

The Rubbiatron

After winning the Nobel prize in Physics in 1984 for his team's detection of the W and Z bosons at CERN, Italian physicist Carlo Rubbia devoted much of his time to researching and advocating for new energy technologies. In the early 1990s, he and colleagues at CERN developed the concept of a thorium reactor where fusion would be driven by neutrons generated by spallation of high-energy protons from an accelerator (cyclotron) beam. The proton beam would use ~5% of the electricity produced by the reactor. Rubbia referred to the design as the energy amplifier; it is also known as an accelerator-driven system, and in Europe, familiarly, as a Rubbiatron. Such a reactor would also be able to use ^{238}U. It is argued that one advantage of using ^{232}Th is that diversion of fissile material to make nuclear bombs would be more hazardous for the bombmaker because the fissionable ^{233}U would be contaminated by ^{232}U, whose decay chain produces penetrating gamma rays. (Admittedly, someone who is intent on killing many people is unlikely to be swayed by mundane concerns of self-preservation, and it is possible to envision reaction conditions where less ^{232}U is produced relative to ^{233}U.) Since the fission rate is controlled by the proton beam, meltdown should be easier to avert. Such a plant would theoretically generate only lighter radioactive isotopes with short lifetimes whose radioactive activity would drop to that of coal ash after 500 years, compared to hundreds of thousands of years for current nuclear waste. In fact, it could fission ^{239}Pu and other heavy elements in current nuclear waste and thus make it less dangerous. It was suggested that such a plant could produce electricity for some 2 cents per kWh, much less than fossil-fueled power stations (R. Fernández, P. Mandrillon, C. Rubbia and J.A. Rubio (1996), "A preliminary estimate of the economic impact of the energy amplifier", CERN report LHC-96-001, http://doc.cern.ch/archive/electronic/cern/preprints/lhc/lhc-96-001.pdf). Given the much higher fission efficiency as compared to using only ^{235}U, thorium and uranium deposits could supply near-current world energy use for ~1000 years. More recently, Rubbia has devoted most of his energy to promoting concentrating solar power, which is beginning to be built on a large scale particularly in Spain, but continues to argue that accelerator-driven fission would be useful for less sunny places, like Hamburg.

Concerns and practicalities

Christoph Pistner provides a summary of possible problems with the 'energy amplifier' idea ("Emerging Nuclear Technologies: The Example of Carlo Rubbia's Energy Amplifier" (1999), International Network of Engineers and Scientists Against Proliferation Bulletin, 17:25, http://www.inesap.org/sites/default/files/inesap_old/bulletin17/bul17art25.htm). Potential hazards associated with the design include failure of reactor vessel due to heating and neutron flux – the liquid lead on its inside, used as coolant and to absorb the proton beam and release neutrons, will prevent it from being inspected closely during operation – and meltdown from surges in the proton beam. Also, the envisioned accelerator beam intensity is larger than any yet developed. Another unproven element is the fuel reprocessing that is needed every few years; this will require working with built-up extremely hazardous ^{232}U.

While research and development into various components of the system continue, no full-scale reactor with this design has been constructed, and none is currently planned. (For a review, see José Rubens Maiorino, Adimir dos Santos, Sérgio Anéfalos Pereira (2003), “The utilization of accelerators in subcritical systems for energy generation and nuclear waste transmutation – the world status and a proposal of a national R&D program”, *Brazilian Journal of Physics* 33(2), http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-97332003000200018.)

Rubbia’s native Italy phased out nuclear power after a referendum on the issue in 1987, although in 2009 the government announced plans to build new nuclear plants in the 2010s. In 1997, Rubbia formed a company, the Energy Amplifier Laboratory (Laboratorio del Amplificador de Energía, Sociedad Anónima [LAESA]), to build a prototype plant in Spain; this effort failed to raise enough money and encountered technical difficulties and opposition from local environmental groups (Daniel Montero and Javier Ortega, “Fracasa el proyecto de energía atómica limpia de Rubbia”, *El Mundo*, 27 September 2001, http://www2.elmundolibro.com/2001/09/27/sociedad/1052922.html). More recently the Norwegian state energy company Statkraft has said it is investigating an accelerator thorium reactor design (Liz Williams, “Green nuclear power coming to Norway”, *Cosmos*, 24 May 2007, http://www.cosmosmagazine.com/news/1341/green-nuclear-power-coming-norway). (Norway also has large thorium deposits.) However, a report commissioned from the Research Council of Norway concluded in 2009 that “The development of an Accelerator Driven System (ADS) using thorium is not within the capability of Norway working alone. Joining the European effort in this field should be considered." ("Thorium committee submits report: Neither dismisses nor embraces thorium fuel", http://www.forskningsradet.no/en/Newsarticle/Neither+dismisses+nor+embraces+thorium+fuel/1236685401100). Currently, Norway has no commercial nuclear reactors of any kind.

In summary, despite decades of research and discussion, reactor designs involving the breakdown of ^{238}U and ^{232}Th have attractive features but show no prospect of playing a significant role in the global energy system within a relevant time frame to, for example, keep carbon dioxide levels from rising further into the dangerous range. The large capital investments and safety and security infrastructure required favor a portfolio of more scalable and lower-tech solutions including radical increases in energy efficiency, discouraging conspicuous energy consumption, and small-scale or modular generation units that tap ambient energy flows.